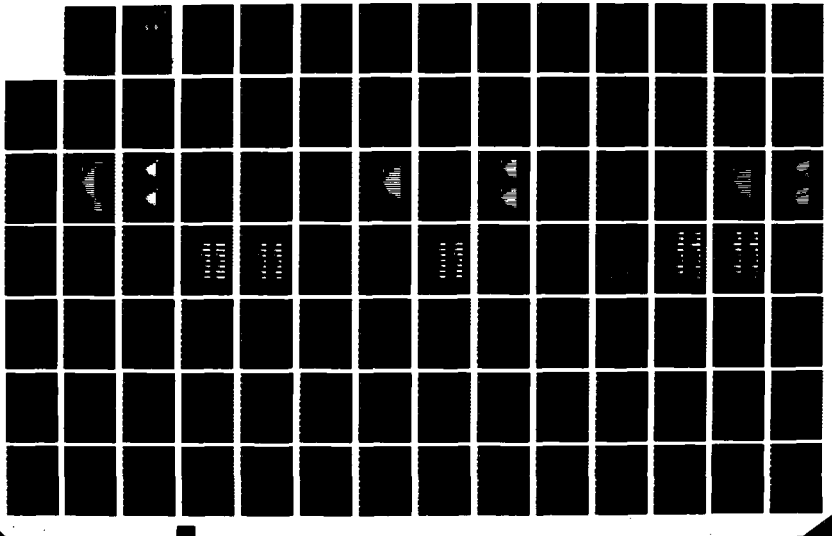

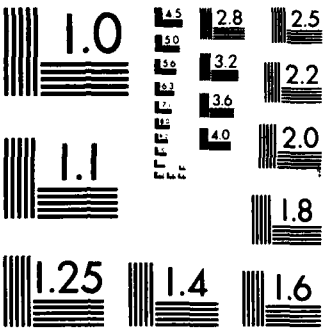

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NATIONAL BUREAU OF STANDARDS-1963-A

Technical Report E06549-38
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COMPILATION OF 1986 ANNUAL REPORTS OF THE NAVY ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM

Volume 1 of 3 Volumes: TABS A-C

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July 1987

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This is the fifth compilation of annual reports for the Navy's ELF Communications System Ecological Monitoring Program. The reports document the progress of ten studies performed during 1986 at the Wisconsin and Michigan Transmitting Facilities. The purpose of the monitoring is to determine whether electromagnetic fields produced by the ELF Communications System will affect resident biota or their ecological relationships.

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19. Abstract (Continued)

A. Herbaceous Plant Cover and Tree Studies
Michigan Technological University
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B. Litter Decomposition and Microflora
Michigan Technological University
Bagley, S.; Bruhn, J.; Pickens, J.B.

C. The Effects of Exposing the Slime Mold Physarum polycephalum to Electromagnetic Fields
University of Wisconsin-Parkside
Goodman, E.M.; Greenebaum, B.

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FOREWORD

The U.S. Navy is conducting a long-term program to monitor for possible effects from the operation of its Extremely Low Frequency (ELF) Communications System to resident biota and their ecological relationships. The program is being implemented by IIT Research Institute (IITRI) under contract to the Space and Naval Warfare Systems Command (SPAWAR). IITRI provides engineering support and coordinates the efforts of investigators. Monitoring projects are being carried out through subcontract arrangements between IITRI and study teams at several universities.

This is the fifth compilation of annual reports prepared by university study teams. Each report chronicles the data collection and analysis activities for a monitoring project during 1986. As in the past, each report has been reviewed by four or more scientific peers. Investigators have considered and addressed reviewer critiques prior to providing their report for printing. Reports have been printed from original copies without change or editing by either IITRI or SPAWAR.

The 1986 compilation is one of a series that documents the activities of the Ecological Monitoring Program since its inception in 1982. Other reports document engineering support and summarize the progress of the Program. Previous reports provide information on the background, overall design, and early development of the Program. All of these reports have been provided to the National Technical Information Service for unlimited distribution. The results of monitoring activities have also been presented at scientific meetings or as journal articles.

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

The Michigan Study Site

Tasks 5.13/5.14

ANNUAL REPORT 1986

SUBCONTRACT NUMBER: E06549-84-C-001

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RELEASING AUTHORITY: S/ Ryel

SCHOOL OF FORESTRY AND WOOD PRODUCTS

MICHIGAN TECHNOLOGICAL UNIVERSITY

HOUGHTON, MICHIGAN

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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 fields cause changes in forest productivity and health. Work elements examining different aspects of these forest ecosystems were initiated to establish a baseline of data that could be used to make preoperational to operational comparisons evaluating possible ELF field effects on these communities.

The overall objectives of these work elements are to determine the impacts of ELF electromagentic 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 our work during the four years of 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

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 level or the pattern of seasonal diameter growth of hardwoods before and after the ELF antenna becomes operational.
II.	There is no difference in the level of diameter growth of red pine seedlings before and after the ELF antenna becomes operational.
III.	There is no difference in the level or rate of height growth of red pine seedlings before and after the ELF antenna becomes operational.
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 operational.
V.	There is no difference in sporocarp production by mycorrhizal fungi before and after the ELF antenna becomes operational.
VI.	There is no difference in the number of different types of mycorrhizal root tips on red pine seedlings before and after the antenna becomes operational.
VII.	There is no difference in the total weight and nutrient concentrations of tree litter before and after the ELF antenna becomes operational.
VIII.	There is no difference in the foliar nutrient concentrations of northern red oak trees or red pine seedlings before and after the ELF antenna becomes operational.
IX.	There is no difference in the rate of development of Armillaria root disease on red pine seedlings before and after the ELF antenna becomes operational.

variability caused by soil, stand and climatic factors (Upland Flora 1985 Report). Consequently, it has been imperative to measure directly both plant growth and important regulators of the growth process such as tree, stand, and site factors to test adequately our hypotheses (Table 2). These measurements and associated analyses are discussed more fully in the various work element sections of this proposal. Work elements group similar measurements and analyses but are interrelated, with data from several elements often used to test a single hypothesis (Table 2).

The experimental design integrates direct measures with site variables and is a common thread through nearly all studies due to the field design of this project. An understanding of this experimental design is essential because of the similarity in analyses for hypothesis testing and the complexity of the overall project. However, the rationale and progress for measurements in each work element of this study are unique and will be presented separately.

Field Design

The electromagnetic fields associated with the ELF system will be different at the antenna and ground locations (Anonymous, 1977). As a consequence, 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 a 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 stand types (subplots) (Figure 1). Pole-sized hardwood stands and red pine (Pinus resinosa Ait.) plantations comprise the treatments for the second level of

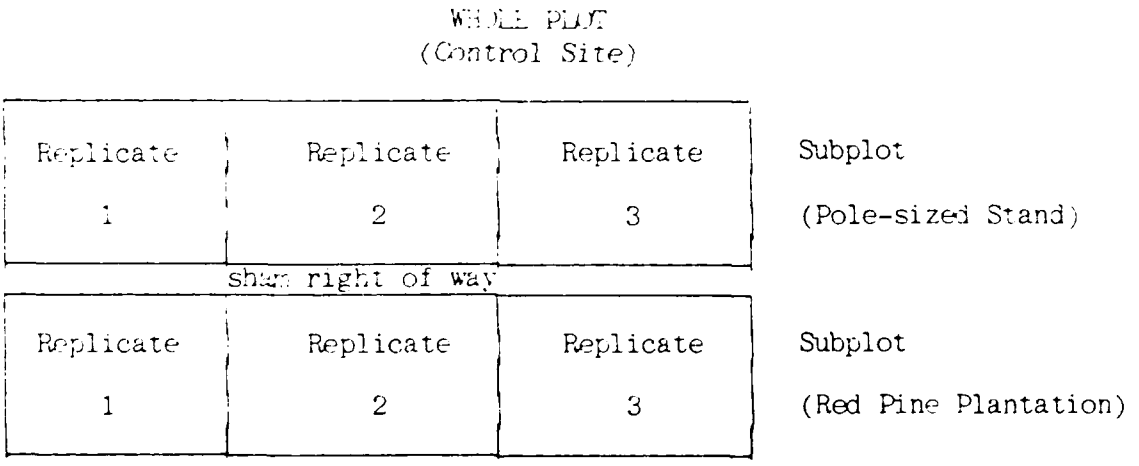
Table 2. Measurements needed to test the critical hypotheses of the ELF environmental monitoring program Upland Flora project, the objective it is related to, and the work elements addressing the necessary measurements and analyses.

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	2	Bi-weekly sporocarp counts by species, climatic variables	1,4
VI	3	Monthly counts of mycorrhizal root tips by type, climatic variables	1,5
VII	5	Periodic collections of litter, nutrient analyses, climatic variables	1,6
VIII	4	Periodic collections of foliage, nutrient analyses, climatic variables	1,6
IX	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

*Underlined print designates the response variable; others listed are covariates.

the design. Each stand type is replicated three times on a site (ELF field exposure) to control variation. The time factor is the number of years in which the experiment is conducted for preoperational 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 plots over a long period of time without rerandomization of plots. 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).

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



Each site follows this design with one exception. There is no pole-sized hardwood stand at the ground because required buffer strips would have resulted in the stands being too distant from the ground for meaningful exposure. Thus, one treatment factor (pole-sized stands) is eliminated at the ground. 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, the stand type treatment factor becomes irrelevant and falls out of the analysis. All other factors remain unchanged.

Analysis of Covariance

Our experimental design directly controls experimental error 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 is one of the most important steps in our analysis.

Covariates under examination vary for a given variable of interest (Table 2). Most analyses are using ambient climatic variables, such as air temperature, soil temperature, soil moisture, precipitation, and relative humidity, as well as those 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, other covariates in the analysis of red pine height growth would include bud size, seedling diameter, and total height of the seedling prior to the current season's growth. Analyses will be conducted to determine

which of these are both statistically significant as well as biological meaningful without violating the necessary assumptions 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.

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 have retained 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 all the environmental factors (natural and man-induced) which influence the physical space 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 these 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 variations before the effect of a single and potentially subtle factor, such as the electromagnetic fields of the ELF antenna, (National Research Council, 1977), can be quantified.

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

1. evaluate the natural climatic differences between the control site and the ground and antenna sites.

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

3. select climatic variables which are independent of ELF system effects. These variables will then be included in an ambient data base 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 the first two objectives will not only document ambient differences among sites and changes in annual climatic conditions but also indicate ambient variables which will be potential candidates for growth and development modeling in the various study elements. An adequate database of ambient measurements will insure a proper analysis of climatic relationships

to other study components as discussed in the design section dealing with covariate analysis. Accomplishing the last objective will give direct measurement of any ELF system influences on such factors as solar radiation in the forest understory that may be affected by overstory biomass. The initiation and schedule of each phase of the objectives are presented in Figure 1.1.

Sampling and Date Collection

System Configuration

The ambient variables being measured in the study are air temperature (30 cm and 2 m above ground), soil temperature and soil moisture at depths of 5 and 10 cm, incoming global solar radiation, relative humidity, photosynthetically active radiation (PAR), and precipitation. The configuration and placement of the sensors on the study site are presented in Appendix B (Table 1) of the 1985 annual report for the Upland Flora project.

Because of the location of individual sensors, air temperature (2 meters above the ground), precipitation, relative humidity, and global solar radiation are independent of possible ecological changes caused by ELF electromagnetic fields. Soil temperature, soil moisture, air temperature (30 cm above the ground), and PAR (30 cm above the ground) may be more sensitive to ecological changes because these variables may be influenced by stand characteristics. The ecological relationships of each individual ambient factor to vegetation was discussed in the 1985 Annual Report.

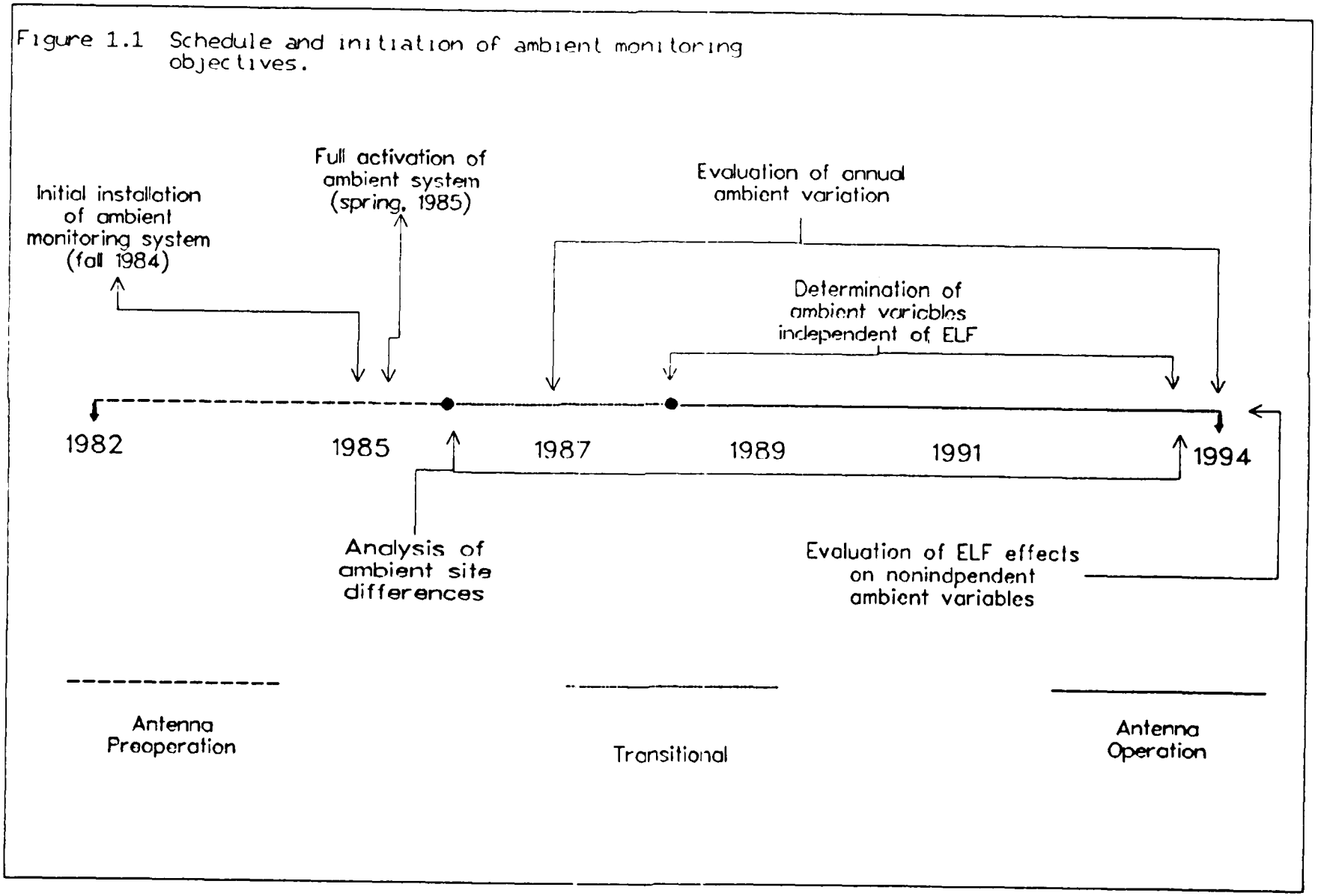


Figure 1.1 Schedule and initiation of ambient monitoring objectives.

Air temperature, soil temperature, PAR, and relative humidity are measured every 30 minutes by the 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 for the air temperature, soil temperature, relative humidity, and PAR measurements while three hour totals are calculated for the precipitation measurements. 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 a computer in Camp Springs, Virginia. The data are disseminated from Camp Springs to an IBM PC at MTU nightly.

This year a soil moisture subsampling procedure was initiated at each site in order to more accurately measure soil moisture over the entire area of each plot. Fifteen soil cores were randomly taken from each of the plots from each site once a month. Moisture content for each depth (5 cm and 10 cm) was determined gravimetrically from a composite of the fifteen cores. These moisture contents were considered to represent the average moisture content for a plot from each site for the day of core sampling.

Differences between the soil moisture calculated from the cores from a plot and soil moisture readings from the soil probes at the plot for the day of core collection were 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) was used to determine the actual monthly soil moisture probe adjustments.

(Equation 1.1) Monthly Adjustment for a specific plot =

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

CSM = Core Soil Moisture from the plot
PSM = Probe Soil Moisture from the plot
M = Month of Adjustment
M - 1 = Previous Month
M + 1 = Following Month

Adjustments for a given month calculated from this equation were weighted more heavily to the month of the adjustment. The monthly adjustments were generally between $\pm$3.0% moisture content at each plot for each of the three sites in 1986.

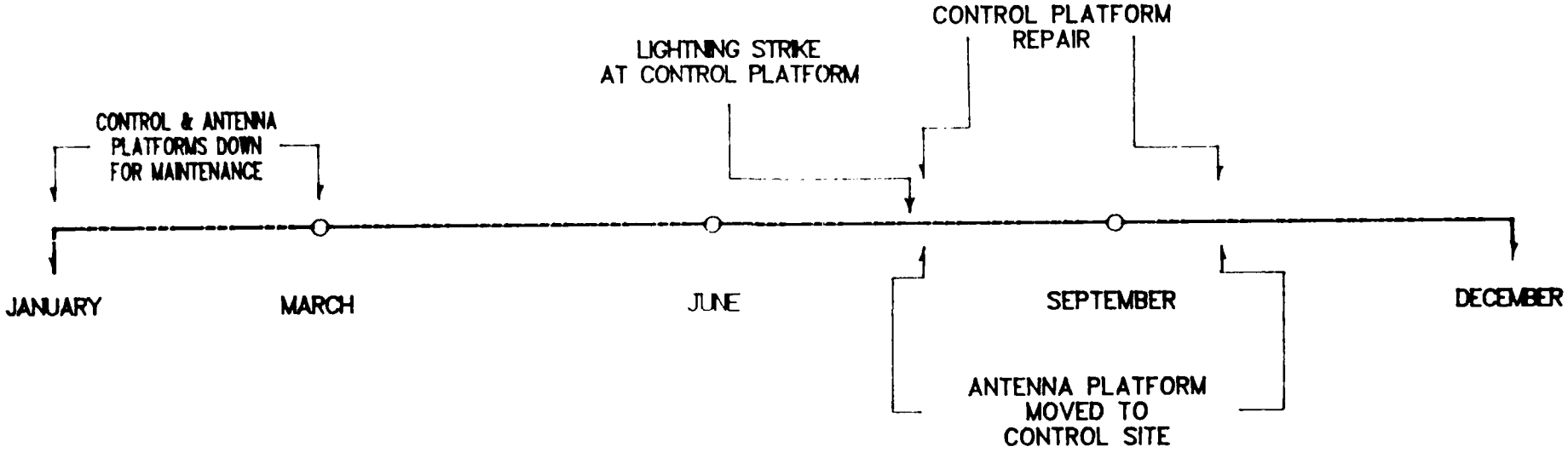
Initial calculations of the soil moisture adjustments, in April and May indicated the calibration technique used in 1985 and early in 1986 for the soil moisture probes were inadequate. The technique used tap water added to dry soil from the sites to produce each of the moisture content calibration points. Calibration curves produced with this method underestimated soil moisture under field conditions. Thus the calibration technique was modified by taking soil from the field when moisture levels were close to field capacity in early May. Each calibration point (e.g. 15% 10%, etc. soil moisture) was achieved by drying the soil down to each moisture level.

April and May probe readings were recalculated with the updated curves with good results. The previous year (1985) data, however, could not be recalculated and could not be used in other parts of the study.

System Maintenance and Performance

Ambient system performance in 1986 (Figure 1.2) was hampered by a lightning strike on the control platform in July. This strike damaged a number of microprocessor boards and sensors at this site. Since the antenna and ground sites are close to each other, the platform at the control was then replaced with the antenna platform. Equations were fitted to the

Figure 1.2 Ambient system performance



observed ground and antenna data, and were used to predict measurements at the antenna site. The control platform was sent to the manufacturer for repairs. Four weeks after the incident, the control platform was returned but it did not function properly and was sent back to the manufacturer. The control platform, when returned in the beginning of October, was functional. A total of 29 downtime days for the control platform and 62 downtime days for the antenna platform was caused by the lightning strike. Lightning rods are being mounted on the system for future protection against lightning strikes. The ground platform performance was excellent and only a minimal amount of information was lost during the year.

Sensor performance was improved this year. Except for the sensors damaged in the lightning strike, downtime due to sensor performance was minimal. Sensors and boards which were damaged by lightning strike are being repaired and calibrated this winte..

Data Management

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

Weekly or seven day summaries comprised the basic ambient unit used by the tree productivity element of the Upland Flora Project. The weekly ambient unit was adjusted to correspond to the weekly measurements of this

element. For example, if red pine height growth and pole-sized tree diameter growth were determined for the seven days from May 9 through May 15, weekly ambient summaries were also calculated for these same seven days. This insured a consistent relationship between ambient data and data recorded in this element. Weekly averages were considered missing and not calculated if less than four daily averages were computed from a sensor. Daily ambient information is the basic unit used for various elements such as the herbaceous study which has no set measurement period.

Monthly averages and totals were 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 were calculated from the daily ambient averages and totals (Table 1.1).

Table 1.1. Example of weekly units.

Date	Week
May 1-7	1
May 8-14	2
May 15-21	3
May 22-31	4

These weeks were used as replicated samples for the month in question (refer to analysis section).

Missing Data Replacement

Due to the amount of platform downtime in the past two years, daily ambient averages or totals were estimated for days in which specific ambient observations were not available. Four hierachial criteria and methods were

used to estimate missing data. The criteria were:

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

2) Missing daily plot summaries from the adjacent ground or antenna sites were replaced by the daily summaries from the plantation stand type on the adjacent site if no significant differences between the two sites or among plots within the sites for a given ambient variable were found. In 1985 and 1986 only air temperatur and precipitation met these criteria.

3) Missing daily plot averages from the ground or antenna site not estimated by the methods outlined in criteria 2 were predicted using regression equations fitted to the observed data from the individual plot and daily averages from the plantation stand type at the adjacent site.

4) Missing plot daily average air temperatures and total precipitation at the control site were estimated from regression equations fitted to the individual observed daily plot averages or site totals and daily observations at the Crystal Falls C#200601 weather station, located 5 miles from the control site, operated by the Michigan Department of Natural Resources in Crystal Falls. Missing plot soil temperature information was estimated using a regression equation fitted to daily average air temperature from the control site and individual plot daily average soil temperatures.

Using these techniques 95% of the missing daily averages or totals could be replaced. Regression equations used in the data replacement along with the related regression statistics are presented in Appendix A (Table

1.1). Coefficients of determination as well as confidence intervals for the equations were well within acceptable limits. A list of days for each site in which missing data was replaced for 1985 and 1986 are presented in Appendix A (1.2 - 1.5)

Data Analysis

Comparisons of site and time differences of the ambient variables generally follow the split-plot in space and time experimental design described in the Introduction. However, due to the variability of soil temperature and moisture in a plot, the plot factor was removed from the experimental design for this element.

The design for this element also includes month of the year as another time factor. This factor along with its associated interaction (Table 1.2) determine if ambient changes occur during a year, if the ambient relationships between sites are constant within a year, and if the ambient relationship between sites are constant over the time period of the study. As mentioned in the data managment section of the element, weekly summaries are the basic unit used in the element. These weekly averages and totals were used as a replicate observation for each month.

Comparison of ambient variables among sites, years, months, etc. were made using analysis of variance tests. Differences between specific months, years, etc., were made using the Student-Newmen-Keuls (SNK) multiple range test after tests with analysis of variance show significant differences for the appropriate factor. Detection limits for each variable were also calculated using this multiple range test. In cases where an adequate number of replicates were not available for analysis of variance testing, pair tests were used to test factor differences.

Table 1.2. Generalized analysis of variance table for Element 1.

Source of Variation	Sum of Squares	Mean Square	F-Ratio
Site	SS_S	MS_S	$MS_S/MS_{E(S)}$
Error (S)	$SS_{E(S)}$	$MS_{E(S)}$	
Stand Type	SS_T	MS_T	$MS_T/MS_{E(ST)}$
Site x Stand Type	SS_{ST}	MS_{ST}	$MS_{ST}/MS_{E(ST)}$
Error (ST)	$SS_{E(ST)}$	$MS_{E(ST)}$	
Years	SS_Y	MS_Y	$MS_Y/MS_{E(SY)}$
Site x Years	SS_{SY}	MS_{SY}	$MS_{SY}/MS_{E(SY)}$
Error (SY)	$SS_{E(SY)}$	$MS_{E(SY)}$	
Stand Type x Year	SS_{TY}	MS_{TY}	$MS_{TY}/MS_{E(TY)}$
Site x Stand Type x Year	SS_{STY}	MS_{STY}	$MS_{STY}/MS_{E(STY)}$
Error (STY)	$SS_{E(STY)}$	$MS_{E(STY)}$	
Month	SS_M	MS_M	$MS_M/MS_{E(MS)}$
Month x Site	SS_{MS}	MS_{MS}	$MS_{MS}/MS_{E(MS)}$
Error (MS)	$SS_{E(MS)}$	$MS_{E(MS)}$	
Year x Month	SS_{YM}	MS_{YM}	$MS_{YM}/MS_{E(YM)}$
Year x Month x Site	SS_{YMS}	MS_{YMS}	$MS_{YMS}/MS_{E(YMS)}$
Error (yms)	$SS_{E(YMS)}$	$MS_{E(YMS)}$	
Stand Type x Month	SS_{TM}	MS_{TM}	$MS_{TM}/MS_{E(TM)}$
Stand Type x Month x Site	SS_{TMS}	MS_{TMS}	$MS_{TMS}/MS_{E(TMS)}$
Error (TM5)	$SS_{E(TMS)}$	$MS_{E(TMS)}$	
Year x Stand Type x Month	SS_{YTM}	MS_{YTM}	$MS_{YTM}/MS_{E(YTM)}$
Year x Stand Type x Month	SS_{YTMS}	MS_{YTMS}	$MS_{YTMS}/MS_{E(TYMS)}$
Error (ytms)	$SS_{E(YTMS)}$	$MS_{E(TYMS)}$	

Progress

This year concludes the second full year of data collection by the ambient monitoring systems. Since operation of the ELF communication system has not begun at this time, progress has been primarily limited to the evaluation of natural climatic differences among the sites, annual climatic changes between years, the climatic relationship between sites over the two year time period, and the detection limits associated with site and year evaluations. The remainder of this element summarizes these comparisons and detection limits for each ambient variable.

Air Temperature (2 m above ground)

Air temperature has a substantial influence on the rate of physiological processes such as photosynthesis, cell division and elongation, chlorophyll synthesis, and enzymatic activity (Kramer and Kozlowski 1978). Thus differences in air temperature between the control and test sites or from one year to the next could have significant effects on vegetation growth and development.

Site Comparisons: Monthly average air temperature of the three sites are presented in Appendix A (1.6). As indicated by these tables and by Figures 1.3 - 1.5 average monthly air temperature during 1985 and 1986 was consistently higher at the control site than at either the ground or antenna sites. Average temperature over the two year study period at the control plantation was 0.6°C higher than at the ground and antenna plantation. While the control pole-size stand type was 0.9°C warmer than the antenna pole-size stand type.

Figure 1.3.

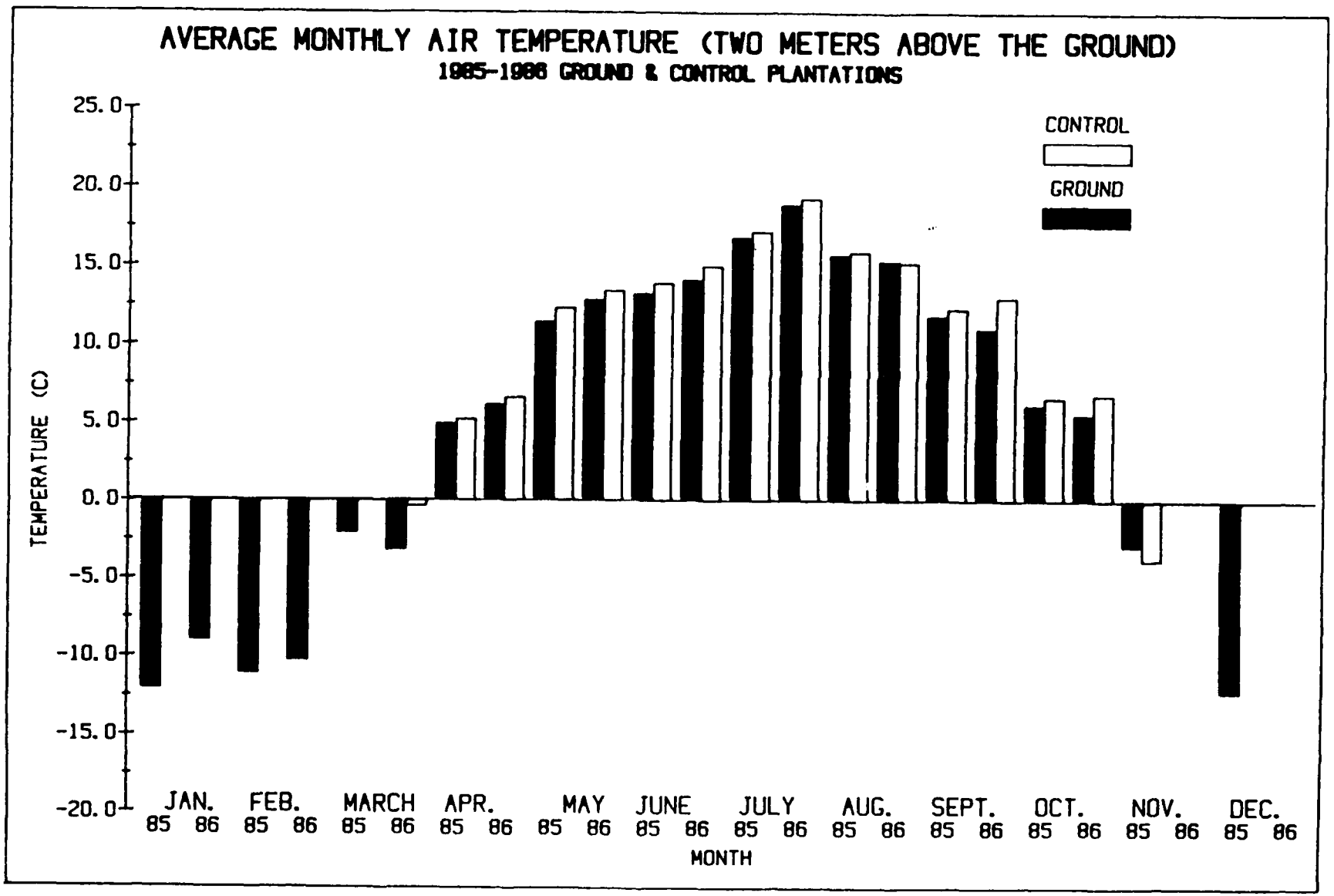

AVERAGE MONTHLY AIR TEMPERATURE (TWO METERS ABOVE THE GROUND)
1985-1986 GROUND & CONTROL PLANTATIONS
CONTROL
GROUND
TEMPERATURE (C)
25.0
20.0
15.0
10.0
5.0
0.0
-5.0
-10.0
-15.0
-20.0
JAN. FEB. MARCH APR. MAY JUNE JULY AUG. SEPT. OCT. NOV. DEC.
85 86 85 86 85 86 85 86 85 86 85 86 85 86 85 86 85 86 85 86 85 86 85 86
MONTH

Figure 1.4.

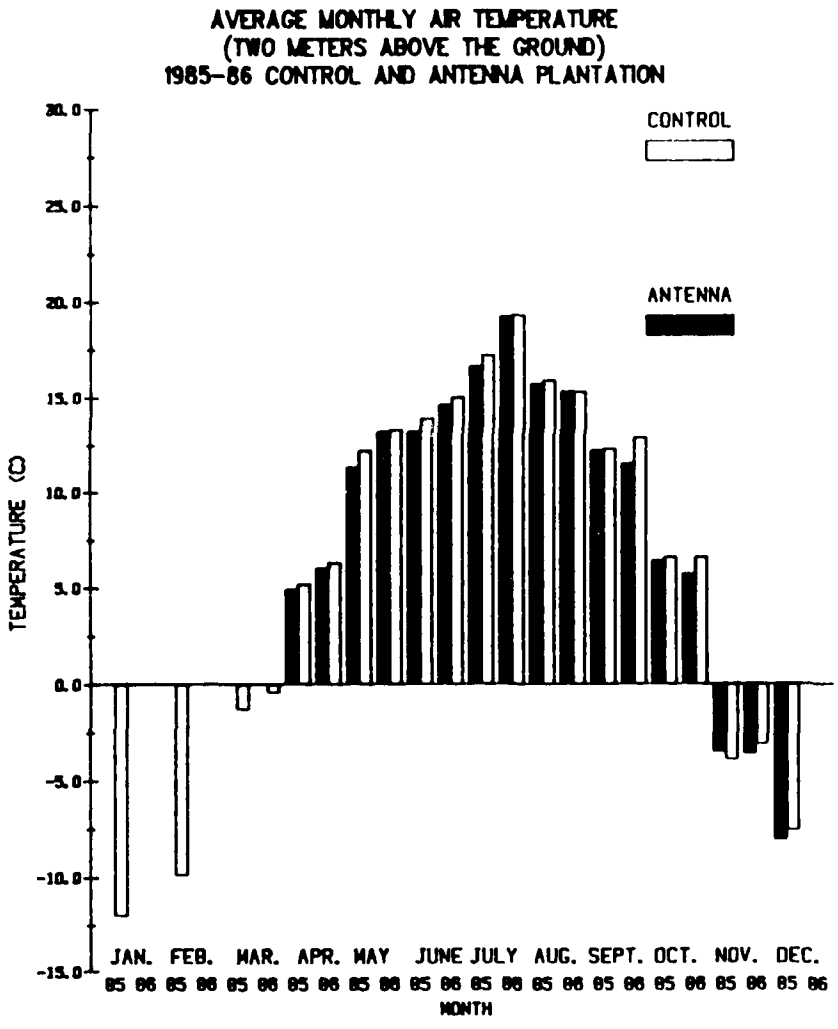


Figure 1.5.

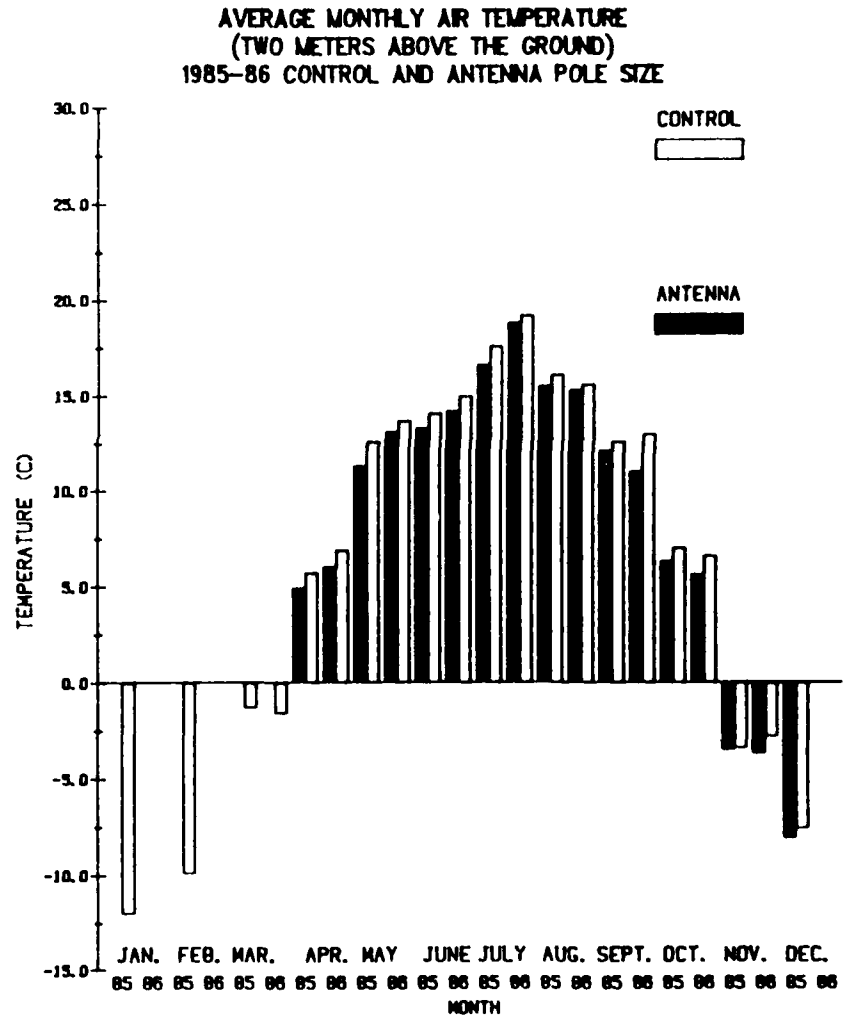


Table 1.3. Average monthly temperature differences between control and test sites for 1985 and 1986 growing season (April - October)

	Plantation		Pole-sized		Plantation	
	1985	**1986**	**1985**	**1986**	**1985**	**1986**
Control	12.1	12.7	12.3	12.9	12.1	12.7
Antenna	11.5	12.1	11.4	12.0	11.4	12.0
Control-Antenna	.6	.6	.9	.9	.7	.7

Although air temperature differences between the control and test sites are consistent within a given year as well as between years, ANOVA tests following the designed outlined in the Introduction of this element showed no significant differences between sites ($p = .05$)

Annual Comparison: Monthly air temperatures in 1986 were consistently higher than in 1985. Monthly averages over the 1986 growing season were .6°C higher for each site-stand type combination.

Table 1.4. Comparison of 1986 growing season average monthly air temperature to 1985 growing season average monthly air temperature.

	Control (°C)		Antenna (°C)		Ground (C)
	Plantation	Pole-size	Plantation	Pole-size	Plantation
1985	12.1	12.3	11.5	11.4	11.4
1986	12.7	12.9	12.1	12.0	12.0
1986-1985	0.6	0.6	0.6	0.6	0.6

These consistent temperature differences indicate that air temperature relationships among sites are extremely stable over time. As with site

comparisons, ANOVA tests showed no significant average air temperature differences between years.

Detection Limits: Although air temperature differences between sites and years appear to be consistent, ANOVA tests found no significant differences. Detection limits calculated from these tests are 100% higher than the observed differences (Table 1.5).

Table 1.5. Detection limits (p = .05) for site and year comparisons of air temperature 2 meters above the ground.

Control vs. Ground

Factor	Detection[1] Limit °C	% Mean[2/]
Site	1.53	12.7
Year	1.06	8.8
Site x Year	2.12	17.7

Control vs. Antenna

Factor	Detection Limit °C	% Mean[2/]
Site	1.44	11.9
Year	1.06	8.7
Year x Site	2.11	17.4
Stand type x Year	.12	.1
Year x Stand type	.204	1.7
Year x Stand type x Site	.36	3.0

[1/] Refer to data analysis section of element.

The high detection limits associated with the experimental design employed in the analysis of variance are a result of the large variation of air temperature within the monthly time interval. In the future instead of using average weekly measurements as replicates they will be nested in months to give more sensitive site and year comparisons.

Soil Temperature

Soil temperature, like air temperature, has a direct influence on plant physiological processes. However, soil temperature also indirectly affects plant growth and development by affecting soil microorganisms responsible for nutrient mineralization and organic matter decomposition. General climatic conditions such as incoming solar radiation, air temperature, and precipitation, as well as the physical characteristics of the mineral soil are the main factors controlling soil temperature.

Soil Temperature (5 cm depth)

Site Comparisons: Average monthly soil temperature at a depth of 5 cm at the control and ground plantations were identical during each growing season of this study (Appendix A, Table 1.6). Although the soil temperature at the ground plantation appeared to warm earlier in the spring than at the control plantation (Figure 1.6), no significant differences were found between sites on a monthly basis ($p = .05$) within any given year.

ANOVA tests indicated no significant differences ($p = .05$) in soil temperature (5 cm) between the control and antenna sites when both stand types were combined. However Figure 1.7 and 1.8 show that site differences are evident when each stand type is compared separately. The antenna plantation is consistently warmer than the control plantation while the control pole-size stand type is warmer than the antenna pole-size stand type. Comparisons of the site treatment interactions showed that the sites were significantly different ($p = .05$) when treatments were compared separately (Table 1.6).

Figure 1.6.

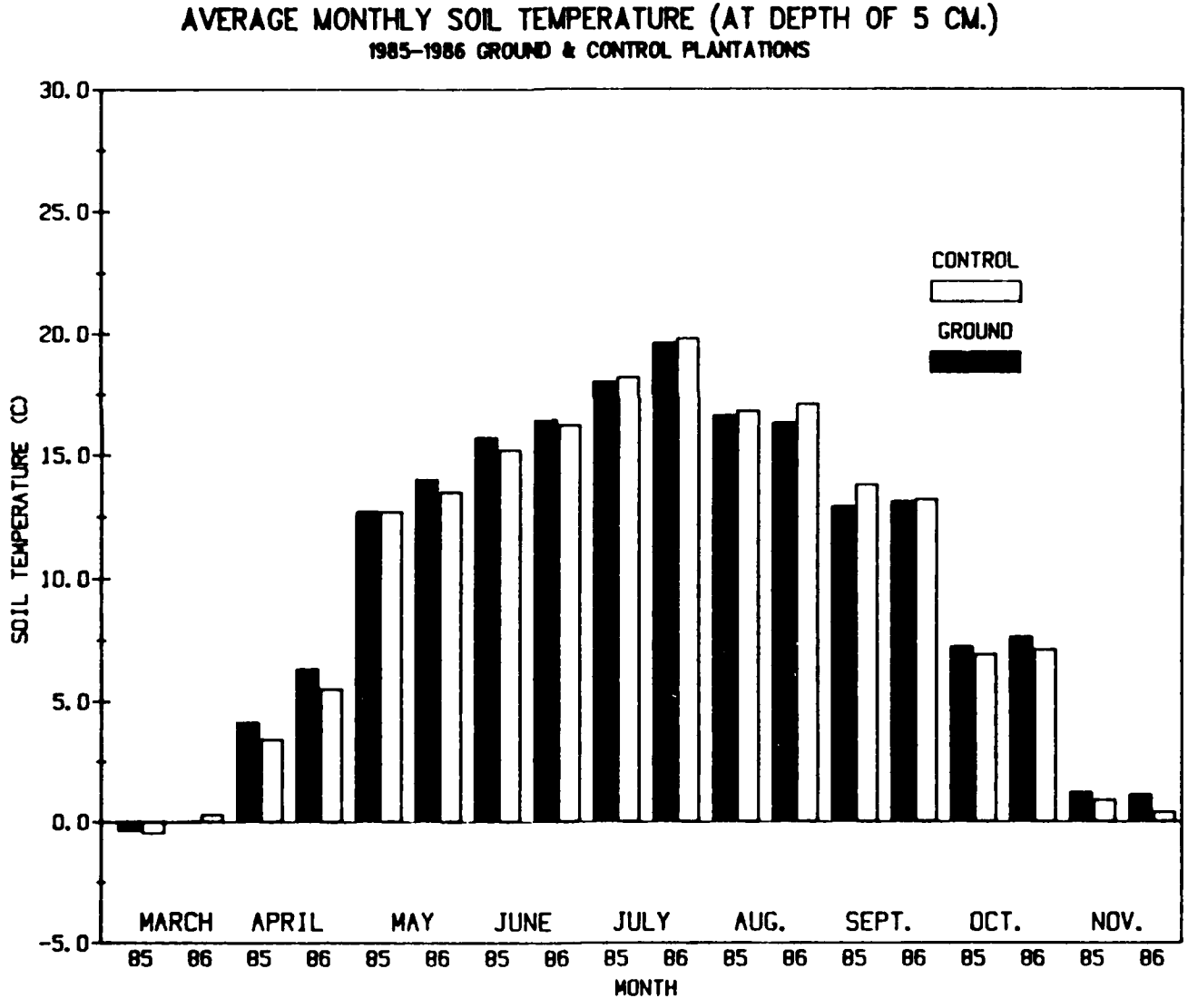

AVERAGE MONTHLY SOIL TEMPERATURE (AT DEPTH OF 5 CM.)
1985-1986 GROUND & CONTROL PLANTATIONS
SOIL TEMPERATURE (C)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
-5.0
CONTROL
GROUND
MARCH
APRIL
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
85 86 85 86 85 86 85 86 85 86 85 86 85 86 85 86 85 86
MONTH

Table 1.6. Comparisons of average monthly soil temperature (5 cm) between control and antenna sites within each stand type.

1985 & 1986 Average Soil Temperature (5 cm)	Stand Type	
	Plantation °C	Pole Size °C
Control	12.9 A	11.3 A
Antenna	13.2 B	10.65 B
Control-Antenna	-0.3	.65

Different letters in a column denotes significant differences (SNK test) between sites for a given stand type.

Site differences appeared to be the greatest at the plantations during the spring and at the pole-size stand type during the latter half of the growing season (Figure 1.7-1.8). However, stand type x month x site interactions were not significant ($p = .05$). Contrasting site relationships on the various stand types appear to be related to a number of factors such as solar radiation reaching the ground, soil moisture, air temperature, vegetation coverage, and litter layer. Thus the effects of ELF electromagnetic radiation on any of these factors could effect soil temperatures on the sites.

Annual Comparisons: Average monthly soil temperature at a depth of 5 cm was found to increase in 1986 compared to 1985 in much of the same manner as air temperature 2 meters above the ground. Soil temperatures were significantly higher ($p = .05$) for each site and stand type in 1986 compared

Figure 1.7.

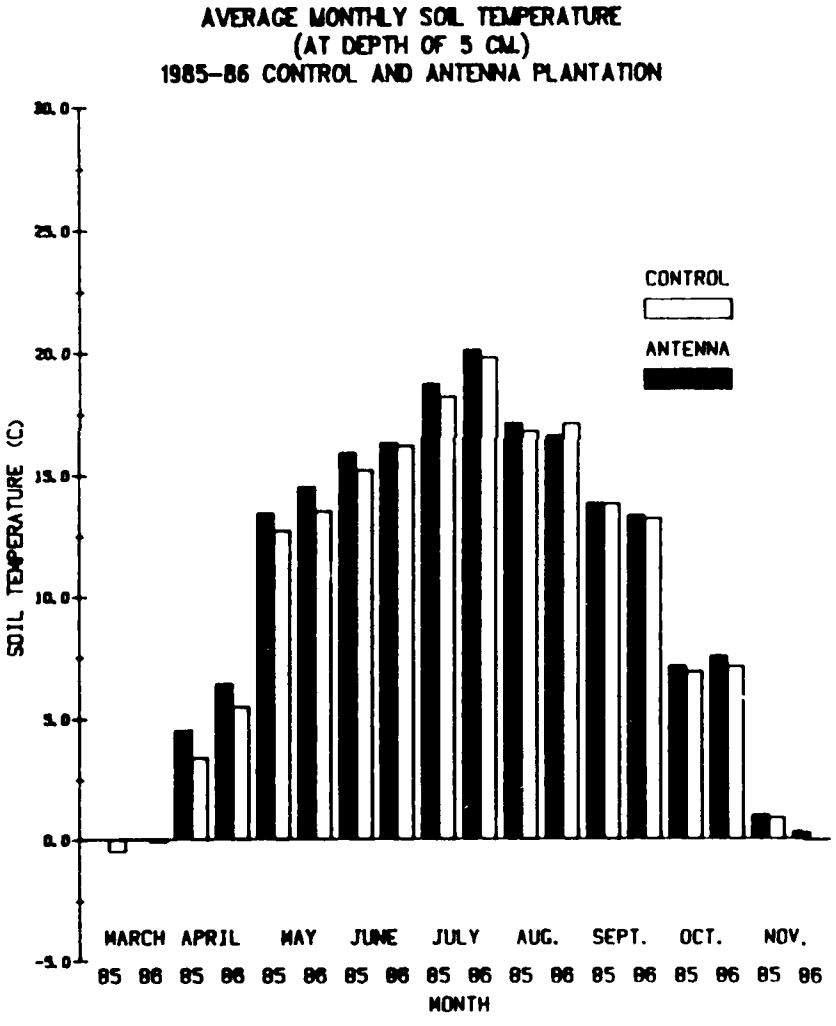
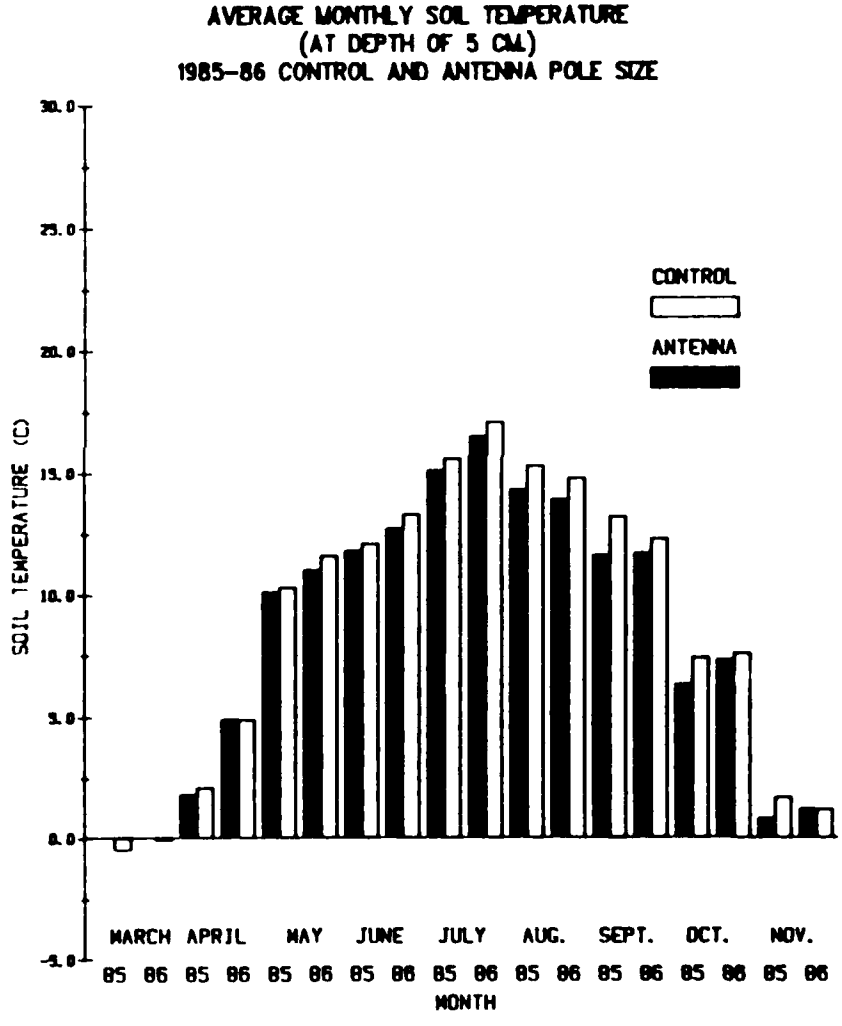


Figure 1.8.



to 1985. Soil temperature increases were more variable among the sites and stand types than they were for air temperature. Table 1.7 presents average monthly soil temperatures at each site and stand type for each year of the study.

With the exception (Table 1.7) of the control and ground plantations, site relationships were unstable. In 1986 the control plantation had a .2°C soil temperature increase compared to the antenna plantation while the control pole-size stand type had a -.3° decrease. These relationships emphasize the relative sensitive response of soil temperature (5 cm) to other climatic factors and vegetational characterstics. Thus, soil temperature (5 cm) may be sensitive to possible ELF reduces ecological changes as a result of ELF.

Detection Limits: Detection limits for soil temperature (5 cm) comparisons are given in Table 1.8. Detection limits for the factors are within an acceptable range. As with air temperature, nesting of weeks within months should improve sensitivity of site comparisons.

Soil Temperature (10 cm depth)

Site Comparison: Soil temperature relationships among sites at a depth of 10 cm were similar to the relationships of soil temperature at 5 cm (Figures 1.9 - 1.11). Soil temperature (10 cm) at the control and ground plantation were not significantly different ($p = .05$) but temperature differences at the control and antenna were significant (Table 1.9).

As found with the soil temperature (5 cm) comparison, apparent differences between sites were greatest during the spring at the plantation and late summer in the pole-size stand type. Stand type x month x site interactions were not significant ($p = .05$).

Table 1.7. Comparisons of soil temperature (5 cm) at each site and stand type for 1985 and 1986, differences between years for a site and stand type, and difference between sites for a stand type.

	Ground Plantation (°C)	Antenna Plantation (°C)	Antenna Pole-size (°C)	Control Plantation (°C)	Control Pole-size (°C)
1985 Growing Season	12.5[A]	12.9[A]	10.1[A]	12.5[A]	10.9[A]
1986 Growing Season	13.3[B]	13.5[B]	11.2[B]	13.3[B]	11.7[B]
1986-1985	.8	.6	1.1	.8	.8

.0[1]

.2

-.3

Yearly average soil temperatures for given site and stand type with the same letter are not significantly different ($p = .05$)

[1]Comparison (control - test site) of annual soil temperature (5 cm) differences between sites for a stand type.

Table 1.8. Detection limits (p = .05) associated with soil temperature (5 cm) comparisons.

Site (Control vs. Ground)

Factor	Detection Limit °C	% Mean
Site	.99	7.6
Year	.53	4.1
Year x Site	.83	6.4

Site (Control vs. Antenna)

Factor	Detection Limit °C	% Mean
Site	.98	8.2
Year	.54	4.5
Stand Type x Site	.25	2.0
Year x Stand Type	.12	1.0
Year x Stand Type x Site	.21	1.8

Figure 1.9.

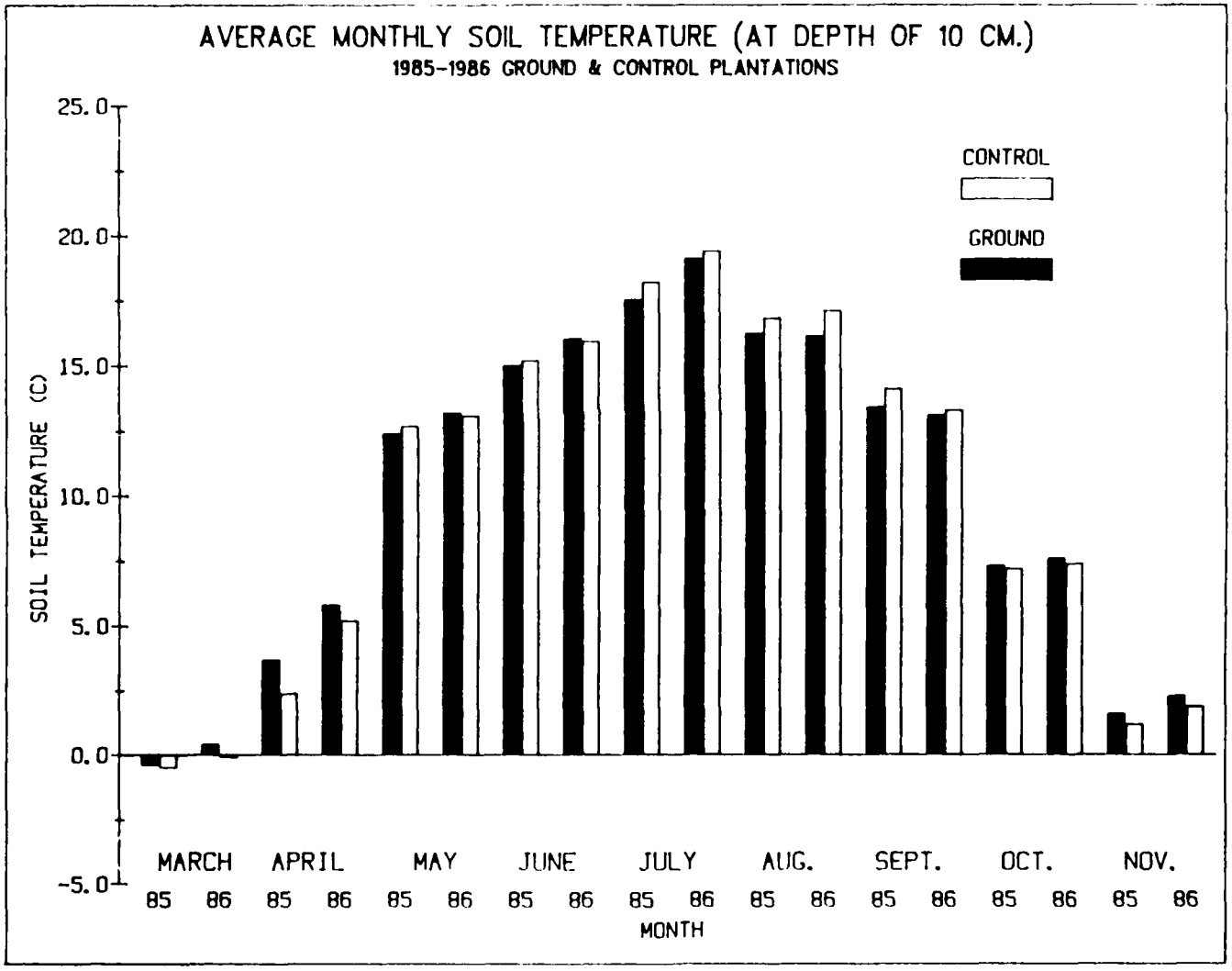

AVERAGE MONTHLY SOIL TEMPERATURE (AT DEPTH OF 10 CM.)
1985-1986 GROUND & CONTROL PLANTATIONS
CONTROL
GROUND
SOIL TEMPERATURE (C)
25.0
20.0
15.0
10.0
5.0
0.0
-5.0
MARCH
APRIL
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
85 86 85 86 85 86 85 86 85 86 85 86 85 86 85 86 85 86
MONTH

Figure 1.10.

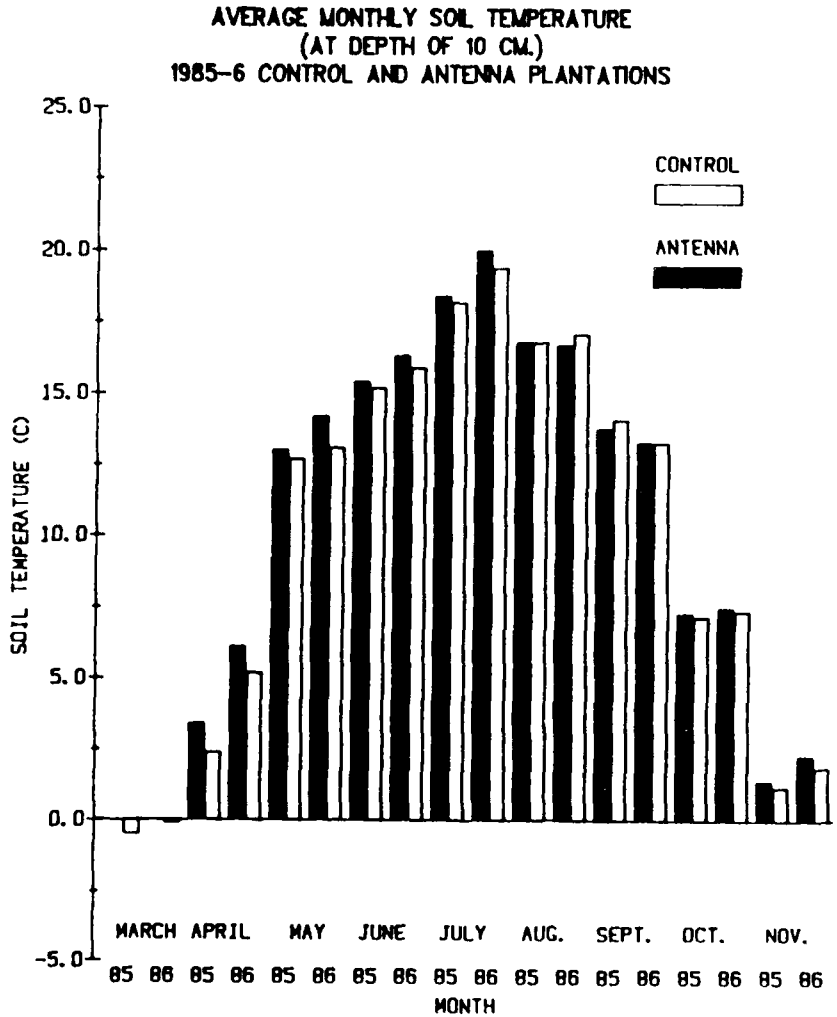


Figure 1.11.

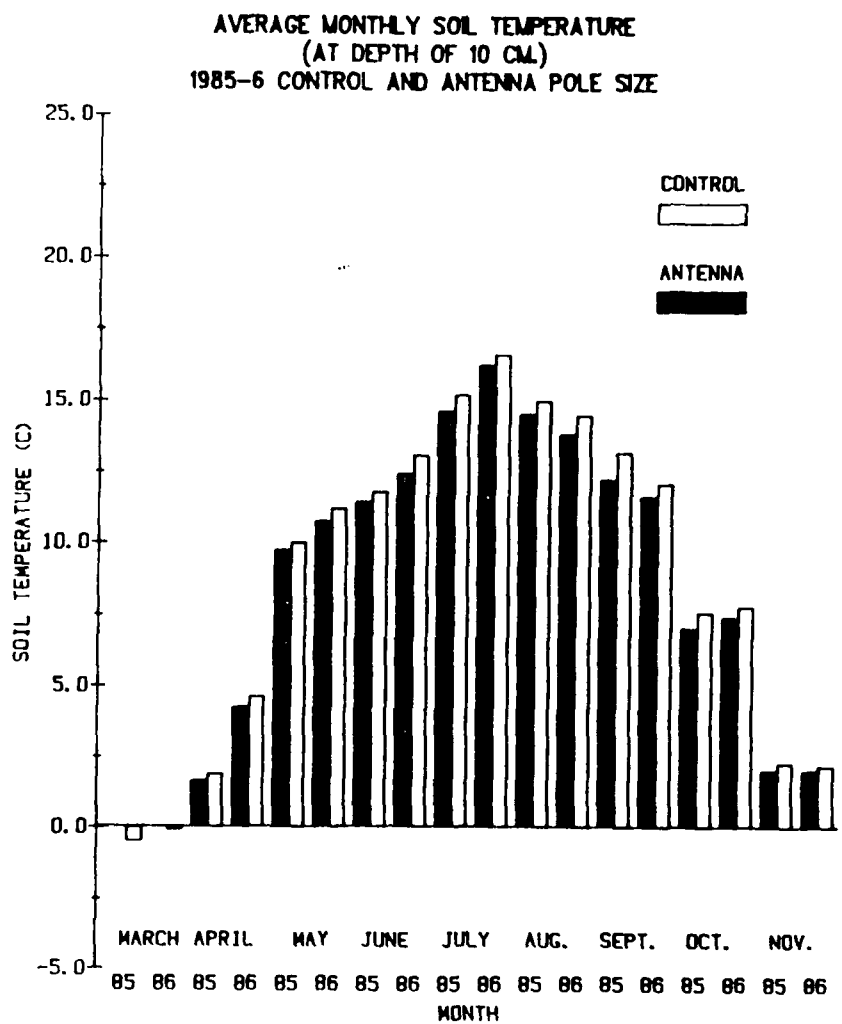


Table 1.9. Site comparison for soil temperature (10 cm) among sites and stand types.

	Plantation °C	Pole-size °C
Control (1985 & 1986)	12.75[A]	
Ground (1985 & 1986)	12.60[A]	
Control-Ground	.15	
Control (1985 & 1986)	12.75[A]	11.15[A]
Antenna (1985 & 1986)	13.05[B]	10.55[B]
Control-Antenna	- .3	+ .6

Site stand type soil temperature averages with the different letters for a specific site comparison are significantly different (p = .05)

Annual Comparisons: Average soil temperature (10 cm) were significantly different (p = .05) between 1985 and 1986. Soil temperature (10 cm) over all sites and stand types average 11.6 in 1985 and 12.4 in 1986. Contrary to results from depths at 5 cm, ANOVA tests of soil temperatures at 10 cm depths showed no significant differences for year x site, year x stand type, or year x stand type x site interactions. Thus, soil temperature (10 cm) site and stand type relationships appear to be more stable over time than these relationships at the 5 cm depth.

Detection Limits: The detection limits associated with soil temperatures at 10 cm are similar to the limits found with the 5 cm depths.

Detection limits were all less than 1°C (Table 1.10) and generally near the precision limits of the sensors.

Table 1.10. Detection limits (p = .05) for site and annual comparison of soil temperatures at 10 cm.

Control vs. Ground Site

Factor	Detection Limit °C	% Mean
Site	.90	7.1
Year	.46	3.6
Year x Site	.93	7.3

Control vs. Antenna Site

Factor	Detection Limit °C	% Mean
Site	.93	7.8
Year	.45	3.8
Year x Site	.90	7.6
Stand type x Site	.23	1.9
Year x Stand type	.11	1.0
Year x Stand type x Site	.20	1.7

Soil Moisture

The amount and availability of soil water is considered a key factor in determining forest site productivity. Water in the soil is the primary media for transportation of nutrients to the plant, and is a reagent in photosynthesis, as well as an essential constituent of cell protoplasm. Apical and radial growth have been shown to be highly correlated to soil

water supply (Zahner 1968). Thus, soil moisture will be an extremely important ambient variable to monitor in the study.

Since new calibration techniques and subsampling procedures were initiated this year, 1985 soil moisture measurements were not included in this report. Thus annual comparisons were excluded from this section and site comparison were only made using the 1986 measurements.

Soil Moisture (5 cm depth)

Site Comparison: Average soil moisture at a depth of 5 cm during the 1986 growing season was significantly higher at the control site compared to the test sites.

Table 1.11. Comparison of soil moisture content (% by weight, 5 cm) among sites.

	Plantation %
Ground	13.0 A
Control	16.0 B
Control-Ground	3.0

	Plantation	Pole Size
Antenna	9.0 A	11.0 A
Control	16.0 B	13.3 B
Control-Antenna	7.0	2.3

Average site soil moisture (5 cm) for a specific stand type and site comparison with the same letters are not significantly different (p = .05)

In all months except August the control site had higher average soil moisture contents at a depth of 5 cm than the test sites. (Figures 1.12 -

Figure 1.12.

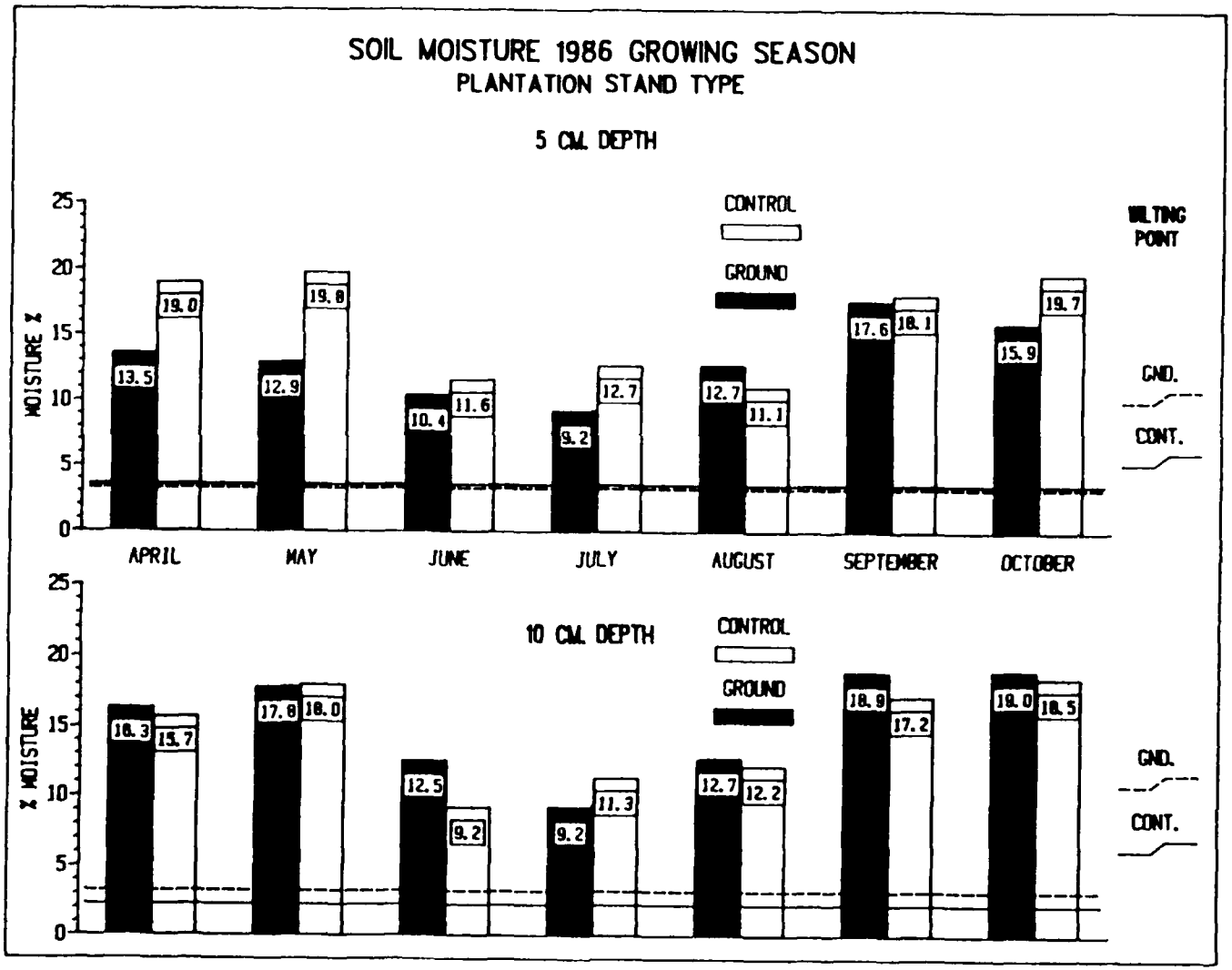
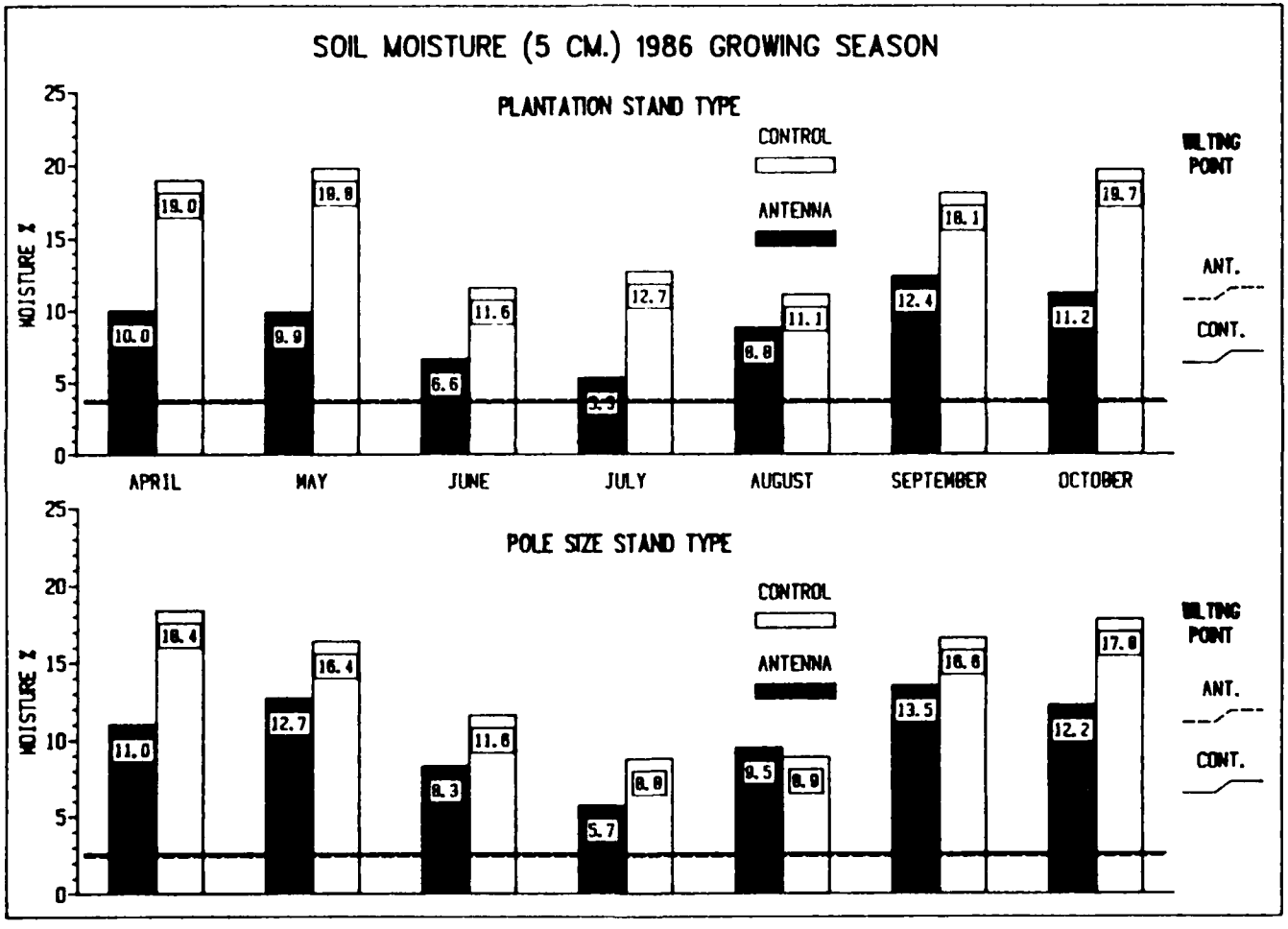

SOIL MOISTURE 1986 GROWING SEASON
PLANTATION STAND TYPE
5 CM. DEPTH
CONTROL
GROUND
WILTING POINT
GND.
CONT.
MOISTURE %
25
20
15
10
5
0
13.5
19.0
12.9
19.8
10.4
11.6
9.2
12.7
12.7
11.1
17.6
18.1
15.9
19.7
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
10 CM. DEPTH
CONTROL
GROUND
% MOISTURE
GND.
CONT.
16.3
15.7
17.8
18.0
12.5
9.2
9.2
11.3
12.7
12.2
18.9
17.2
18.0
18.5

Figure 1.13.


SOIL MOISTURE (5 CM.) 1986 GROWING SEASON
PLANTATION STAND TYPE
CONTROL
ANTENNA
WILTING POINT
ANT.
CONT.
MOISTURE %
25
20
15
10
5
0
10.0
19.0
9.9
19.8
6.6
11.6
12.7
8.8
11.1
12.4
18.1
11.2
19.7
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
POLE SIZE STAND TYPE
CONTROL
ANTENNA
WILTING POINT
ANT.
CONT.
MOISTURE %
11.0
18.4
12.7
16.4
8.3
11.6
5.7
8.8
9.5
8.9
13.5
16.8
12.2
17.8

1.13). Soil moistures at all sites were above the permanent wilting point the entire 1986 growing season.

Detection Limits: Detection limits associated with site comparisons were within 6.0% of the mean (Table 1.12). However detection limits for month comparison between sites (month x site interaction) or month comparisons between site for a stand type (month x site x stand type interactions) were only 20 to 30 percent of the mean.

Table 1.12. Detection limits B (p = .05) for soil moisture at a depth of 5 cm.

Control vs. Ground		
Factor	Detection Limit (%)	% Mean
Site	.71	5.9
Month x site	4.38	31.1
Control vs. Antenna		
Factor	Detection Limit (%)	& Mean
Site	.55	4.4
Stand Type x Site	2.37	19.2
Month x Site	3.05	24.7
Stand Type x Month x site	3.74	30.3

Inclusion of another year ambient information to the testing process should decrease detection limits associated with these interaction terms.

Soil Moisture (10 cm depth)

Site Comparison: Average soil moisture content for each site and month are presented in Appendix A (Table 1.6). Average soil moisture content (10 cm) at the control site during the 1986 growing season was significantly higher than at the antenna site (Table 1.13). However, the average moisture content (10 cm) at the ground site was higher than the average moisture content at the control site. Although the differences in moisture content between the control and ground site were consistent throughout the growing season, site differences were not significant (p = .05).

Table 1.13. Comparisons of average soil moisture at a depth of 10 cm during the growing season among the sites and stand types

Control vs. Ground %

	Plantation
Ground site	15.0 A
Control site	14.1 A
Control-Ground	-.9

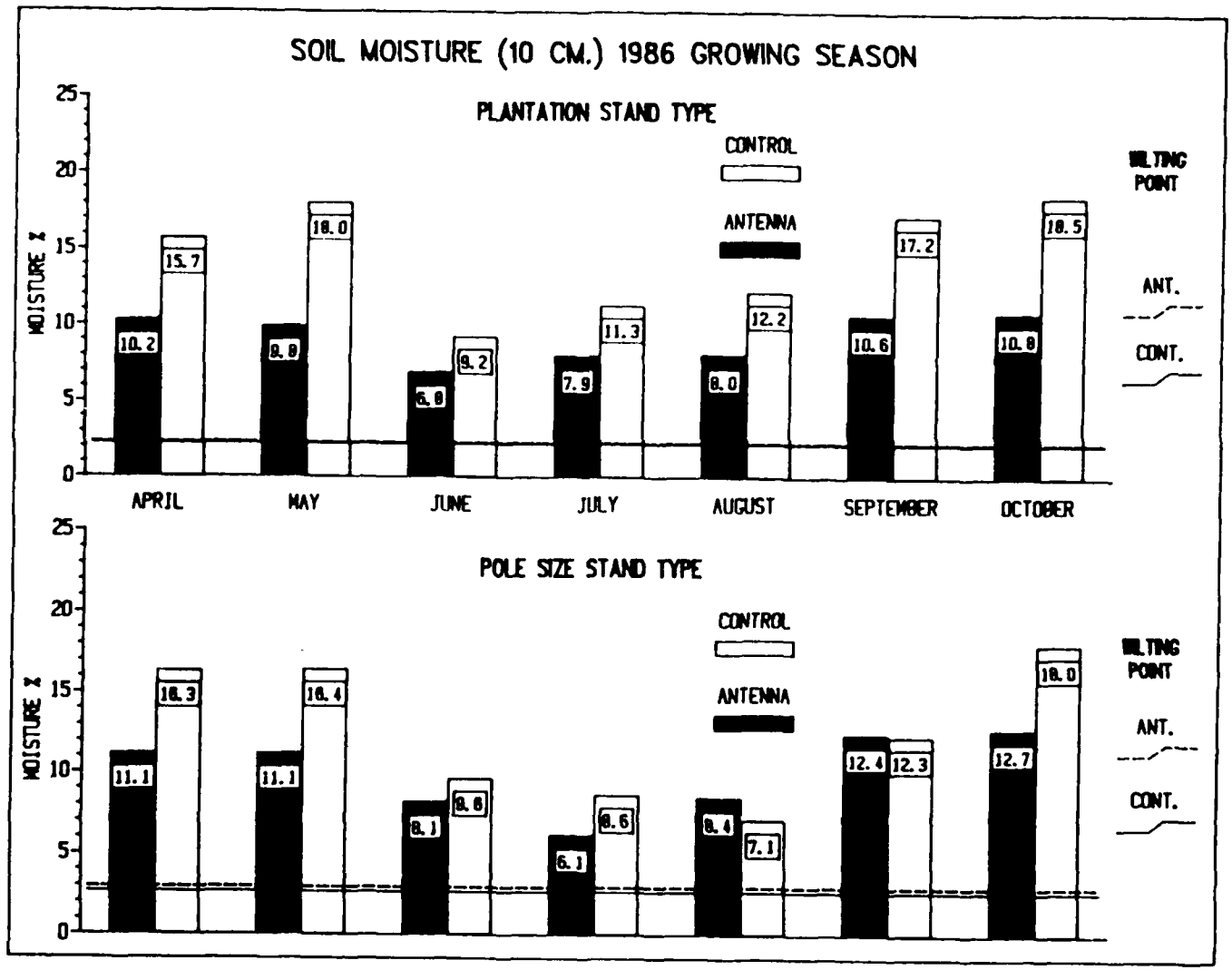
Control vs. Antenna

	Plantation	Pole Size
Antenna site	9.1 A	9.8 A
Control site	14.1 B	12.2 B
Control-Antenna	5.0	2.4

Average site soil moisture (10 cm) for a specific stand type and site comparison with the same letters not significantly different (p = .05)

Generally differences between the control and test sites were greatest during the spring and late fall when moisture was near the field capacity of the soil (Figures 1.12 - 1.14). Thus it would appear that differences in

Figure 1.14.


SOIL MOISTURE (10 CM.) 1986 GROWING SEASON
PLANTATION STAND TYPE
CONTROL
ANTENNA
WILTING POINT
ANT.
CONT.
MOISTURE %
25
20
15
10
5
0
10.2
15.7
9.8
18.0
6.8
9.2
7.9
11.3
8.0
12.2
10.6
17.2
10.8
18.5
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
POLE SIZE STAND TYPE
CONTROL
ANTENNA
WILTING POINT
ANT.
CONT.
MOISTURE %
11.1
16.3
11.1
16.4
8.1
9.6
6.1
8.6
8.4
7.1
12.4
12.3
12.7
18.0

moisture content is a function of the physical differences among the soils at the sites.

Detection Limits: Variation of the soil moisture content (10 cm) appears to be greater than the variation associated with moisture contents at a depth of 5 cm.

Table 1.14. Detection limits (p = .05) for soil moisture at a depth of 10 cm.

Control vs. Ground

Factor	Detection Limit	% Mean
Site	1.26	8.6
Month x Site	4.85	33.3

Control vs. Antenna

Factor	Detection Limit	% Mean
Site	1.06	9.4
Site x Stand type	.36	3.2
Month x Site	4.06	36.1
Stand type x Month x Site	1.86	16.5

Detection limits associated with site difference at a depth of 10 cm. (Table 1.14) are 100% higher than site differences associated with soil moisture content at 5 cm. Additional years of measurement or more sensitive statistical designs outlined in the air temperature section should reduce the detection limits.

Available Water

Although moisture content of soil gives a good indication of the amount of water in the soil, not all of the water contained in the soil is available to plant growth. Water held at a tension below the permanent wilting point (<15 bar) is generally considered unavailable for plant use. Soil moisture content was used to calculate the amount of average daily available water on a 1 cm soil basis for each plot and day using equations from Appendix B.

Available Water (5 and 10 cm)

Site Comparison: Site comparisons made with available water were similar to site comparisons using soil moisture content (Figures 1.15 - 1.17). ANOVA test using available water as the response variable show, as did tests using soil moisture content, that the control site (Table 1.15) has higher amounts of soil water than the antenna (5 and 10 cm) and ground sites (5 cm). However, the relative differences between sites varied in reaction to the response variable (available water or soil moisture content) used for comparison. When the response variable used was available water instead of moisture content differences between the control and test sites plantations increased while differences between the pole size stand types decreased (Table 1.16).

Figure 1.15.

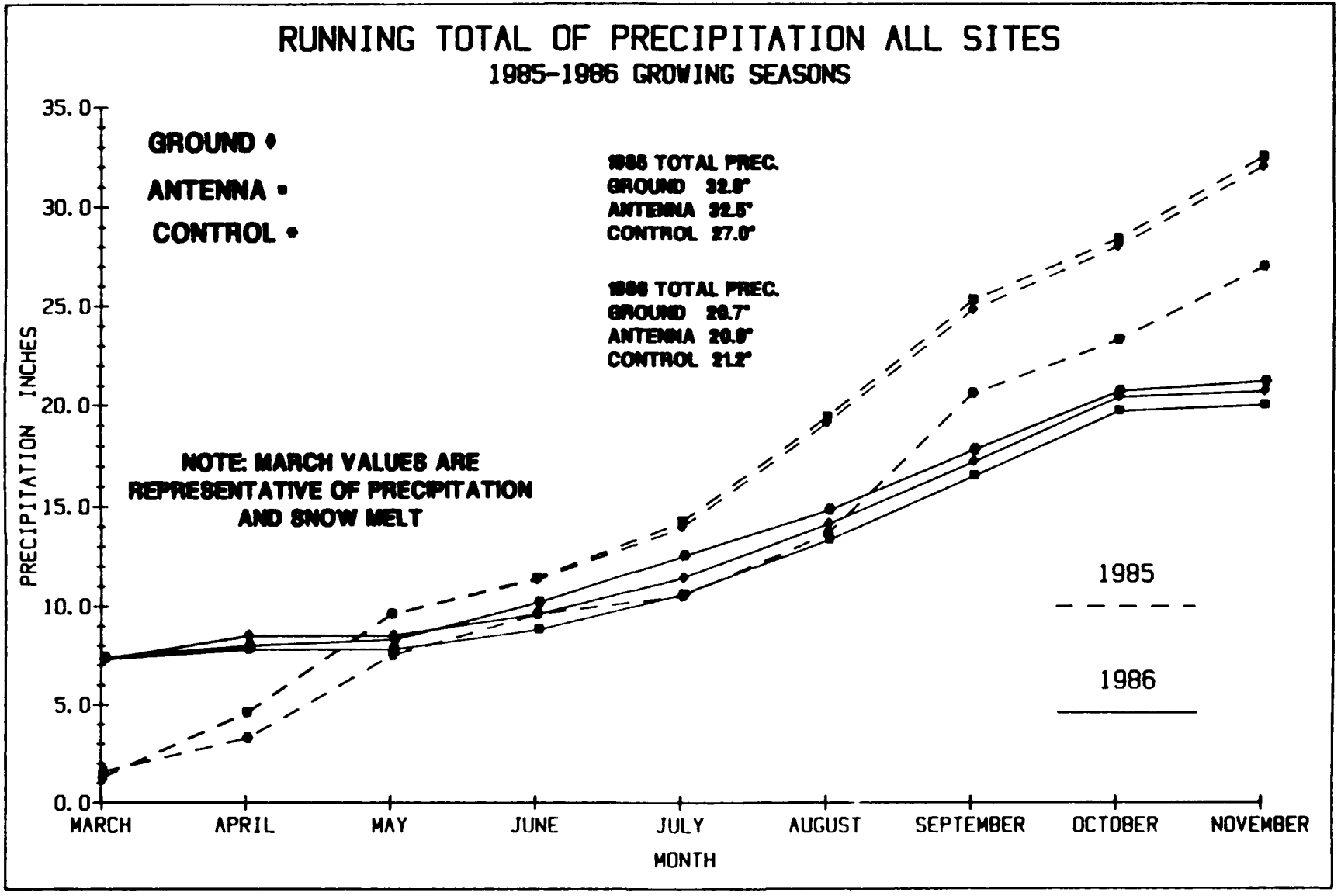

RUNNING TOTAL OF PRECIPITATION ALL SITES
1985-1986 GROWING SEASONS
GROUND •
ANTENNA •
CONTROL •
1985 TOTAL PREC.
GROUND 32.8"
ANTENNA 32.5"
CONTROL 27.0"
1986 TOTAL PREC.
GROUND 20.7"
ANTENNA 20.8"
CONTROL 21.2"
NOTE: MARCH VALUES ARE REPRESENTATIVE OF PRECIPITATION AND SNOW MELT
1985
1986
PRECIPITATION INCHES
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER
NOVEMBER
MONTH

Figure 1.16.

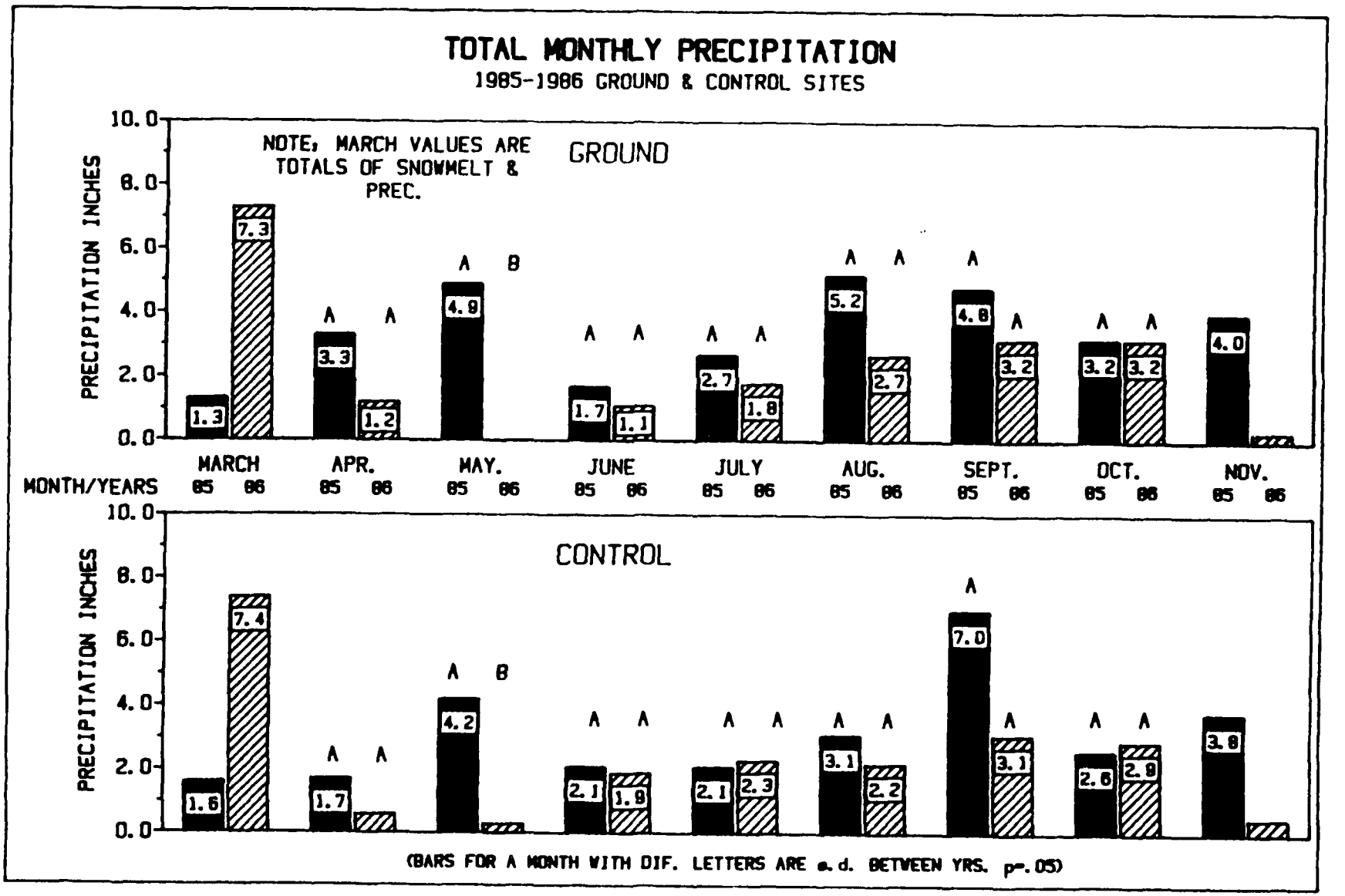

TOTAL MONTHLY PRECIPITATION
1985-1986 GROUND & CONTROL SITES
NOTE; MARCH VALUES ARE TOTALS OF SNOWMELT & PREC.
GROUND
CONTROL
PRECIPITATION INCHES
10.0
8.0
6.0
4.0
2.0
0.0
MONTH/YEARS
MARCH 85 86
APR. 85 86
MAY. 85 86
JUNE 85 86
JULY 85 86
AUG. 85 86
SEPT. 85 86
OCT. 85 86
NOV. 85 86
1.3
7.3
3.3
1.2
4.9
1.7
1.1
2.7
1.8
5.2
2.7
4.8
3.2
3.2
3.2
4.0
1.6
7.4
1.7
4.2
2.1
1.8
2.1
2.3
3.1
2.2
7.0
3.1
2.6
2.9
3.8
A B
(BARS FOR A MONTH WITH DIF. LETTERS ARE s.d. BETWEEN YRS. p=.05)

Figure 1.17.

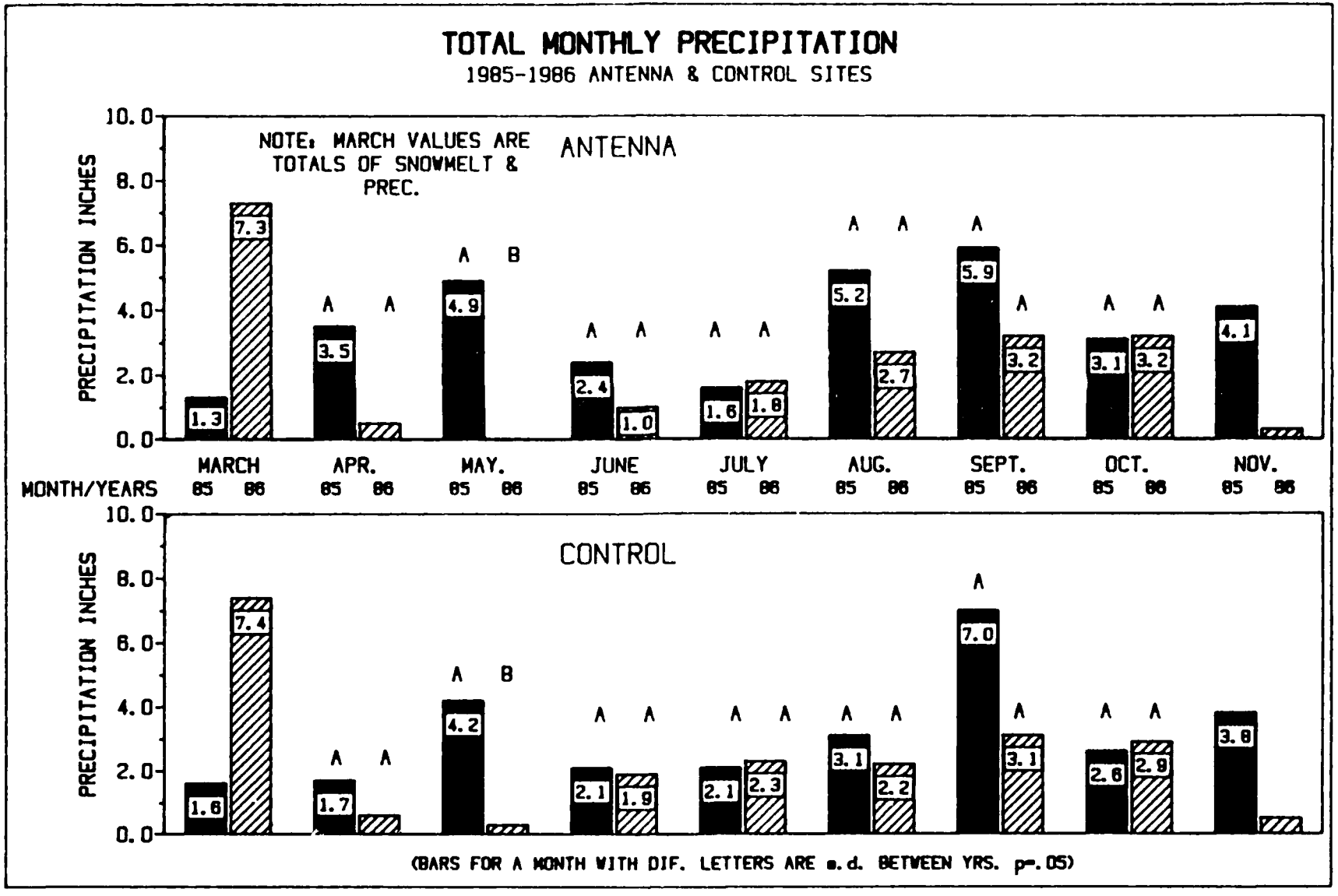

TOTAL MONTHLY PRECIPITATION
1985-1986 ANTENNA & CONTROL SITES
NOTE: MARCH VALUES ARE TOTALS OF SNOWMELT & PREC.
ANTENNA
PRECIPITATION INCHES
10.0
8.0
6.0
4.0
2.0
0.0
1.3
7.3
3.5
4.9
2.4
1.0
1.6
1.8
5.2
2.7
5.9
3.2
3.1
3.2
4.1
MARCH
APR.
MAY.
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
MONTH/YEARS
85 86
CONTROL
1.6
7.4
1.7
4.2
2.1
1.9
2.1
2.3
3.1
2.2
7.0
3.1
2.6
2.9
3.8
(BARS FOR A MONTH WITH DIF. LETTERS ARE s.d. BETWEEN YRS. p=.05)

Table 1.15. Average available water (cm water/cm soil) for each site and stand type during the 1986 growing season.

Available Water (cm/cm of soil)

	Plantation (5 cm depth)	Plantation (10 cm depth)
Ground	.12 A	.14 A
Control	.18 B	.15 A
Control-Ground	.06	.01

	Plantation (5 cm depth)	Pole Size (5 cm depth)	Plantation (10 cm depth)	Pole Size (10 cm depth)
Antenna	.07 A	.9 A	.10 A	.9 A
Control	.18 B	.15 B	.16 B	.12 B
Control-Antenna	.11	.06	.06	.03

Average site available water for a specific stand type, depth, and site comparison with the same letters are not significantly different at ($p = .05$)

Table 1.16. Differences among sites using available water and soil moisture content expressed as a % of test site average

	Soil Moisture Content	
	Plantation	Plantation
	5 cm	5 cm
Control-Ground / Ground	23.1%	-6.0%
	Plantation Pole Size	Plantation Pole Size
	(5 cm)	(10 cm)
Control-Antenna / Antenna	77.8% 20.9%	54.9% 24.5%
	Available Water	
	Plantation	Plantation
Control-Ground / Ground	50.0%	7.1%
	Plantation Pole Size	Plantation Pole Size
Control-Antenna / Antenna	157% 6.7%	60% 3.3%

Available water is more closely related to tree growth than soil moisture content, thus available water should more accurately depict actual site and annual productivity relationships. Since the wilting points of each site stand type are very similar, differences between site relationships with respect to soil moisture content and available water is due to differences in field capacity, rock fraction, and or bulk density of the soils on the sites.

Detection Limits: The detection limits associated with available water site comparisons are higher than limits associated with soil moisture content (Table 1.17). This is a result of additional variation among sites

related to soil factors used for calculating available water. Although available water may be more accurately related to vegetational development of the sites than moisture content, variation associated with the available water may make it less sensitive to site and yearly comparisons.

Table 1.17. Detection limits (p = .05) for available water at 5 and 10 cm.

Factor	Detection Limit	% Mean
Control vs. Ground		
	5 cm	
Site	.010	6.4
Month x site	.071	48.5
	10 cm	
Site	.018	12.3
Month x site	.059	41.3
Control vs. Antenna		
	5 cm	
Site	.019	14.9
Site x stand type	.022	17.3
Month x site	.057	44.6
Stand type x month x site	.128	100.0
	10 cm	
Site	.010	9.0
Site x stand type	.013	11.6
Month x site	.045	40.3
Stand type x month x site	.037	33.1

Precipitation

The amount of precipitation received and the distribution of precipitation over time are is one of the primary factors controlling the amount and timing of the availability of water for plant growth. Thus,

precipitation, like soil moisture, affects plant growth both directly and indirectly in a number of ways.

Site Comparisons: Total precipitation received among the sites appears to be homogenous (Figure 1.15). In 1986 there was a .5 inch difference between the sites which receive the greatest (control) and the least (ground) amounts of precipitation. ANOVA tests showed no significant differences, ($p = .05$) in average monthly precipitation received among the sites during the growing season (Table 1.18).

Table 1.18. Average monthly precipitation at each site during the growing season (inches).

Ground	Antenna	Control
2.84a	2.82a	2.50a

Monthly averages with the same letter are not significantly different ($p = .05$).

Annual comparisons: During 1985 total precipitation was respectively 11.5, 11.6, and 5.8 inches greater at the ground, antenna, and control sites than in 1986. This was an extremely large decrease considering that there was a 500% increase in water received as snow melt in 1986 compared to 1985. Thus, total precipitation received during the 1986 growing season was close to 50% less than during the 1985 growing season (Table 1.19)

Table 1.19. Comparison of average monthly precipitation during the 1985-1986 growing seasons at each site.

	Average Monthly (Ground)	Total	Average Monthly (Antenna)	Total	Average Monthly (Control)	Total
1985	3.81A	26.67	3.87A	27.09	2.10A	21.70
1986	1.87B	13.04	1.77B	12.39	1.90B	13.30
1985-1986	-1.94	13.58	-2.10	14.60	-1.73	8.40

Monthly averages for a site with the same letter are not significantly different (p = .05).

Difference in monthly precipitation between years were significant (p = .05) for all sites. Decreases in rainfall during May of 1986 compared to 1985 accounted for 33% to 50% 1985-1986 yearly difference of rainfall at each site (Figure 1.16 and 1.17). Multiple range tests (Figure 1.16 - 1.17) indicated the differences in annual rainfall during the growing seasons were primarily due to differences in May rainfall.

Detection Limits: Due to the limit of only one of precipitation sensor at each of the sites, detection limits for site and annual comparisons are high (Table 1.20). Although the detection limits associated with this analysis are high, the amount of rainfall over a given site (2-4 hectares) is extremely homogenous. Thus, measurements from only one rain sensor per site will be adequate for covariate analyses in the elements of the Upland Flora project.

Table 1.20. Detection limits associates with monthly precipitation during 1985-1986 growing seasons (inches).

Factor	Detection Limits	% Mean
Control vs. Ground		
Site	.48	18.0
Year	.23	8.6
Site x Year	.61	22.9
Control vs. Antenna		
Site	.49	18.3
Year	.28	10.5
Site x Year	.55	20.6

Nutrient Concentrations of Precipitation

As part of the ambient montoring program the nutrient concentrations of rainwater samples were determined to estimate nutrient inputs from precipitation at all three sites during the growing seasons. A collection bucket having a fitted funnel attachment was placed on one plantation plot at each study site. The buckets were checked once a week and if rainfall had occurred a water sample was removed for nutrient analysis. Phenolmercuric acetate was added to each bucket to prevent nutrient changes due to microbial activity prior to collection. The water samples were frozen and stored at -7.8°C until chemical analysis. Cation concentrations were detemined on a Perkin-Elmer Model 5000 atomic absorption spectrometer. Anions were analyzed on a Dionex Model 10 chromatograph.

Average yearly cation concentrations were higher in 1986 than in 1985 but no differences were found for NO_3 and SO_4 (Table 1.21). However, there

were no significant concentration differences for any of the nutrients analyzed among the three study locations for either year. Total nutrient additions/site are being calculated from weekly nutrient concentration values and rainfall amounts, and will be presented in the next annual report.

Table 1.21. Average nutrient concentrations of rainwater at the three ELF study sites.*

	PPM				
Site	Ca	Mg	K	NO_3	SO_4
		1985			
Ground	1.48	0.31	0.64	1.41	3.21
Antenna	1.92	0.31	0.62	1.55	3.54
Control	1.78	0.36	0.83	1.61	3.67
Average	1.74^A	$.31^A$	$.70^A$	1.53^A	3.49^A
		1986			
Ground	2.25	0.83	1.25	1.77	3.67
Antenna	2.64	0.77	1.24	1.54	3.35
Control	2.17	0.65	0.96	2.04	4.24
Average	2.34^B	$.75^B$	1.03^B	1.80^A	3.79^A

* PO_4 concentrations were analyzed but were less than 0.1 ppm for all samples.

Values for a given cation with same letter not significantly different at $p = .05$.

Global Solar Radiation

Solar radiation is the primary energy source for photosynthesis as well as the primary factor controlling climatic conditions. Thus the measurement of solar radiation is essential to the project.

Annual Comparisons: Average daily global solar radiation during the 1985 and 1986 differed by 27.0 langleys/day. Differences between years were not significant, however monthly averages for July were sigificantly different between the two years. Global solar radiation during July in 1985 averaged 553.6 compared to 387.8 langleys/day in 1986 (Figure 1.18).

Detection Limits: The amount of the global solar radiation reaching the canopy of vegetation is dependent on cloud cover and other atmospheric particulates which reflect solar radiation. Variation is extremely high on a daily and weekly basis. Thus, detection limits associated with annual comparisons for this variable are relatively high compared to analyses made with other climatic variables (Table 1.22)

Table 1.22. Detection limits (p = .05) associated with global solar radiation analyses.

Factor	Ground Site Detection Limits (langleys/day)	% Mean
Year	75.3	19.8%
Year x Month	156.3	41.9%

Although detection limits for year x month interactions are 41% of the mean, significant differences were found between 1985 and 1986 July averages.

Figure 1.18.

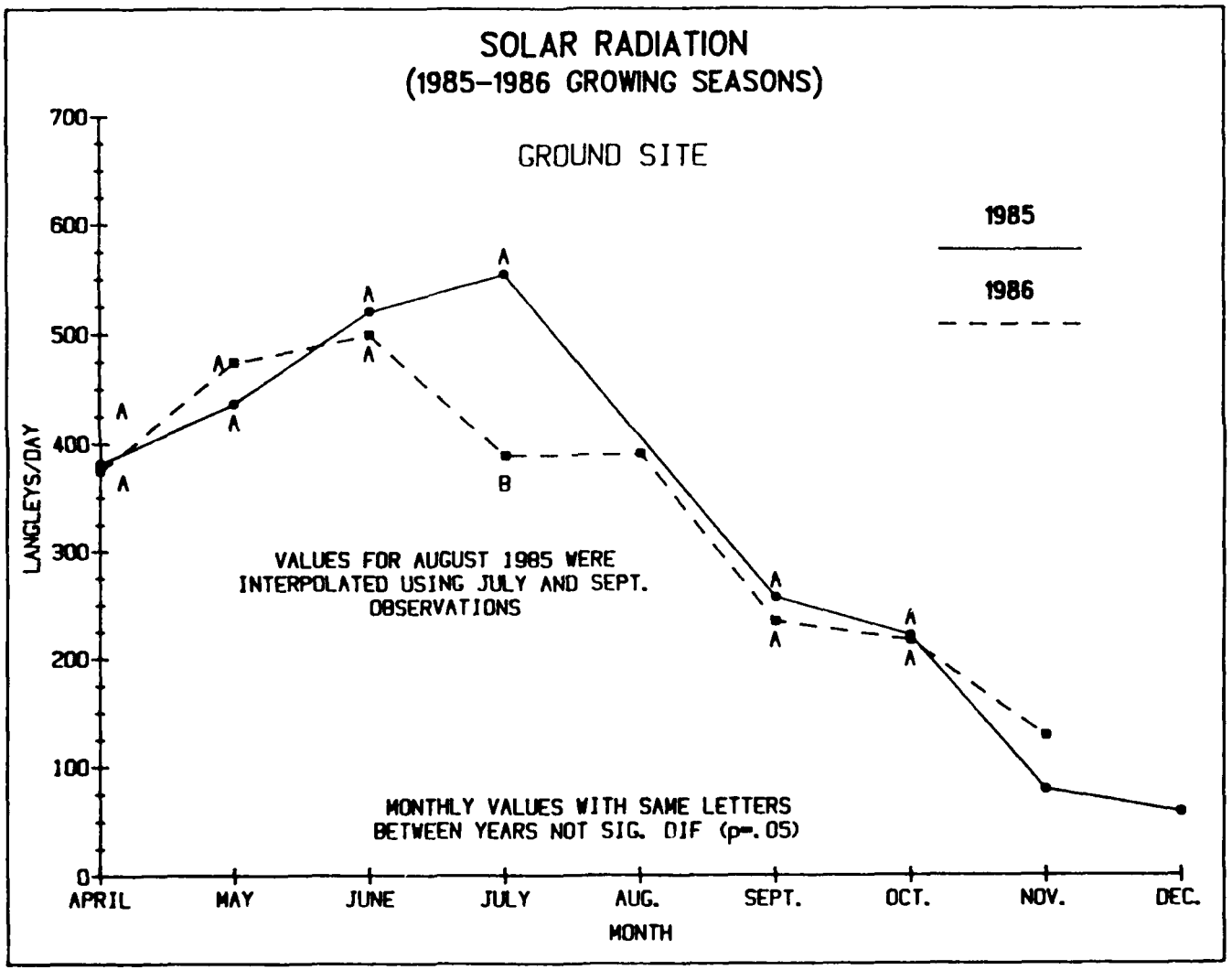
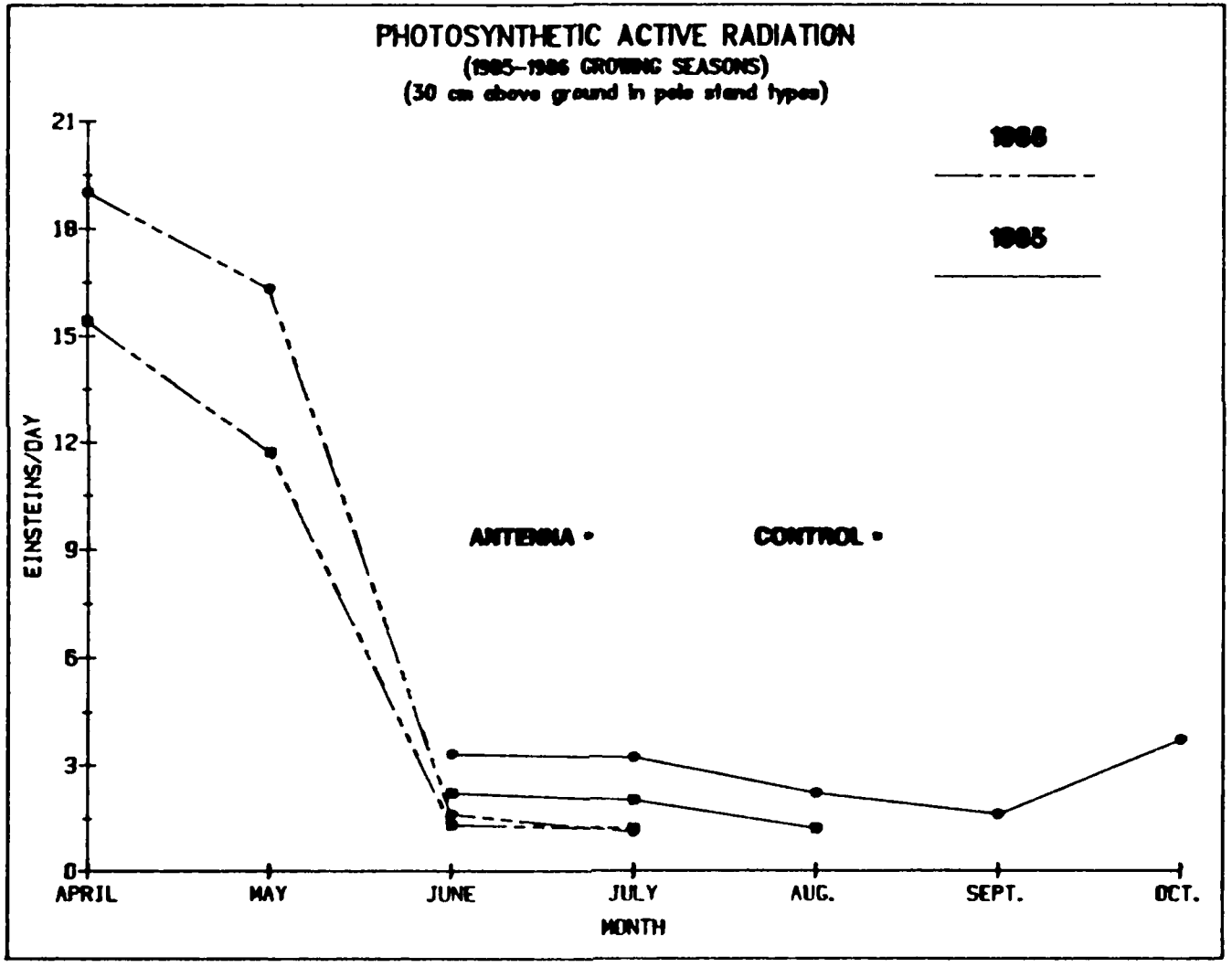

SOLAR RADIATION
(1985-1986 GROWING SEASONS)
GROUND SITE
1985
1986
LANGLEYS/DAY
700
600
500
400
300
200
100
0
A
A
A
A
A
B
A
A
A
A
VALUES FOR AUGUST 1985 WERE
INTERPOLATED USING JULY AND SEPT.
OBSERVATIONS
MONTHLY VALUES WITH SAME LETTERS
BETWEEN YEARS NOT SIG. DIF (p=.05)
APRIL
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
NOV.
DEC.
MONTH

Figure 1.19.


PHOTOSYNTHETIC ACTIVE RADIATION
(1985-1986 GROWING SEASONS)
(30 cm above ground in pole stand types)
1986
1985
ANTENNA •
CONTROL •
EINSTEINS/DAY
21
18
15
12
9
6
3
0
APRIL
MAY
JUNE
JULY
AUG.
SEPT.
OCT.
MONTH

Relative Humidity

Due to repairs in sensors during 1985 and the lightning strike at the control site 1986, platform in 1986, site comparisons or annual comparisons can not be made at this time. For the present, work is focusing on developing equations to predict missing relative humidity measurements at the control site from relative humidity measurements taken at the Crystal Falls weather station.

Vegetation Air Temperature (30 cm above the ground) and Photosynthetically Active Radiation PAR)

Air temperature (30 cm above the ground) and photosynthetically active radiation (300nm - 700 nm) are being measured in the pole-size tree plots for use by the herbaceous phenology study. Typically these sensors give a more accurate measurement of climatic variables at the ground - air interface than sensors discussed previously.

Site and annual comparisons: Air temperature (30 cm) for the two-year period averaged 11.8°C during the growing season at the antenna pole-size stand type and 12.5°C at the control pole-size stand type. These differences were found not to be significant. Likewise, annual changes were small (1986 - 1985 antenna .7°C and control .6°C) and not significantly different. Site relationships of air temperature (30 cm) were extremely stable over the two year period. The difference between the average temperature of the two sites during the growing season in 1985 was .7°C and in 1986 .6°C. This stable site relationship and the location of the sensors in the pole size stand type makes it a possible indicator of ELF effects on the microclimate.

Detection Limits: Air temperature is extremely variable on a daily and weekly basis. This variation is highest in early spring and fall when daily averages may differ by 10 to 15 °C. Thus, detection limits associated with air temperature at 30 cm are large in comparison to other climatic variables. (Table 1.23).

Table 1.23. Detection limits (p = .05) for air temperature 30 cm above the ground in the pole-size stand type °C.

Factor	Confidence Limits	% Mean
Site	1.86	15.3
Year	.58	4.7
Site x Year	1.15	9.5

Photosynthetically Active Radiation (30 cm above ground in the pole-sized stand type

Site comparisons: Comparison of sites for PAR is limited to the months of April, May, June, and July due to the down time of the platforms. Since PAR sensor operation did not begin until June of 1985 the site comparisons were also limited to only 1986. As seen in Figure 1.19 PAR is drasticaly reduced in June when leafout occurs in the pole-size stand. In 1986 the four month average PAR at the control site was 9.5 einsteins/day compared to 7.4 einsteins/day at the antenna. Differences between sites for these four months in 1986 were not significant.

Detection Limits (PAR): Table (1.24) presents the detection limits for (PAR). Variation of PAR values makes detection limits associated with the site factors large. Inclusion of next year measurements should decrease detection limits of this variable.

Table 1.24. Detection limits of PAR in 1986 (antenna and control).

Factor	Confidence Limits	% Mean
Site	3.5	37.2
Site x Month	9.7	102.3

Future Considerations

Experimental Design and Missing Data Replacement

An experimental design which nests weekly measurements into the monthly factor will be evaluated in the near future. This design will decrease detection limits associated with ambient variables which are extemely variable on a daily and weekly basis, while preserving the monthly comparisons.

Increased effort will be placed on developing equations used in replacing missing ambient information. A refinement of these types of equations will decrease variation of the predicted variables and enhance the quality of the ambient database.

ELEMENT 2. TREE PRODUCTIVITY

Tree growth is sensitive to a variety of environmental disturbances. In order to detect any changes in growth due to site disturbance, 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. The installation of permanent dendrometer bands on the stem of a tree allow measurements of minute changes (0.008 cm) in diameter over a short time interval (Husch et al. 1982). Two additional advantages in using dbh as a measurement of tree growth are the responsiveness of cambial activity to environmental effects (Smith 1962) and the strong correlation existing between dbh and total biomass of the tree (Crow 1978). Consequently, measurement of diameter increment is the primary response variable for assessing ELF fields on 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 examined by monitoring tree reproduction and mortality. Stand structure (the distribution of trees by diameter classes) changes from year to year due to natural growth, reproduction, and mortality of trees. Any environmental disturbances could produce an effect on these two factors. Thus, ingrowth and mortality are being monitored and recorded in order to distinguish natural changes from those caused by site disturbances. Therefore, to achieve a complete picture of possible ELF effects on the tree and stand production dbh, height, ingrowth and mortality are being measured.

In addition to tree productivity in pole-sized stands, regeneration studies involving planted red pine seedlings are being conducted on the

ground, antenna, and control sites. This study was initiated in response to a need for a larger number of conifers in the ectomycorrihizal studies (Element 6) as well as for the Michigan DNR concerns on forest regeneration. Since young trees often exhibit rapid growth rates, possible ELF field effects on these seedlings may be more easily detected than in older trees. Again, as in the case of trees in the pole-sized hardwood stands, dbh, height, and mortality are being measured.

Hardwoods

Diameter increment is the primary response variable for assessing effects of ELF in the pole-sized hardwood stands located on the antenna and control study sites. Permanently installed dendrometer bands allow continual measurements 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.

Pole-sized hardwood stands on both study sites are classified in the Acer-Quercus-Vaccinium habitat type (Coffman et al. 1983). Those species common to both sites and considered in the analysis include northern red oak (Quercus rubra), paper birch (Betula papyrifera), bigtooth aspen (Populus grandidentata), 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 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 level or the pattern of seasonal diameter growth before and after the ELF antenna becomes operational.

Table 2.1. Summary of pole-sized stand information for the antenna and control sites at the beginning of the 1986 growing season.

SPECIES	Average DBH (cm)	Average Basal Area (m^2/ha)	Number of Stems Per Hectare	Site Index	Age (yrs)
Antenna					
Northern Red Oak	22.69	6.57	143	68	46
Paper Birch	20.42	0.86	25	66	54
Aspen[A/]	25.37	2.43	48	68	49
Red Maple	15.23	7.78	410	56	41
Control					
Northern Red Oak	20.82	20.00	556	72	51
Paper Birch	16.30	2.92	127	60	53
Aspen	22.82	3.33	79	65	54
Red Maple	11.85	0.52	48	58	44

[A/] The two aspen species are combined.

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

	1984	1985	1986	1987[A/]
Antenna				
Northern Red Oak	22.18	22.45	22.69	22.88
Paper Birch	20.02	20.22	20.42	20.56
Aspen[B/]	24.59	25.01	25.37	25.67
Red Maple	14.87	15.09	15.23	15.33
Control				
Northern Red Oak	20.45	20.62	20.82	20.97
Paper Birch	16.12	16.23	16.30	16.36
Aspen	22.21	22.55	22.82	23.03
Red Maple	11.37	11.64	11.85	12.01

[A/] Values given for the beginning of the 1987 growing season were taken in the fall of 1986.

[B/] The two aspen species are combined.

Each year prior to a fully operational system, a baseline of each stand's structure and the relationship between the two sites will be established through tests of the following hypothesis:

H_0: There is no difference in the level or the pattern of seasonal diameter growth between the antenna and control sites within a year.

Tests of rate or distribution of diameter growth are made using the diameter growth model discussed later in this section. Changes in the parameters of the growth model will be examined prior to antenna operation to test the above hypothesis. This test for differences in growth model parameters will indicate whether or not different seasonal growth patterns are occurring on the different sites. Similar procedures will be used to detect changes in seasonal growth pattern after the antenna is operational. Differences in level or amount of seasonal diameter increment are detected through analysis of the split plot in space and time design. Assuming the covariate changes over time, the ANOVA table used in this study is found in Table 2.3. If the covariate does not change over time, the second covariate term in the ANOVA table drops out and the degrees of freedom for the Error (SY) increases by the number of covariates.

Sampling and Data Collection

To monitor diameter growth at both sites, permanent dendrometer bands were installed in 1984 on all trees greater than or equal to 10 cm at 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.

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

Source of Variation	df	SS	MS	F
Covariate Group[A/] (A)	# group A covariates	SS_C	MS_C	$MS_C/MS_{E(S)}$
Site	1	SS_S	MS_S	$MS_S/MS_{E(S)}$
Error(S)	#trees-2-#covariates	$SS_{E(S)}$	$MS_{E(S)}$	
Years	#years-1	SS_Y	MS_Y	$MS_Y/MS_{E(SY)}$
Site X Years	(1)(#years-1)	SS_{SY}	MS_{SY}	$MS_{SY}/MS_{E(SY)}$
Covariate Group (B)	# group b covariates	SS_{CY}	MS_{CY}	$MS_{CY}/MS_{E(SY)}$
Error(SY)	(# trees-2-#covariates)(#yrs-1)	$SS_{E(SY)}$	$MS_{E(SY)}$	

[A/]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.

Bands were read to the nearest .01 inches of circumference at both study sites beginning on April 9 in an attempt to insure monitoring of diameter growth initiation. Weekly readings continued until October 1 when growth had slowed considerably (at least 95% of total incremental growth had occurred) and over 50% of leaf fall had taken place. This provided a total of 26 measurement periods during the 1986 growing season.

Other variables which were collected on a regular basis for both study sites included tree diameter and height. These seasonal measurements were collected in a continued effort to update the status of the study sites through time and to verify the dendrometer band readings. A monthly collection of 20 soil samples per plot was also made on both study sites using a soil probe inserted to a depth of 15 cm. These samples were composited to 5 per plot and will be analyzed for nutrient content by plot. Each nutrient will then be tested as a covariate or an independent variable in the regression analysis of diameter growth as described later in this section. Data for 1986 are presented in Appendix C.

Progress

Growth Analysis

Levels and rates of diameter increment were examined for each species. Varying growth rates among species require separate analyses for each tree species. Each of the four species is also separated into 5 cm diameter classes and diameter classes are compared across sites. Five diameter classes are presently identified and include trees with diameters of 10.0 cm to 14.9 cm, 15.0 cm to 19.9 cm, 20.0 cm to 24.9 cm, 25.0 cm to 29.9 cm, and 30.0 cm to 34.9 cm.

Analysis of tree diameter increment is approached in two ways. Analysis of the split plot design in space and time coupled with significant

covariates will be used to determine if there is any change in the level of average yearly diameter growth due to operational ELF fields. Secondly, regression models will be used to test changes in both total annual diameter increment and seasonal growth pattern during a year due to ELF effects. Though overall average annual diameter growth may not change due to operational ELF fields, the rates of growth within a year and the relationship with site and climatological variables may vary and could be detected. Both analyses will incorporate tree, site, and climatological information.

Analysis of Total Seasonal Diameter Growth

At present, three years (1984, 1985, and 1986 field seasons) of diameter increment data have been collected from trees on the study sites. In 1984, first incremental growth was not recorded until early June due to a relocation of the control site. Due to this, total diameter increment in 1984 is not derived from dendrometer band data, but from the spring and fall diameter tape measurements of individual trees; these data are more variable than the data from 1985 and 1986. Table 2.4 presents the total diameter growth by species for each of the growing seasons.

Preliminary analyses without the introduction of any covariates was made for each species. Significant site and yearly differences were found ($p = .05$) for northern red oak and red maple. Analysis of paper birch trees only found significant differences in diameter growth between the two sites ($p = .05$); yearly differences were insignificant ($p = .1852$). Analysis of aspen found yearly differences ($p = .05$), but there were no significant differences between the two sites ($p = .0548$).

The observed difference in annual diameter growth on northern red oak at the antenna site between 1984 and 1985 was 0.039 ($\pm$ .046 cm) and between

Table 2.4. Average seasonal diameter growth (cm) for tree species on each site for the 1985 and 1986 growing seasons.

	Sample Size	1984	1985	1986
		cm		
Northern Red Oak				
Antenna	45	0.2778	0.2389	0.1991
Control	174	0.1707	0.2030	0.1508
Paper Birch				
Antenna	8	0.2000	0.2038	0.1500
Control	40	0.1050	0.0765	0.0652
Aspen				
Antenna	15	0.4133	0.3653	0.2993
Control	44	0.3386	0.2643	0.2164
Red Maple				
Antenna	129	0.2163	0.1374	0.1017
Control	15	0.2667	0.2040	0.1533

1985 and 1986 was 0.040 (±.019 cm); on the control site the observed difference between 1984 and 1985 was 0.031 (± 0.019 cm) and between 1985 and 1986 was 0.052 (± .007 cm). In the analysis of variance, a difference in diameter growth of as little as 0.0183 cm between any two years would be significant ($p = .05$), hence the significance among the diameter growths of the three field seasons.

Initial analyses on each tree species with several tree and stand variables as covariates has yet to explain most site differences. Diameter at breast height in 1984 was used as a covariate to eliminate the need for analyses by diameter classes; it is considered independent of treatment as no testing of the antenna was conducted earlier than the summer of 1986.

This measure of diameter was a significant covariate ($p = .0001$) for all four species. The use of this covariate reduced the unexplained variation in site differences by up to 50 percent in all cases (for northern red oak the mean square error dropped from .0486 to .0238), but site and yearly differences remained significant. These differences are being examined so that after the antenna becomes operational any significant effects due to ELF may be more easily distinguished from the natural variation in the system.

Other stand variables such as water holding capacity, rooting volume, and measures of competition as well as yearly climatic and ambient variables are now under examination for possible use as covariates. The influences of these variables will be quantified and useful variables will be incorporated into the analysis as covariates in order to reduce the unexplained site as well as annual variability in the system. The diameter growth model (following section) may also be used to explain natural variation existing between the sites and across the years. At least partially explaining site to site and/or year to year variation will lead to direct decreases in the limits of detection of possible ELF effects on the diameter growth of the pole-sized hardwoods.

Diameter Growth Model

To supplement the analysis of variance described above, growth models are being developed to help account for variability in diameter growth over sites and years. Following the 1985 growing season, it was determined that existing growth models did not adequately predict the diameter growth of individual trees on the study sites (1985 Annual Report). An analysis was undertaken to develop diameter growth models for the four species on the study sites (northern red oak, paper birch, bigtooth aspen, and red maple).

Since seasonal pattern of diameter growth as well as total annual growth could be subject to ELF effects, the weekly cumulative diameter growth (cm) was selected as the response variable.

There are several differences in diameter growth between the antenna and control sites which have been observed in 1985 and 1986. Our goal is to use the time period prior to the ELF antenna becoming operational to develop models explaining the natural variation between sites and years. To the extent that these differences can be accounted for in the pre-operational phase of the study, the ability of these analyses to detect possible ELF effects on tree diameter growth will be improved. The observed differences in diameter growth include:

1) Regardless of the species or diameter class within a species, trees on the control site start growing sooner, putting on 25%, 50%, and 75% of their total seasonal growth approximately two weeks earlier than comparable trees on the antenna site.

2) The pattern of seasonal diameter growth was consistent between species for both sites. Northern red oak accumulated growth the fastest, paper birch and aspen were similar in pattern of development and were one to two weeks behind northern red oak in reaching 25%, 50%, and 75% of their total growth; red maple was the slowest of all, generally later than aspen and paper birch by an additional week.

3) There were considerable differences in the amount of diameter growth from year to year. In 1986, there was 14% to 30% less growth than in 1985 for each species on each site (Table 2.2). Stand conditions (basal area per acre, trees per acre, crown competition factor, etc.) did not drastically change in one year; the observed differences in annual diameter

growth are probably due to differences in climatic conditions between years.

Through an initial variable screening, including correlation analysis, the total set of 93 tree, stand, and ambient variables was reduced for each species. Through further regression analysis, including, initially, stepwise regression and then specified multiple regressions, variables affecting cumulative diameter growth for each species were determined (Table 2.5). The variables selected at this point for further analysis were important in determining diameter growth on both the control and the antenna sites.

By breaking cumulative diameter growth into the component parts of total annual growth and proportion of total growth completed by the date of observation, the effect of tree, stand, or ambient variables on each of these diameter growth components could be examined. Cumulative diameter growth to time t is therefore represented by:

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

These were examined separately and a model was developed for each species for each component of cumulative diameter growth. This is not only logical from a biological point of view, but it also simplifies the testing of ELF effects on tree diameter growth.

Seasonal Diameter Growth

When looking at the seasonal diameter growth pattern, which is defined as the proportion of total annual growth obtained by time t, the cumulative air temperature degree days to time t was the most important variable affecting growth of all four species on both sites. After examining the

Table 2.5 Tree, stand, and ambient variables affecting cumulative diameter growth on the ELF study sites.

	Northern Red Oak	Red Maple	Paper Birch	Quaking Aspen	Bigtooth Aspen
Tree Variables					
	DBH_2 DBH^2	DBH Height	DBH^2	DBH Height	DBH Height
Stand Variables					
	CCF[A/] Trees/ha		Trees/ha	CCF	CCF
Ambient Variables					
	ATDD[B/]	ATDD Tot. Precip[C/] Monthly K (ppm)[D/]	ATDD	ATDD	ATDD

[A/] Crown competition factor

[B/] Air temperature degree days (4.4°C basis)

[C/] Total Annual Precipitation

[D/] Monthly Potassium Concentration (for details on nutrients see Appendix C)

1985 data, a model form relating proportion of growth completed to air temperature degree days was developed:

$$PG_t = 1 - e^{-(ATDD_t/b)^c}$$

where PG_t is proportion of total annual diameter growth completed by time t, $ATDD_t$ is the cumulative air temperature degree days to time t, b and c are constants to be estimated for each species. This model form is similar to that of the two-parameter Weibull probability distribution function; it is

very flexible in terms of its ability to represent different patterns of diameter growth. The coefficients estimated for each species are given in Table 2.6. These equations fit the 1985 data very well, explaining in excess of 95 percent of the variation in seasonal diameter growth for each species on each site. The differences in timing of diameter growth between sites (1985 Annual Report), such as the earlier completion of fifty percent of the total growth of all species on the control site, were accounted for by the differences in degree day accumulation between the sites.

It appears that ambient variables indicating moisture (precipitation, soil moisture, available water, etc.) are not important in determining the timing of diameter growth on the study sites. This seems to be due to the fact that there have not been times of severe moisture stress on the sites. In Figures 2.1 and 2.2, the relationship between soil moisture and the saturation and wilting points of the two sites indicate that, especially at the greater depths below the surface, the soil moisture never approaches the wilting point in 1986, a year which had a drought early in the growing season. The relationship between soil moisture and water available to plants will be investigated further in 1987 but, at this time, it does not appear that soil moisture is important in determining the timing of tree diameter growth on the study sites.

A comparison of the predicted seasonal growth pattern for each species is given for a hypothetical growing season with 1800 degree days in Figure 2.3. The proportions are scaled as follows:

$$PG_t = \frac{1-e^{-(ATDD/b)^c}}{1-e^{-(1800/b)^c}}$$

Table 2.6. Parameters and test statistics for the model of seasonal diameter growth for each species in 1985.

Species	b	c	Sample Size[B]	Proportion of Variation Explained[C]		
				All	Control	Antenna
Northern Red Oak	716.447[A] (39.837)	1.398 (0.094)	2760	.977	.978	.973
Paper Birch	754.852 (34.644)	2.264 (0.240)	826	.966	.961	.978
Aspen	740.476 (21.470)	2.378 (0.172)	1072	.971	.957	.983
Red Maple	847.765 (35.662)	2.303 (0.191)	1725	.978	.966	.978

[A] Values in parentheses are standard errors of the estimated coefficient.

[B] The sample size given here is the number of weekly observations multiplied by the number of trees, data from the two sites were combined for estimation in 1985.

[C] The proportion of variation explained is calculated by:

$$PVE = \frac{\sum_{n}(y_i - \bar{y})^2 - \sum_{n}(\hat{y}_i - \bar{y})^2}{\sum_{n}(y_i - \bar{y})^2}$$

This scaling forces the cumulative proportion of diameter growth to range from zero to one throughout the season. The predicted growth patterns of each species reflect observations made on growth rates in the previous section and in previous years (1985 Annual Report). The rapid early growth and prolonged growth period of northern red oak indicated by it's rapidly reaching fifty percent of its total growth compared to the other species is reflected in the predicted growth patterns. The similarity between paper

Figure 2.1.

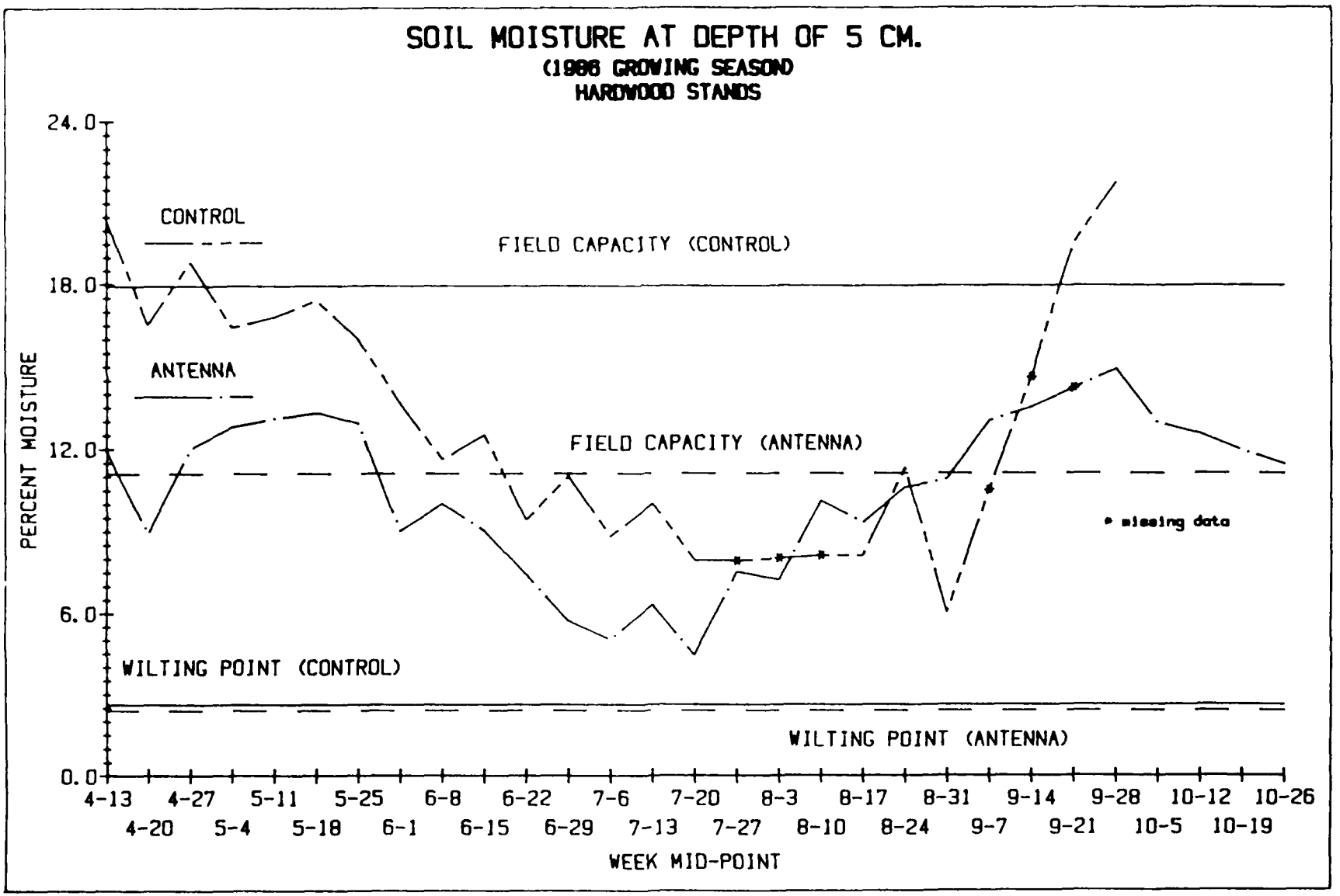

SOIL MOISTURE AT DEPTH OF 5 CM.
(1986 GROWING SEASON)
HARDWOOD STANDS
24.0
18.0
12.0
6.0
0.0
PERCENT MOISTURE
CONTROL
FIELD CAPACITY (CONTROL)
ANTENNA
FIELD CAPACITY (ANTENNA)
* missing data
WILTING POINT (CONTROL)
WILTING POINT (ANTENNA)
4-13
4-20
4-27
5-4
5-11
5-18
5-25
6-1
6-8
6-15
6-22
6-29
7-6
7-13
7-20
7-27
8-3
8-10
8-17
8-24
8-31
9-7
9-14
9-21
9-28
10-5
10-12
10-19
10-26
WEEK MID-POINT

Figure 2.2.

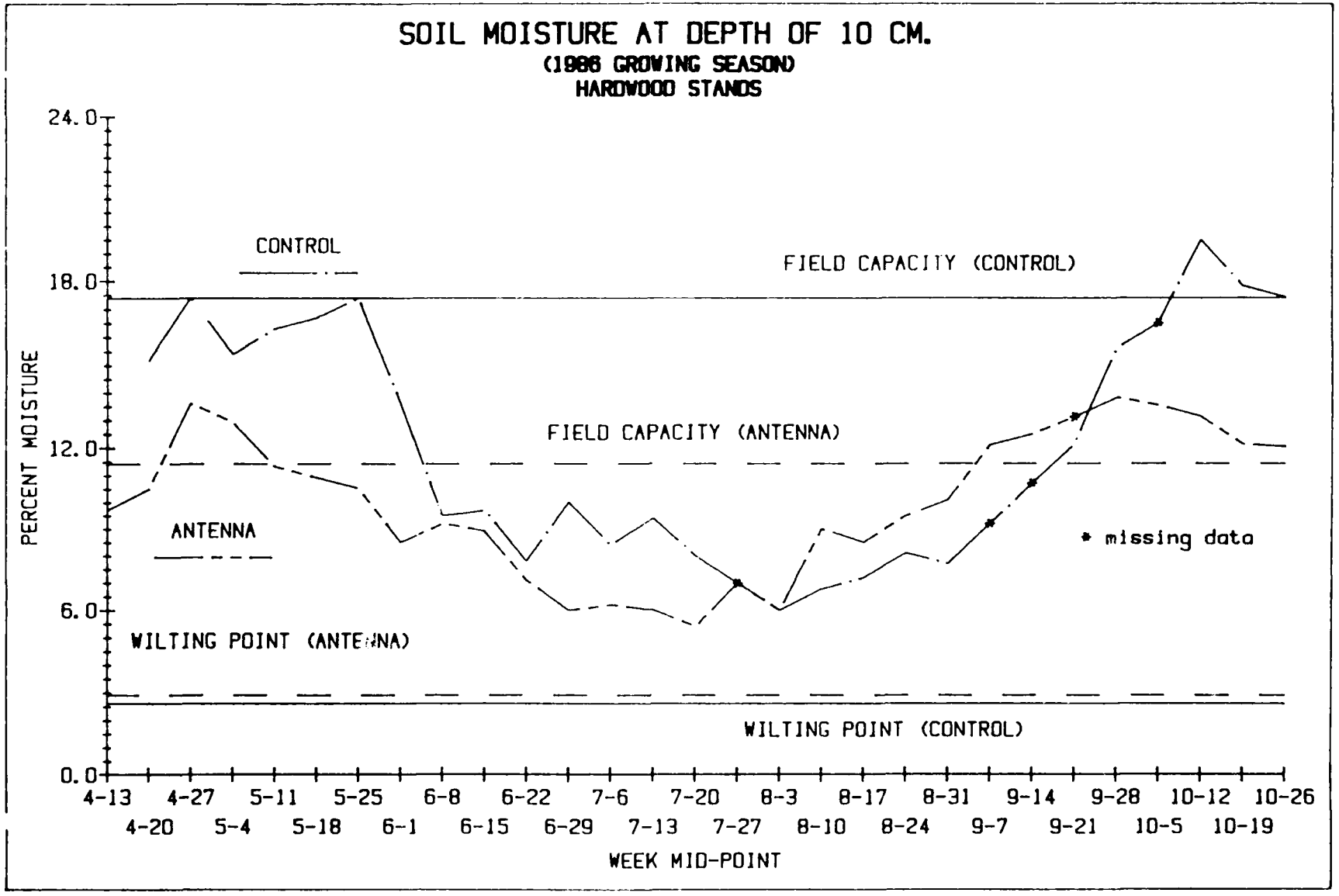
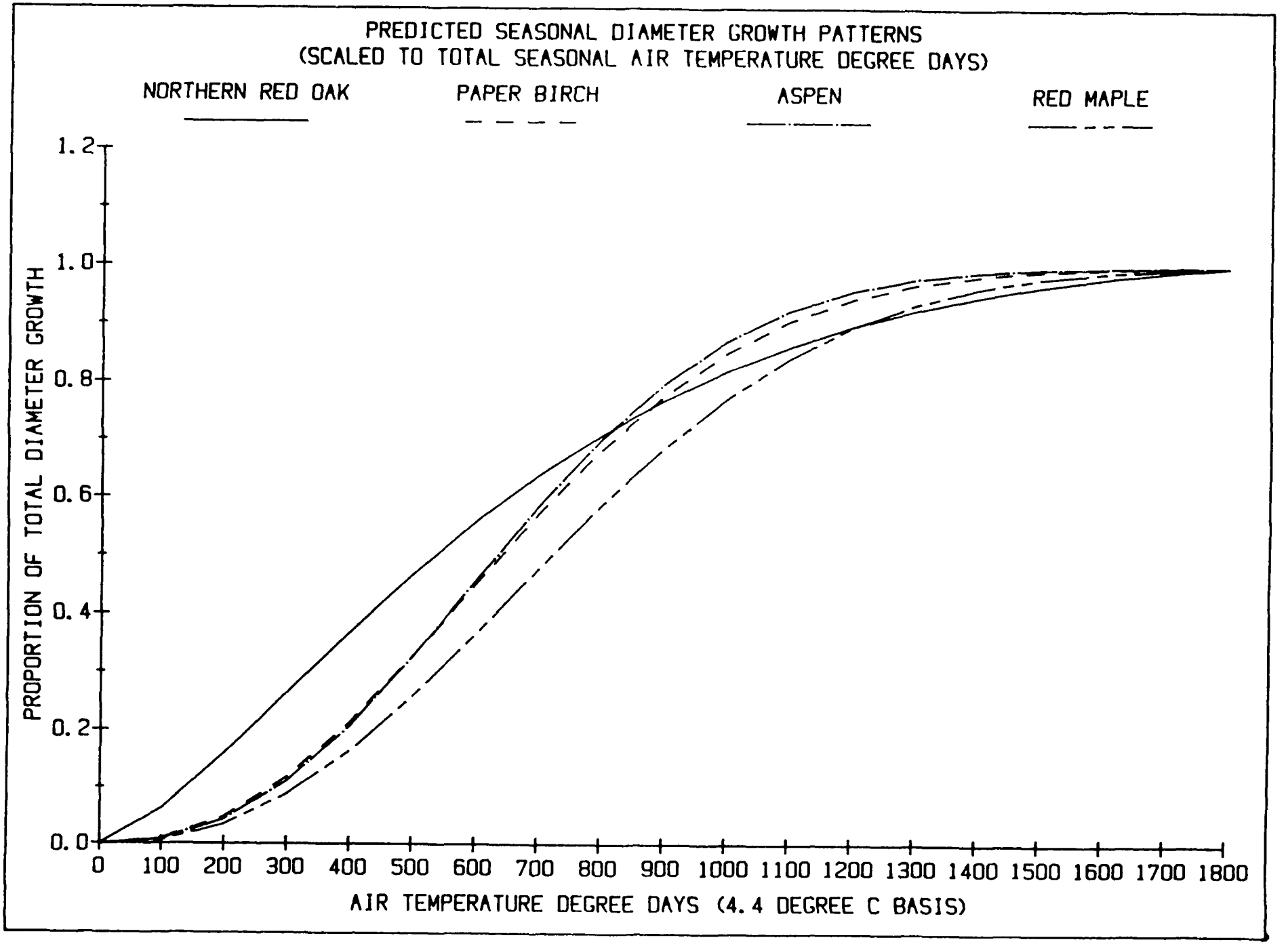

SOIL MOISTURE AT DEPTH OF 10 CM.
(1986 GROWING SEASON)
HARDWOOD STANDS
24.0
18.0
12.0
6.0
0.0
PERCENT MOISTURE
CONTROL
FIELD CAPACITY (CONTROL)
FIELD CAPACITY (ANTENNA)
ANTENNA
* missing data
WILTING POINT (ANTENNA)
WILTING POINT (CONTROL)
4-13
4-20
4-27
5-4
5-11
5-18
5-25
6-1
6-8
6-15
6-22
6-29
7-6
7-13
7-20
7-27
8-3
8-10
8-17
8-24
8-31
9-7
9-14
9-21
9-28
10-5
10-12
10-19
10-26
WEEK MID-POINT

Figure 2.3.


PREDICTED SEASONAL DIAMETER GROWTH PATTERNS
(SCALED TO TOTAL SEASONAL AIR TEMPERATURE DEGREE DAYS)
NORTHERN RED OAK
PAPER BIRCH
ASPEN
RED MAPLE
PROPORTION OF TOTAL DIAMETER GROWTH
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0 100 200 300 400 500 600 700 800 900 1000 1100 1200 1300 1400 1500 1600 1700 1800
AIR TEMPERATURE DEGREE DAYS (4.4 DEGREE C BASIS)

birch and aspen and the slow early growth of red maple are all represented by the equations. The differences in seasonal pattern by diameter class, with small trees growing faster earlier in the season than large trees, is not reflected in this seasonal growth model and will require further investigation to be incorporated into the model.

The equations developed using data from 1985 were tested on measurements from the 1986 growing season. The results (Table 2.7) show that the equations performed nearly as well in 1986 as they had in 1985, explaining in excess of 89% of the variation in height growth pattern for each species on each site. The equations seemed to predict equally well for all tree dbh classes; there were no definite trends of increasing or decreasing performance based on tree dbh. The equations were refit to 1986 data and the coefficients for each species are given in Table 2.8. Since there are no differences in coefficients between 1985 and 1986 ($p = .05$), we conclude that the diameter growth pattern was equivalent between the two years. The data from the two years will be combined to estimate the coefficients of the model relating degree day accumulation on a site to seasonal pattern of diameter growth. This procedure will be repeated after the antenna becomes operational to test for possible effects of ELF on the seasonal pattern of diameter growth in pole-sized hardwood stands.

Total Annual Growth

Total annual growth was much more difficult to estimate than the seasonal growth pattern. The experience on the ELF sites is similar to that found by other investigators in hardwoods (Harrison et al. 1986); it is very unusual to be able to explain more than fifty percent of the variation of annual diameter growth in hardwoods. A number of methods were tested for their ability to estimate annual diameter growth of the four species on the

Table 2.7. Performance of the 1985 seasonal diameter growth equations on the data from 1986.

Species	Diameter Class (cm)	Proportion of Variation Explained		
		Antenna	Control	Combined
Northern Red Oak				
	10.0-14.9	.942	.934	.949
	15.0-19.9	.940	.937	.947
	20.0-24.9	.917	.902	.916
	25.0-29.9	.901	.903	.906
	30.0-39.9	.892	.883	.888
	35.0-39.9	.895	.952	.936
	40.0-44.9	.940	---	.940
	45.0-49.9	---	.863	.863
	60.0-64.9	.923	---	.923
	All	.934	.935	.935
Paper Birch				
	10.0-14.9	.897	.900	.935
	15.0-19.9	.939	.944	.944
	20.0-74.9	.882	.942	.938
	25.0-29.9	.874	.958	.926
	All	.916	.949	.941
Aspen				
	10.0-14.9	.878	.864	.906
	15.5-19.9	---	.929	.929
	20.0-24.9	.943	.914	.921
	25.0-29.9	.899	.927	.917
	30.0-34.9	.953	.763	.958
	All	.921	.936	.931
Red Maple				
	10.0-14.9	.922	.892	.924
	15.0-19.9	.878	---	.878
	20.0-24.9	.858	---	.858
	25.0-29.9	.926	---	.926
	All	.904	.892	.903

ELF sites. Various regression equations using the factors for each species listed on Table 2.5 and refitting of published equations (Botkin et al. 1972) were tried. The most promising were combined with the model for seasonal growth pattern and refit to the cumulative diameter growth data.

Table 2.8. Performance and estimated coefficients of the seasonal growth model when estimated using data from 1986.

Species	b	c	Proportion of Variation Explained[B/] Antenna	Control	Combined
Northern Red Oak	732.078 (19.456)[A/]	1.693 (0.072)	.914	.918	.918
Paper Birch	736.609 (33.135)	2.418 (0.284)	.922	.953	.949
Aspen	712.636 (16.459)	2.564 (0.169)	.930	.944	.941
Red Maple	803.814 (24.781)	2.020 (0.114)	.918	.909	.918

[A/] Values in parentheses are standard errors of the estimated coefficient.
[B/] The proportion of variation explained is calculated by:

$$PVE = \frac{\sum_{n}(y_i - \bar{y})^2 - \sum_{n}(\hat{y}_i - \bar{y})^2}{\sum_{n}(y_i - \bar{y})^2}$$

The best performing model was obtained by refitting the equation given by Botkin et al. (1972):

$$AG_t = \frac{GD(1-DH/DH_{MAX}H_{MAX})}{274+3b_2D-4b_3D^2}$$

where AG_t is total annual diameter growth, D is tree DBH, H is tree height, D_{MAX} and H_{MAX} are the maximum observed tree diameter and height, respectively, for a species, and G, b_2, and b_3 are constants to be estimated for each species.

The estimated coefficients for the 1985 data and performance statistics for the equations are given in Table 2.9. Even though there were considerable differences in the proportion of variation explained by site, there were no significant (p = .05) differences between the coefficients

Table 2.9. Estimated coefficients and performance statistics for the annual diameter growth model using 1985 data.

Species	G	b_2	b_3	Sample Size			Average Residual (cm)			Proportion of Variation Explained	
				Antenna	Control	Combined	Antenna	Control	Combined	Antenna	Control
Northern Red Oak	1.343 (0.082)	-3.586 (0.159)	-0.0433 (0.0025)	45	175	220	.011 (4.6%)	-.011 (-5.4%)	.006 (3.1%)	-.110	.636
Paper Birch	0.520 (0.313)	-5.959 (0.106)	-0.0770 (0.0026)	8	40	48	.056 (27.5%)	-.008 (-10.5%)	.003 (2.7%)	.343	.331
Aspen	0.313 (0.022)	-6.818 (0.053)	-0.1022 (0.0013)	15	15	44	.080 (21.9%)	-.001 (-0.3%)	.020 (8.1%)	-.117	.660
Red Maple	1.929 (0.353)	-3.417 (0.316)	-0.0642 (0.0303)	129	15	144	-.016 (-11.7%)	.091 (44.6%)	-.005 (-3.4%)	.272	.104

estimated for each site. Also, even though the proportion of variation explained was not that high, the average residuals were relatively close to zero for the 1985 data.

The equations based on the 1985 data were used to predict the expected annual diameter growth in 1986. The results (Table 2.10) indicate that there were relatively small differences in the proportion of variation explained between years, but there were decreases in the average diameter growth in 1986 compared to the growth achieved in 1985. The coefficients of the annual diameter growth model were re-estimated using the data from 1986. As in 1985, there were no significant ($p = .05$) differences in the estimated coefficients between sites. There were significant ($p = .05$) differences between the estimated coefficients from 1985 and those from 1986 (Table 2.11).

It is obvious that there are differences between years in the amount of annual diameter growth accounted for by the model. Current efforts are concentrating on incorporating ambient variables into the model of annual diameter growth to at least partially explain the year to year variation in growth. The ability to explain the natural year to year variation in annual diameter growth will lead to direct decreases in the limits of detection of possible ELF effects on pole-sized hardwoods.

In addition to incomplete accounting of year to year variation in annual diameter growth, the proportion of variation explained by the current models is not as high as it could be. Even though the models in this study are equivalent in performance to those from other studies involving hardwoods (Harrison et al. 1986), there is still room for improvement. In 1985, there were significant ($p = .05$) correlations between the residual values (observed annual diameter growth minus the predicted growth) and individual tree variables for each species (Table 2.12). There appear to be

Table 2.10. Performance statistics for the 1985 annual diameter growth model when predicting expected growth in 1986.

Species	Average Residual (cm)			Proportion of Variation Explained	
	Antenna	Control	Combined	Antenna	Control
Northern Red Oak	-.030 (32.0%)	-.065 (-43.3%)	-.058 (-36.1%)	.013	.648
Paper Birch	.014 (9.3%)	-.023 (-34.8%)	-.017 (-14.7%)	.215	.200
Aspen	.015 (5.0%)	-.052 (-24.1%)	-.035 (-14.7%)	-.570	.492
Red Maple	-.054 (-52.9%)	.035 (22.9%)	-.045 (-41.7%)	.402	.123

Table 2.11. Estimated coefficients for the annual diameter growth model using data from 1986.

Species	G	b_2	b_3
Northern Red Oak	0.730*	-3.813	-0.040
	(0.024)	(0.066)	(0.001)
Paper Birch	0.350*	-5.071*	-0.064
	(0.043)	(0.366)	(0.008)
Aspen	0.360	-6.195*	-0.089*
	(0.027)	(0.089)	(0.002)
Red Maple	0.508*	-7.277*	-0.138*
	(0.031)	(0.179)	(0.005)

* Indicates a significantly different value (p = .05) from that estimated using 1985 data.

Table 2.12. Tree and stand variables having a significant (p = .05) correlation with annual diameter growth residuals (observed minus predicted values) in 1985.

Species	Antenna	Control
Northern Red Oak	APA[A/] CARA[D/]	DBH[B/] CW
Paper Birch	—	--
Aspen	APA CARA	APA CARA
Red Maple	DBH APA CW[C/] CA	--

A/ Area Potentially Available (Brown 1965)
B/ Potential Crown Width (Ek 1974)
C/ Potential Crown Area (π $CW^2/4$)
D/ Potential Crown Area/Area Potentially Available

differences between sites in the relationships between these variables and variation unaccounted for by the current models. Some variables, such as crown class, did not seem to be able to account for any variability over and above tree dbh and height. The most promising variables involve spatial relationships and indices of competition levels on individual trees. These data are available from the stand maps (1985 Annual Report); current efforts are investigating these relationships. This will hopefully lead to increased understanding of the natural variation in the system and to an improved sensitivity in detection of possible ELF effects on tree growth.

To summarize, the cumulative diameter growth model is obtained by multiplying the model for annual diameter growth and the model for seasonal growth pattern:

$$CG_t = \frac{GD(1-DH/D_{MAX}H_{MAX})}{274+3b_2D-4b_3D^2} (1-e^{-(ATDD_t/b)^c}$$

The resulting five-parameter growth model was fit to data from each species. It was determined that the site variation in pattern of seasonal growth was accounted for in the seasonal growth component model by differences in air temperature degree days between sites (see earlier discussion). In 1985, for instance, differences were noted in the dates at which trees on each site achieved fifty percent of their total growth. For trees of comparable species and diameter class, fifty percent of annual growth was achieved approximately two weeks earlier on the control site than the antenna site. In late May and early June, when all species and diameter classes achieved fifty percent of their total annual diameter growth, the antenna site was about two weeks (65 - 90 degree days) behind the control site in degree day accumulation. With both the 1985 and 1986 equations, changes in the coefficients resulting in an achievement of fifty percent of

annual growth 100 to 200 degree days earlier or later (2 - 5 weeks) would be significant at the five percent level. With the combination of 1985 and 1986 data, and possible modification of the model to include other site and climatic factors whose effects become clearer after additional years, this limit of detection of possible ELF effects will be further reduced.

The prediction of total annual diameter growth is not as easy to accomplish. Within a year, the performance of the equations developed in this study is equivalent to that from other studies on hardwoods. There seems to be a good chance of improving this performance within a year by utilizing the spatial information from the stand maps. The year to year differences are a different story and current efforts are attempting to reduce this source of variability using climatic variables. By explaining at least part of the variability from year to year, the ability to detect possible increases or decreases in total annual diameter growth will be improved and the size of the effect which can be detected will be reduced accordingly.

Red Pine Seedling Growth

The overall objective in this phase of the Tree Productivity studies is 1) to collect baseline data on red pine seedling growth prior to operation of the ELF antenna system, and 2) use these data to evaluate possible changes in red pine seedling growth and survival due to ELF electromagnetic fields. Since young trees exhibit rapid growth rates, possible effects on growth due to ELF may be more easily detected on seedlings than on older more slowly growing individuals. Other justifications for investigating red pine seedlings are: 1) the response to Michigan DNR concerns over lack of monitoring of 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. Construction of the ground antenna through a red pine plantation would allow study trees to be closer to the electromagnetic source than would any mature tree plot requiring a buffer strip of trees along the right-of-way. Red pine plantations would thus be configured to subject seedlings to specific ELF electromagnetic field strengths.

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 two overall null hypotheses tested in this phase of the study are:

H_0: There is no difference in the level of diameter growth on planted red pine seedings before and after the ELF antenna becomes operational.

Table 2.13. ANOVA table for red pine seedling growth studies.

Source of Variation	df	SS	MS	F
Plot	2	SS_P	MS_P	$MS_P/MS_{E(S)}$
Site	2	SS_S	MS_S	$MS_S/MS_{E(S)}$
Covariates	# Covariates	SS_C	MS_C	$MS_C/MS_{E(S)}$
Error(S)	# Seedlings-4-# Covariates	$SS_{E(S)}$	$MS_{E(S)}$	
Year	# yrs-1	SS_Y	MS_Y	$MS_Y/MS_{E(Y)}$
Site x Year	2(# yrs-1)	SS_{SY}	MS_{SY}	$MS_{SY}/MS_{E(Y)}$
Plot x Year	2(# yrs-1)	SS_{PY}	MS_{PY}	$MS_{PY}/MS_{E(Y)}$
Covariates	# Covariates	SS_{CY}	MS_{CY}	$MS_{PY}/MS_{E(SY)}$
Error(SY)	# Seedlings-5(# yrs-1)# Covariates	$SS_{E(Y)}$	$MS_{E(Y)}$	

H_0: There is no difference in the level or the rate of total height growth on planted red pine seedlings before and after the ELF antenna become operational.

In addition, diameter and total height will be measured to establish relationships between the sampling sites. The null hypotheses tested are:

H_0: There is no difference in the level of diameter growth on planted red pine seedlings between the ground, antenna, and control sites within a year.

H_0: There is no difference in the level or the rate of total height growth on planted red pine seedlings between the ground, antenna, and control sites within a year.

As described earlier, if the covariate changes over time, the ANOVA table found in Table 2.13 is applicable; if the covariate does not change over time, the second covariate term in the ANOVA table drops out and the degrees of freedom for the Error (SY) increases by that number of covariates. This table is applicable for both diameter and height growth analyses.

Sampling and Data Collection

Small areas at the antenna, ground, and control sites were [illegible] harvested in the spring of 1984. These areas were immediately [illegible] 3-0 stock red pine seedlings at a 1 m by 1 m spacing. [illegible] provide adequate numbers of seedlings for destructive sampling [illegible] the study period, allow for natural mortality [illegible] stand when the study is completed. [illegible] each site were randomly [illegible] [illegible]

AD-A184 561 COMPILATION OF 1986 ANNUAL REPORTS OF THE NAVY ELF (EXTREMELY LOW FREQUEN (U) IIT RESEARCH INST CHICAGO IL JUL 87 IITRI-E06549-38-VOL-1 N00039-84-C-0070 2/5

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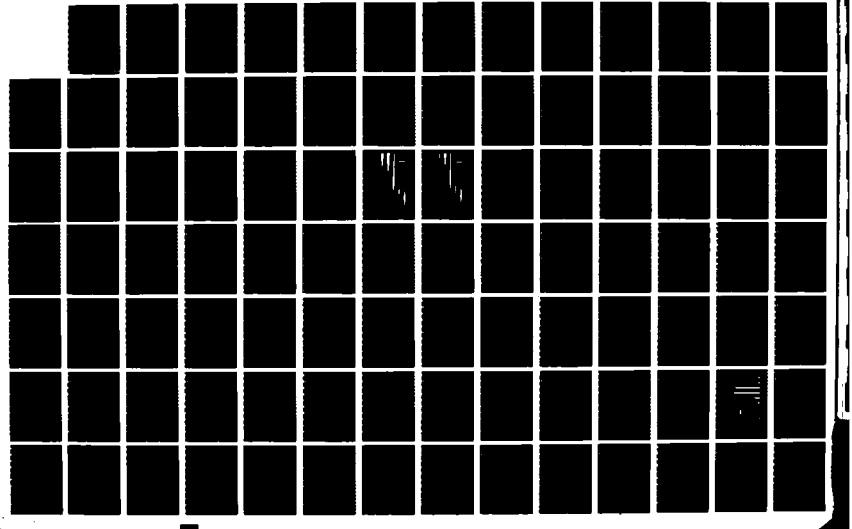
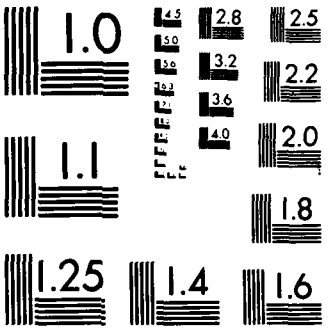




Natural mortality following the first full growing season (1985) was 43 percent at the ground site, 37 percent at the antenna site, and 28 percent at the control site. This mortality appears to be a carryover of initial planting shock as well as some poor handling and planting practices; these seedlings were not able to adapt well to the field conditions. In addition, Mroz et al. (1987) 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 factors had a significant effect in causing this mortality.

The mortality that occurred in 1985 was not evident in 1986. Only a few seedlings died during the course of the growing season. In 1985 the number of seedlings was reduced to 170 at the ground site, 188 at the antenna site, and 217 at the control site. In 1986 these numbers were further reduced to 147 seedlings, 184 seedlings, and 211 seedlings respectively.

Vegetative recovery following whole-tree harvesting in 1984 increased in 1986. This vegetation competes with the red pine seedlings for physical resources such as moisture, nutrients, and light. To prevent the competing vegetation from affecting the unrestricted growth of the seedlings in 1986 and in future years, some measure of vegetation control was necessary. Therefore, in early July 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 over-topped seedlings and essentially eliminating competition in 1986. It appears that maintenance to keep competing vegetation under control will be necessary each year until

the red pine seedlings become dominant on the sites. This effort will not be as extensive in the future as it was in 1986.

For red pine growth analysis each of the 300 permanently marked seedlings on each site were measured at the end of the growing seasons in 1984, 1985, and 1986 and the following information recorded:

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

Observations of microsite, physical damage, and multiple leadered seedlings were made for consideration as possible covariates in the growth analysis. Microsite describes the physical environment in the immediate vicinity of the seedling such as rocky soil surface, proximity to stump, or proximity to skid trails. Any physical damage to the seedling such as frost or animal damage was also recorded. It was further observed that some seedlings possessed two or more leaders, none of which expressed dominance over the others. This situation was noted and will continue to be monitored in the future.

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. Weekly measurements were obtained in 1985 and 1986 beginning in mid April and continuing until mid July when shoot elongation has been completed. Measurements were made from the center of the previous year's whorl to the meristematic tip or tip of the new terminal bud.

Progress

Total height (cm) and basal diameter (cm) of the red pine seedlings are the response variables in this study. Evaluation of possible effects of ELF electromagnetic fields on height growth are approached in two forms: the total amount of height growth in a season is analyzed through the split plot in space and time design and the rate or pattern of height growth within a growing season is described through a height growth model. Each of these analyses examines site differences as well as any existing differences between growing seasons. Basal diameter growth is evaluated solely through the split plot in space and time; this analysis examines site and/or yearly differences in the total amount of basal diameter.

Total Annual Height and Diameter Growth

The seasonal height growth and basal diameter growth of red pine seedlings are examined among the three sites and from year to year. At this point there are two years of growth measurements available. The average total heights and basal diameters at the end of each growing season are found in Table 2.14.

The observed difference in survivor seedling height growth from 1985 to 1986 at the ground site is 9.06 ($\pm$ 0.80 cm), at the antenna site is 10.31 ($\pm$ 0.85 cm), and at the control site is 15.03 ($\pm$ 0.83 cm). Without any covariates to explain site or yearly differences, there is a significant difference in height growth among the three sites and between the 1985 and 1986 growing seasons. With the existing variation in the data, a difference of as little as 1.67 cm among the three sites could be detected ($p = .05$). A difference of as little as 0.48 cm growth between the 1985 and 1986 growing seasons could also be detected ($p = .05$) (see Table 2.15). As mentioned earlier, if no covariates were used any differences in height

Table 2.14. Average total height and basal diameter of red pine seedlings at the end of the growing season for the ground, antenna, and control sites.

	Sample Size	Total Height (cm)	Standard Deviation	Basal Diameter (cm)	Standard Deviation
1986					
ground	147	37.21	11.36	12.78	3.61
antenna	184	40.22	10.89	12.61	3.11
control	211	50.58	12.20	13.55	3.37
1985					
ground	171	22.70	6.20	7.30	2.24
antenna	191	23.90	6.80	6.70	2.53
control	217	28.30	8.00	7.92	1.86
1984					
ground	300	16.80	4.60	0.45	0.12
antenna	300	16.60	3.90	0.44	0.10
control	300	17.90	6.30	0.46	0.10

Table 2.15. Observed survivor height growth (cm) for red pine seedlings during 1985 and 1986 and the amount of growth detectable (p = .05) for a given analyses.

	1985	1986	Amount Detectable Among Sites	Amount Detectable Between Years
		Without Covariates		
Ground	6.21	15.27	1.665	0.484
Antenna	7.73	18.04		
Control	9.91	24.99		
		Covariates		
Ground	6.21	15.27	0.611	0.480
Antenna	7.73	18.04		
Control	9.91	24.99		

the effects of ELF fields would have to be at least as great as these amounts.

Initial examination of covariates to explain these site and yearly significances show a reduction in the unexplained variation, but significant differences still exist ($p = .05$). Several variables considered significant as covariates in the analyses so far include seedling diameter and height at the end of the growing season in 1985, rooting volume in the 30-50 cm strata (see appendix B for description), and average air temperature degree days (4.4°C basis) for the month of April in 1985 and 1986. Each of these variables is considered independent of ELF treatments. Seedlings have been exposed to electromagnetic fields in some degree after 1986 height measurements were taken and use of diameter and height measurements taken after 1986 for use as covariates is inappropriate.

Without the use of any covariates the mean square error used to test for site differences is approximately 44.62 and the mean square error used to test for yearly differences is 16.54. Incorporating the above mentioned covariates reduced the mean square error used to test site differences to 18.94 and the mean square error to test yearly differences to 16.30. These mean square errors are used to calculate the difference in growth detectable in an analysis. As mentioned, site and yearly differences are still significant, but the amount of growth difference detectable among sites and between years was reduced (see Table 2.15). Current analyses underway are examining a height equation (Lungren and Dolid 1970) for red pine seedlings where the residuals (observed seedling height - predicted seedling height) incorporated into the split plot in space and time analysis may at least partially explain the site and yearly differences still existing. Explaining these natural variations or understanding the causes of these variation increases the ability to determine any possible effects of ELF on red pine seedling height growth.

Differences in survivor seedling basal diameter growth between 1985 and 1986 ranged from 5.25 (± 0.44 mm) on the ground site to 5.71 (± 0.39 mm) on the antenna site, and 5.65 (± 0.34 mm) on the control site. As in the case of height growth, significant differences exist among the three sites and between the 1985 and 1986 growing seasons ($p = .05$) when no covariates are entered in the analyses. At this point as little as 0.58 mm among the three sites and between the two growing seasons as little as 0.26 mm are significant at $p = .05$ (see Table 2.16).

Covariates initially under consideration have been more successful in explaining both site and yearly differences ($p = .05$) for basal diameter growth. Those variables most significant in the analyses so far include seedling diameter and height at the end of the 1985 growing season, average air temperature degree days for the month of April in 1985 and 1986 (4.4°C basis), and available water at the 0-10 cm strata for the month of April in 1985 and 1986. As discussed earlier, these covariates are all assumed independent of ELF treatments.

Mean square errors testing for site differences were reduced from 5.42 with no covariates to 2.85 when the above mentioned covariates were included in the analysis; this removed the significant site differences ($p = .4155$). The mean square error used in testing for yearly differences was reduced from 4.62 to 4.42 and all yearly differences were no longer significant ($p = .1128$).

Analyses for both height and basal diameter growth red pine seedlings are still underway. Other variables need to be examined as possible covariates, and in the case of height growth analyses, site and yearly differences still need to be explained. The extent to which these differences can be explained prior to the operation of the antenna will increase the ability of the analyses to detect possible ELF effects.

Table 2.16. Observed survivor diameter growth (cm) for red pine seedlings during 1985 and 1986 and the amount detectable (p = .05) for a given analyses.

	1985	1986	Amount Detectable Among Sites	Amount Detectable Between Years
			Without Covariates	
Ground	7.04	5.25	0.580	0.256
Antenna	6.50	5.71		
Control	7.42	5.65		
			Covariates	
Ground	7.04	5.25	0.421	0.250
Antenna	6.50	5.71		
Control	7.42	5.65		

Seasonal Pattern of Height Growth

To evaluate any changes in the rate or timing of growth in a given year and from year to year, growth models were developed to predict total height growth at a given time during the growing season. The model developed is of the form:

$$h_t = b_0 + (1 - e^{-b_t})^{b_2}$$

where h_t is the proportion of the annual total amount of height growth completed at time t, t is the number of weeks since height growth initiated, and b_0, b_1 and b_2 are coefficients to be estimated.

Initial work has found time from which growth initiates for a given season to be a significant variable in the prediction model. A possible explanation is that red pine is a species with 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 climatic and ambient conditions. Climatic and ambient variables from the current and previous growing seasons now need to be evaluated for possible inclusion in a refined model.

Height growth models were developed for each of the three sites and for both the 1985 and 1986 growing seasons. Using the subsample of weekly height measurements, the proportion of total annual height growth achieved by time t was the dependent variable. Each seedling's height growth at a given week is considered to be an observation. Forty percent of the total number of observations on a given site in a given year were randomly selected for use as validation data and were not used in the estimation process. Both the developmental and the validation data sets are summarized in Table 2.17.

Table 2.17. Summary of the developmental and validation data for height growth of red pine seedlings on the ground, antenna, and control sites during the 1985 and 1986 growing seasons.

	Sample Size	Average [A/]	Standard Deviation
Developmental Data			
1986			
ground	666	0.6535	0.3545
antenna	787	0.6562	0.3547
control	761	0.6473	0.3683
1985			
ground	961	0.5709	0.3920
antenna	1053	0.6231	0.4016
control	1015	0.6575	0.3879
Validation Data			
1986			
ground	425	0.6584	0.3539
antenna	536	0.6665	0.3548
control	524	0.6509	0.3663
1985			
ground	321	0.5882	0.3914
antenna	331	0.6096	0.4046
control	325	0.6543	0.3878

[A/] Average height growth has been standarized to range from 0 to 1.

The three coefficients in the model were estimated for each of the three sites during both the 1985 and the 1986 growing season using the developmental data sets. To evaluate the equations the validation data sets were used to calculate the average residual (observed proportion of total seedling height growth- predicted proportion of total seedling height growth), the standard deviation of the residuals, and, since there are no true R^2 values, an analogous statistic, the proportion of variation explained. These statistics are given for each equation in Table 2.18.

The proportion of variation explained ranged from 0.94 to 0.96 in 1986 and from 0.90 to 0.92 in 1985. This indicates a relatively precise estimate of seasonal height growth, with a better estimate in 1986 than 1985. Among sites in either year the ranges of residuals were quite small. All of the estimates appear unbiased as indicated by the average residuals which are quite close to 0; the average residuals were all less than one percent.

The two data sets, developmental and validation, were combined for the final estimation of the three parameters. Estimates of the parameters and confidence intervals about the estimates are found in Table 2.19. The models developed explain 98 to 99 percent of the variation in the system at each of the three sites during the 1986 growing season. In 1985 the models explain 90 to 93 percent of the variation. Examples of the predicted versus the observed height growth curves for each site during 1986 are found in Figures 2.4, 2.5, and 2.6.

Changes in the parameters of the growth model are being examined prior to antenna operation. The test for differences will indicate whether or not different seasonal growth patterns are occurring on the three sites and may explain the natural variation among the sites. Similar procedures will be incorporated after the antenna is operational.

Table 2.18. Performance of the height growth equations of red pine seedlings on the ground, antenna, and control sites during the 1985 and 1986 growing seasons.

	Average Residual [A/]	Standard Deviation of Residuals	Proportion of Variation Explained [B/]
1986			
ground	-0.0013	0.0585	0.9449
antenna	0.0016	0.0497	0.9646
control	0.0072	0.0624	0.9405
1985			
ground	0.0055	0.0789	0.9011
antenna	-0.0091	0.0670	0.9289
control	0.0007	0.0641	0.9232

A/ Residual = (Observed value - Predicted value)

B/ Proportion of Variation Explained = $$PVE = \frac{\sum_{n} (y_i - \bar{y})^2 - \sum_{n} (y_i - \bar{y})^2}{\sum_{n} (y_i - \bar{y})^2}$$

where y = the observed value, y = the predicted value, and $\bar{y}$ = the average value.

Table 2.19. Estimates of the three coefficients b_0, b_1, b_2 for the height growth models on the ground, antenna, and control sites during the 1985 and 1986 growing seasons.

	b_0	Assymptotic 95% Confidence Interval	b_1	Assymptotic 95% Confidence Interval	b_2	Assymptotic 95% Confidence Interval
1986						
ground	0.0532	(0.0442, 0.0622)	0.4215	(0.4043, 0.4387)	6.7192	(6.1055, 7.3329)
antenna	0.0603	(0.0541, 0.0665)	0.4294	(0.4173, 0 4415)	7.3196	(6.8440, 7.7953)
control	0.0548	(0.0494, 0.0602)	0.4799	(0.4672, 0.4928)	10.4020	(9.6765, 11.1276)
1985						
ground	0.0240	(0.0135, 0.0346)	0.3191	(0.3047, 0.3335)	8.2844	(7.3720, 9.1969)
antenna	0.1872	(0.0116, 0.0258)	0.4255	(0.4093, 0.4418)	13.8314	(12.2889, 15.3738)
control	0.0048	(-0.0021, 0.0118)	0.4445	(0.4267, 0.4623)	10.8027	(9.6329, 11.9725)

Figure 2.4.

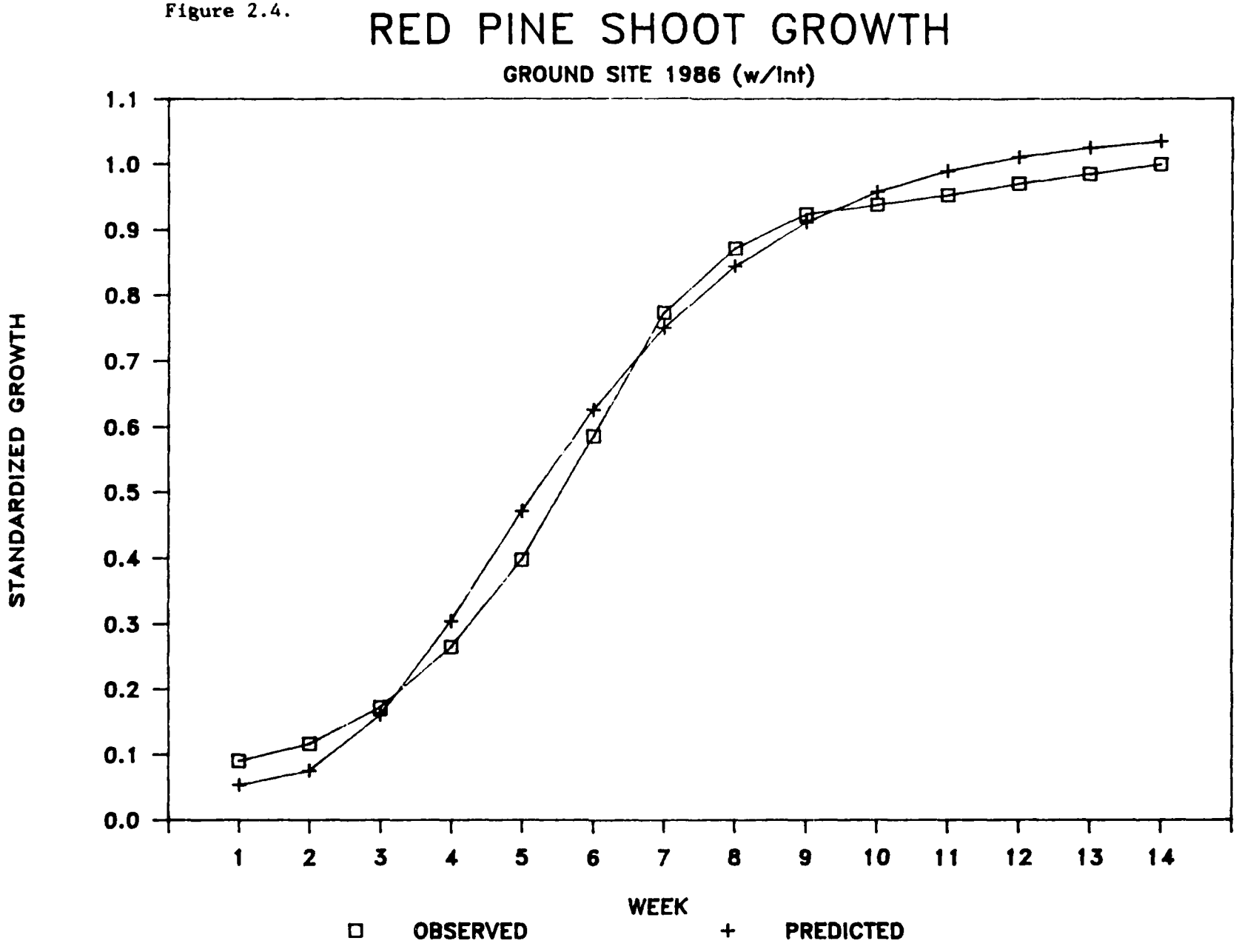

RED PINE SHOOT GROWTH
GROUND SITE 1986 (w/Int)
STANDARDIZED GROWTH
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
WEEK
OBSERVED
PREDICTED

Figure 2.5.

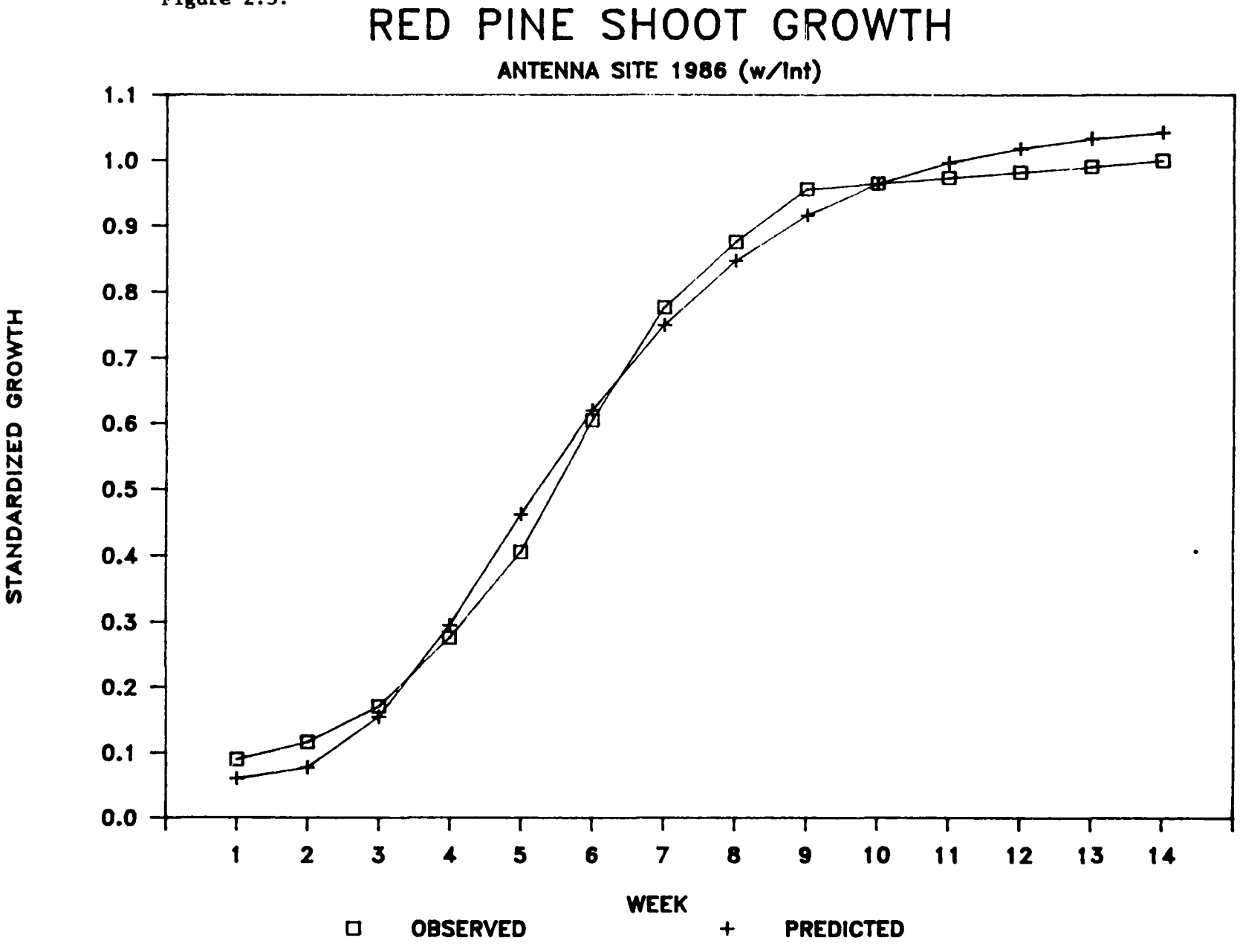
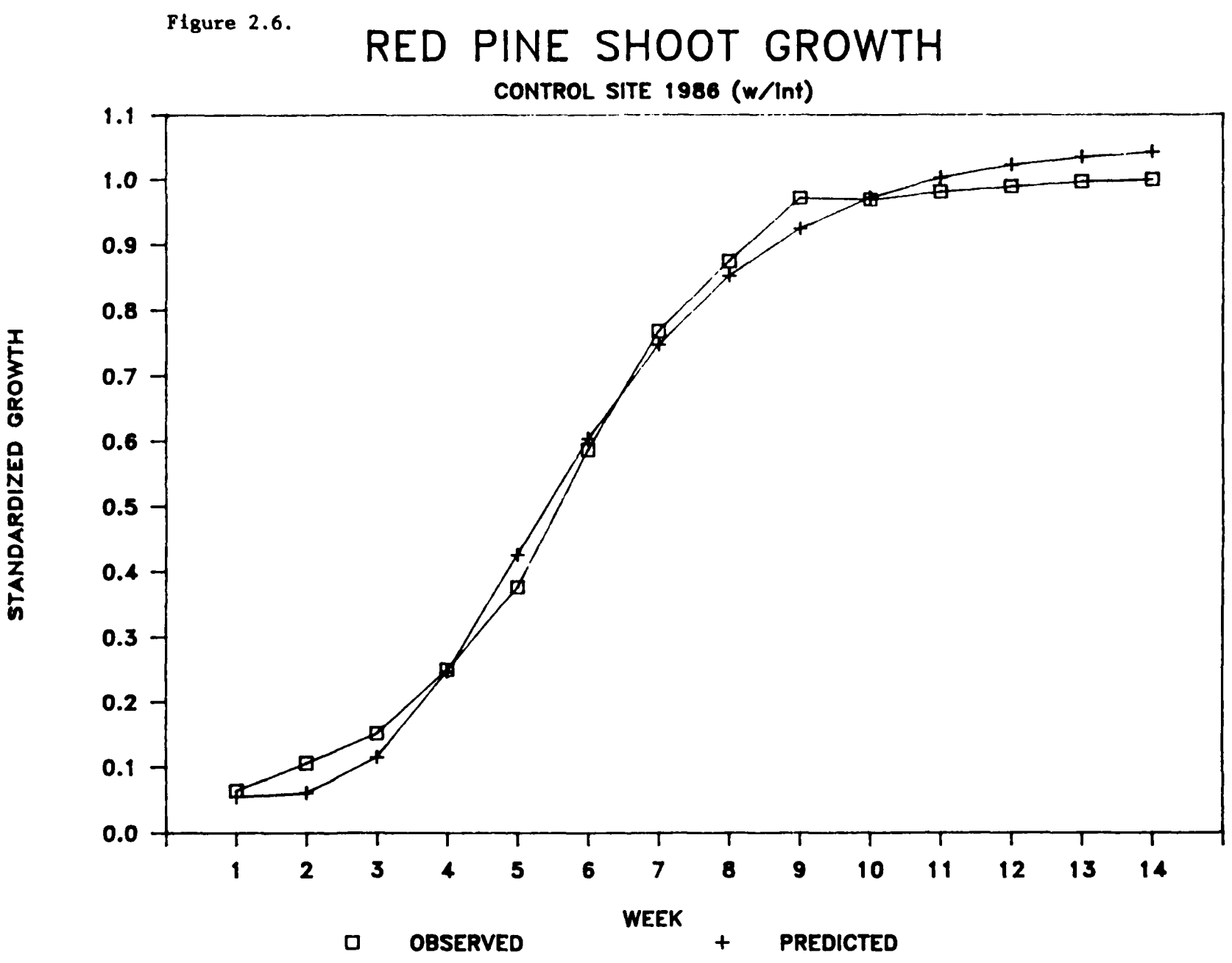

RED PINE SHOOT GROWTH
ANTENNA SITE 1986 (w/Int)
STANDARDIZED GROWTH
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
WEEK
OBSERVED
PREDICTED

Figure 2.6.


RED PINE SHOOT GROWTH
CONTROL SITE 1986 (w/Int)
STANDARDIZED GROWTH
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
WEEK
OBSERVED
PREDICTED

Among the three sites during a given year there were little or no significant differences in the estimates of the parameters. In the case of b_1, the estimate of the control site was significantly different from the other two estimates in 1986, and the estimate for the ground site was significantly different from the other two estimates in 1985. In 1986 the seedlings on the control site appear to be a little quicker in reaching 90% of their total height growth for the season and in 1985 the seedlings on the ground site appear to be a little quicker in achieving 90% of the total height growth for the season. When considering b_2, in 1986 again, only the estimate for the control site differed significantly. In 1985 all three estimates were significantly different; this is the result of a much larger growth rate of the seedlings on the control site followed by the seedlings on the antenna site and finally those on the ground site.

There is a significant change in most of the parameters from 1985 to 1986. These changes in the estimates of the model parameters can be ued to infer changes in growth patterns. During the 1986 growing season 50 percent of total height growth was obtained a little less than two weeks before the same amount in 1985. The differences in model coefficients indicate that is a significant difference ($p = .05$). Less than one week's growth difference could have been detected giving the detection limits on differences in the estimates of the model parameters ($p = .05$).

Current efforts towards quantifying site and yearly differences using and ambient information from the previous year is underway. Variables such as cumulative air temperature degree days (4.4°C basis) and cumulative precipitation may be important in accounting for these differences. By reducing the unexplained differences among sites and across years, any possible differences in the red pine height growth pattern due to the effects of ELF fields would be more apparent and more easily detected.

Red Pine Moisture Stress

Plant moisture stress (PMS) as determined by xylem water tension is a measure of the internal moisture status of plants and can be a useful indication of overall physiological condition. Optimal tree growth is dependent on many factors such as healthy root systems which allow adequate uptake of water and nutrients. Similarly, the aboveground biomass must function properly to translocate water and nutrients from the roots to provide photosynthates for growth. A physiological change that would effect the functions 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 PMS may indicate changes in physiological processes that affect growth. Consequently, PMS will be considered as a covariate to help evaluate red pine growth before and after the ELF antenna becomes operational.

Plant moisture stress 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 is genetically uniform, 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 processes are also not optimal and may be reflected in internal moisture status. Plant moisture stress measurements will also be considered as a covariate to help explain growth differences between the study sites.

In addition to reflecting possible physiological changes, PMS values can be used to indicate moisture stress during drought periods. Extended drought can reduce water uptake and reduce growth and survival of red pine

seedlings. The PMS values can help explain differences in year to year growth that are due to drought conditions. In effect, PMS reflects the integrated effects of physiological processes and environmental conditions on seedling growth as indicated by internal moisture status. The overall objective of the red pine moisture stress study is to quantify the PMS/growth relationship prior to and after the activation of the ELF antenna and evaluate the usefulness of PMS as a covariate in the growth analysis of red pine.

Sampling and Data Collection - Field Study

Sampling was conducted bi-weekly beginning on May 30 and continuing until September 2. Sampling was not conducted after this time due to cold temperatures at the scheduled time of sampling and frozen xylem water in the seedling; this results in high moisture stress values that are not an accurate reflection of seedling moisture status. Fifteen actively growing seedlings were randomly selected on each site. A lateral shoot was severed from each seedling in the pre-dawn hours and immediately placed in a plant moisture stress meter to determine xylem water potential. During the daylight hours prior to PMS determination, basal diameter, shoot elongation, total height, and bud formation status were measured. The remaining stem and roots were excavated the afternoon following PMS determination to measure aboveground/belowground biomass (shoot-root ratio), and mycorrhiza numbers (see Element 6).

Progress

Support Study

In 1985, a support study was conducted in a controlled environment to help determine the effects of PMS on seedling growth. This study

investigated which aspects of seedling growth were most affected by moisture stress and at what critical levels of PMS measureable differences in growth occur. The results of the support study help explain PMS data collected on red pine in the field.

The experiment was conducted on 300 potted red pine seedlings subjected to five different watering regimes. Moisture regimes varied from field capacity to below permanent wilting point for the duration of the study. A plastic shelter was erected over the pots to minimize additional water from precipitation. This covering was placed in such a way to prevent reductions in air movement and its subsequent effects on plant respiration and transpiration.

A complete discussion of results can be found in Becker et al. (1987). Overall, moisture stress as measured with a pressure bomb, was highly correlated with seedling growth and survival. While shoot elongation during the drought period was unaffected, stressed seedlings showed pronounced decreases in cambial activity, secondary needle elongation, subsequent bud formation, root length, and number of active mycorrhizal root tips per centimeter compared to control treatments. [illegible] resulted in reduced top and root dry-matter production. Watering [illegible]tments with average seasonal internal moisture stress values in the [illegible] of -.8 to -.11 MPa showed no measurable reductions in seedling growth.

Results indicate that PMS can be a valuable measure to use as a covariate explaining drought induced stress. Presently, however, PMS has not been an important part of modeling efforts because drought stress in the range suggested by our support experiments has not been evident at our study site seedlings.

Field Study

Mean PMS values for 1985 and 1986 are presented in Table 2.20. The more negative the PMS value the greater the internal moisture stress. For 1986 data, significant differences were found between sampling dates ($p = 0.000$) and sites ($p = 0.012$), but the site by date interaction was not significant ($p = 0.122$). Although these differences exist, the PMS values do not indicate internal water deficits at any time during the growing season or between sites. The support study on PMS and seedling growth suggested that seasonal PMS values ranging between -.8 and -1.1 MPa did not produce measurable reductions in seedling growth or other phisological response (Becker 1986). The 1986 field PMS means range between -.36 and -.92 MPa which further suggests that there was no internal moisture deficit. In addition, soil moisture levels at 10 cm at each site were well above the wilting point and during the spring and during the fall they exceeded field capacity (Figure 2.7). Compared with 1985, the 1986 PMS values are higher but, because of the favorable moisture conditions, any changes in growth processes would not be attributed to internal moisture stress.

Correlation coefficients were calculated for PMS with a number of climatic and seedling parameters (Table 2.21). Significant correlations were found with several of the variables tested. Seedling variables significantly correlated with PMS were basal diameter, aboveground biomass, and belowground biomass indicating that larger plants (also larger root systems) had lower PMS. However, total height was not significantly correlated with PMS which was also the case in the support study (Becker 1986). Climatic variables significantly correlated with PMS were weekly air and soil (5 cm) temperature, weekly air and soil (5 cm) temperature degree days and precipitation. However soil moisture, available soil water, and

Table 2.20. Average plant moisture stress values 1985 and 1986 (-MPa).

	1986								
	5/30	6/10	6/24	7/8	7/22	8/5	8/19	9/2	Overall
Ground	.68	.62	.73	.66	.59	.45	.37	.39	.56[A] A/
Antenna	.77	.68	.86	.72	.63	.46	.39	.36	.61[A]
Control	.70	.80	.74	.74	.92	.62	.56	.47	.69[B]
Overall	-.72[FG]	-.69[FH]	.72[G]	.71[FG]	.71[FG]	.51[HI]	.44[I]	.41[I]	

	1985				
	5/21*	6/18	7/16	8/21	9/25*
Ground	2.32	.50	.63	.59	1.94
Antenna	2.17	.50	.65	.57	2.15
Control	1.10	.64	.68	.64	2.25
Overall	1.86[K]	5.5[L]	.65[L]	.60[L]	2.22[M]

* Xylem water within the seedlings was frozen at the time of measurement.

A/ Means followed by the same letter are not significantly different (p = .05).

Figure 2.7.

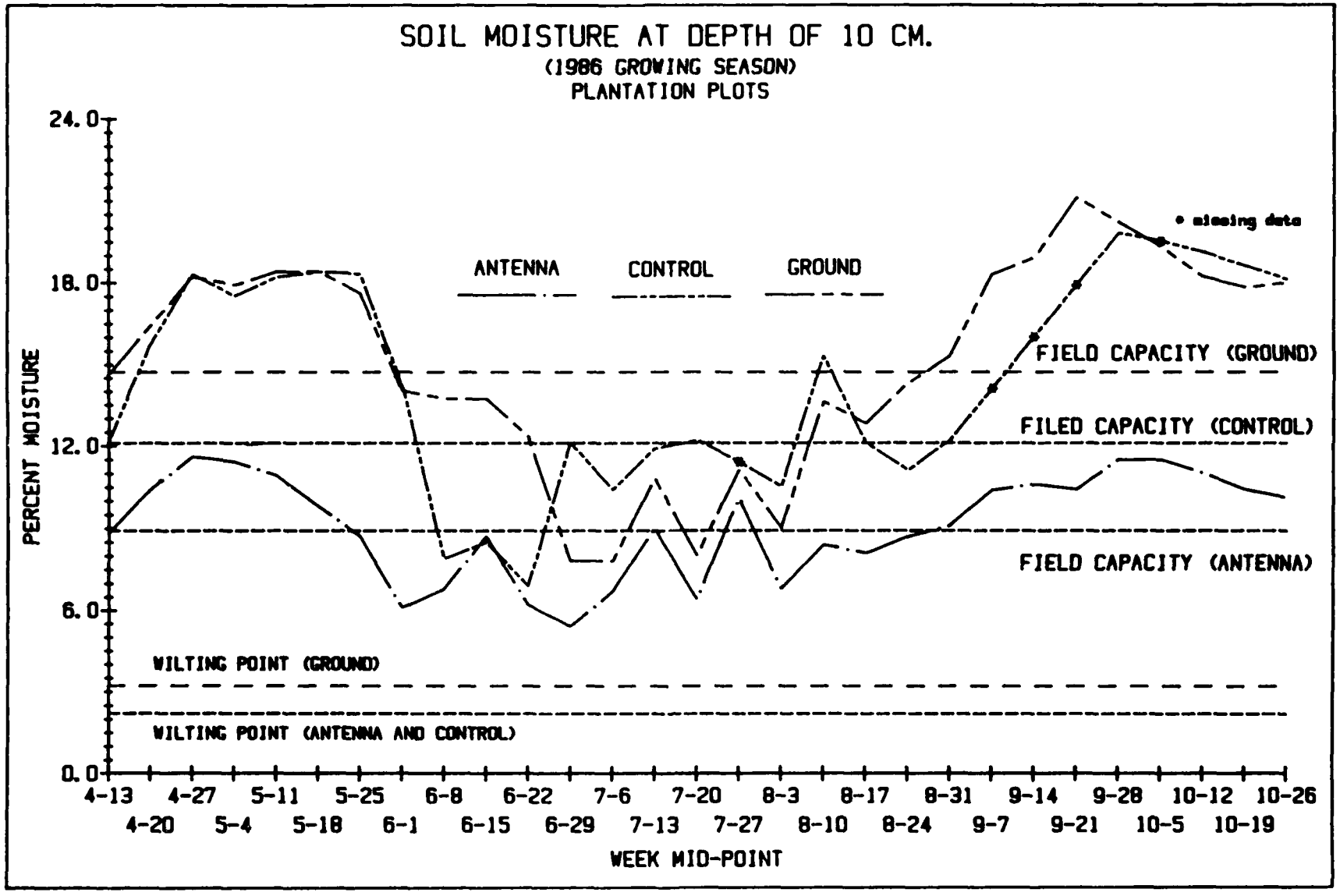

SOIL MOISTURE AT DEPTH OF 10 CM.
(1986 GROWING SEASON)
PLANTATION PLOTS
24.0
18.0
12.0
6.0
0.0
PERCENT MOISTURE
* missing data
ANTENNA
CONTROL
GROUND
FIELD CAPACITY (GROUND)
FILED CAPACITY (CONTROL)
FIELD CAPACITY (ANTENNA)
WILTING POINT (GROUND)
WILTING POINT (ANTENNA AND CONTROL)
4-13
4-20
4-27
5-4
5-11
5-18
5-25
6-1
6-8
6-15
6-22
6-29
7-6
7-13
7-20
7-27
8-3
8-10
8-17
8-24
8-31
9-7
9-14
9-21
9-28
10-5
10-12
10-19
10-26
WEEK MID-POINT

Table 2.21. Pearson product-moment correlation coefficients between PMS and selected trees, stand, and ambient variables.

	PMS
Basal diameter at time of sampling	.14*
Total height at time of sampling	-.04
Shoot elongation at time of sampling	-.02
Aboveground biomass at time of sampling	.23**
Belowground biomass at time of sampling	.15*
Shoot/root ratio at time of sampling	.10
Number of mycorrhizal root tips at time of sampling	-.11
Average weekly air temperature	-.13*
Average weekly soil moisture at 10 cm	.03
Average weekly soil moisture at 5 cm	.01
Average weekly soil temperature	-.12
Average weekly soil temperature at 5 cm	-.14*
Average weekly available soil water at 5 cm	-.02
Average weekly available soil water at 10 cm	-.02
Total precipitation during the week	.31**
Number of days in week with $\geq$.01 inches precipitation	.15*
Number of days in week with $\geq$.10 inches precipitation	.16*
Weekly average of daily relative humidity	-.08

Significant at: * p = .01
** p = .001

relative humidity were not significantly correlated, probably because there were no moisture deficits in 1986. Air and soil temperatures were negatively correlated indicating higher PMS during warmer periods. It is at these times when internal moisture flow due to transpiration is greatest resulting in higher moisture stress.

The PMS values during 1986 remained at levels where seedling growth was not reduced because of water deficits. This was due to adequate precipitation and soil moisture throughout the period. The PMS and variables significantly correlated with PMS will be evaluated in 1987 for use as covariates in the red pine growth analysis.

Red Pine Seedling Mortality - Armillaria Root Disease

Low levels of red pine seedling mortality were associated Armillaria root disease on all three study plantations during 1986. Armillaria root disease is the only infectious disease associated with measurable mortality in the red pine plantation plots. Additional seedling mortality, consistent with present levels of the root disease, is expected to develop over the lifetimes of the study plantations. We are therefore evaluating both seedling mortality and possible growth loss due to Armillaria root disease (Singh 1980) in support of our red pine seedling growth studies.

The causal agent, Armillaria mella sensu lato (Wargo and Shaw III 1985), is an opportunistic pathogen which successfully attacks conifer seedlings growing too close to an inoculum source, especially if those seedlings are under physiological stress. The pathogen is actually a complex of very closely related Armillaria species, all of which are white rot wood decay fungi. Several of these species are ubiquitous inhabitants of north temperature hardwood forests, where they colonize and decay woody debris, dead roots, and stumps as foodbases. A portion of the energy derived from the decay process is then utilized for growth through the soil and colonization of new foodbases by means of shoestring-like rhizomorphs, which are capable of penetrating and infecting the roots of vulnerable conifer seedlings. Infection may also take place when healthy seedling roots grow into contact with infested foodbase stump/root systems.

Root disease development is regulated by a number of biological and physical site factors which ultimately determine the levels of root disease mortality witnessed in an area. First, root disease development is favored by abundant, large, and evenly-distributed hardwood stump foodbases (Pronos and Patton 1977). Such conditions would place a high proportion of plantation seedlings in close proximity to inoculum sources. Second,

rhizomorph growth through the soil is most efficient in well-aerated, light textured soils with low rock content (Rishbeth 1978, Singh 1981). Third, environmental factors which stress conifer seedlings, such as severe drought, favor root disease infection when suitable inoculum is present. As a possible additional environmental stress factor, the effect of ELF fields on Armillaria root disease mortality levels will be tested.

Sampling and Data Collection

Armillaria root disease of conifer seedlings is easily diagnosed. Once sufficient root mortality has taken place to cause needle color to turn dull gray-green, white mycelial fans of Armillaria have invaded the phloem and cambium of the root collar at or near the soil line (Singh 1980). The pathogen is easily isolated into pure culture from mycelial fan tissue (Mallett and Hiratsuka 1985). A 100 percent inventory of each plantation plot was made periodically during 1986, in order to map root disease mortality and to culture the pathogen from diseased seedlings.

The spatial distributions of the Armillaria clones (genetically uniform vegetative population units or individuals) responsible for seedling mortality are being determined by performing a series of confrontations on agar plates between isolates cultured from dying seedlings and others cultured from nearby stump foodbases or sporocarps. Isolates from the same clone grow together and intermingle freely, whereas isolates from different clones form lines of demarcation where they grow into contact (Anderson et al. 1979, Kile 1986, Korhonen 1978, Mallett and Hiratsuka 1986, Siepmann 1985). Knowledge of the exact route of Armillaria spread from stumps to seedlings will help us to determine how important stump species, size, and density are as factors affecting mortality levels. This information will help us to plan the details of our covariate analysis.

Seedling mortality due to Armillaria root disease will continue to be inventoried monthly during the growing season for the remainder years of the study. The levels of root disease mortality observed will be analyzed through the split plot in space and time design discussed in the Introduction. Covariates to be considered will include soil texture and rock content, weather variables indicative of seedling stress (e.g. cumulative seasonal precipitation), seedling size as an indication of health, and variables describing the potential stump foodbase resource available to Armillaria spp. Stump diameter and spatial distribution will be measured by species in 1987 on each plantation plot.

Progress

Armillaria root disease mortality at all three plantation plots during 1986 (Table 2.22) was very low. The distributions of the Armillaria spp. occurring on the nine plantation plots were determined throughout the 1986 growing season. The pathogen was isolated from a total of 149 stumps and 109 sporocarp collections, as well as from the 76 seedlings killed by the disease. All cultures and sporocarp collections of Armillaria are being held for reference. Sampled locations have been permanently marked in the field and mapped. Cultural confrontations based on the 1986 isolations are nearly completed; preliminary maps of the clones responsible for 1986 mortality will be available by the beginning of the 1987 field season.

Table 2.22. **Mortality of planted red pine seedlings due to Armillaria root disease on each of the nine plantation plot replicates during 1986, presented both as the number of seedlings killed and as the percentage killed of the original number of seedlings planted.**

	Plantation plot					
	Ground		Antenna		Control	
plot Replicate	Number	Percent	Number	Percent	Number	Percent
1	0	0.00	14	0.82	15	0.69
2	4	0.16	2	0.12	20	0.92
3	5	0.20	11	0.64	5	0.23

ELEMENT 3. PHENOPHASE DESCRIPTION AND DOCUMENTATION

The overall objective of this element is to: 1) describe and document specific phenological events of an herbaceous species during the baseline study period, and 2) use these data to test hypotheses related to possible changes in physiological and phenological processes due to ELF electromagnetic fields when the system becomes operational. By documenting these biological events during the baseline period, a database will be developed to compare to similar data collected when ELF is operational. This will allow monitoring of any possible shifts in the timing of the selected phenophases that may be due to ELF fields. However, we must first be able to separate any shifts in phenophases that are due to variation in natural conditions. It is important, therefore, to include detailed climatic data when describing and documenting phenophases that will be used to evaluate possible effects due to ELF electromagnetic fields.

The herbaceous layer of a northern hardwood ecosystem is an ecologically important component of the system with respect to edaphic and vegetative factors. Phenology, the study of the timing of life cycle events relative to environmental cues (Barbour et al. 1980), has been used to quantitatively describe the herbaceous component of a northern hardwood forest (Mahall and Bormann 1978). The onset of definable vegetative and reproductive phenophases characteristic of an herbaceous species will be the primary response variables in assessing effects due to ELF fields.

The focus species of this study is Trientalis borealis Raf., starflower. Starflower is common and in sufficient numbers on the antenna and control sites and flowers more frequently than other forest floor species examined. The phenophases of starflower have also been well

documented in northern Wisconsin by Anderson and Loucks (1973). Many herbaceous studies focusing on phenology focus on reproductive and vegetative organs; thus, emphasis is given to quantitative observations of these organs of starflower in order to define characteristic phenophases with greater confidence. Prior to a fully operational system, timing and the proportion of flowering as well as timing of leaf expansion and amount of leaf area need to be examined both between the two study sites as well as between years. The null hypothesis tested each year before the antenna becomes operational is:

H_0: There is no difference in the onset of flowering and the timing of leaf expansion of Trientalis borealis Raf. between the antenna and control sites within a year.

The hypothesis to be tested overall is:

H_0: There is no difference in the onset of flowering and the timing of leaf expansion of Trientalis borealis Raf. before and after the ELF antenna becomes operational.

Sampling and Data Collection

To ensure an adequate representation of starflower phenophases, a minimum sample size of 200 individual plants per site was maintained at 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 meter square subplots. Individual plants within plots were numbered and tagged until the observation period when a normal distribution of individual stem length, an indicator of the plant's potential sexual productivity, was attained. A normal distribution of stem length ensures an adequate representation of the population. The number of meter square subplots required to attain a minimum sample size

of 200 plants varied with each site and observation period. To reduce bias in choosing the 200th individual, all individuals were tagged in the subplot where the 200th individual was observed, hence the unequal sample size on any given day (Mahall and Bormann 1978). The sample size was maintained until tagged individuals began to die. Thereafter, observations were taken only on the remaining tagged individuals.

During the 1986 field season, data were collected during 27 observation periods at the antenna site and 28 observation periods at the control site between April 24 and September 1. Observations were most frequent between April 24 and June 23 (approximately every three days) so as to delineate flowering periods and leaf expansion with greater precision. Thereafter, observations were taken every seven days at each site. Parameters measured per plant during each observation period included stem length, length and width of the largest leaf, number of leaves, number of buds, flowers and fruit, and number of yellow and brown leaves.

Progress

A normal distribution of individual stem length was attained at both sites by May 13. On the control site, flowering and fruit production were first observed on May 13 and 22 respectively (Figure 3.1). The same phenophases at the antenna site were observed on May 15 and 26, respectively (Figure 3.2). A difference of two (2) days between the sites is apparent for the onset of flowering and four (4) days for the beginning of fruit production. In 1985 the same phenophases both differed by six (6) days. Characteristics of the starflower population sampled between sites and between years are presented in Table 3.1. The increased number of plants producing flowers than plants producing buds and an even larger number of plants producing fruit than those producing flowers is a function

Figure 3.1

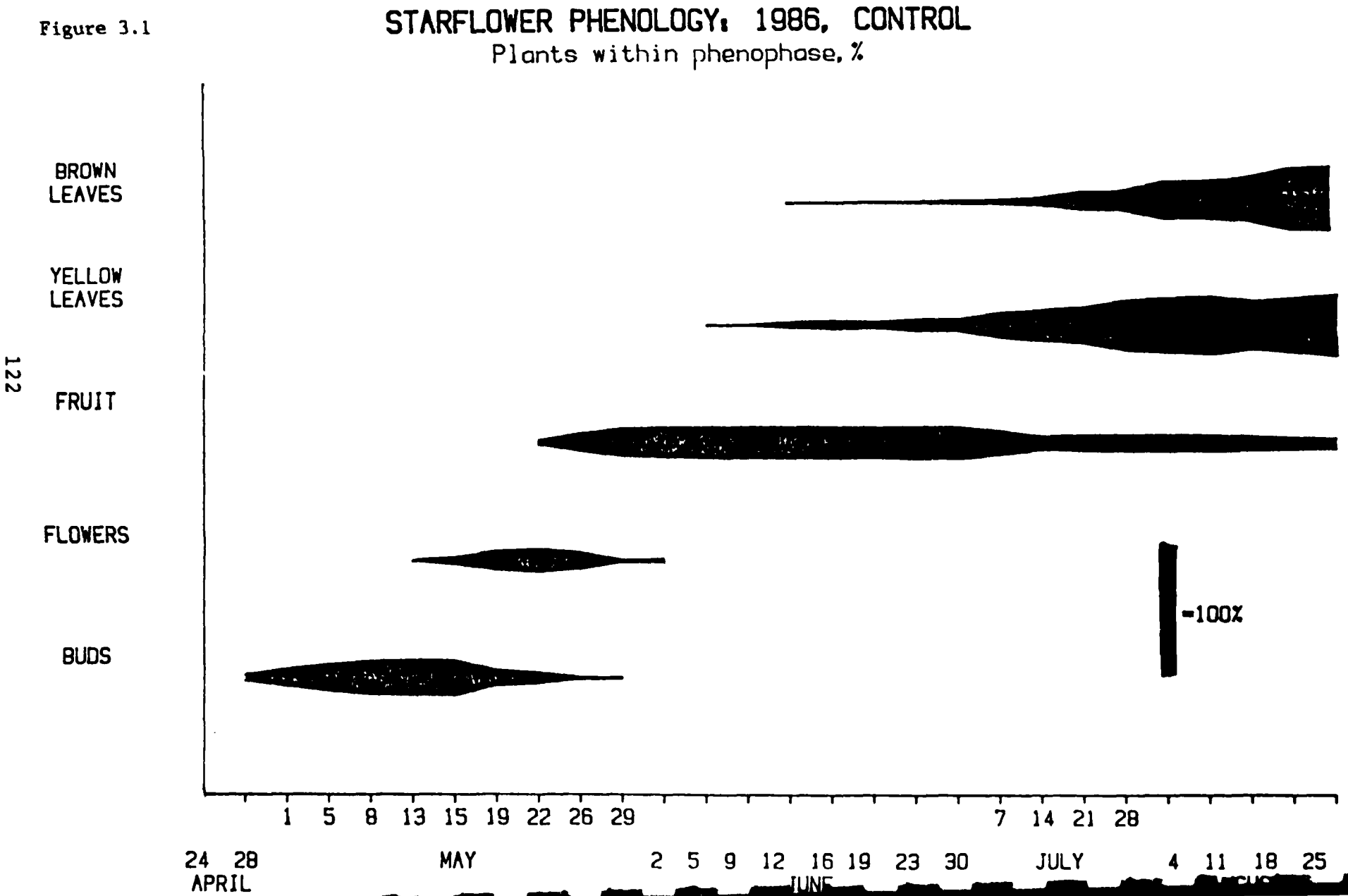

STARFLOWER PHENOLOGY: 1986, CONTROL
Plants within phenophase, %
BROWN LEAVES
YELLOW LEAVES
FRUIT
FLOWERS
BUDS
=100%
1 5 8 13 15 19 22 26 29
7 14 21 28
24 28
APRIL
MAY
2 5 9 12 16 19 23 30
JUNE
JULY
4 11 18 25

Figure 3.2

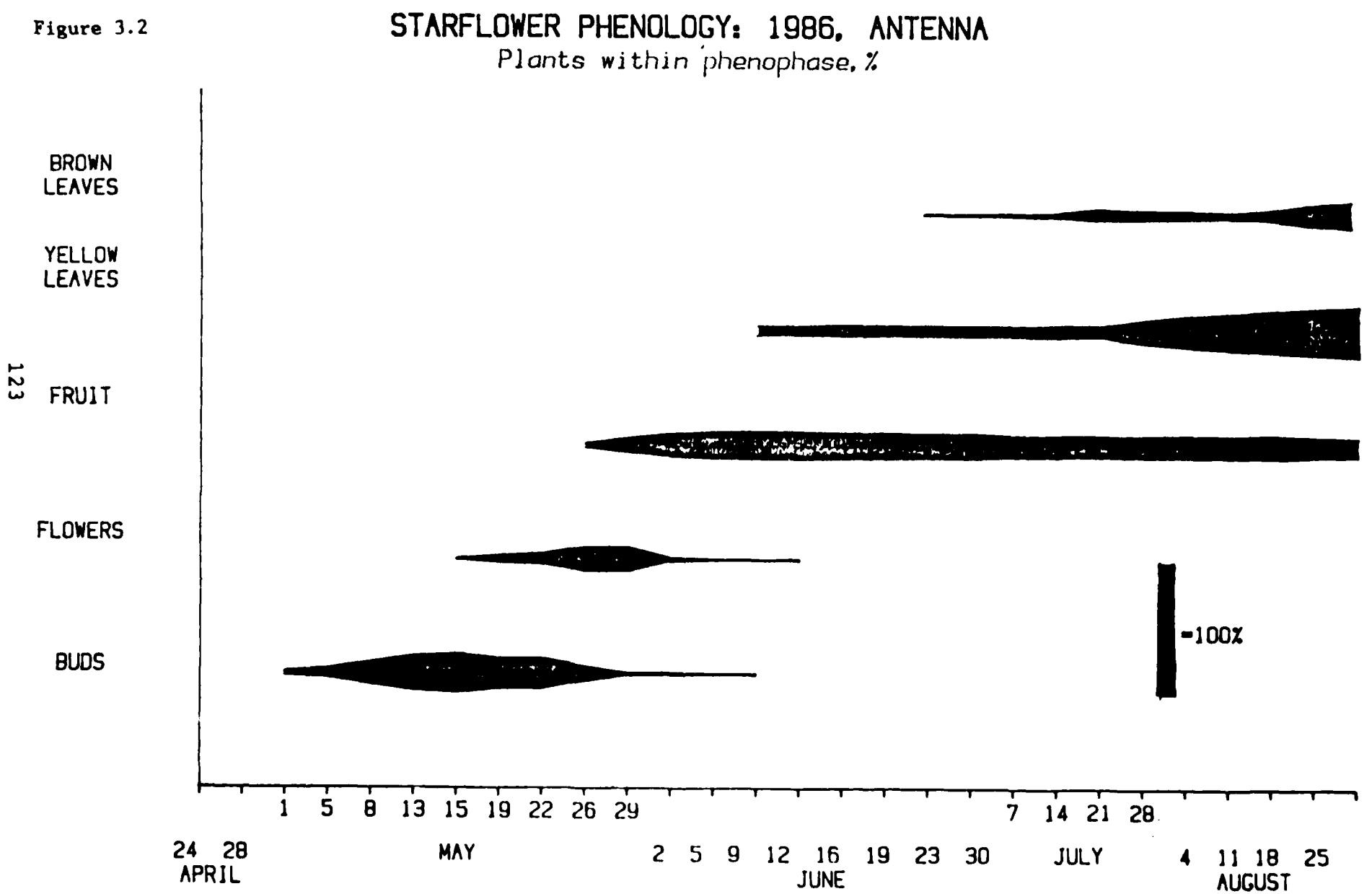

STARFLOWER PHENOLOGY: 1986, ANTENNA
Plants within phenophase, %
BROWN LEAVES
YELLOW LEAVES
FRUIT
FLOWERS
BUDS
=100%
1 5 8 13 15 19 22 26 29
7 14 21 28
24 28
APRIL
MAY
2 5 9 12 16 19 23 30
JUNE
JULY
4 11 18 25
AUGUST

Table 3.1. Sample characteristics of the starflower population between sites and between years.

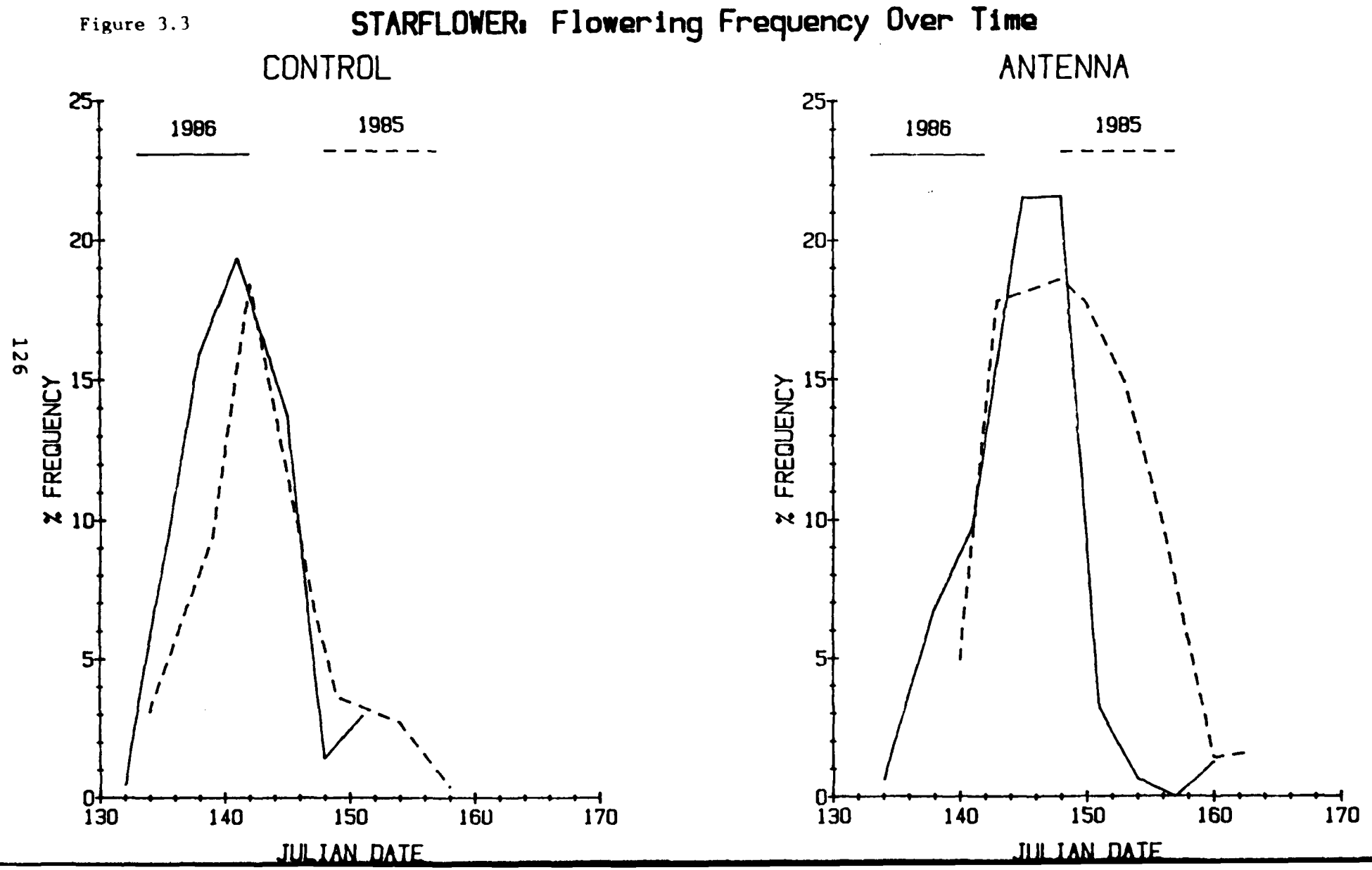
	Control		Antenna	
	1985	1986	1985	1986
Unique plants observed	347	346	245	273
Plants forming buds	69	95	87	91
Plants forming flowers	71	69	71	55
Plants forming fruit	79	68	78	45
Herbivory (plants lost/obs. period)	4.2	3.0	2.0	2.9
Flowering plants/Unique plants observed during flowering period	.2700	.3224	.3021	.3198
Average leaf expansion (%) at onset of flowering (SE)	80.54 (±4.18)	81.27 (±3.50)	86.70 (±3.06)	90.41 (±3.86)

of the sampling design. When tagged plants were removed from the sample, usually due to herbivory, other plants which had already progressed through the bud and flowering phenophases, were added to the sample so as to maintain the minimum sample size of 200 plants. During the 1986 data collection period, herbivory was most pronounced on the antenna site when approximately 35 tagged plants were destroyed between May 8 and May 13. Thereafter, the sample size maintained was between 160 and 170 plants per sampling period until the tagged plants began to die at the end of June.

Observational data collected during the 1985 and 1986 field seasons has defined the flowering phenophase characteristic of each site. Past research indicated that flowering frequency curves over time are species specific (Schemske et al. 1978). The flowering frequency curves of starflower for the control and antenna sites during 1985 and 1986 are presented in Figure 3.3. Observed flowering was most frequent at a single point in time on the control site during both years, whereas observed flowering was most frequent over seven (7) days in 1985 and three (3) days in 1986 on the antenna site. Observations were made within one day of each other between sites in 1985 and on the same day at both sites in 1986. The distribution of flowering over time was not significantly different ($p = .05$) between sites when the Kolmogorov-Smirnov test was applied.

The proportion of flowering plants observed between sites as well as between the years 1985 and 1986 were not significantly different ($p = .05$). Between the 1985 and 1986 growing season, the observable difference in the proportion of flowering plants was 1.8% ($\pm$ 9.3%) at the antenna site and 5.3% ($\pm$ 7.9%) at the control site. A difference of at least 12.9% would have to occur before a significant difference between growing seasons would be detected at the antenna site ($p = .05$) and a difference of at least 11.7% would have to occur before a significant

Figure 3.3


STARFLOWER: Flowering Frequency Over Time
CONTROL
ANTENNA
1986
1985
% FREQUENCY
JULIAN DATE
0
5
10
15
20
25
130
140
150
160
170

difference between growing seasons would be detected at the control site ($p = .05$). Further analyses incorporating climatic information to further explain any variation in the system both between the two sites as well as between each growing season will be done in 1987.

Flowering appears to be responsive to microclimatic conditions, particularly air temperature (Lindsey and Newman 1956, Jackson 1966). Flowering begins when starflower leaves are at 95% of full expansion in Wisconsin (Anderson and Loucks 1973). The average percent leaf expansions at the onset of flowering for each site during the 1985 and 1986 field seasons are shown in Table 3.1. The onset of flowering relative to leaf expansion appears to be site specific as there is no significant difference ($p = .05$) between years on either the control or antenna site using analysis of variance tests, however there is a significant difference ($p = .05$) between sites. Models predicting the onset of flowering incorporating both physiological and climatic variables are under development. The coefficients of the models will be used to test for any shifts in the timing of flowering both between the two sites and between each growing season prior to an operational antenna to establish natural variation in the system. Similar tests of coefficients after the antenna is operational will follow. Correlation matrices between plant growth variables and the onset of flowering show significant correlation of the onset of flowering with leaf expansion as a percentage, stem length, and number of buds present on the plant. The relationship of climatic variables with the onset of flowering also needs to be examined in the coming year to aid in explaining any shifts in the onset flowering that might occur from year to year.

Leaf expansion is a vegetative phenophase which provides an opportunity to test the effects of ELF electromagnetic fields on an herbaceous species

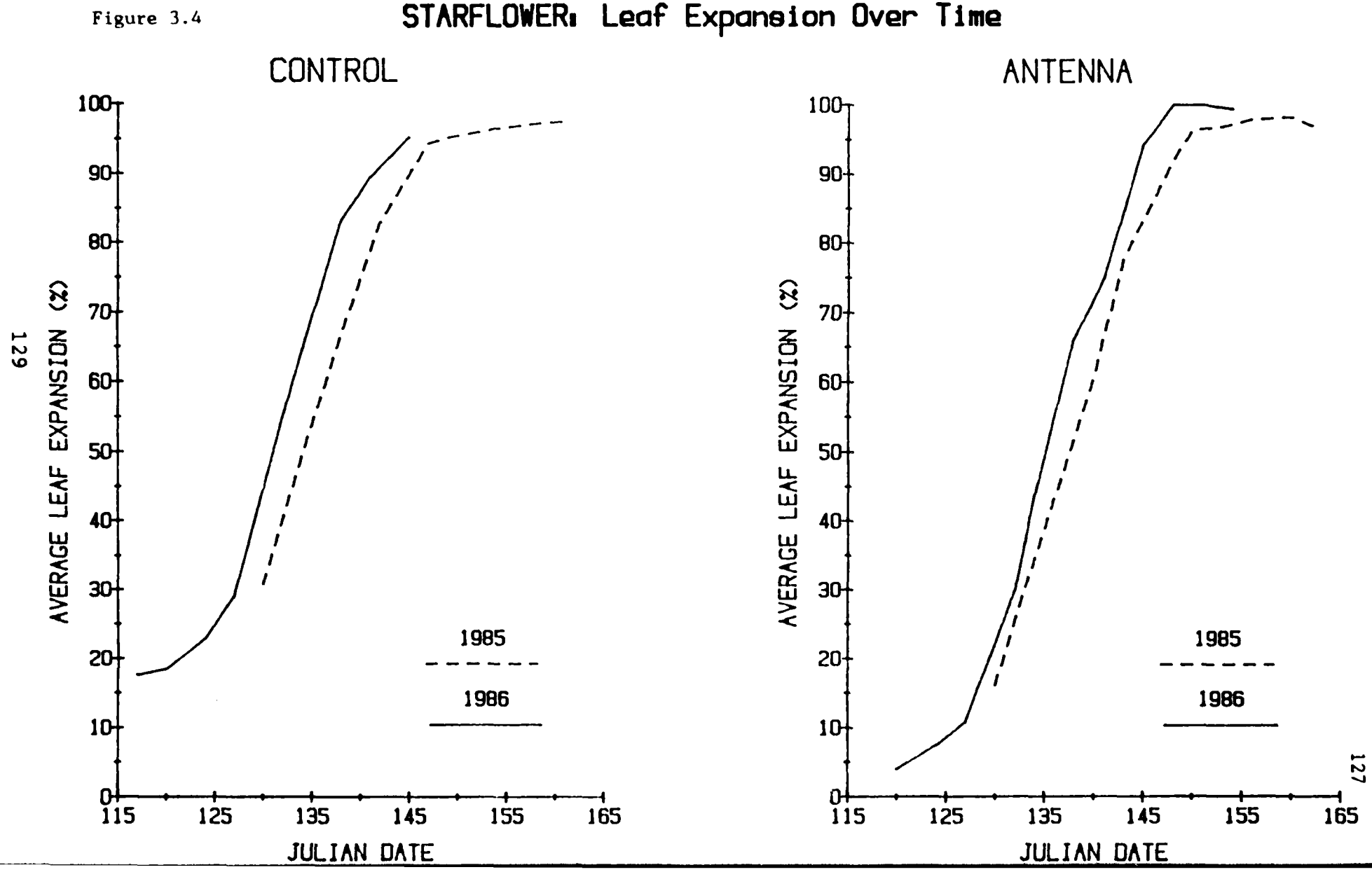
if flowering is insufficient for study in any year. The rate of leaf expansion appears to be primarily due to temperature as shown in both greenhouse and field studies of starflower (Anderson and Loucks 1973). Models predicting the rate of leaf expansion allow tests of coefficients to establish any shifts in the timing of this event. Leaf expansion over time is depicted graphically in Figure 3.4. When the shapes of the curves were tested between years and sites, using the Kolmogorov-Smirnov test at the $p = 0.05$ level, there was no significant difference between the sites or between years. The relationships of temperature and other climatic and physiological information with the rate of leaf expansion are currently being determined.

At the same time the maximum leaf area occurring on each site will be tested using analyses of variance techniques to determine any significant differences between sites and years. Leaf area was estimated for plants at each site using data collected during the 1986 field season. The resulting equations were as follows:

$$LA_C = .15002 + .54530\ (LW)(LL)$$
$$LA_A = .08290 + .55458\ (LW)(LL)$$

Where LA_C is the leaf area of a plant at the control site, LA_A is the leaf area of a plant at the antenna site, LW is the leaf width, and LL is the leaf length. These equations explain 98.9% and 99.3% of the variation in the system. Climatic information, used as covariates, may further explain any site or yearly variation that might exist relative to leaf area.

Figure 3.4


STARFLOWER: Leaf Expansion Over Time
CONTROL
ANTENNA
AVERAGE LEAF EXPANSION (%)
JULIAN DATE
1985
1986
0
10
20
30
40
50
60
70
80
90
100
115
125
135
145
155
165
129
127

Diameter Growth in Hardwood Species

Sampling and Data Collection

The onset and cessation of cambial activity was determined from weekly readings of permanently installed dendrometer bands at the antenna and control sites. For each tree, the dendrometer band data were examined and the data recorded for the onset and termination of growth. Cambial activity was then expressed as the number of trees growing (in percent) for each weekly measurement. Figures showing cambial activity at each site for 1985 and 1986 are presented in Appendix D.

The onset of growth in 1985 at the control was not detected due to band slack that existed when dendrometer bands were replaced following the vandalism that occurred in 1984. Trees must grow enough to take up this slack before growth can be detected. For additional details concerning band slack and cambial activity refer to the 1985 annual report.

Progress

The cambial activity period was longer in 1985 than in 1986 at both the antenna and control sites for all species. The onset of growth was about the same for both years but the growth period extended later into the season in 1985. Although it appears that the onset of growth did not change substantially between sites and years, the timing in the amount of growth did vary. The diameter growth models discussed in Element 2 - Tree Productivity, account for these differences and quantify the timing of the diameter growth event. To further quantify the timing of diameter growth, climatic data was incorporated into the growth models. As a result, air temperature degree days explained approximately 95 percent of the variation in the timing of diameter growth between sites and between years. Refer to

Element 2 - Tree Productivity for complete details concerning the relationship between climatic variables and diameter growth. Thus the diameter growth models will be used to evaluate shifts in the timing of diameter growth.

Cambial activity described as the number of trees growing is useful as a tool to display the growth pattern of hardwood species. Since timing of diameter growth is quantified elsewhere, the graphical representation shown in Appendix C will serve to support those efforts.

ELEMENT 4: HERBACEOUS VEGETATION COVER

The overall objectives of this element are to 1) collect and evaluate data on the frequency and coverage of herbaceous plants on selected plots within the ELF antenna and control sites prior to the operation of the antenna, and 2) use these baseline data to evaluate the possible effects of ELF electromagnetic fields on the diversity, frequency, and coverage of herbaceous plants. Since the composition of the herbaceous plant community has been known to be influenced by environmental changes, ELF fields may cause changes in the diversity and abundance of herbaceous plant species. An ELF effect could be reflected by a change in:

1) number of species present,

2) species composition, and

3) the relative importance of individual species.

Trends in species composition over time may be detected by monitoring the previously stated variables on a yearly basis. Comparisons of each stand type will be made between the antenna and control sites. Although differences exist in vegetative structure between these sites, the magnitude of these differences will be monitored as one indicator of possible ELF effects.

Sampling and Data Collection

Percent cover and frequency were obtained on four randomly located 1-m^2 subplots along three permanently marked transects within each plot on the herbaceous plant reserves (total = 36). Similarly, 12 subplots were randomly located on permanently marked transects on the red pine plantations and in an area adjacent to the plots, that were not subjected to weed control measures. See Element 2, Tree Productivity for details regarding

weed control on the plantation plots. At the antenna and control sites, percent cover was recorded for each species occurring on each subplot was recorded. Field work was conducted in August when species diversity and plant biomass are greatest. Relative cover, relative frequency, and importance values for each species were calculated as follows:

$$\text{Relative cover (\%)} = \frac{\text{Percent cover of species "A" x 100}}{\text{Total cover}}$$

$$\text{Relative frequency (\%)} = \frac{\text{\# of subplots species "A" present in x 100}}{\text{Total \# of subplots}}$$

$$\text{Importance value} = \text{Relative frequency + relative cover}$$

Progress

Analysis

Quantifying subtle species shifts from year to year will prove to be a difficult task. We intend to focus efforts this year on evaluating the performance of various analysis techniques for three years of data collection. A major problem in the work element has been matching practical field techniques with effective statistical analyses. For example, percent plant cover is estimated on 1-m^2 plots in the field and it is difficult to accurately estimate plant cover from plot to plot consistantly and precisely. To correct this problem, coverage classes were established and are defined as:

Coverage Class	% Coverage
1	0-.4
2	.4-1
3	1-5
4	6-15
5	16-35
6	36-65
7	66-95
8	95-100

To analyze such information, the midpoints of the classes are used. Consequently, there is no measure of variation within classes; only among plots. Because of the large amount of variation among plots, ELF fields would have to cause relatively large changes in plant coverage to be detectable using these measures. More precise field measures are impractical when considering the time and effort involved. Ordination techniques, cluster analysis, categorical data analysis or discriminant analysis could be used to determine if distinct groupings of species change from year to year. At this point we are uncertain whether these improvements can overcome the basic imprecision in data due to the difficulties in gathering coverage information in the field.

Herbaceous Reserves

The ten most important species on the herbaceous reserves at the antenna and control site are listed in Table 4.1. A summary of the data is presented below.

Control site 1985 vs. 1986

Pteridium aquilinum was the most important species in both years. Four of the five most important species in 1985 were also found among the five most important in 1986 with Waldstienia fragarioides replacing Oryzopzis asperifolia. Similarly, seven of the ten most important species in 1985 remained in that group in 1986. Overall, six species increased in rank from 1985 to 1986 while six decreased.

Antenna site 1985 vs. 1986

Pteridium aquilinum was also the highest ranking species at the antenna site in both years. It was followed by Gaultheria procumbens and Aster

Table 4.1 The ten most important species on the herbaceous reserves at the antenna and control sites.

SPECIES	IMPORTANCE VALUE				RANKING			
	ANTENNA		CONTROL		ANTENNA		CONTROL	
	1985	1986	1985	1986	1985	1986	1985	1986
Pteridium aquilinum	101.6	126.1	102.3	138.4	1	1	1	1
Gaultheria procumbens	99.6	80.5	40.9	39.7	2	2	7	7
Aster macrophyllus	51.5	40.3	78.2	81.1	3	3	3	2
Rubus allegheniensis	41.6	35.2	30.1	-	4	5	10	-
Vaccinium membranaceum	40.5	27.9	-	-	5	6	-	-
Trientalis borealis	23.7	38.6	90.9	73.1	6	4	2	3
Rubus parviflorus	-	27.1	-	-	-	7	-	-
Anemone quinqefolia	20.5	-	56.3	-	7	-	6	-
Rubus idaeus	18.1	-	-	32.6	8	-	-	9
Oryzopsis asperifolia	17.9	26.8	67.0	51.4	9	8	4	6
Carex umbellata	-	23.7	-	-	-	9	-	-
Prunus pennsylvanica	-	17.5	-	-	-	10	-	-
Dieruilla lonicera	17.7	-	-	-	10	-	-	-
Maianthemum canadense	-	-	57.3	60.2	-	-	5	4
Lycopodium obscurum	-	-	39.0	31.4	-	-	8	10
Aralia nudicaulis	-	-	38.1	36.7	-	-	9	8
Waldsteinia fragarioides	-	-	-	53.7	-	-	-	5

macrophyllus which maintained their rankings between 1985 and 1986. Species comprising the six most important species did not change between years but their rankings varied somewhat. Similarly, seven of the ten most important species in 1985 were among the ten most important in 1986. Overall, four species increased in rank while five decreased in rank.

Antenna vs. Control 1986

Of the ten most important species at each site only five are common to both sites. Pteridium aquilinum had the highest ranking on both sites. Other common species include Gaultheria procumbens, Aster macrophyllus, Trientalis borealis, and Oryzopzis asperifolia. Rubus alleganiensis and Anemone quinquefolia were represented in this group in 1985 but not in 1986. This change can be partially attributed to the difficulties described above in estimating plant coverage and the coverage classes that were used in the field.

Red Pine Plantations

The dynamic nature of the frequency and coverage of species in the red pine plantations does not provide a good baseline from which to evaluate possible changes to the herbaceous community due to ELF fields. Because of the rapid changes that take place in the plantations, our efforts have concentrated on the herbaceous reserve plots in the hardwood stands where the plant community is more stable, and successional changes are much slower. Measurement of herbaceous cover on the plantations are conducted to further characterize the study sites and help in the evaluation of the fundamental differences that exist between the sites. In addition, the effort needed to collect and summarize these data is minimal.

Importance values and rankings of the ten most important species on the antenna and control plantations are presented in Table 4.2. The ranking of species by importance value clearly demonstrate how rapidly year to year changes can occur in early successional communities. For example, Gaultheria procumbens on the antenna site was ranked second in 1985 but was not found among the ten most important species in 1986. Furthermore, Prunus pennsylvanica was not ranked among the ten most important species at the antenna site in 1985 but was ranked third in 1986. Changes at the control site were not as dramatic but still reflect the changing compositions that exists in the plantations.

As mentioned above, we intend to concentrate our efforts on evaluating various analysis techniques to help overcome the basic problem caused by placing field estimates of plant coverage into classes. Without sound analytical techniques to test year to year and site to site differences we will not be able to test whether such differences are due to a treatment effect (i.e. ELF fields) or are due to the natural variation within the plant community.

Table 4.2 The ten most important species on the plantations at the antenna and control sites.

SPECIES	IMPORTANCE VALUE				RANKING			
	ANTENNA		CONTROL		ANTENNA		CONTROL	
	1985	1986	1985	1986	1985	1986	1985	1986
Pteridium aquilinum	95.3	113.9	115.9	79.8	1	2	2	3
Gaultheria procumbens	70.2	-	-	-	2	-	-	-
Crataegus spp.	69.6	-	52.8	-	3	-	5	-
Diervilla lonicera	68.3	-	-	-	4	-	-	-
Carex umbellata	65.3	115.1	52.6	56.2	5	1	6	6
Oryopsis asperifolia	58.6	45.7	36.1	78.1	6	5	10	4
Rubus allegheniensis	46.8	44.8	74.9	135.1	7	6	3	1
Polygonum cilinode	45.7	47.7	-	-	8	4	-	-
Vaccinium membranaceum	44.7	25.3	44.0	27.0	9	9	-	10
Rubus parviflorus	44.2	42.0	-	-	10	7	-	-
Prunus pensylvanica	-	64.5	-	-	-	3	-	-
Panicum implicatum	-	26.0	-	-	-	8	-	-
Trientalis borealis	-	25.3	-	-	-	9	-	-
Waldsteinia fragiodes	-	-	71.5	60.3	-	-	4	5
Lycopodium obscurum	-	-	51.2	42.5	-	-	7	8
Aster macrophyllus	-	-	135.5	92.2	-	-	1	2
Maianthemum canadense	-	-	44.0	-	-	-	-	-
Comptonia peregrina	-	-	-	47.0	-	-	-	7
Amelanchier spp.	-	-	-	33.7	-	-	-	9

ELEMENT 5. POPULATION DYNAMICS OF MYCORRHIZAL MACROFUNGI VIA SPOROCARP PRODUCTION

Mycorrhizae are essential to healthy plant growth because they serve as the integrating bridge between plant root systems and the surrounding soil. Because the mycorrhizal relationship is a mutualistic one, mycorrhizae are sensitive indicators of effects on either the host or the obligately parasite mycorrhizal fungus, or both. Evidence suggesting treatment effects on one component of the relationship can be weighed against possible effects on the other component. In addition, recent studies demonstrating the existence of naturally produced transcellular electrical fields in fungi suggest a possible avenue by which artifically produced electrical fields (e.g. ELF fields) might interfere with healthy mycorrhizal fungus growth and reproduction (Gow 1984, Harold et al. 1985, Kropf et al. 1985). For these reasons, mycorrhizae are an obvious object of study in the evaluation of possible ecosystem pertubations such as those associated with ELF fields (e.g. Tyler 1985, 1984, Reich et al. 1985).

Detailed study of ectomycorrhiza formation has been directed at the three red pine study plantations (Element 2) because of the considerable base of existing knowledge on red pine growth and mycorrhizae, and the relative ease of studying red pine seedling root systems as opposed to those of mature hardwoods. Nevertheless, the mixed hardwood polestands at the antenna and control sites offer an excellent opportunity to describe and quantify the indigenous ectomycorrhizal fungus communities via the population dynamics of sporocarp production.

The mixed hardwood forest was originally selected for study because 1) it represents a large proportion of the forest area transected by the ELF antenna system, and 2) it contains a substantial component of ectomycorrhizal tree species. Ectomycorrhizae lend themselves to more

straightforward study than do endomycorrhizae for several reasons, one being that many ectomycorrhizal fungi (referred to as macrofungi) produce large, often showy, fruiting bodies (sporocarps). Sporocarp production represents an investment of fungal energy (obtained from the host) in perpetuation of the fungal species. As such, the extent of sporocarp production reflects the combined vigor of the host-parasite system. Biologically meaningful environmental impacts on either the host or parasite populations should result in altered fruiting patterns by the mycorrhizal fungi present in the stand. Consequently, the main objective of this work element is to characterize the indigenous ectomycorrhizal macrofungus community at each polestand herbaceous reserve subplot replicate via fruiting dynamics of major component species, for comparison between years and among sites both before and after the ELF system antenna becomes operational.

Sampling and Data Collection

The population dynamics of ectomycorrhizal macrofungi in the polestand subplots are being evaluated through periodic nondestructive monitoring of sporocarp production on two sets of three contiguous 30 m x 35 m herbaceous reserve subplot replicates located at the antenna and control sites. Tallied sporocarps were slit vertically through the pileus *in situ* with a sharp knife so that they would not be re-recorded during subsequent visits. In general, tallied specimens were left on the plots 1) to sporulate, and 2) in order to avoid artifactual impact on the next flush (Manachere 1985). The slit pileus was often the only mark of the survey. Sporocarps were only picked as necessary for identification. The large size of each study plot minimizes the variability among sporocarp counts between years by absorbing the effect of spatial redistribution of sporocarp production around host trees between years. Sporocarp production is closely tied to host photosynthetic activity (Last *et al.* 1984), and host genotype (Last *et al.*

1984, Mason et al. 1984), and can therefore be expected to proceed as regularly as the relatively stable study stands and climate will permit.

Because local microclimate and host tree species (or genotype) distributions vary somewhat between the study plots in each stand, it is not surprising to find substantial differences in the representation of mycorrhizal fungus species among contiguous plots. This is viewed as evidence of the sensitivity of these fungi to their immediate environs. As a result, quantitative study of sporocarp production dynamics must focus on 1) explanation of patterns of annual fluctation in fruiting abundance, and 2) explanation of the relative abundance of sporocarp production among subplot replicates at each site. Clearly, individual fungus species need not be uniformly distributed over the subplot replicates or between sites in order to contribute meaningfully to evaluation of environmental perturbation. At this point, it is important to identify the the relationships between fruiting and weather variables so that annual fluctuations in fruiting at the sites can be properly interpreted.

Factors which regulate sporocarp production include light, temperatuare and fungal nutrition (Manachere, 1985). Reduced light intensity or shortened daylength are known to affect fruiting. Reduced temperature can also stimulate sporocarp maturation. Sporocarp primordia of some fungi form only when mycelial growth slows in association with carbohydrate depletion in the growth medium. Sporocarp development then becomes dependent on the nutrient reserves of the mycelium. Also, the availability of water as precipitation probably affects fruiting abundance, considering the high moisture content of sporocarps.

These environmental relationships help to explain why the preponderance of mycorrhizal fruiting in the study stands takes place between August and early October. Patterns of distribution for air and soil temperature, solar

radiation, total precipitation and frequency of precipitation events are currently being evaluated for 1985 and 1986 with respect to sporocarp survey results. Timing of litterfall and stem diameter growth are also being considered, as factors related to host metabolic activity. If fruiting is tied to carbohydrate supply, mycorrhizal fruiting could be partially explained by events leading to host dormancy in the autumn since mycorrhizal fungi are heavily dependent on their hosts for energy (Gadgil and Gadgil 1971).

Survey activity began again in 1986 shortly after reports of fruiting were received from the field crew. Thereafter, study plots were carefully surveyed on a weekly to biweekly basis (eight visits) between August 4 and October 2. Visits terminated with cessation of fruiting, which has coincided from 1984 through 1986 with the end of litterfall. The forest floor is not disturbed during visits. No doubt, many immature sporocarps and those which develop between visits were missed.

Annual counts are used to determine 1) dates of earliest and latest record, 2) dates by which 50 percent of the year's total fruiting had occurred, and 3) date(s) of peak fruiting for each of 32 common ectomycorrhizal macrofungi. Techniques for characterizing and comparing fungal populations via fruiting body production have been published (Grainger 1946, Parker-Rhodes 1951, Hering 1966, Richardson 1970, Fogel 1976, Fogel 1981, Dighton et al. 1986). Another quantitative concept which may prove useful in comparing data sets is the coefficient of community (Pielou 1977). Orloci's sums of squares method based on standardized distances (Orloci 1967) has been developed to some extent to explain differences among subplot replicates and years. Work is underway to determine the most useful tests of population parameters.

Progress

Sporocarps of 32 macrofungus species, presumed from the literature to be mycorrhizal, were censused from 1984 through 1986. Tables 5.1 and 5.2 present summaries of the 1986 and 1985 survey results by site. Weighted midpoint dates coincide closely with mode dates for both sites during both years, as might be expected. Fruiting for most species peaked earlier in 1986 than in 1985, especially at the control site. None of the species selected for study had previously demonstrated population peaks coinciding with the first or last survey dates. In 1986, however, six species had population modes on 4 August. Weather and tree growth data for 1985 and 1986 are being evaluated in connection with this apparent general shift of the fruiting season.

Table 5.3 presents total counts by site recorded for 1984 through 1986. Table 5.4 presents the same counts by subplot replicates within sites. Comparison of annual sporocarp counts made between 1984 and 1986 for all six subplot replicates shows distinct patterns of association for each fungus species with certain subplot replicates. The basis for these associations will be investigated during 1987, and is likely to hinge largely on the spatial distribution of host tree species among the three subplot replicates at each site. Differences between 1985 and 1986 in precipitation during the fruiting period of early August through early October may be responsible for the lower 1986 sporocarp counts, especially for several species which appear to require cooler temperatures prior to host dormancy in order to fruit normally. The influences of weather between years is being examined, as are the influences of host tree species distribution among the subplot replicates.

Table 5.1 Seasonal distribution of fruiting by ectomycorrhizal fungi on the three 35 m x 30 m herbaceous reserve subplots replicates at the antenna and control study sites between 4 August and 2 October, 1986.

Family	Genus	Species	Earliest Record		Latest Record		Weighted Midpoint[a]		Mode[b]	
			Antenna	Control	Antenna	Control	Antenna	Control	Antenna	Control
Amanitaceae	Amanita	bisporigera	11 Sept.	----	25 Sept.	----	25 Sept.	----	25 Sept.	---
		brunnescens	13 Aug.	4 Aug.	11 Sept.	27 Aug.	27 Aug.	4 Aug.	21 Aug.	4 Aug.
		citrina	21 Aug.	7 Sept.	2 Oct.	7 Sept.	25 Sept.	7 Sept.	25 Sept.	7 Sept.
		muscaria	4 Aug.	----	25 Sept.	----	27 Aug.	----	27 Aug.	----
	Amanitopsis	fulva	----	13 Aug.	----	11 Sept.	----	27 Aug.	----	27 Aug.
		vaginata	27 Aug.	4 Aug.	7 Sept.	18 Sept.	27 Aug.	4 Aug.	27 Aug, 7 Sept.[c]	4 Aug.
Boletaceae	Boletellus	russellii	----	----	----	----	----	----	----	----
	Boletus	piperatus	4 Aug.	----	7 Sept.	----	21 Aug.	----	13 Aug.	----
	Leccinum	scabrum	7 Sept.	----	7 Sept.	----	7 Sept.	----	7 Sept.	----
Cantharellaceae	Cantharellus	lutescens	----	13 Aug.	----	27 Aug.	----	13 Aug.	----	13 Aug.
Cortinariaceae	Cortinarius	alboviolaceus	7 Sept.	21 Aug.	25 Sept.	25 Sept.	11 Sept.	7 Sept.	7 Sept.[c]	21 Aug.
		armillatus	7 Sept.	27 Aug.	11 Sept.	11 Sept.	7 Sept.	7 Sept.	7, 11 Sept.[c]	7 Sept.
		flavifolius	21 Aug.	----	7 Sept.	----	21 Aug.	----	21 Aug.	----
		semisanguineus	27 Aug.	----	7 Sept.	----	7 Sept.	----	7 Sept.	----
		sphaerosporus	27 Aug.	----	25 Sept.	----	7 Sept.	----	7 Sept.	----
		trivialis	27 Aug.	----	25 Sept.	----	11 Sept.	----	7 Sept.	----
	Rozites	caperata	27 Aug.	----	2 Oct.	----	7 Sept.	----	27 Aug.	----
Hydnaceae	Dentinum	repandum	----	----	----	----	----	----	----	---[c]
	Hydnellum	zonatum	----	21 Aug.	----	7 Sept.	----	21 Aug.	-- 21 Aug, 7 Sept	
Russulaceae	Lactarius	argillaceifolius	4 Aug.	4 Aug.	25 Sept.	11 Sept.	27 Aug.	27 Aug.	27 Aug.	27 Aug.
		rufus	13 Aug.	4 Aug.	25 Sept.	2 Oct.	7 Sept.	21 Aug.	7 Sept.	21 Aug.[c]
		subvellereus	21 Aug.	4 Aug.	27 Aug.	11 Sept.	21 Aug.	13 Aug.	21 Aug.	
		torminosus	----	21 Aug.	----	11 Sept.	----	27 Aug.	----	27 Aug.
	Russula	brevipes	27 Aug.	4 Aug.	11 Sept.	7 Sept.	27 Aug.	4 Aug.	27 Aug.	4 Aug.
		emetica	4 Aug.	13 Aug.	2 Oct.	11 Sept.	7 Sept.	13 Aug.	7 Sept.	13 Aug.
		fragilis	13 Aug.	21 Aug.	25 Sept.	7 Sept.	7 Sept.	27 Aug.	7 Sept.	27 Aug.
		laurocerasi	21 Aug.	4 Aug.	25 Sept.	13 Aug.	7 Sept.	4 Aug.	7 Sept.	4 Aug.
		paludosa	21 Aug.	4 Aug.	7 Sept.	7 Sept.	27 Aug.	4 Aug.	7 Sept.	4 Aug.
		variata	4 Aug.	4 Aug.	25 Sept.	27 Aug.	21 Aug.	4 Aug.	21 Aug.	4 Aug.
Tricholomataceae	Laccaria	laccata	27 Aug.	21 Aug.	25 Sept.	25 Sept.	7 Sept.	27 Aug.	7 Sept.	27 Aug.
	Tricholoma	flavovirens	7 Sept.	25 Sept.	25 Sept.	25 Sept.	25 Sept.	25 Sept.	25 Sept.	25 Sept.
		resplendens	----	---	----	----	----	----	----	---

a. Date by which 50 percent of the season's fruiting had taken place.
b. Date of most abundant fruiting.
c. The mode is shared by more than 1 date.

Table 5.2 Seasonal distribution of fruiting by ectomycorrhizal fungi on the three 35 m x 30 m herbaceous reserve subplot replicates at the antenna and control study sites between 20 August and 13 October, 1985.

Family	Genus	Species	Earliest Record		Latest Record		Weighted Midpoint[a]		Mode[b]	
			Antenna	Control	Antenna	Control	Antenna	Control	Antenna	Control
Amanitaceae	Amanita	bisporigera	20 Aug.	----	18 Sept.	----	4 Sept.	----	4 Sept.	----
		brunnescens	20 Aug.	27 Aug.	18 Sept.	13 Oct.	11 Sept.	11 Sept.	18 Sept.	11 Sept.
		citrina	20 Aug.	4 Sept.	13 Oct.	13 Oct.	18 Sept.	18 Sept.	18 Sept.	18 Sept.
		muscaria	20 Aug.	11 Sept.	18 Sept.	11 Sept.	27 Aug.	11 Sept.	27 Aug.	11 Sept.
	Amanitopsis	fulva	----	4 Sept.	----	11 Sept.	----	11 Sept.	----	11 Sept.
		vaginata	18 Sept.	20 Aug.	18 Sept.	18 Sept.	18 Sept.	27 Sept.	18 Sept.	27 Sept.
Boletaceae	Boletellus	russellii	----	27 Aug.	----	27 Aug.	----	27 Aug.	----	27 Aug.
	Boletus	piperatus	20 Aug.	27 Aug.	11 Sept.	27 Aug.	27 Aug.	27 Aug.	27 Aug.	27 Aug.
	Leccinum	scabrum	27 Aug.	20 Aug.	18 Sept.	18 Sept.	11 Sept.	11 Sept.	11 Sept.	18 Sept.
Cantharellaceae	Cantharellus	lutescens	----	20 Aug.	----	13 Oct.	----	11 Sept.	----	11 Sept.
Cortinariaceae	Cortinarius	alboviolaceus	27 Aug.	4 Sept.	13 Oct.	18 Sept.	11 Sept.	11 Sept.	11 Sept.	11 Sept.
		armillatus	20 Aug.	20 Aug.	11 Sept.	13 Oct.	11 Sept.	11 Sept.	11 Sept.	11 Sept.
		flavifolius	20 Aug.	27 Aug.	11 Sept.	18 Sept.	11 Sept.	27 Aug.	11 Sept.	27 Aug.
		semisanguineus	27 Aug.	4 Sept.	11 Sept.	11 Sept.	11 Sept.	11 Sept.	11 Sept.	11 Sept.
		sphaerosporus	4 Sept.	4 Sept.	18 Sept.	4 Sept.	11 Sept.	4 Sept.	11 Sept.	4 Sept.
		trivialis	20 Aug.	27 Aug.	13 Oct.	18 Sept.	11 Sept.	11 Sept.	11 Sept.	11 Sept.
	Rozites	caperata	27 Aug.	4 Sept.	18 Sept.	18 Sept.	11 Sept.	11 Sept.	11 Sept.	11 Sept.
Hydnaceae	Dentinum	repandum	----	20 Aug.	----	18 Sept.	----	11 Sept.	----	11 Sept.
	Hydnellum	zonatum	----	4 Sept.	----	11 Sept.	----	11 Sept.	----	11 Sept.
Russulaceae	Lactarius	argillaceifolius	20 Aug.	20 Aug.	18 Sept.	18 Sept.	4 Sept.	11 Sept.	4 Sept.	11 Sept.
		rufus	20 Aug.	20 Aug.	18 Sept.	18 Sept.	4 Sept.	11 Sept.	11 Sept.	11 Sept.
		subvellereus	----	4 Sept.	----	18 Sept.	----	11 Sept.	----	11 Sept.
		torminosus	11 Sept.	27 Aug.	13 Oct.	18 Sept.	11 Sept.	11 Sept.	11 Sept.	11 Sept.
	Russula	brevipes	11 Sept.	4 Sept.	11 Sept.	13 Oct.	11 Sept.	11 Sept.	11 Sept.	11 Sept.
		emetica	20 Aug.	20 Aug.	13 Oct.	13 Oct.	11 Sept.	11 Sept.	11 Sept.	11 Sept.
		fragilis	20 Aug.	20 Aug.	18 Sept.	13 Oct.	11 Sept.	11 Sept.	11 Sept.	4 Sept.
		laurocerasi	27 Aug.	20 Aug.	11 Sept.	11 Sept.	4 Sept.	11 Sept.	27 Aug.	11 Sept.
		paludosa	20 Aug.	20 Aug.	18 Sept.	18 Sept.	4 Sept.	11 Sept.	4 Sept.	11 Sept.
		variata	20 Aug.	20 Aug.	18 Sept.	18 Sept.	4 Sept.	11 Sept.	c	11 Sept.
Tricholomataceae	Laccaria	laccata	20 Aug.	20 Aug.	13 Oct.	13 Oct.	11 Sept.	11 Sept.	11 Sept.	11 Sept.
	Tricholoma	flavovirens	4 Sept.	11 Sept.	13 Oct.	13 Oct.	18 Sept.	11 Sept.	18 Sept.	11 Sept.
		resplendens	11 Sept.	11 Sept.	11 Sept.	18 Sept.	11 Sept.	18 Sept.	11 Sept.	18 Sept.

a. Date by which 50 percent of the season's fruiting had taken place.
b. Date of most abundant fruiting.
c. The mode is shared by more than 1 date.

Table 5.3. Total numbers of sporocarp observations recorded in 1984, 1985, and 1986 for 32 presumed ectomycorrhizal macrofungi on three 30 m x 35 m herbaceous reserve subplot replicates located at the Antenna and Control study sites. Six sets of observations were made in each of the first two years (between 4 August and 13 October in 1984, and between 20 August and 13 October in 1985); 8 sets of observations were made in 1986 (between 4 August and 2 October).

			Total Number of Records					
			Antenna			Control		
Family	Genus	Species	1984	1985	1986	1984	1985	1986
Amanitaceae	Amanita	bisporigera	22	7	3	2	--	--
		brunnescens	40	17	48	22	15	11
		citrina	18	7	9	8	7	2
		muscaria	52	114	125	—	3	—
	Amanitopsis	fulva	—	--	--	7	12	6
		vaginata	3	1	2	20	7	1
Boletaceae	Boletellus	russellii	—	—	--	12	1	—
	Boletus	piperatus	17	30	38	1	1	—
	Leccinum	scabrum	4	11	1	20	31	--
Cantharellaceae	Cantharellus	lutescens[B]	—	—	—	99	74	69
Cortinariaceae	Cortinarius	alboviolaceus	148	223	49	102	183	7
		armillatus	16	9	2	40	81	21
		flavifolius	15	2	15	13	8	—
		semisanguineus	10	21	7	7	2	—
		sphaerosporus	95	84	26	5	1	--
		trivialis	105	272	53	44	29	—
	Rozites	caperata	47	132	25	79	93	--
Hydnaceae	Dentinum	repandum	—	—	—	28	8	--
	Hydnellum	zonatum	—	--	--	11	2	2
Russulaceae	Lactarius	argillaceifolius	108	41	59	12	48	37
		rufus[AB]	898	59	90	76	29	19
		subvellereus	7	—	19	49	11	4
		torminosus	6	16	—	30	49	12
	Russula	brevipes	2	1	5	41	39	38
		emetica	171	351	238	126	18	33
		fragilis	26	29	42	24	44	12
		laurocerasi	18	7	8	52	3	10
		paludosa	17	63	55	13	61	156
		variata	145	66	84	336	93	213
Tricholomataceae	Laccaria	laccata	103	74	23	85	101	39
	Tricholoma	flavovirens	16	36	16	--	7	2
		resplendens	3	6	—	16	13	--

A. Because of the clumped distribution and small size of individual sporocarps, clumps rather than individuals were tallied.

B. In 1984, individual sporocarps of L. rufus were tallied at first.

Table 5.4. Distribution of sporocarp observations recorded in 1984, 1985, and 1986, for 32 presumed ectomycorrhizal macrofungi on three 30 m x 35 m herbaceous reserve subplot replicates located at the Antenna and Control study sites. Six sets of observations were made in each year (between 4 August and 13 October in 1984, and between 20 August and 13 October in 1985); 8 sets of observations were made in 1986 (between August 4 and October 2).

Antenna Site - Total Counts

			Replicate 1			Replicate 2			Replicate 3		
Family	Genus	Species	1984	1985	1986	1984	1985	1986	1984	1985	1986
Amanitaceae	Amanita	bisporigera	7	0	0	15	6	1	1	1	2
		brunnescens	1	1	1	9	8	13	30	8	34
		citrina	9	2	3	6	1	1	9	4	5
		muscaria	13	25	27	33	80	93	7	9	5
	Amanitopsis	fulva	0	0	0	0	0	0	0	0	0
		vaginata	1	0	1	1	1	1	1	0	0
Boletaceae	Boletellus	russellii	0	0	0	0	0	0	0	0	0
	Boletus	piperatus	4	6	15	9	22	21	4	2	2
	Leccinum	scabrum	5	4	1	1	3	0	0	4	0
Cantharellaceae	Cantharellus	lutescens (a)	0	0	0	0	0	0	0	0	0
Cortinariaceae	Cortinarius	alboviolaceus	52	69	10	114	149	38	1	5	1
		armillatus	6	4	1	4	5	0	6	0	1
		flavifolius	7	1	6	0	0	0	9	1	9
		semisanguineus	5	7	5	5	13	2	0	1	0
		sphaerosporus	56	28	9	52	50	16	0	6	2
		trivialis	79	131	28	69	135	23	0	6	2
	Rozites	caperata	39	70	21	28	62	4	0	0	0
Hydnaceae	Dentinum	repandum	0	0	0	0	0	0	0	0	0
	Hydnellum	zonatum	0	0	0	0	0	0	0	0	0
Russulaceae	Lactarius	argillaceifolius	28	6	13	31	12	20	51	23	26
		rufus (ab)	31	7	6	484	6	4	382	46	80
		subvellereus	7	0	2	0	0	1	0	0	16
		torminosus	5	7	0	1	2	0	0	7	0
	Russula	brevipes	1	1	0	0	0	2	1	0	3
		emetica	96	186	122	58	112	93	21	53	23
		fragilis	18	20	22	10	9	18	0	0	2
		laurocerasi	7	2	5	9	3	2	3	2	1
		paludosa	4	16	11	7	36	28	6	11	16
		variata	59	33	33	35	13	8	51	20	43
Tricholomataceae	Laccaria	laccata	24	25	9	26	17	4	53	32	10
	Tricholoma	flavovirens	3	10	5	15	26	11	1	0	0
		resplendens	3	3	0	0	3	0	0	0	0

(a) Because of the clumped distribution and small size of individual sporocarps, clumps rather than individuals were tallied.
(b) In 1984, individual sporocarps of L. rufus were tallied at first.

Table 5.4. (Continued) Distribution of sporocarp observations recorded in 1984, 1985, and 1986, for 32 presumed ectomycorrhizal macrofungi on three 30 m x 35 m herbaceous reserve subplot replicates located at the Antenna and Control study sites. Six sets of observations were made in each year (between 4 August and 13 October in 1984, and between 20 August and 13 October in 1985); 8 sets of observations were made in 1986 (between August 4 and October 2).

Antenna Site - Total Counts

Family	Genus	Species	Replicate 1			Replicate 2			Replicate 3		
			1984	1985	1986	1984	1985	1986	1984	1985	1986
Amanitaceae	Amanita	bisporigera	1	0	0	1	0	0	0	0	0
		brunnescens	1	1	5	4	8	1	17	6	5
		citrina	1	0	0	3	2	1	4	5	1
		muscaria	0	2	0	0	1	0	0	0	0
	Amanitopsis	fulva	1	5	0	5	7	4	1	1	2
		vaginata	13	3	1	5	2	0	2	2	3
Boletaceae	Boletellus	russellii	12	1	0	0	0	0	0	0	0
	Boletus	piperatus	0	0	0	0	0	0	1	1	0
	Leccinum	scabrum	4	6	0	16	20	0	0	5	0
Cantharellaceae	Cantharellus	lutescens (a)	35	31	17	20	8	4	44	35	118
Cortinariaceae	Cortinarius	alboviolaceus	4	14	3	32	51	3	66	48	1
		armillatus	4	8	4	35	64	14	1	9	3
		flavifolius	1	3	0	1	3	0	11	2	0
		semisanguineus	5	2	0	0	0	0	2	0	0
		sphaerosporus	0	0	0	0	1	0	5	0	0
		trivialis	4	7	0	29	17	0	11	15	0
	Rozites	caperata	2	2	0	55	63	0	22	28	0
Hydnaceae	Dentinum	repandum	4	3	0	5	4	0	19	1	0
	Hydnellum	zonatum	11	2	2	0	0	0	0	0	0
Russulaceae	Lactarius	argillaceifolius	4	20	10	6	17	16	2	11	11
		rufus (ab)	1	5	1	70	17	15	5	7	3
		subvellereus	9	2	0	14	8	3	26	1	1
		torminosus	3	14	7	22	33	3	5	2	2
	Russula	brevipes	24	27	26	4	4	5	13	8	7
		emetica	13	3	7	45	9	14	68	6	12
		fragilis	7	10	1	12	23	5	5	11	6
		laurocerasi	9	0	6	17	1	3	26	2	1
		paludosa	4	17	43	6	22	67	3	22	46
		variata	139	56	105	101	27	70	96	20	35
Tricholomataceae	Laccaria	laccata	12	26	3	28	35	20	45	40	16
	Tricholoma	flavovirens	0	0	0	0	0	0	0	7	2
		resplendens	0	1	0	2	1	0	14	11	0

(a) Because of the clumped distribution and small size of individual sporocarps, clumps rather than individuals were tallied.

(b) In 1984, individual sporocarps of L. rufus were tallied at first.

Fifteen fungal species contributed at least five percent to the 1985 grand total sporocarp count and thus were designated as major species for further population study. Total annual sporocarp counts for each of the 15 major study species on each of the six subplot replicates are being used to mathematically define the mycorrhizal fungus community on each subplot replicate in "15-space", where the abundance of each major fungus species is plotted along its own coordinate axis (dimension). Figure 5.1 illustrates the concept of the standardized vs. absolute distances between two communities j and h, based on the abundance of two species, each of which occurs in both communities. The standardized distances between the points (in 15-space) representing each possible pair of communities have been calculated, and the communities are presently being agglomerated (Orloci 1967) to clarify similarities and differences. Table 5.5 presents the standardized distances (in 15-space) separating each possible pair of subplot replicate communities within the 1985 and 1986 data sets. The standardized distance in n-space (based on n species) between any two communities j and h, is termed D and is calculated as:

$$D_{j,h} = \sqrt{\left[\sum_{e=1}^{n} (X_{e,j}/V_j - X_{e,h}/V_h)^2\right]} \quad \text{,where}$$

$$V_j = \sqrt{\left[\sum_{e=1}^{n} X^2_{e,j}\right]} = \text{the distance in n-space separating community j from the origin, where}$$

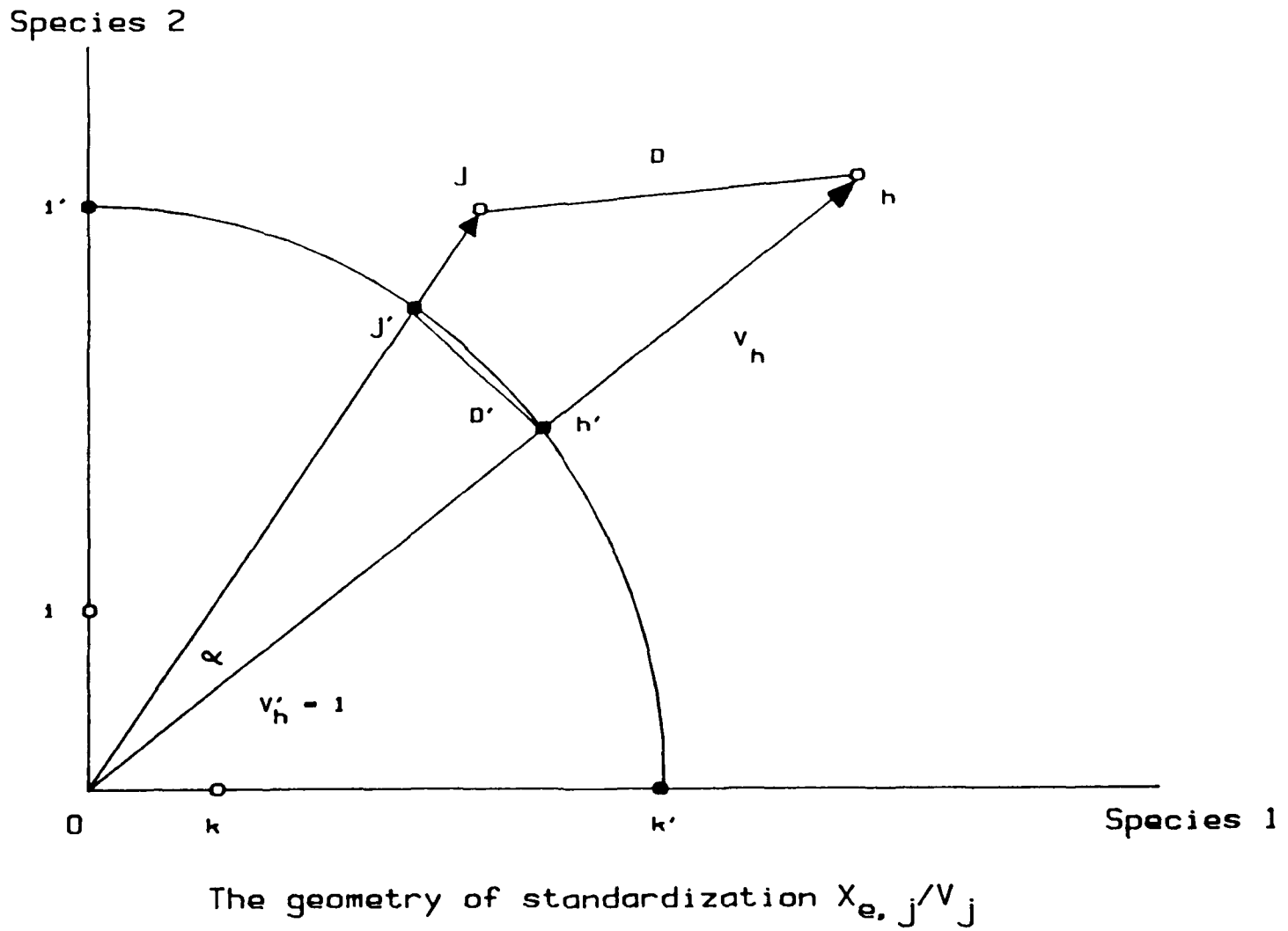
$X_{e,j}$ = the abundance of the e^{th} species in community j

In general, the distances calculated for 1985 and 1986 between any pair of subplot replicate communities are very similar. A few pairs of communities appear to have substantially different distance values for 1985

Table 5.5 Comparison of standardized distances (Orloci 1967) between pairs of ectomycorrhizal fungus communities existing in the three 35 m x 30 m herbaceous reserve subplot replicates at the control and antenna sites, based on sporocarp counts made in 1985 and 1986 representing the 15 most abundant ectomycorrhizal macrofungi.

		Antenna Site			Control Site		
Plot	Year	A1	A2	A3	C1	C2	C3
A1	1985		497	867	1206	1032	1053
	1986		609	1087	1176	1118	1166
A2	1985			1035	1208	958	800
	1986			1178	1281	1192	1212
A3	1985				1038	1099	1179
	1986				1006	885	1085
C1	1985					952	989
	1986					483	722
C2	1985						776
	1986						637

Figure 5.1. Standardized distances between two communities based on the abundance of two species common to each community (after Orloci 1967).



and 1986. However, examination of the underlying data permits evaluation of the details of such shifts in distance. For instance, subplot replicates A2 and C3 appeared to separate between 1985 and 1986 while C1 and C2 appeared to approach one another. Data examination show that both changes were caused at least in part by the poor fruiting record of Cortinarius alboviolaceus in 1986. Experimental adjustment of population values and recalculation of intercommunity distances can establish the magnitude of the effect involved. Calculation of "distances" between population data for the same community during different year is underway. Agglomeration of communities into clusters based on their separation in n-space is also planned for 1987.

ELEMENT 6. MYCORRHIZA CHARACTERIZATION AND ROOT GROWTH

Mycorrhizal Numbers and Morphology

Mycorrhizae embody finely balanced physiological relationships between the roots of higher plants and a number of highly specialized fungi beneficial to plant growth. Mycorrhizal fungi are obligately parasitic, requiring host photosynthate for energy. The matrix of mycorrhizal mycelium permeating the forest floor from infected roots provides the host with scarce minerals and water much more efficiently than could the host's roots alone.

Mycorrhizae are sensitive indicators of subtle environmental perturbations. As obligate symbionts, mycorrhizal fungi are intricately involved with more of the ecosystem than are many other components. They are sensitive not only to factors directly affecting their own physiological mechanisms, but also to factors which affect other living elements of the ecosystem, especially their hosts.

Mycorrhizae have been selected for evaluation in other studies which required a sensitive indicator of subtle changes that might not measurably affect all organisms. Recent studies designed to monitor the effects of acid rain and ozone on natural ecosystems have used the percentage of host fine roots infected by mycorrhizal fungi as a criterion for evaluating host condition and the state of the symbiotic relationship as impacted by air pollution (Reich et al. 1985). Mycorrhizal studies are especially valuable for comparison with other measures of plant response, such as growth and plant moisture stress. It is possible that electromagnetic ELF effects, too weak to directly invoke a measurable tree response, could detectably alter the trees' mycorrhizal fungus component.

Another characteristic of fungi in general which may render mycorrhizae relatively sensitive to electromagnetic ELF effects is the dependence of fungal mycelium on intercellular electrical currents for growth. This electrical aspect of fungal physiology is currently being developed (Gow 1984, Harold et al. 1985). The physiological mechanisms which drive trancellular currents in fungi are still not clear, nor are the purposes for electrical current generation. Very low electrical currents have been found in all major groups of fungi (Gow 1984) and have been postulated to function in polarization of growth and in chemotrophic orientation (Harold et al. 1985). Most recently, it has been shown that trancellular currents in fungi are responsible for amino acid uptake, an essential process (Kropf et al. 1985). For whatever reasons, the apparent dependence of fungi on very low electrical current generation for healthy growth may condition their susceptibility to other sources of electrical energy introduced into the ecosystem, such as those generated by the ELF system.

Populations of mycorrhizae developing at each plantation subplot are being compared with each other at monthly intervals and with corresponding values from previous years. The basic population units are individual seedlings. Individual mycorrhizae are categorized into morphological types which are produced by different fungal associations with red pine. Changes in both the partial frequencies of occurrence for different mycorrhizal types and the total numbers of mycorrhizae per seedling were quantified for analysis both within and between years as well as among sites. Data for analysis are expressed as the mean number of mycorrhizae per gram (oven dry weight, 60°C) of seedling root mass. The working null hypothesis is that no differences will be found in the population densities of different types of mycorrhizae root tips on red pine seedlings at the antenna, ground and control subplots, before and after the ELF antenna becomes operational.

Changes reflected by alternative hypotheses include shifts in population species composition, increases or decreases of total mycorrhiza density, and changes in character of morphology types.

Sampling and Data Collection

In conjunction with plant moisture stress and tree growth studies (Element 2 - Tree Productivity), fifteen seedlings per subplot (five per subplot replicate) were sampled monthly during 1986. All seedlings analyzed for mycorrhizal development were also measured for top and root growth parameters and moisture stress, as was done in the 1985 sample. Seedlings were excavated and mycorrhizae were counted as follows.

To obtain as much of the seedling root system as possible, soil was loosened with a shovel approximately 30 cm from the base of the seedling. With soil retained on roots, seedlings are individually tagged, placed in plastic bags and transported to the laboratory where they are refrigerated. Within two to three days, root systems are separated from their tops, washed gently in tap water, and stored in a fresh volume of tap water in the refrigerator. Counting commences immediately.

A shallow white porcelain pan containing a small amount of water is used during the cutting and counting operation. Secondary lateral roots are cut from the tap root and divided into segments approximately 3 - 5 cm long. Usually, few mycorrhizae are found on the tap root; these are counted and added to the total. A mycorrhiza is defined, for counting purposes, 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. The cut lengths of secondary root are selected at random from the pan and mycorrhizae are counted with the aid of a dissecting microscope. When at least one thousand mycorrhizae have been counted, the

root sections bearing these are dried separately from the rest of the secondary roots. The number of mycorrhizae and the weight of the counted segments are used to calculate proportionally the number of mycorrhizae for the entire secondary root system. This method has been verified by comparison to entire root system counts and found to be accurate to within seven percent ($p = 0.05$). At the end of the counting operation, any mycorrhizae remaining in the bottom of the pan, freed as a result of manipulating the root system, are counted and added to the total.

Since these are nursery seedlings which were originally grown in fumigated soil, the mycorrhizae formed on the root systems still have a fairly uniform morphology. They range in color from tan to deep red-brown and are formed primarily by Thelephora terrestris and Laccaria laccata (sensu lato, Fries and Mueller, 1984). Some of the mycorrhizae are beginning to take on a darker, nearly black appearance due to colonization by Cenococcum graniforme, an abundant mycorrhizal fungus in the original and surrounding hardwood forests. Occasionally some white to tan wooly forms are found, presumably colonized by Hebeloma sp. or Boletus sp. All morphology types are counted 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. Mycorrhizae per gram of root is based on the total mycorrhizae divided by the weight of the entire oven-dried (60°C) root system.

Descriptions of Red Pine Mycorrhizal Types Recovered From ELF Plantations

Type 3

Macroscopic: Light buff to dark red brown, sometimes nearly black, usually lighter at 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 common and most numerous type of mycorrhiza found originally on the nursery red pine seedlings and which is still predominant. The causal fungi 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. This fungus might therefore be expected to maintain its dominance in the plantations.

Type 5

Macroscopic: Black, sometimes with lighter apex; usually fuzzy, with abundant attached, coarse hyphae; 1-3 mm long X 0.5-1.0 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 Type 3 hyphae; Hartig net hyphae bulbous and also with interlocking pattern.

Comments: This is a later stage mycorrhiza, appearing to form a darker sheath over an initially developed mycorrhiza. The causal fungus is Cenococcum graniforme, which is commonly isolated from these mycorrhizae.

Type 6

Macroscopic: White to 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 corralloid clusters of multiply bifurcated tips; in water, air bubbles become entrapped in loose surface hyphae causing free individuals to float.

Microscopic: Surface hyphae colorless, abundant, septate, 3-6 um diameter, multiply branched at septae; setae lacking; mantle of loose hyphae 25-100 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 is a later stage mycorrhiza appearing to form a sheath over an initially developed mycorrhiza. Based on cultural characteristics, the causal fungus is probably a member of the Boletaceae.

Progress

Non-mycorrhizal root tips are rarely encountered on the red pine seedlings (Table 6.1), which indicates there is abundant viable mycorrhizal inoculum at the study sites. The only significant difference ($p = .05$) in non-mycorrhizal root tips per gram of root occurred in August when fewer tips were counted at the ground site than at the control. For that month, the antenna site had an intermediate number of non-mycorrhizal root tips and did not differ significantly from the other sites. Unlike 1985, when non-mycorrhizal root tips fell in number as the season progressed, in 1986 there

Table 6.1. Mean and standard deviation of non-mycorrhizal root tips per gram of root (o.d.w.) for red pine seedlings in 1986.

Month	Ground		Antenna		Control	
	Mean	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**
May	2.28^{A}_{B} [1/]	4.48	1.02^{A}_{B}	1.14	0.26^{A}_{B}	0.77
June	0.18_{C}	0.71	0.08_{C}	0.32	0_{C}	0
July	0.37_{D}	0.14	0.15_{DE}	0.39	0.47_{E}	1.48
August	0.01_{F}	0.06	0.24_{F}	0.60	0.49_{F}	0.85
September	0.49_{G}	0.85	0.84_{G}	1.53	0.33_{G}	0.51
October	0.10	0.24	0.06	0.15	0.11	0.25

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

Table 6.2. Mean and standard deviation of Type 3 mycorrhizal root tips per gram of root (o.d.w.) for red pine seedlings in 1986.

Month	Ground		Antenna		Control	
	Mean	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**
May	$689^{A1/}_{B}$	384	603^{A}_{B}	326	765^{A}_{B}	326
June	534_{C}	419	557_{C}	331	468_{C}	304
July	563_{D}	404	650_{D}	312	597_{D}	314
August	384_{E}	159	366_{E}	189	323_{E}	227
September	274_{F}	175	261_{G}	134	199_{G}	146
October	73^{F}	64	122^{G}	68	147^{G}	57

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

were consistently low levels throughout the year.

Type 3 mycorrhizae are by far the most common type encountered on the red pine seedlings (Table 6.2). Unlike 1985 when Type 3 accounted for over ninety percent of total mycorrhizae, Type 5 mycorrhizae numbers increased in 1986, especially in the later months of the season when Type 3 mycorrhizae accounted for only sixty to eighty percent of the total (Table 6.5). There was only one month with a significant ($p = .05$) difference in the number of Type 3 mycorrhizae per gram of seedling root between plantation subplots; this was in October when the ground site had fewer than the antenna or control sites.

Type 5 mycorrhizae increased markedly in occurrence from 1985 levels (Table 6.3) and also as the 1986 season progressed. This is taken as an indication of seedling establishment and root system adaptation to later-stage fungal colonization. There were no significant differences ($p = .05$) between plantation subplots for any given month in the number of Type 5 mycorrhizal root tips per gram of seedling root. C. grainforme, the causal agent of Type 5 mycorrhizae occurs abundantl in the surrounding forest stands.

Seedlings bearing Type 6 mycorrhizae were not found in 1986, though they had been in 1985. This unique type is extremely sporadic in occurrence, being encountered only on a very few seedlings on two sites in 2 of the 6 months of 1985.

Since Type 3 mycorrhizae still represent the predominant type occurring on the plantation red pine seedlings it follows that data total for mycorrhizae per gram of seedling root mass (Table 6.4) parallel the values for Type 3 mycorrhizae. As with Type 3, there was only one month with a significant difference in total mycorrhizae per gram of root mass between

Table 6.3. Mean number and standard deviation of Type 5 mycorrhizal root tips per gram of root (o.d.w.) for red pine seedlings in 1986.

Month	Ground		Antenna		Control	
	Mean	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**
May	$23_B^{A1/}$	47	44_B^A	57	51_B^A	61
June	61_C	88	51_C	32	66_C	65
July	44_D	60	68_D	79	60_D	98
August	62_E	66	77_E	49	56_E	49
September	65_F	51	78_F	70	59_F	40
October	49_F	57	36_F	22	36_F	23

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

Table 6.4. Mean and standard deviation of total mycorrhizal root tips per gram of root (o.d.w.) for red pine seedlings in 1986.

Month	Ground		Antenna		Control	
	Mean	**S.D.**	**Mean**	**S.D.**	**Mean**	**S.D.**
May	$712_B^{A1/}$	378	647_B^A	339	816_B^A	327
June	594_C	450	608_C	351	534_C	314
July	607_D	430	718_D	340	656_D	348
August	445_E	194	442_E	215	378_E	262
September	339_F	193	339_{FG}	170	258_G	151
October	123_F	86	158_{FG}	75	182_G	55

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

Table 6.5. Mycorrhizal types as % of total mycorrhizal types per gram of root (o.d.w.) for red pine seedlings in 1986.

Month	Ground		Antenna		Control	
	Type 3	Type 5	Type 3	Type 5	Type 3	Type 5
May	96.8	3.2	93.2	6.8	93.7	6.3
June	89.7	10.3	91.6	8.4	87.6	12.4
July	92.8	7.2	90.5	9.5	90.9	9.1
August	86.1	13.9	82.6	17.4	85.2	14.8
September	80.8	19.2	77.0	23.0	77.1	22.9
October	60.2	39.8	77.2	22.8	80.2	19.8

plantation study sites; again this was October, when the ground site had fewer than the control site, but was not significantly different than the antenna site. Total mycorrhizae per gram of root decreased in 1986 compared to 1985, probably reflecting seedling establishment, increasing structural root mass and the difficulty in excavating the entire root system.

In accordance with the overall statistical design described in the Introduction, correlation matricies were calculated using seedling growth

variables and weather variables with the mycorrhizae data. The best correlated parameters will then be used as covariates in covariate analysis to reduce between-year and among-site variation in mycorrhizae counts. Total mycorrhizae are positively ($p = .001$) correlated with seedling root weight ($r = .33$), seedling top weight ($r = .27$), seedling stem diameter ($r = .32$), seedling total height ($r = .45$), and seedling shoot elongation ($r = .30$). This shows that high densities of mycorrhizae are well correlated with other des rable seedling traits. Increases in these seedling parameters are indications of plant vigor or health.

Correlation matrices performed between total mycorrhizae and local weather data (means based on the monthly period between sampling dates) show that total mycorrhizae is positively correlated ($p = .01$) with average daily maximum air temperature ($r = .60$), air temperature degree days ($r = .55$), and soil temperature at 5 cm degree days ($r = .55$). Total mycorrhizae is negatively correlated ($p = .01$) with average precipitation ($r = -.66$), total precipitation ($r = -.59$), daily maximum precipitation ($r = -.58$), number of days with greater than 0.01 cm precipitation ($r = -.56$), running total of air temperature degree days ($r = -.59$), running total of soil temperature at 5 cm degree days ($r = -.61$), and running total of soil temperature at 10 cm degree days ($r = -.59$). Additionally, total mycorrhizae was negatively correlated at the $p = .001$ level with running total of precipitation ($r = -.68$). The most meaningful and highly correlated of these weather variables will be selected to serve as covariates to reduce variation among sites as analyses progress.

The mycorrhiza counting methods employed from 1984 through 1986 are based upon destructive sampling of entire seedling root systems. Prior to improvement through covariate analysis, the data showed that differences ($p = .05$) in mycorrhiza counts of 20% to 50% can be detected among sites (Table 6.6). However, the root systems of the red pine study seedlings have grown to such an extent that it will no longer be feasible to excavate entire seedling root systems in 1987. An alternative mycorrhizae sampling method was tested in 1986 in which a soil sample approximately 22 cm on a side is excavated to a depth of 22 cm adjacent to each study seedling. Red pine seedling roots are extracted from the soil for determination of mycorrhiza numbers. Only mycorrhiza-bearing lateral roots will be weighed for the estimation of mycorrhizal densities per seedling. This sampling method represents the mycorrhiza population of the seedling as to levels and numbers of types of mycorrhizae per gram

Table 6.6. Detectable differences based on 95 percent confidence intervals in total mycorrhizae per gram of root mass (oven dry, 60°C) achieved during 1985 and 1986, for total seedling root systems, expressed as a percentage of the monthly means by study site (15 seedlings per site) and prior to covariance analysis.

Month	Detectable Difference (%) by Site and Year					
	Ground		Antenna		Control	
	1985	1986	1985	1986	1985	1986
May	39	29	32	29	35	22
June	30	41	25	32	48	33
July	33	39	47	26	25	29
August	18	24	48	27	40	38
September	28	32	32	27	24	33
October	47	38	38	26	33	17

of root system. Estimates of total mycorrhiza densities ($r = .43$, $p = .01$) and densities for Type 3 ($r = .43$, $p = .01$) and Type 5 ($r - .52$, $p = .001$) obtained by both techniques were significantly correlated. Also, this sampling technique revision will permit more appropriate between-year comparisons (as study seedlings continue to grow), since structural root material in the sample will be minimized. The revised technique will be implemented in 1986 for the duration of the study.

We expect that use of seedling growth, soil, and weather variables as covariates in our analyses will improve our ability to detect population changes. Evaluation of covariates will be completed by the beginning of the 1987 field season. Increasing sample sizes beginning in 1987 will also be considered as an alternative means to reduce standard errors and improve associated limits of detection.

Thus far, we have seen few significant differences between sites in the densities of mycorrhizae or non-mycorrhizal roots. Counts of mycorrhizae were lower ($p = .05$) at the antenna and ground sites than at the control site for October of 1985. However, only the ground site had lower mycorrhiza counts than the Control site in October of 1986. Work to date supports the null hypothesis that there is no difference between the ELF study sites in the abundance of the major mycorrhiza morphology types occurring on the planted red pine seedlings.

ELEMENT 7. 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, a baseline relationship of the ecological systems is established through tests of the following hypotheses:

H_0: There is no difference in the total weight of litter fall between the antenna and control site within a year.

H_O: There is no difference in the foliar nutrient concentrations of northern red oak trees between the antenna and control site within a year.

The resulting ANOVA table for the analysis of litter components and northern red oak foliage concentration each year is shown below (Table 7.1).

Table 7.1. 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	$MS_S/MS_{E(S)}$
Error(s)	26	$SS_{E(S)}$	$MS_{E(S)}$	
Year	#yrs-1	SS_Y	MS_Y	$MS_Y/MS_{E(Y)}$
Site x year	(1)(#yrs-1)	SS_{SXY}	MS_{SXY}	$MS_{SXY}/MS_{E(Y)}$
Error (y)	24+4(#yrs-1)	$SS_{E(Y)}$	$MS_{E(Y)}$	

Sampling and Data Collection

Five $1m^2$ meter litter traps are being used to monitor tree litter production on each permanent measuring 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 would adequately represent the distribution of red oak on each site. Three trees of each diameter were located off of 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

In 1986, the major litter fall in the ELF study area started by September 25 and was completed by October 8 on both the antenna and control sites (Figure 7.1) This leaf litter fall occurred earlier in 1986 than either 1984 or 1985 (Figure 7.2). Periodic litter fall amounts varied considerably between the antenna site and the control site at all collection times in the fall (Figure 7.3). These differences in weekly leaf fall were related to the variable tree species composition at each site. The leaf litter at the antenna site has a much higher proportion of red maple and big tooth aspen than the control. In contrast, northern red oak litter predominates on the control site (Table 7.2). Oak leaves remain on the trees longer than the maple or aspen and account for much of the litter fall variations between locations.

Figure 7.1.

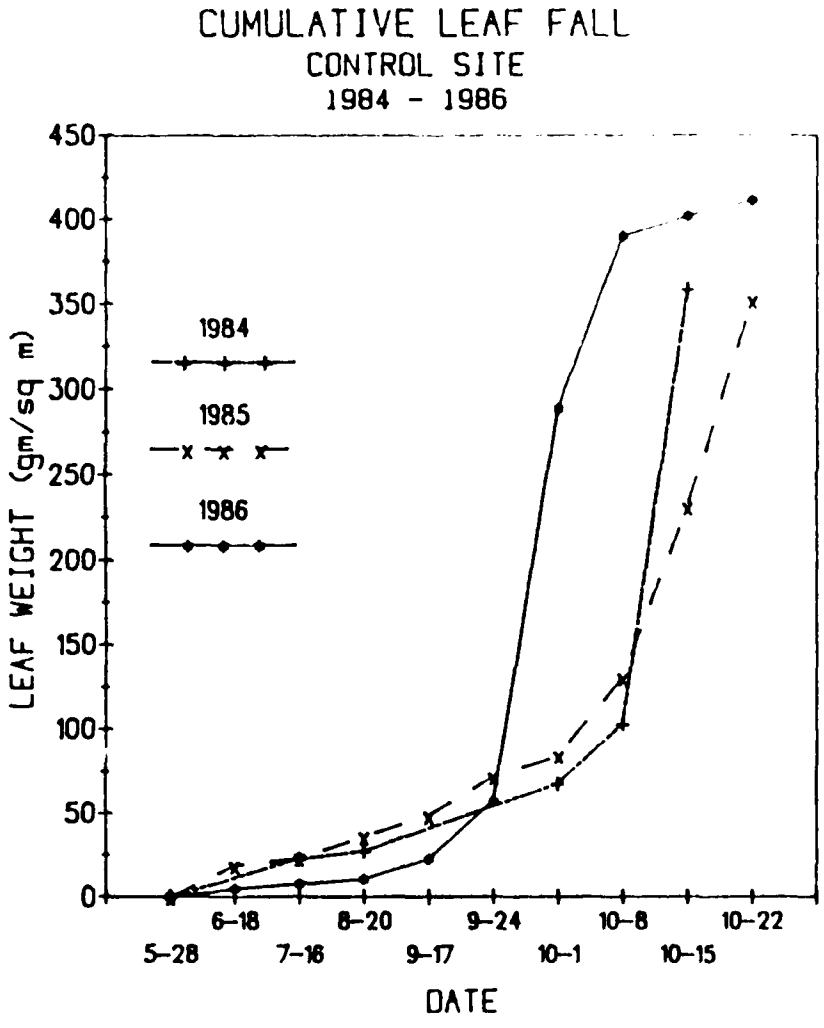
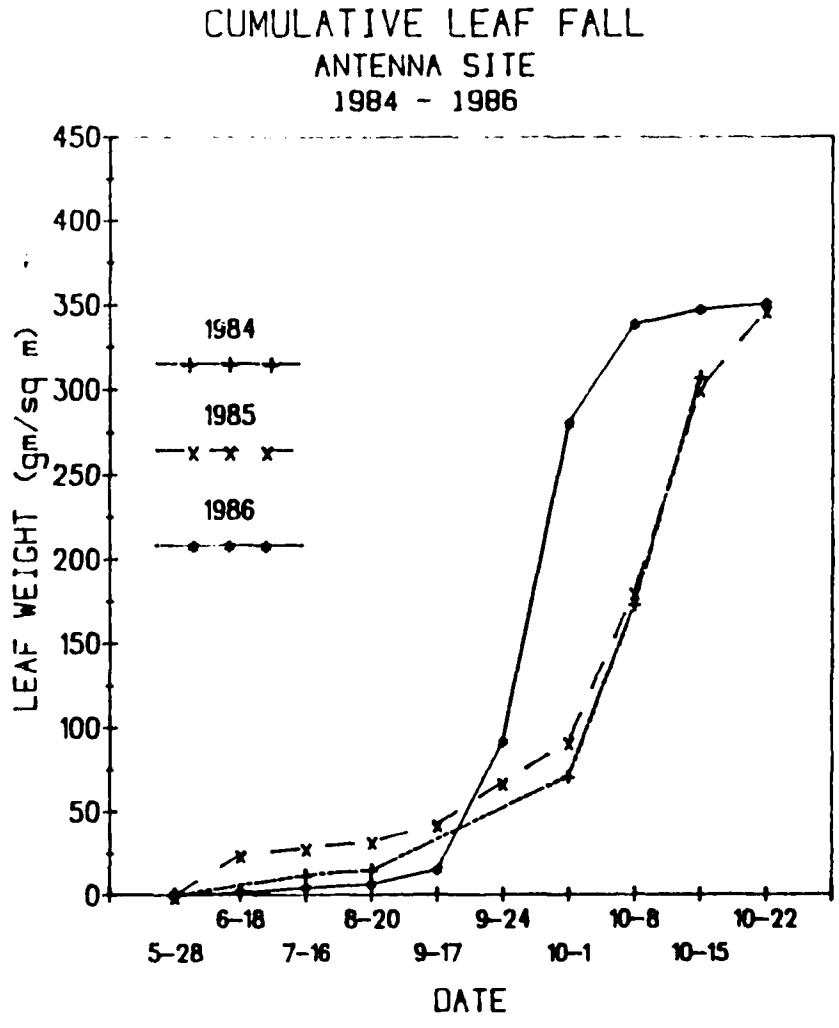


Figure 7.2.



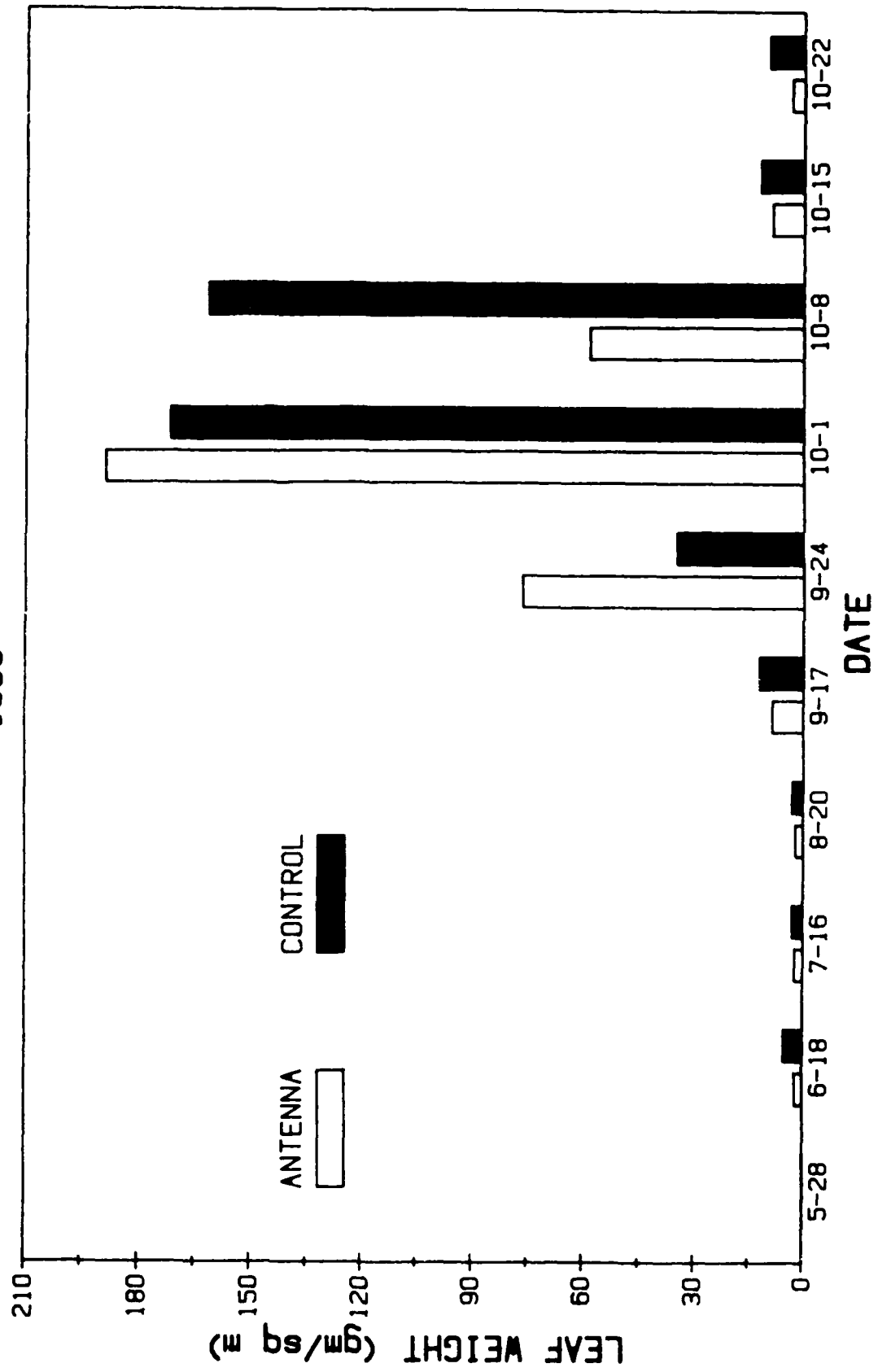

LEAF LITTER FALL
1986
ANTENNA
CONTROL
LEAF WEIGHT (gm/sq m)
0
30
60
90
120
150
180
210
5-28
6-18
7-16
8-20
9-17
9-24
10-1
10-8
10-15
10-22
DATE

Figure 7.3.

Table 7.2. Leaf litter fall by tree species at the antenna and control sites - 1985/1986.

Tree Species	Antenna				Control			
	1985		1986		1985		1986	
	Weight*	%	Weight	%	Weight	%	Weight	%
Red Maple	135	45	147	43	42	14	55	17
Red Oak	93	31	120	35	227	73	226	69
Bigtooth Aspen	45	15	52	15	14	4	17	5
Quaking Aspen	1	<1	1	<1	11	13	9	3
Paper Birch	25	9	21	6	19	6	22	6
Red Pine	1	<1	1	<1	11	13	9	3

* Weight expressed in gm/m^2

Results from litter collections for 1984, 1985 and 1986 have shown that differences in total leaf weight between the antenna and ground site were not significant ($p = .05$) in 1985, but were significant in 1984 and 1986 (Table 7.3). Wood and miscellaneous litter fall showed no significant differences between sites over the three-year period.

The occurrence of a significant difference in litter fall between sites, such as happened in 1984 and 1986, would complicate the determination of possible ELF field effects after the antenna becomes operational. Consequently, attempts were made to reduce litter fall variability between the antenna and control site by using stand factors which influence total foliage production in covariate analyses. When the initial stand basal area on each site was used as a covariate, leaf litter differences in all three years became nonsignificant.

Preliminary results from these tree litter studies have shown that litter weight and leaf nutrient concentrations would be suitable indicators of possible ELF field effects on forest stands. Three years of litter

Table 7.3. Total litter fall at the antenna and control sites.

		Antenna	Control
		——gm/m^2——	
Leaves			
1984		307.2	357.0
1985		322.4	333.1
1986		350.9	411.7
	Average	**326.8**	**367.3**
Wood			
1984		44.0	53.8
1985		25.0	34.7
1986		42.7	57.9
	Average	**37.2**	**48.8**
Miscellaneous			
1984		33.8	27.5
1985		30.5	24.8
1986		32.4	28.5
	Average	**32.2**	**26.9**

Collection Period: 1984 - June 20, 1984 - October 24, 1984
1985 - Oct. 20, 1984 - October 23, 1985
1986 - Oct. 23, 1985 - October 22, 1986

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

collection indicated that a difference of 55 gm/m^2, or only a 16% change, in yearly leaf litter weight can be detected between the antenna and the control site by the current use of 15 traps at each location. This bounds of estimation is well within acceptable variability standards for litter production studies (Gosz et al. 1973).

Chemical analysis of the 1985 litter and foliage samples have not been completed. A major renovation of the MTU School of Forestry Analytical Laboratory this past summer resulted in a shutdown of plant analysis facilities for a three-month period. These samples are currently being processed and the results will be presented in next year's report.

LITERATURE CITED

Anderson, R.C. and O.L. Loucks. 1973. Aspects of the biology of Trentalis borealis Raf. Ecology 54. 789-808.

Anonymous. 1977. Seafarer ELF Communication System Draft Environmental Impact Statement for Site Selection and Test Operations. Appendix E, Biological and Ecological Information. Dept. of the Navy, ELectronics Systems Command.

Becker, C.A., G.D. Mroz and L.G. Fuller. 1987. Effects of moisture stress on red pine (Pinus resinosa Ait.) seedling rot and mycorrhizae development. Can. Jour. For. Res. In Press.

Botkin, D.B., J.F. Janak, and J.R. Wallis. 1972. Some ecological consequences of a computer model of forest growth. J. Ecol. 60:849-873.

Brown, G.S. 1965. Point density in stems per acre. New Zealand Forest Res. Notes No. 38. 13 p.

Coffman, M.S., E. Alyanak, J. Kotar, an dJ.E. Ferris. 1983. Field Guide, Habitat Classification System for the Upper Peninsula of Michigan and Northeastern Wisconsin. CROFS; Dept. of For., Michigan Tech. Univ., Houghton, MI.

Crow, T.R. 1978. Biomass and production in three contiguous forests in northern Wisconsin. Ecology, 59:265-273.

Dighton, J., J.M. Poskitt and D.M. Howard. 1986. Changes in occurrence of basidiomycete fruit bodies during forest stand development with specific reference to mycorrhizal species. Trans. Br. Mycol. Soc. 87:163-171.

Fogel, R. 1976. Ecological studies of hypogeous fungi. II. Sporocarp phenology in a western Oregon Douglas-fir stand. Can. J. Bot. 54:1152-1162.

Fogel, R. 1981. Quantification of sporocarps produced by hypogeous fungi. In The Fungal Community, D.T. Wicklow and G.C. CArroll (ed.) Dekker, New York, pp. 553-568.

Gadgil, R.L. and P.D. Gadgil. 1971. Mycorrhizae and litter decomposition. Nature 233:133

Gale, M.R., and D.F. Grigal. 1987. Vertical root distribution of northern tree species in relation to successional status. Can. J. For. Res. (in press)

Gosz, J.R., G.E. Likens and F.H. Bormann. 1973. Nutrient release from decomposing leaf and branch litter in the Hubbard Brook Forest, New Hampshire.

Harrison, W.C., T.E. Burk, and D.E. Beck. 1986. Individual tree basal area increment and total height equations for Appalachian mixed hardwoods after thinning. Southern Journal of Applied Forestry. 10:99-104.

Hering, T.F. 1966. The terricolous higher fungi for four Lake District woodlands.Trans. Br. Mycol. Cos. 49:369-383.

Jackson, M.T. 1966. Effects of microclimate on spring flowering phenology. Ecology 47:407-415.

Kile, G.A. 1986. Genotypes of Armillaria hinnulea in wet schlerophyll eucalypt forest in Tasmania. Transactions of the British Mycological Society 87:312-314.

Korhonen, K. 1978. Interfertility and clonal size in the Armillariella mellea complex. Karstenia 18:31-42.

Liming, F.G. 1957. Homemade dendrometers. J. For. 55:575-577.

Lindsey, A.A. and J.E. Newman. 1956. Use of official weather data in spring time - temperature analysis of an Indiana phenological record. Ecology 37:812-823.

Lundgren, A.L. and W.A. Dolid. 1970. Biological growth functions describe published site index curves for Lake States timber species. U.S.D.A. For. Ser. Res. Paper. N.C.-36, 9 p.

Mallett, K.I. and Y. Hiratsuka. 1985. The "trap-log" method to survey the distribution of Armillaria mellea in forest soils. Can. J. For. Res. 15:1191-1193.

Mallett, K.I., and Y. Hiratsuka. 1986. Nature of the "black line" produced between different biological species of the Armillaria mellea complex. Can. J. Bot. 64:2588-2590.

Mroz, G.D., P.J. Cattelino, and C.A. Becker. 1987. Terminal buds indicate early red pine planting survival. N. J. Appl. For. (in press).

Orloci, L. 1967. An agglomerative method for classification of plant communities. J. Ecol. 55:193-206

Schemske, D.W., M.F. Willson, M.N. Melampy, L.J. Miller, L. Verner, K.M. Schemske, and L.B. Best. 1978. Flowering ecology of some spring woodland herbs. Ecology 59:351-366.

Siepman, R. 1985. Uber das vorkommen von Armillaria-arten und -klonen in benachbarten koniferenbestanden, mischbestanden und in laubwald. European J. For. Pathology 15:71-80.

Singh, P. 1980. Armillaria root rot: Artificial inoculation and development of the disease in the greenhouse. European J. For. Path. 10:420-431.

Wargo, P.M. and C.G. Shaw. 1985. Armillaria root rot: The puzzle is being solved. Plant Disease 69:826-832.

Parker-Rhodes, A.F. 1051. The basidiomycetes of Skokholm Island: Some floristic and ecological calculations. New Phytologist 50:227-243.

Pronos, J. and R.F. Patton. 1977. Armillaria root rot of red pine planted on oak sites in Wisconsin. Plant Dis. Reptr. 61:955-958.

Reich, P.B., A.W. Schoettle, H.F. Stroo, J. Troiano, and R.G. Amundson. 1985. Effects of O_3, SO_2, and acid rain on mycorrhizal infection in northern red oak seedlings. Can. J. Bot. 63:2049-2055.

Rishbeth, J. 1978. Effects of soil temperature and atmosphere on growth of Armillaria rizomorphs. Trans. Br. Mycol. Soc. 70:213-220.

Shafer, S.R., L.F. Grand, R.I. Bruck, and A.S. Heagle. 1985. Formation of ectomycorrhizae on Pinus taeda seedlings exposed to simulated acidic rain. Can. J. For. Res. 15:66-71.

Shugart, H.H., and D.C. West. 1977. Development of an Appalachian deciduous forest succession model and its application to assessment of the impact of the chestnut blight. J. Environ. Manag. 5:161-179.

Singh, P. 1981. Armillaria Mellea: Growth and distribution of rhizomorphs in the forest soils of Newfoundland. Eur. J. For. Path. 11:208-220.

Smith, D.M. 1962. The practice of silviculture. John Wiley and Sons. New York.

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

U.S. Department of Agriculture, Forest Service. 1979. A generalized forest growth projection system applied to the Lake States region. U.S Dep. Agric. For. Serv., Gen. Tech. Rep. NC-49, 96p. Nor. Cent. For. Exp. Stn., St. Paul, Minnesota.

UPLAND FLORA PUBLICATIONS

Becker, C.A. 1986. The effects of plant moisture stress on red pine (Pinus Resinosa) seedling growth and establishment. M.S. Thesis. School of Forestry and Wood Products, Michigan Technological University, Houghton, MI.

Becker, C.A., G.D. Mroz and L.G. Fuller. 1987. Effects of moisture stress on red pine (Pinus resinosa Ait.) seedling root and mycorrhizae development. Proc. of the Conf. on Roots in Forest Soils: Biology and Symbiosis. Victoria, B.C. Canada. In Press.

Brooks, R.H. and P.J. Cattelino. 1987. Determining fine soil bulk density in rocky soils. In preparation.

Cattelino, P.J., G.D. Mroz, and E.A. Jones. 1985. Soil/climatic factors affecting red pine seedling growth in Northern Michigan. Agronomy Abstracts. American Society of Agronomy Annual Meeting, Chicago, IL.

Cattelino, P.J., C.A. Becker, and L.G. Fuller. 1986. Construction and installation of homemade dendrometer bands. North. J. Appl. For. 3:73-75.

Cattelino, P.J., H.O. Liechty, G.D. Mroz and D.L. Richter. 1986. Relationships betweeen initiation of red pine seedling root growth, ectomycorrhize counts and microclimate in Northern Michigan. Abstracts of the Conference on roots in Forest Soils: Biology and Symbiosis. Victoria, B.C. Canada.

Fuller, L.G., P.J. Cattelino, and D.D. Reed. 1986. Dendrometer bands and climatic data collection: a system of ecological diamter growth model development. IN: G.D. Mroz and D.D. Reed Eds. Proceedings of a Conference on the Northern Hardwood Resource: Management and Potential. Michigan Technological University, Houghton, MI. p. 425.

Fuller, L.G., P.J. Cattelino, and D.D. Reed. Correction equations for dendrometer band measurements of five hardwood species. (Submitted to the Northern Journal of Applied Forestry).

Fuller, L.G. and D.D. Reed. 1987. A model of seasonal diameter growth development for four northern hardwood species. (In Preparation).

Fuller, L.G., M.J. Holmes, and D.D. Reed. 1987. Development and testing of a seasonal diameter growth model for four northern hardwood species. To be presented at the International Union of Forest Research Organization Meeting on Forest Growth Modelling and Prediction to be held August 24-28, 1987.

Fuller, L.G. 1986. Modeling northern hardwood dimater growth using weekly climatic factors in northern Michigan. M.S. Thesis, School of Forestry and Wood Products, Michigan Technological University, Houghton, MI.

Jones, E.A., D.D. Reed, P.J. Cattelino, and G.D. Mroz. 1987. Seasonal height growth development in young red pine plantations. In Preparation.

Jurgensen, M.F., M.J. Larsen, G.D. Mroz and A.E. Harvey. 1987. Timber harvesting soil organic matter and site productivity. In: C.T. Smith Ed., Proceedings: Productivity of Northern Forests Following Biomass Harvesting. Univ. of New Hampshire, Durham. p. 43-52.

Liechty, H.O., and G.D. Mroz. 1987. Changes in micro climate after clear cutting a northern hardwood covertype. In preparation.

Mroz, G.D., P.J. Cattelino, and M.F. Jurgensen. 1985. Whole tree harvest effects on Forest Floor and Soil/Climatic Factors affecting red pine seedling growth in Northern Michigan. Agronomy Abstracts. American Society of Agronomy Annual Meeting, Chicago, IL.

Mroz, G.D., P.J. Cattelino, and C.A. Becker. 1987. Terminal buds can be a useful indicator of early red pine planting survival. Submitted to the Northern Journal of Applied Forestry.

Richter, D.L. and J.N. Bruhn. 1987. Shifts in mycorrhizal fungus populations on red pine seedlings following outplanting on clear hardwood sites in Michigan's Upper Peninsula. In preparation.

Appendix A

Ambient Monitoring Data

Table 1.1. Equations 1985-1986 to predict missing data.

1985 Missing Data Equations

Plot	Equation	$\bar{X}$	Standard Error	R^2	Confidence Interval
	Soil Temperature Antenna Plantation Plots				
1	$y = 1.055(X)-.264$	13.5	.442	.992	$\bar{X} \pm .08$
2	$y = 1.015(X)-.234$	13.0	.347	.994	$\bar{X} \pm .07$
3	$y = 0.981(X)+1.300$	17.2	.551	.947	$\bar{X} \pm .15$

X = average daily soil temperature 5 cm on ground site
y = plot average daily soil temperature 5 cm on antenna site

1	$y = 1.081(X)-.407$	13.0	.266	.997	$\bar{X} \pm .05$
2	$y = 1.041(X)-.356$	12.7	.262	.997	$\bar{X} \pm .05$
3	$y = 1.010(X)-.711$	13.3	.502	.988	$\bar{X} \pm .10$

X = average daily soil temperature 10 cm on ground site
y = plot average daily soil temperature 10 cm on antenna site

	Soil Temperature Antenna Pole-size Plots				
1	$y = .843(X_1)+.038(X_2)-1.808$	9.3	1.639	.840	$\bar{X} \pm .31$
2	$y = .929(X_1)\ .464(X_2)-.4082$	11.6	.643	.971	$\bar{X} \pm .12$
3	$y = .888(X_1)+.334(X_2)-2.941$	11.1	.683	.966	$\bar{X} \pm .07$

X_1 = average daily soil temperature 5 cm on ground site
X_2 = month of year (i.e. ...6, 7, 8)
y_2 = plot average daily soil temperature 5 cm on antenna site

1	$y = .779(X_1)+.504(X_2)-3.200$	10.7	.528	.965	$\bar{X} \pm .10$
2	$y = .865(X_1)+.478(X_2)-3.292$	11.5	.531	.973	$\bar{X} \pm .10$
3	$y = .925(X_1)+.277(X_2)-3.343$	10.6	.612	.972	$\bar{X} \pm .11$

X_1 = average daily soil temperature 10 cm on ground site
X_2 = month of year (i.e. ...6, 7, 8)
y = plot average daily soil temperature 10 cm on antenna site

Table 1.1. Equations 1985-1986 to predict missing data (continued).

1985 Missing Data Equations

Plot	Equation	$\bar{X}$	Standard Error	R^2	Confidence Interval
	Soil Temperature Ground				
1	$y = 1.011(X_1)+.103(X_2)-1.487$	12.7	.618	.983	$\bar{X} \pm .12$
2	$y = .902(X_1)-.074(X_2)+1.589$	13.0	.423	.991	$\bar{X} \pm .08$
3	$y = .961(X_1)+.130(X_2)-.670$	13.1	.400	.992	$\bar{X} \pm .08$

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

1	$y = 1.004(X_1)+.072(X_2)-1.421$	12.4	.504	.987	$\bar{X} \pm .09$
2	$y = .917(X_1)-.033(X_2)+1.052$	13.0	.419	.990	$\bar{X} \pm .08$
3	$y = .912(X_1)+.177((X_2)-.530$	12.9	.441	.987	$\bar{X} \pm .08$

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

Control Average Daily Air Temperature (30 cm)

	$y = 1.0111(X_1)-13.2(X_2)+.778$	12.5	.287	.997	$\bar{X} \pm .08$

X_1 = air temperature daily average on control pole-sized sited
X_2 = month of year (i.e. ...6, 7, 8)
y = vegetation temperature control site

Antenna Average Daily Air Temperature (30 cm)

	$y = .967(X_1)-.035(X_2)+.663$	13.1	.330	.990	$\bar{X} = .05$

X_1 = air temperature daily average on antenna pole-size stand
X_2 = month of year (i.e. ...6, 7, 8)
y = daily average vegetation temperature on antenna site

Relative Humidity Ground Site

	$y = .900(X_1)-1.362(X_2)+30.17$	75.7	4.77	.826	$\bar{X} \pm .65$

X_1 = daily relative humidity at antenna site
X_2 = month of year
y = daily relative humidity at ground site

Table 1.1. Equations 1985-1986 to predict missing data (continued).

1986 Missing Data Equations

Plot	Equation	$\bar{X}$	Standard Error	R^2	Confidence Interval
	Soil Temperature Antenna Pole-sized Plots				
1	$y = .569(X_1)+.732(X_2)-3.22$	11.3	.639	.963	$\bar{X} \pm .12$
2	$y = .389(X_1)+.782(X_2)-1.412$	11.9	.751	.965	$\bar{X} \pm .13$
3	$y = .161(X_1)+.913(X_2)-2.091$	12.0	.824	.967	$\bar{X} \pm .15$

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

1	$y = .502(X_1)+.743(X_2)-2.524$	10.7	.526	.979	$\bar{X} \pm .09$
2	$y = .252(X_1)+.844(X_2)-1.264$	11.6	.707	.972	$\bar{X} \pm .12$
3	$y = .129(X_1)+.912(X_2)-2.100$	10.9	.755	.973	$\bar{X} \pm .13$

X_1 = month of year (i.e...6, 7, 8)
X_2 = average daily soil temperature 5 cm on ground site
y = plot average; daily soil temperature 10 cm on antenna site

	Soil Temperature Antenna Plantation Plots				
1	$y = 1.064(X)-.720$	14.4	.349	.946	$\bar{X} \pm .06$
2	$y = 1.011(X)-.655$	13.3	.415	.997	$\bar{X} \pm .08$
3	$y = 1.046(X)+.326$	14.7	.792	.990	$\bar{X} \pm .14$

X = average daily soil temperature 5 cm on ground site
y = plot average; daily soil temperature 5 cm on antenna site

1	$y = -.055(X_1)+ 1.083(X_2)-.115$	13.9	.416	.994	$\bar{X} \pm .07$
2	$y = .037(X_1)1.037(X_2)-.580$	14.1	2.69	.997	$\bar{X} \pm .05$
3	$y = -.296(X_1)+1.028(X_2)+2.468$	14.2	.782	.980	$\bar{X} \pm .13$

X_1 = month of year (i.e....6, 7, 8)
X_2 = average daily soil temperature 10 on ground site
y = plot average daily soil temperature 10 cm on antenna site

Table 1.1. Equations 1985-1986 to predict missing data (continued).

1986 Missing Data Equations

Plot	Equation	$\bar{X}$	Standard Error	R^2	Confidence Interval
	Soil Moisture Antenna Plantation Plots				
1	$y = .807(X)-.354$	8.6	1.13	.787	$\bar{X} \pm .23$
2	$y = .755(X)+.634$	7.9	1.44	.661	$\bar{X} \pm .28$
3	$y = .669(X)-.847$	6.7	2.09	.420	$\bar{X} \pm .41$
	X = average daily soil moisture 5 cm on ground site y = plot average; daily soil moisture 5 cm on antenna site				
1	$y = .365(X)+3.40$	8.8	1.27	.609	$\bar{X} \pm .22$
2	$y = .412(X)+2.09$	7.5	2.43	.335	$\bar{X} \pm .32$
3	$y = .460(X)+2.97$	7.9	1.66	.571	$\bar{X} \pm .21$
	X = average daily soil moisture 10 cm on ground site y = plot average; daily soil moisture 10 cm on antenna site				
	Soil Moisture Antenna Tree Plots				
1-3	$y = 2.42(X_1)-10.04(X_2)+.603(X_3)+8.79$	11.5	1.74	.733	$\bar{X} \pm .34$
	X_1 = average daily soil moisture 5 cm on ground site X_2 = monthly indicator (0,1), (0-before June)(1 - after May) X_3 = (monthly indicator * x_1) y^3 = plot average, daily soil moisture 5 cm on antenna site				
1-3	$y = .648(X)+.229$	10.4	1.19	.843	$\bar{X} \pm .20$
	X = average daily soil moisture 10 cm on ground site y = plot average; daily soil moisture 10 cm on antenna site				
	Soil Temperature Control Plantation Plots (Equation created using July-October data)				
1-3	$y = .516(X_1)-2.138(X_2)+25.446$	14.7	1.389	.935	$\bar{X} \pm .30$
	X_1 = air temperature average control plantation plots X_2 = month of year (i.e...6,7,8) y^2 = plot average, daily soil temperature 5 cm on control site.				

Table 1.1. Equations 1985-1986 to predict missing data (continued).

1986 Missing Data Equations

Plot	Equation	$\bar{X}$	Standard Error	R^2	Confidence Interval
1-3	$y = .441(X_1)-2.189(X_2)+26.933$	14.7	1.498	.915	$\bar{X} \pm .32$

X_1 = air temperature daily average control plantation plots
X_2 = month of year (i.e...6.7.8)
y = plot average, daily soil temperature 10 cm on control site

Soil Temperature Control Pole-sized Plots
(equation created using July - October data)

1-3	$y = .514(X_1)-1.011(X_2)+16.672$	13.2	1.067	.921	$X \pm .22$

X_1 = air temperature daily average control plantation plots
X_2 = month of year (i.e...6,7,8)
y = plot average; daily soil temperature 5 cm on control tree plots

1-3	$y = .429(X_1)-1.137(X_2)+16.672$	13.2	1.067	.921	$\bar{X} \pm .24$

X_1 = air temperature daily average control plantation plots
X_2 = month of year (i.e...6,7,8)
y = plot average; daily soil temperature 10 cm on control tree plots

Antenna Average Air Temperature (30 cm)

$y = -.185(X_1)+.922(X_2)+2.396$	13.1	.558	.996	$\bar{X} \pm .10$

X_1 = month of year (i.e...6,7,8)
X_2 = daily average air temperature on ground site
y = vegetation temperature daily average on antenna site

Control Average Air Temperature (30 cm)

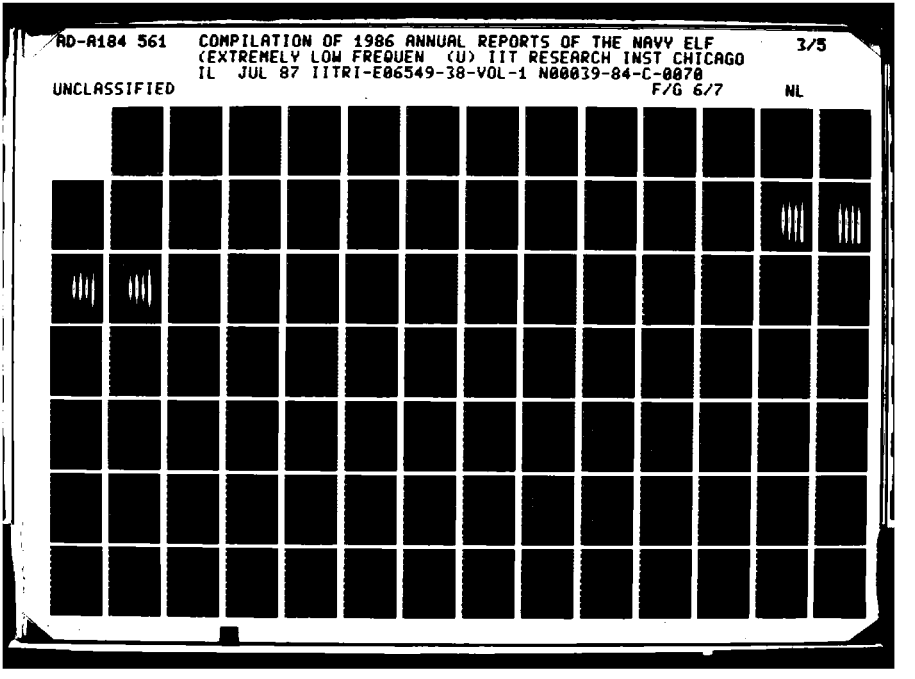
$y = .0522(X_1)+.977(X_2)-.268$	12.8	.308	.997	$\bar{X} \pm 0$

X_1 = month of year (i.e....6,7,8)
X_2 = daily average air temperature on antenna site
y = vegetation temperature daily average on control site

Antenna Relative Humidity

$y = 1.01(X_1)+5.43$	79.3	3.74	*	

X_1 = relative humidty daily average at ground site
y = relative humidity daily average for antenna site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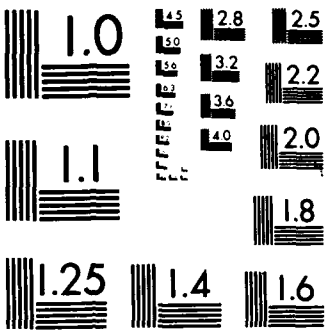

MICROCOPY RESOLUTION TEST CHART
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Table 1.1. Equations 1985-1986 to predict missing data (continued).

1986 Missing Data Equations

Plot	Equation	$\bar{X}$	Standard Error	R^2	Confidence Interval
	Control Average Daily Air Temperature				
	$y = .333+.920(X)$	14.5	1.69	.900	$\bar{X} \pm .30$

X = average daily air temperature at Crystal Falls DNR station
y = predicted average daily air temperature on pole-sized stand at control site

	$y = .592+.906(X)$	15.6	1.74	.843	$\bar{X} \pm .32$

X = average daily air temperature at Crystal Falls DNR station
y - predicted average daily air temperature plantation plots at control site

Table 1.2. Dates of measurements replaced by one of the four replacement methods for 1985 growing season.

AIR TEMPERATURE 1985

Plot 1		Plot 2		Plot 3	
		Ground Plantation			
May	14	April	19-30	May	14
	20				20
	29	May	01-14		29
	31		20		31
			29		
June	04-06		31	June	10-14
	11-14				18-28
	18-28	June	01-30		
July	15	July	04-22	July	25
	31		31		31
August	02-31	August	02-31	August	02-31
September	01-03	September	01-03	September	01-03
	05		05		05
December	11-31			December	11-31
		Antenna (Plantation)			
April	01-30	April	01-30	April	01-30
May	01-31	May	01-06	May	01-06
June	01-30				
July	01-04	September	15-17		
October	01-31				
November	01-30				
		Antenna (Pole-size)			
April	01-30	April	01-30		
May	01-06	May	01-06		
July	09				
		Control (Plantation)			
April	21-23	April	20-23		
			26		
			30		
		May	01-14	May	07-09
		June	07-30		
August	05	July	01-31		
September	25	August	02-05	September	25
		Control (Pole-size)			
September	25	April	27	April	21-23
					23-30
				May	01-31
				August	01
				September	25

Table 1.2. Continued.

SOIL TEMPERATURE (5cm.) 1985					
Plot 1		Plot 2		Plot 3	
		Ground Plantation			
May	01-14	May	14	April	12-30
	20		20	May	01-06
June	06	June	06		14
	11		11		20
	14		14	June	02-06
	19-28		19-28		11
July	15	July	15		14
August	04-31	August	04-31		19
September	01-04	September	01-03		20-28
December	11-31	October	24	July	15
				August	04-31
				Septmber	01-03
				December	11-31
		Antenna (Plantation)			
April	01-30	April	01-30	April	01-30
May	01-06	May	01-06	May	01-06
		August	22	August	08
			23		24-31
		September	15-17	September	01-30
				October	01-31
				November	01-30
				December	01-10
		Antenna (Pole-size)			
April	01-30	April	01-30	April	01-30
May	01-06	May	01-06	May	01-06
	11-14				
July	29-30				
September	20				
November	21				
		Control (Plantation)			
April	28-29	April	20-23	April	01-23
			26-30		
May	07-09	May	01	May	16-31
August	04-05			June	01-11
		Control (Pole-size)			
August	01-06	April	01-23	April	26-30
			30	May	01
		May	01		03-09
			09	August	06
		September	25		

Table 1.2. Continued.

SOIL TEMPERATURE (10 cm.) 1985					
Plot 1		Plot 2		Plot 3	
		Ground Plantation			
				April	12-30
				May	1-6
May	14	May	14		14
	20		20		20
June	6	June	6	June	6
	11		11		
	14		14		19-28
July	15	July	15	July	15
August	4-31	August	4-31	August	4-31
September	1-3	September	1-3	September	1-3
	5				5
December	11-31			December	11-31
		Antenna (Plantation)			
April	1-30	April	1-30	April	1-30
May	1-13	May	1-6	May	1-6
June	20-30				
July	1-4	July	6-9		
		September	15-17		
		Antenna (Pole-size)			
April	1-30	April	1-30	April	1-30
May	1-6	May	1-6	May	1-6
		Control (Plantation)			
April	28	April	28	April	26
	29		29		27
May	7-9				
		Control (Pole-size)			
April	1-19			April	26-30
				May	1
					3-9
		July	1-5		
August	6	August	6		

Table 1.3. Dates of measurements replaced by one of the four replacement methods for 1986 growing season.

AIR TEMPERATURE 1986

Plot 1		Plot 2		Plot 3	
		Ground Plantation			
April	01-07	September	02-11	April	01-07
				August	08-31
				September	01
					09-11
				October	03
					05
					08-31
		Antenna (Plantation)			
April	11-30	April	12-16	April	10-16
			22		22
May	01-02				
July 31		July	31	July	31
		August	01-06	August	01-06
September	01-11		08-31		08-31
	13-17				
	26-30	September	01-11	September	01-11
			13-17		13-17
October	01-03		26-30		26-30
		October	01-03	October	01-03
		Antenna (Pole-size)			
April	11-30	April	11-30	April	11-30
May	01-02	May	01-02	May	01-02
July	31	July	31	July	31
August	01-06	August	01-06	August	01-06
	08-31		08-31		08-31
September	01-11	September	01-11	September	01-11
	13-17		13-17		13-17
	26-30		26-30		26-30
October	01-03	October	01-03	October	03-03
		Control (Plantation)			
April	11-23	April	11-23	April	11
					15
May	21	May	21-23	May	21
June	03-04	June	03-04	June	03-04
July	24	July	24-25	July	24
	26-31				26-31
August	07	August	01-31	August	07
	15				15
September	20	October	09-10	September	04-05
	28				08-17
					20
					28
				October	02
					06-10

Table 1.3. Continued.

SOIL TEMPERATURE (5 cm.) 1986					
Plot 1		Plot 2		Plot 3	
		Ground Plantation			
April	01-07	April	08-11	April	01-07
		Antenna (Plantation)			
April	11-23	April	10-16	April	10-16
July	31	July	31	July	31
August	01-31	August	01-31	August	01-31
September	01-11	September	01-11	September	01-11
	13-17		13-17		13-17
	29-30		29-30		29-30
October	01-03	October	01-03	October	01-03
		Antenna (Pole-size)			
April	10-30	April	10-16	April	10-23
July	31	July	31	July	31
August	01-31	August	01-31	August	01-31
September	01-11	September	01-11	September	01-11
	13-17		13-17		13-17
	29-30		29-30		29-31
October	01-03	October	01-03	October	01-03
		Control (Plantation)			
April	12-16				
July	24	July	24	July	24
	26-31		26-31		26-31
September	04-05	September	04-05	September	04-05
	08-17		08-17		08-17
	20		20		20
October	02	October	02	October	02
	06-09		06-31		06-09
		Control (Pole-size)			
April	10			April	10
	22-28				12-16
July	24	July	24	July	24
	26-31		26-31		26-31
		August	01-15	August	01-31
September	04-05	September	04-05	September	01-05
	08-17		08-17		08-17
	20		20		20-30
	28		28		20-30
October	02		02		
	06-10		06-10		06-10

Table 1.3. Continued.

SOIL TEMPERATURE (10 cm.) 1986

Plot 1		Plot 2		Plot 3	
		Ground Plantation			
April	01-07	April	08-11	April	01-07
		Antenna (Plantation)			
April	11-16	April	10-30	April	1-16
June	12				
	14-18				
July	31	July	31	July	31
August	01-31	August	01-31	August	01-31
September	01-11	September	01-11	September	01-11
	13-17		13-17		13-17
	26-27		26-27		26-27
	29-30		29-30		29-30
October	01-03	October	01-03	October	01-03
		Antenna (Pole-size)			
April	10-16	April	10-16	April	10-16
June	13	June	13		
July	31	July	31	July	31
August	01-31	August	01-31	August	01-31
September	01-11	September	01-11	September	01-11
	13-17		13-17		13-17
October	01-03	October	01-03	October	01-03
		Control (Plantation)			
April	12-23				
July	24	July	24	July	24
	26-31		26-31		26-31
September	04-05	September	04-05	September	04-05
	08-17		08-17		08-17
	20		20		20
October	02	October	02	October	02
	06-10		06-10		06-10
		Control (Pole-size)			
April	10			April	10
July	24	July	24	July	24
					26-31
August	01-15			August	01-31
September	04-05	September	04-05	September	01-05
	08-17		08-17		20-30
	28		28		
October	02	October	02	October	01-02
	06-10		06-10		

Table 1.3. Continued.

SOIL MOISTURE (5 cm.) 1986

Plot 1		Plot 2		Plot 3	
		Ground Plantation			
April	11-23	April	10-16	April	10-16
July	31	July	31	July	31
August	01-31	August	01-31	August	01-31
September	01-17	September	01-17	September	01-17
	26-27		26-27		26-27
	29-30		29-30		20-30
October	01-31	October	01-31	October	01-31
		Antenna (Plantation)			
April	10-23	April	10-16	April	10-23
July	31	July	31	July	31
August	01-31	August	01-31	August	01-31
September	01-17	September	01-17	September	01-17
	26-27		26-27		26-27
	29-30		29-30		29-30
October	01-31	October	01-31	October	01-31
		Antenna (Pole-size)			
April	11-16				
Ausugt	16-31	August	16-31		
September	01-03	September	01-03		
	21-27		21-27		
	29-30		29-30		
October	01	October	01		
	11-31		11-31		
		Control (Plantation)			
April	11-16	April	12-16		
June	04				
August	15-31			August	15-31
September	01-03			September	01-03
	21-24				21-24
	27				27
	29-30				29-30
October	01			October	01

Table 1.3. Continued.

SOIL MOISTURE (10 cm.) 1986					
Plot 1		Plot 2		Plot 3	
		Ground Plantation			
		April	80-30		
		September	25	September	29
		Antenna (Plantation)			
April	11-16	April	10-30	April	10-16
June	12-18				
July	31	July	31	July	31
August	01-31	August	01-31	August	01-31
September	01-17	September	01-17	September	01-17
	26-27		26-27		26-27
	29-30		29-30		29-30
October	01-02	October	01-31	October	01-31
		Antenna (Pole-size)			
April	10-16	April	10-16	April	10-16
July	31-31	July	31	July	31
August	01-31	August	01-31	August	01-31
September	01-17	September	01-17	September	01-17
	26-27		26-27		26-27
	29-30		29-30		29-30
October	01-31	October	01-31	October	01-02
		Control (Plantation)			
April	12-16		April	12-16	
August	01-31	August	01-15		
September	01-03	September	25-27		
			29-30		
		October	01		
			11-31		
		Control (Pole-size)			
August	01-14	August	01-31		
September	01-03	September	01-03		
October	11-31	October	11-15		

Table 1.4. Dates where replacement estimates were used for missing data in 1985.

Precip-Rain Guage	Solar Radiation	Relative Humidity	Vegetative Temperature
	Ground Site 1985		
6/14 6/20-6/28 8/5-9/3	none	6/18-6/25 6/27-6/28 7/15 7/31 8/2-9/3 9/5	none
	Antenna Site 1985		
4/1-4/30 5/1-5/5	none	none	4/1-4/30 5/1-5/7 5/9-5/24
	Control Site 1985		
4/24	none	8/23-8/30	4/1-4/23 4/26-5/23 8/1 9/25

Table 1.5. Dates where replacement estimates were used for missing data in 1986.

	Ground Site		
none	none	6/13	none
	Antenna Site 1986		
4/10 4/12-4/14 8/1-9/17 9/25-10/2	none	4/8-4/23 7/31-8/6 8/8-9/11 9/13-9/17 9/26-9/27 9/29-10/8	4/1-4/22 7/31-9/11 9/13-9/17 9/26-9/27 9/29-10/3 10/8
	Control Site 1986		
7/26-7/30 8/1-8/31 9/8-9/17 10/3-10/7	none	none	4/1-4/14 5/21 6/3-6/4 7/26-9/5 9/8-9/17 9/20-9/27 9/29-10/2 10/6-10/29

Table 1.6 Monthly ambient air temperatures,soil temperatures, and soil moistures.

1985

1985 GROWING SEASON	AIR TEMP. (deg. C.)	SOIL TEMP.-5cm-SOIL MOIST. (deg. C.)	(percent)	SOIL TEMP.-10cm-SOIL MOIST. (deg. C.)	(percent)
		GROUND SITE - PLANTATION			
APRIL	4.9	4.1		3.7	
MAY	11.2	12.8		12.4	
JUNE	13.3	15.5		15.0	
JULY	16.8	18.0		17.5	
AUGUST	15.7	16.6		16.2	
SEPT.	12.0	13.4		13.4	
OCT.	6.1	7.2		7.3	
$\bar{X}$=	11.4	12.5		12.2	
		ANTENNA SITE - PLANTATION			
APRIL	4.9	4.5		3.4	
MAY	11.3	13.5		13.0	
JUNE	13.2	15.9		15.4	
JULY	16.6	18.7		18.5	
AUGUST	15.7	17.1		16.9	
SEPT	12.2	13.8		13.8	
OCT.	6.4	7.1		7.3	
$\bar{X}$=	11.5	12.9		12.6	
		ANTENNA SITE - POLE SIZED			
APRIL	4.9	1.8		1.6	
MAY	11.3	10.1		9.7	
JUNE	13.3	11.8		11.4	
JULY	16.6	15.1		14.6	
AUGUST	15.5	14.3		14.4	
SEPT.	12.1	11.6		12.2	
OCT.	6.3	6.3		7.0	
$\bar{X}$=	11.4	10.1		10.2	
		CONTROL SITE - PLANTATION			
APRIL	5.2	3.4		2.4	
MAY	12.2	12.8		12.7	
JUNE	13.9	15.2		15.2	
JULY	17.2	18.2		18.2	
AUGUS	15.9	16.8		16.9	
SEPT.	12.3	13.8		14.1	
OCT.	6.6	7.0		7.2	
$\bar{X}$=	12.1	12.5		12.4	
		CONTROL SITE - POLE SIZED			
APRIL	5.8	2.1		1.9	
MAY	12.6	10.3		10.0	
JUNE	14.1	12.1		11.8	
JULY	17.6	15.6		15.2	
AUGUST	16.1	15.3		15.1	
SEPT.	12.6	13.2		13.2	
OCT.	7.0	7.4		7.6	
$\bar{X}$=	12.0	10.9		10.8	

Table 1.6 continue

1986

1986 GROWING SEASON	AIR TEMP. (deg. C.)	SOIL TEMP.-5cm (deg. C.)	SOIL MOIST. (percent)	SOIL TEMP.-10cm (deg. C.)	SOIL MOIST. (percent)
		GROUND SITE - PLANTATION			
APRIL	6.1	6.3	13.5	5.8	16.3
MAY	12.8	14.0	12.9	13.2	17.8
JUNE	14.1	16.4	10.4	16.0	12.5
JULY	18.9	19.6	9.1	19.1	9.2
AUGUST	15.3	16.3	12.7	16.1	12.7
SEPT.	11.0	13.1	17.6	13.0	18.9
OCT.	5.5	7.6	15.9	7.6	19.0
$\bar{x}$=	12.0	13.3	13.0	13.0	15.0
		ANTENNA SITE - PLANTATION			
APRIL	6.0	6.4	10.0	6.1	10.2
MAY	13.2	14.5	9.9	14.1	9.8
JUNE	14.6	16.3	6.6	16.3	6.8
JULY	19.2	20.0	5.2	20.0	7.9
AUGUST	15.3	16.6	8.8	16.7	8.1
SEPT.	10.5	13.2	12.4	13.3	10.6
OCT.	5.7	7.5	11.2	7.5	10.8
$\bar{x}$=	12.1	13.5	9.0	13.5	9.0
		ANTENNA SITE - POLE SIZED			
APRIL	6.0	4.9	11.0	4.2	11.1
MAY	13.0	11.0	12.7	10.7	11.1
JUNE	14.2	12.7	8.3	12.4	8.0
JULY	18.8	16.5	5.7	16.2	6.1
AUGUST	15.3	13.9	9.5	13.8	8.4
SEPT.	11.0	11.7	13.5	11.6	12.4
OCT.	5.6	7.7	12.2	7.3	12.7
$\bar{x}$=	12.8	11.2	10.2	10.9	9.8
		CONTROL SITE - PLANTATION			
APRIL	6.3	5.5	19.0	5.2	15.7
MAY	13.3	13.5	19.8	13.1	18.0
JUNE	15.0	16.2	11.6	15.9	9.2
JULY	19.3	19.8	12.7	19.4	11.3
AUGUST	15.3	17.0	11.1	17.1	12.2
SEPT.	12.9	13.2	18.1	13.3	17.2
OCT.	6.6	7.1	19.7	7.4	18.5
$\bar{x}$=	12.7	13.3	16.0	13.1	14.1
		CONTROL SITE - POLE SIZED			
APRIL	6.8	4.9	18.4	4.7	16.3
MAY	13.7	11.6	16.4	11.2	16.4
JUNE	15.0	13.3	11.6	13.1	9.6
JULY	19.2	17.0	8.8	16.6	8.6
AUGUST	15.6	14.8	8.9	14.5	7.1
SEPT.	13.0	12.2	16.6	12.1	12.3
OCT.	6.6	7.6	17.8	7.9	18.0
$\bar{x}$=	12.9	11.7	13.3	11.5	12.2

Table 1.7 Precipitation totals, solar radiation, air temperature (30 cm. above the ground), and relative humidity.

1985

1985 GROWING SEASON	MONTHLY PRECIPITATION (in.)		SOLAR RADIATION	AIR TEMP. 30 cm. (deg. C.)	RELATIVE HUMIDITY (percent)
			GROUND SITE		
APRIL	3.33		381.1 (Langley/		
MAY	4.93		435.8 Day)		
JUNE	1.70		519.8		85.6
JULY	2.66		553.6		78.0
AUGUST	5.17				76.5
SEPT.	4.76		255.8		82.1
OCT.	3.19		220.4		75.8
Total=	26.68	$\bar{x}$=	473.4		79.6
			ANTENNA SITE		
APRIL	3.33			5.3	
MAY	4.94		(Eins.	11.6	
JUNE	2.43		3.3 /day)	13.0	79.5
JULY	1.60		3.2	16.5	71.7
AUGUST	5.17		2.2	15.4	71.5
SEPT.	5.92		1.6	12.2	82.4
OCT.	3.09		3.7	6.2	73.1
Total=	27.08	$\bar{x}$=	2.8	11.5	75.6
			CONTROL SITE		
APRIL	1.72			6.1	
MAY	4.19			12.8	
JUNE	2.13		2.2	14.2	
JULY	.85		2.0	17.8	77.4
AUGUST	3.14		1.2	16.0	79.4
SEPT.	7.00			12.3	77.5
OCT.	2.64			6.5	75.1
Total=	21.67	$\bar{x}$=		11.7	77.4

Table 1.7 continued

1986

1985 GROWING SEASON	MONTHLY PRECIPITATION (cm.)	SOLAR RADIATION	AIR TEMP. 30 cm. (deg. C.)	RELATIVE HUMIDITY (percent)
		GROUND SITE		
APRIL	1.21	373.9 (Langley/		58.8
MAY	0.00	473.8 Day)		60.4
JUNE	1.06	498.5		71.2
JULY	1.80	387.8		76.8
AUGUST	2.70	389.3		68.5
SEPT.	3.16	233.5		65.7
OCT.	3.18	215.9		85.3
Total=	13.11	$\bar{x}$= 375.0		70.0
		ANTENNA SITE		
APRIL	.50	19.0 (Eins.	6.6	63.6
MAY	.01	17.2 /Day)	13.6	67.3
JUNE	.98	1.6	14.1	76.2
JULY	1.84	1.1	18.5	85.8
AUGUST	2.70		15.1	74.6
SEPT.	3.16		10.9	71.6
OCT.	3.22		5.7	90.6
Total=	12.41	$\bar{x}$= 9.7	12.2	76.2
		CONTROL SITE		
APRIL	.58	15.4	6.7	53.3
MAY	.34	11.9	13.4	58.7
JUNE	1.86	1.3	14.5	69.8
JULY	2.33	1.2	18.9	75.8
AUGUST	2.24		15.4	
SEPT.	3.08		12.9	
OCT.	2.90		6.9	
Total=	13.33	$\bar{x}$= 7.5	12.8	

APPENDIX B

Estimation of Coarse Fragment Content of ELF Study Site Soils

Rock fragments are unattached pieces of rock 2mm in diameter and larger. Such fragments influence moisture storage, infiltration rates, runoff and land use. They protect fine particles from washing and blowing away. Rocks also reduce the volume of soil material that roots can penetrate and thus limit the amount of nutrients available to plants.

The presence of rocks in a soil poses a serious problem in the determination of available soil water, soil nutrients and bulk density. Whole soil volume must be adjusted by the amount of rock present before calculating these parameters to avoid overestimation when expressed on an area basis.

Sampling and Data Collection

Soil pits were dug adjacent to each plot in the red pine plantations and the pole-sized stands at each of the three study sites. The pits were dug to a depth of 50 cm. This depth represents approximately 90% of the vertical root distribution of trees (Gale and Grigal, 1987).. Sampling was stratified at depths of 0 - 10 cm, 10 - 30 cm, and 30 - 50 cm. The surface organic matter was scraped away from a 50 x 50 cm area that was dug to a depth of 10 cm. All material removed was passed through a 2.54 cm sieve. The soil less than 2.54 cm diameter was weighed and a representative sample of this material (approx. 3 - 5000 gms) was placed in plastic bags and returned to the laboratory to determine the fraction of rock present. Material greater than 2.54 cm was then separated into big rocks (greater than 5 cm diameter), little rocks, and roots. The big rocks were weighed in the field, whereas the smaller rocks were taken back to the lab for identification and determination of specific gravity. The roots were placed in sealed plastic bags for volume and weight determination in the lab. Two bulk density samples were taken on opposite sides of the pit. The pit was

then dug to a depth of 30 cm. The same procedure described above was then applied to the 10 - 30 cm depth and the 30 - 50 cm depth. The rocks collected in the field were washed, identified and analyzed for specific gravity. The subsamples of soil less than 2.54 cm were placed in large tin containers, weighed wet and then oven dry weight determined. Material less than 2.54 cm was passed through a 2mm mesh sieve and each fraction weighed. Moisture content, percent rock, and percent soil for each subsample was determined. Soil weights obtained in the field were then adjusted by moisture content.

The bulk density samples were oven dried at 105°C, weighed, and average bulk density of each pit by depth was determined. These samples were then sieved to 2mm and each fraction weighed. With this information, a corrected bulk density was calculated for soil <2mm. In addition, water holding capacity was determined for this soil fraction.

Roots were weighed in a wet (green) state and volume determined by displacement in water. Roots were then dried at 60°C and dry weights obtained.

Progress

From the weight and density data the volume of the whole soil for each sampling depth was described in terms of the volume of rocks and roots present. The whole soil could then be expressed as:

whole soil = volume rocks + volume roots + volume soil <2mm

Whole soil can now be described as the sum of fraction of the components:

whole soil = volume rocks (%) + volume roots (%) + volume soil <2mm (%)

This information can now be used in moisture and nutrient calculations. Rocks have the largest effect in reducing whole soil volume available for moisture and nutrient storage. A summary of the rock content is presented in Table A.1.

Similarly, nutrient data can be expressed on an area basis. If nutrient data is given in percent of sample by weight, then:

Nutrient on area basis =

$$\text{Nutrient \%} * \text{Corrected Bulk Density} * \left[1-(\text{Rock Vol \%} + \text{Root Vol \%})\right] * \text{Area Factor}$$

where:

Nutrient % = Soil test result in % of sample by weight
Area factor = constant to expand units to Kg/ha

Rock data will be considered as a covariate to help explain variation in the response variables. It can also be used to adjust other variables (i.e. nutrients) that are also being considered as covariates.

Table A.1. Average rock content of ELF study sites.

	% by Rock Volume	
	Plantation	Pole-sized Stands
Ground		
0 - 10 cm	4.7	---
10 - 30 cm	15.4	---
30 - 50 cm	31.1	---
Antenna		
0 - 10 cm	5.3	1.5
10 - 30 cm	9.2	5.8
30 - 50 cm	8.8	7.6
Control		
0 - 10 cm	5.9	5.0
10 - 30 cm	9.9	6.4
30 - 50 cm	9.1	9.9

n = 3 for each value

To illustrate the use of this information, water holding capacity would be calculated in the following manner:

$$WHC = \left(\frac{10^{th}\text{BAR} - 15\ \text{BAR}}{100}\right) * \text{Corrected Bulk Density} * \left[1-(\text{Rock Vol \%} + \text{Root Vol \%})\right]$$

where:

WHC = water holding capacity (cm H_2O/cm^3 soil <2mm)
10th bar = % moisture held at .1 bar
15 bar = % moisture held at 15 bars
Corrected Bulk Density = gm soil (<2mm/cm^3 soil <2mm)

Appendix C

Soil Nutrients (1985 Samples)

Tree productivity analyses done this past year indicated that soil nutrients are potentially valuable as covariates or terms in growth models. To refine the tree growth models soil nutrient sampling has been expanded this past year to include both pole-size and plantation plots. A monthly collection of 20 soil samples per replicate is conducted during the growing season using a soil probe inserted to a detph of 15 cm. These samples are composited to 5 per plot and are analyzed for Kjeldahl N, water soluble P and exchangeable K, Ca, and Mg. Because of lab renovation this past year only the pole-size plot samples from 1985 wre analyzed in time for this report.

Soil nutrient concentrations were generally greater at the control rather than the antenna site for nearly all sampling dates in 1985 (Figures C.1 and C.2). Considerable temporal variation in each nutrient measured was also evident. Nutrient concentrations are converted to a weight per unit area basis before being used in tree productivity analyses. The technique for doing this has been revised this past year with emphasis on soil rock content correcitons. A complete discussion of this calculation is presented in Appendix B. Tree productivity analyses will evaluate whether temporal variation in soil nutrient contents are related to tree growth pattern.

Figure C.1. Comparison of soil soluable P and Kjeldahl N between sites and sampling dates. Different letters denote significant differences in nutrient concentration among time periods within a site at the p=.05 level.

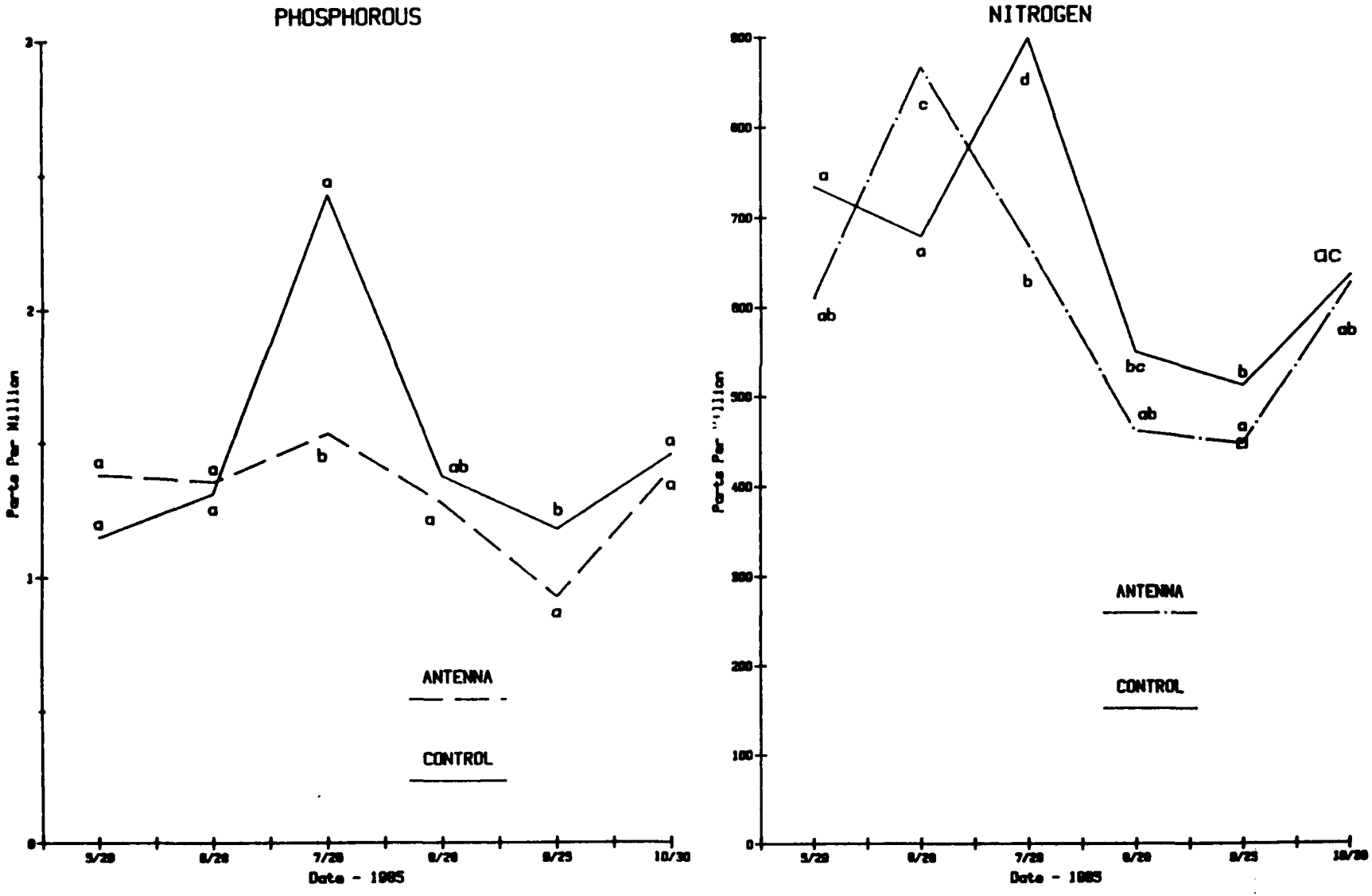
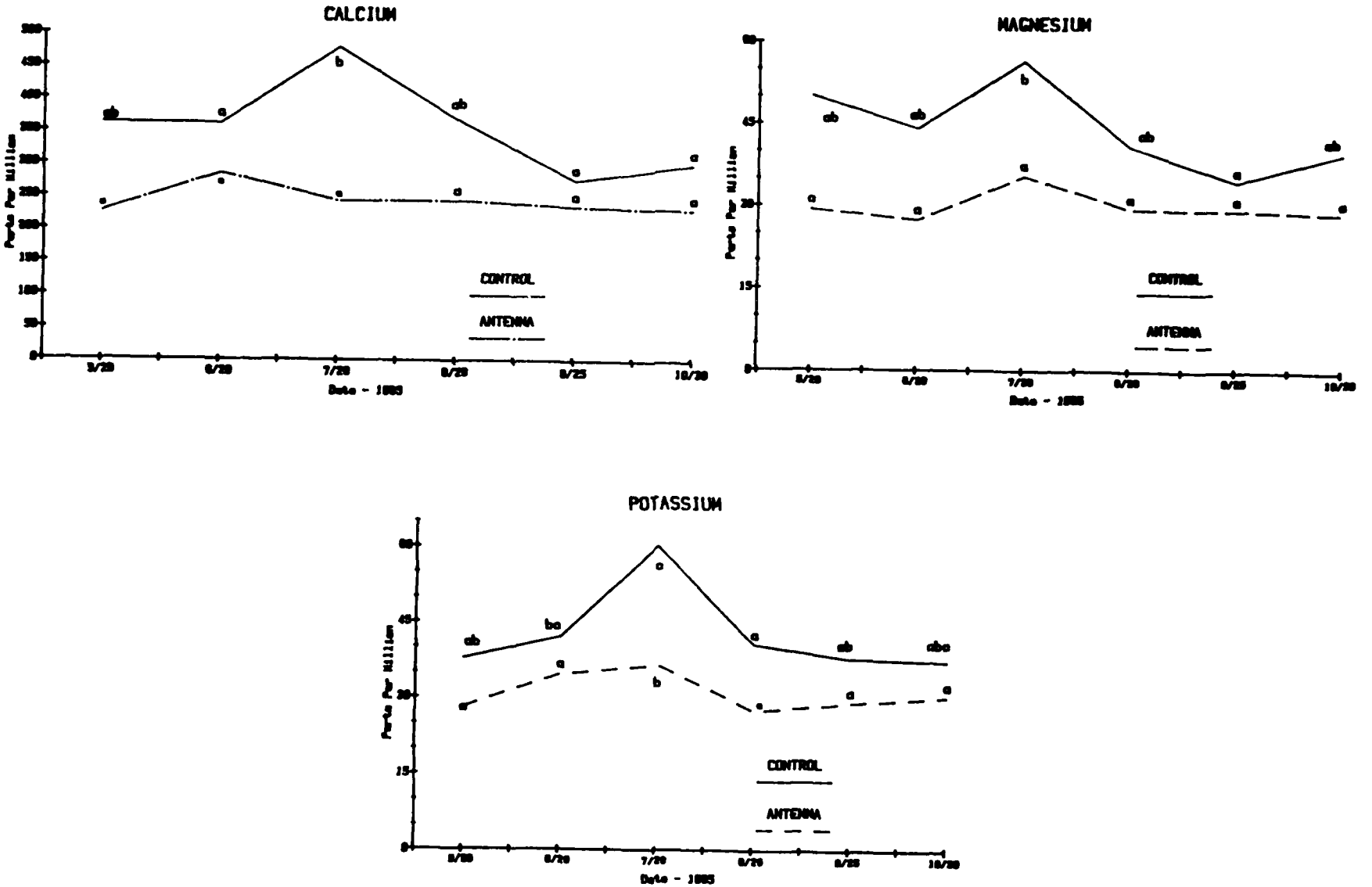
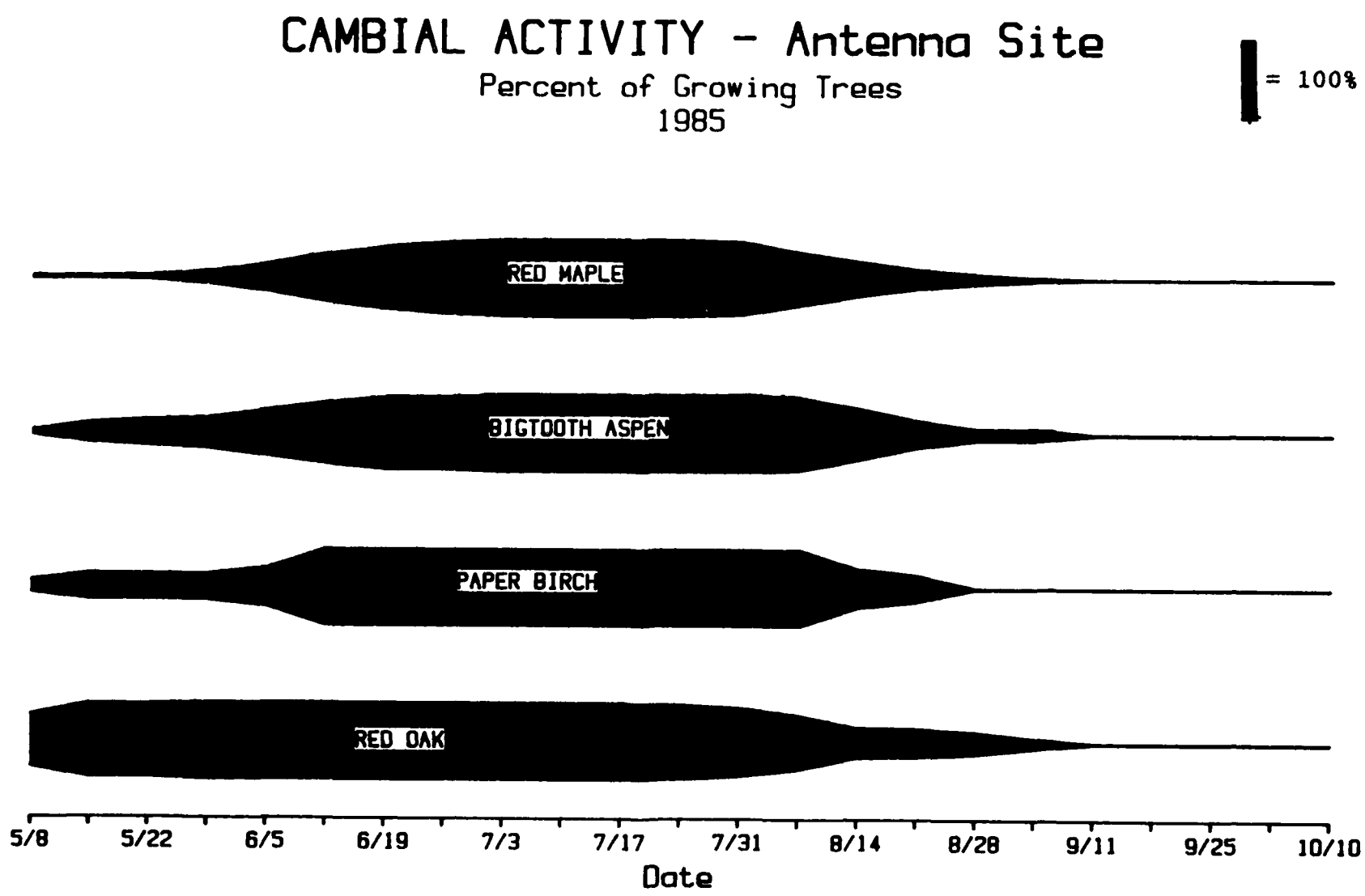


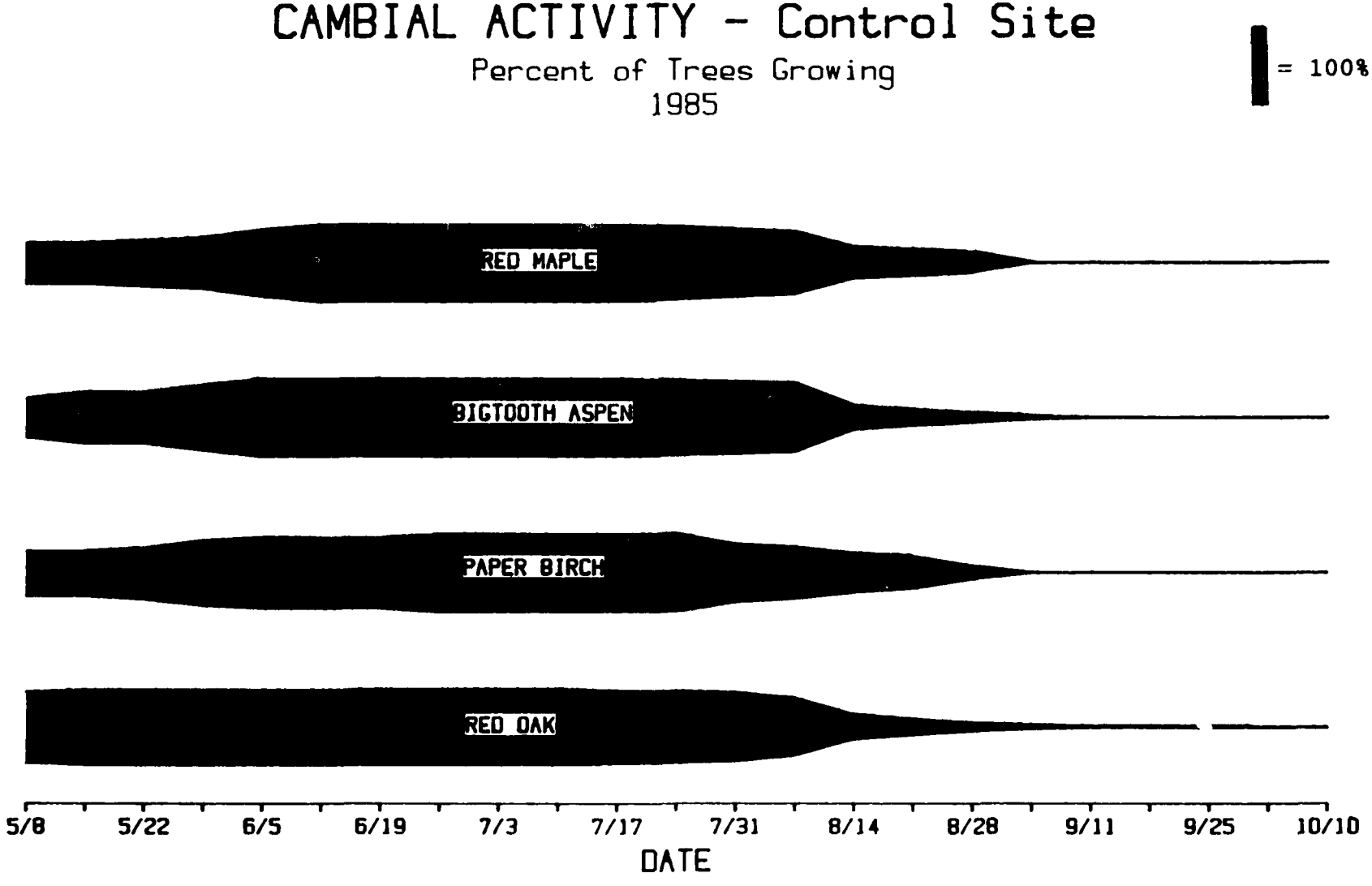
Figure C.2. Comparison of soil exchangeable nutrients between sites and sampling dates. Different letters denote significant differences in nutrient concentration among time periods within a site at the p=.05 level.

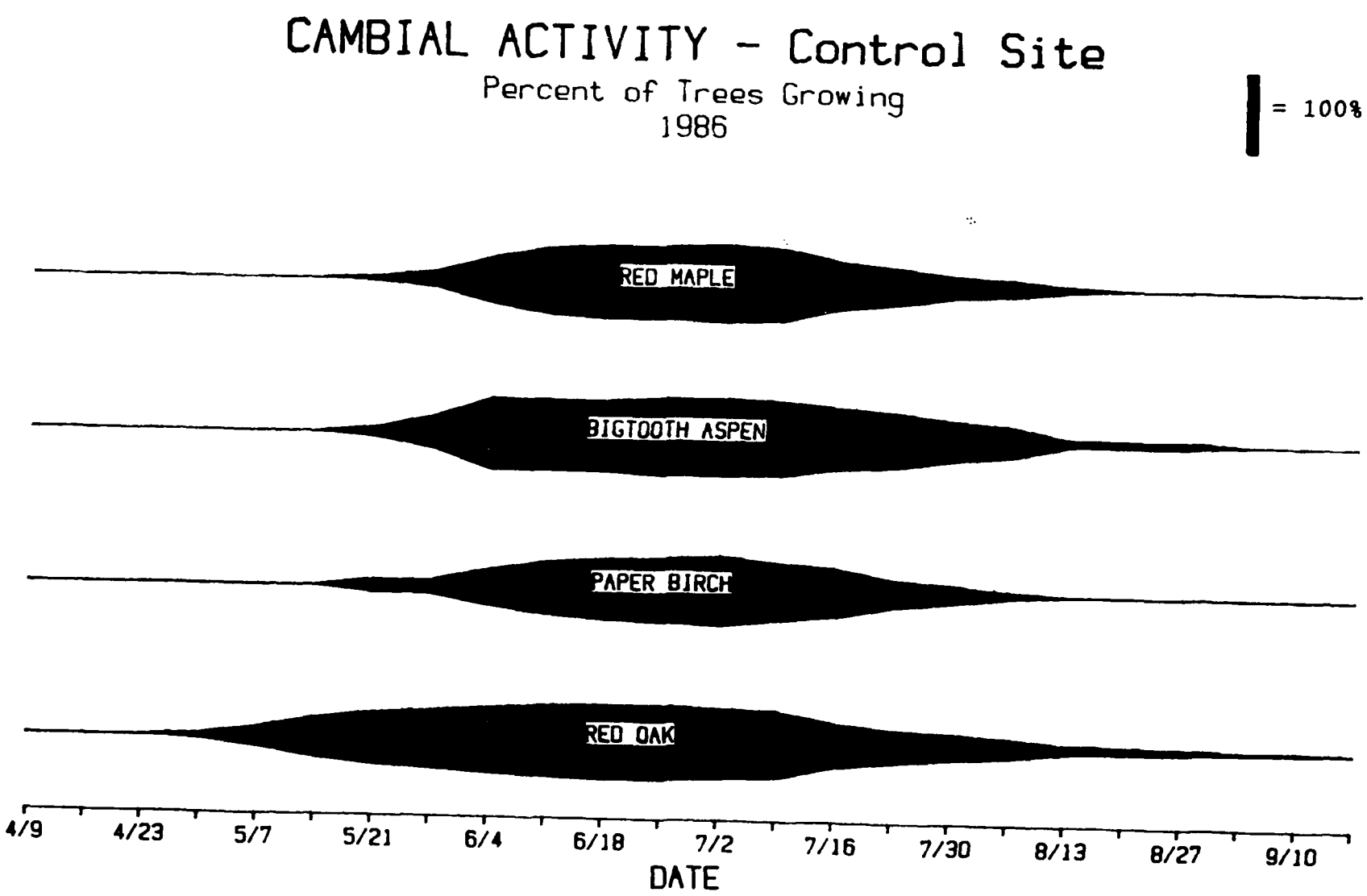


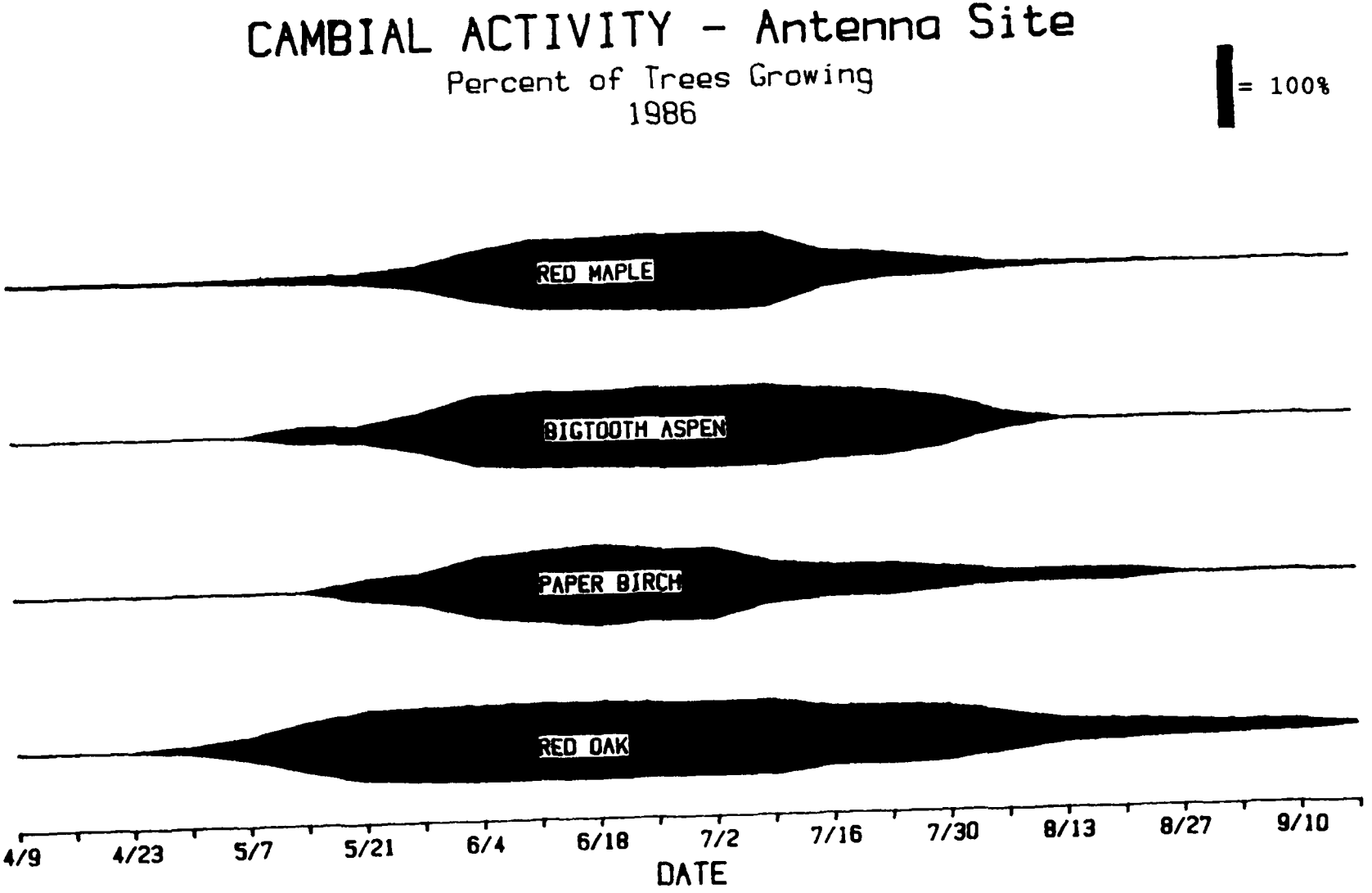
Appendix D

Cambial acivity - hardwood species


CAMBIAL ACTIVITY - Antenna Site
Percent of Growing Trees
1985
= 100%
RED MAPLE
BIGTOOTH ASPEN
PAPER BIRCH
RED OAK
5/8
5/22
6/5
6/19
7/3
7/17
7/31
8/14
8/28
9/11
9/25
10/10
Date


CAMBIAL ACTIVITY - Control Site
Percent of Trees Growing
1985
= 100%
RED MAPLE
BIGTOOTH ASPEN
PAPER BIRCH
RED OAK
5/8
5/22
6/5
6/19
7/3
7/17
7/31
8/14
8/28
9/11
9/25
10/10
DATE


CAMBIAL ACTIVITY - Control Site
Percent of Trees Growing
1986
= 100%
RED MAPLE
BIGTOOTH ASPEN
PAPER BIRCH
RED OAK
4/9
4/23
5/7
5/21
6/4
6/18
7/2
7/16
7/30
8/13
8/27
9/10
DATE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RED OAK
4/9
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5/21
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6/18
7/2
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8/27
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DATE

ELF COMMUNICATIONS SYSTEM ECOLOGICAL MONITORING PROGRAM: LITTER DECOMPOSITION AND MICROFLORA

The Michigan Study Site

ANNUAL REPORT, 1986

SUBCONTRACT NUMBER: E06549-84-C-002

MICHIGAN TECHNOLOGICAL UNIVERSITY
HOUGHTON, MICHIGAN

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SUBCONTRACT NUMBER: E06549-84-C-002

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HOUGHTON, MICHIGAN

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SUMMARY

Litter Decomposition and Nutrient Flux

Two full years of experience with red pine, northern red oak, and red maple foliar litter decomposition have been completed on all three study plots (including 2 pole-stand and 3 plantation subplots). An additional year of useful data for red pine was collected in 1983-84 at the antenna pole-stand subplot, and the samples for the third complete study have been installed in the field. The experimental 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 and 1984-85 studies are nearly complete, while bulk samples from the 1985-86 study await analysis.

Experiments conducted on the control plot as part of the 1984-85 and 1985-86 studies have demonstrated that there is no significant effect imposed on litter decomposition by our nylon mesh litter envelopes (3 mm openings). Experience to date also indicates that bulk and individual fascicle/leaf samples of pine and oak litter decompose at very similar rates. Maple was the only litter species which demonstrated different patterns of dry matter mass loss for bulk vs individual leaf dry matter mass loss.

The level of precision obtained in the 1985-86 study for bulk and individual fascicle/leaf samples of each litter species was expressed for convenience as the minimum shift in each sample mean which would be detected ($\alpha = .05$). Precision has been highest in the pole-stand subplots. Among the three study species, pine has provided the most precise information, while maple data are by far the least precise. For example, the largest minimum detectable difference between individual fascicle pine sample means for any combination of our treatments was 5 percent. Com-

parable figures for oak and maple are 7 percent and 89 percent, respectively. For most treatment combinations, much smaller differences were detectable. In the pole-stand subplots, maple sample mean differences of 28 percent or less were detectable. In an effort to explain the variability of maple leaf decomposition rate in the 1985-86 study, individual maple leaves were confined in separate portions of litter envelopes to prevent overlapping, and the relationship of mass loss to leaf surface area and mass per unit surface area was analyzed. Neither oak nor maple leaf decomposition rate was significantly correlated with either leaf surface area or leaf mass per unit surface area.

Dry matter mass loss data have been transformed to the arc sine square root of X (the proportion of original mass remaining) to homogenize variances prior to analysis of variance. Two-way ANOVA, for differences between years and sampling dates, detected that bulk samples of all three litter species decomposed faster in 1985 than in 1986 at each of the five study subplots. The difference between years was striking only for maple, and especially in the two pole-stands. In general, decomposition proceeded most rapidly in mid to late summer and early autumn. Two-way ANOVA, for differences between subplots and sampling dates during each study, detected a number of significant differences between subplots. Generally, bulk samples of all three species decomposed faster on the plantation subplots than in the pole-stand subplots during 1986. The same was true for maple and oak in 1985, while pine demonstrated no clear difference in pattern or level between plantations and pole-stands. Nevertheless, even though they were statistically significant, the differences between subplots for each of the three species were not striking. The differences detected by ANOVA in dry matter mass loss patterns between years, subplots, and sampling dates may well be explained as covariate analysis progresses in 1987.

Analysis of untransformed nutrient data indicated that there were no significant differences in the patterns or levels of pine litter nitrogen or calcium flux on the antenna pole-stand between 1984 and 1985. Nevertheless, higher levels of phospho-

rus, potassium, and magnesium were retained by pine litter during 1985 than during 1984. These differences may be related to the fact that pine litter decomposed slightly faster in 1985 than in 1984. Patterns of nutrient flux among subplots and sampling dates were also detected by ANOVA. Higher levels of potassium and magnesium were retained by pine litter samples in the pole-stand than in the plantation subplots. Higher levels of all nutrients were retained by oak litter samples in the pole-stand than in the plantation subplots. Higher levels of nitrogen, phosphorus, potassium and magnesium were retained by maple samples in the pole-stand than in the plantation subplots. Differences between the three litter species studied, in their patterns of both dry matter mass loss and nutrient flux for the five elements studied, strongly suggest that pine, oak, and maple decompose 1) according to different strategies, and 2) under the control of substantially different microbial populations. Therefore, the chance of detecting a modest environmental perturbation is increased by continued study of all three litter species rather than just one or two of them.

Our experimental design is clearly powerful enough to identify very subtle differences in the rates and patterns of bulk and individual fascicle/leaf decomposition, especially for pine and oak in the pole-stand subplots. Our efforts in 1987 are focusing on 1) collection of another year's data, and 2) use of covariate analysis to explain observed differences between years, sampling dates, and subplots. Correlation analysis has revealed strong relationships between dry matter mass loss from litter samples and running totals of mean daily air temperature, air and soil temperature degree days, precipitation, and frequency of days receiving at least .01 or .10 inches of precipitation. Though these variables are all time-dependent, they represent vital inputs of energy and water to the decomposition process. Correlation coefficients were higher for bulk samples and for decomposition in the pole-stands than in the plantation subplots. Among the litter species, correlation coefficients were highest for pine and lowest for maple. Correlation of monthly dry matter

mass loss progress with measures of temperature- and moisture-related variables for corresponding monthly periods was not as successful, emphasizing the importance of annual weather patterns on the buildup of microbial populations and their activities. These analyses indicate that cumulative measures of temperature- and moisture-related weather variables have strong potential to contribute to successful covariate analysis, along with between-plot parameters of soil texture and fertility.

Rhizoplane Streptomycetes

The emphasis of this work element during 1986 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 plantation subplots. In order to increase the statistical power of our experimental design, sample sizes were doubled to six per subplot on each of the six sampling dates. Pre-weighed washed mycorrhizal fine root subsamples were macerated, serially diluted, and spread-plated onto starch casein agar amended with cyclohexamide and nystatin. After 14 days incubation, counts of total streptomycete numbers as well as numbers of morphotypes present were made, and representatives of each morphotype were subcultured for further characterization. Plate count data were transformed to $\log_{10}$ prior to analysis of variance (ANOVA) for detection of differences between years, sampling dates, and plantations.

Based on 95 percent confidence intervals for individual sample means, estimates of minimum detectable differences in streptomycete levels are: between 13 and 50 percent (mean 25 percent) at the control plantation, between 11 and 20 percent (mean 17 percent) at the antenna plantation, and between 8 and 29 percent (mean 18 percent) at the ground plantation. Corresponding estimates for streptomycete morphotype numbers are: between 16 and 31 percent (mean 25 percent) at the control plantation, between 18 and 39 percent (mean 25 percent) at the antenna plantation, and between 14 and 36 percent (mean 19 percent) at the ground plantation. Actual minimum differences detectable over entire field seasons through ANOVA are smaller. There were no significant differences in either streptomycete levels or morphotype numbers between the control, antenna and ground plot plantations during the 1986 field season. There was, however, a significant seasonal pattern to both levels and morphotype numbers at each of the three plantations. Streptomycete levels during the early part of the growing season were significantly higher than October levels at all three plantations. A more gradual

decline in streptomycete morphotype numbers occurred at all three plantations as the field season progressed. However, thew early growing season numbers were also significantly higher than the October numbers.

There were no differences between 1985 and 1986 in the levels of streptomycetes detected at the antenna and ground plantations. Streptomycete levels during June at the control plantation were significantly higher in 1986, apparently due to a low observed sample value in 1985. The increased sample size instituted in 1986 will help to prevent this kind of difference from occurring in the future. Significantly larger numbers of streptomycete morphotypes were observed during August and/or September of 1986 at all three plantations. These differences in observed numbers of morphotypes between years may well be due to the increased sample size in 1986. As in 1985, the streptomycete morphotype designated "type B" was the most commonly isolated morphotype at all three plantations on all sampling dates. Four other morphotypes, designated C, F, O, and T, were also frequently detected at all three plantations throughout both the 1985 and 1986 field seasons. In addition, all morphotypes recovered during 1985 were again detected in 1986. These results indicate that similar, relatively stable streptomycete populations have become established on the red pine seedlings at all three ELF study plantations.

During 1987, this work element will focus on two objectives: 1) obtaining another year's data for streptomycete levels and morphotype numbers associated with red pine mycorrhiza morphotype 3, and 2) development of covariate analysis to help explain differences in streptomycete levels and morphotype numbers between years, sampling dates, and plantations. Covariates likely to prove useful include temperature- and moisture-related weather variables, soil pH, and soil fertility.

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 heterotrophic 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 Trees project and the Litter Decomposition and Microflora project. Work elements examining 1)rates of litter decomposition and associated nutrient flux and 2) mycorrhizoplane streptomycete population dynamics were initiated simultaneously with those of the Herbaceous Plant Cover and Trees project and on

the same study plots. The two work elements comprising this project complement and extend the baseline studies of the Herbaceous Plant Cover and 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 four 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 and associated nutrient flux 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.

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 levels of foliar litter nutrient (N, P, K, Ca, Mg) flux achieved, or the seasonal patterns by which they proceed, for each study species (northern red oak, red maple, or red pine), that cannot be explained using factors unaffected by ELF antenna operation.
III.	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.
IV.	There is no difference in the representation of different identifiable strains of mycorrhizosphere streptomycetes on the planted red pine seedlings that cannot be explained using factors unaffected by ELF antenna operation.

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 Herbaceous Plant Cover and Trees project, permitting us to take full advantage of both that project's basic experimental design and the extensive data collected by that project on the tree, stand and site factors which influence or regulate the processes and populations we are measuring (Table 2). The measurements made and the associated analyses are discussed more thoroughly in the following sections.

The experimental design integrates direct measures with site variables, and is 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 will be different at the antenna and ground locations (Anonymous, 1977). As a consequence, 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.

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*; climatic variables, soil nutrients, litter nutrients	1,(1),(6)[1]
II	1	Monthly determinations of nutrient (N, P, K, Ca, Mg) mass flux, for 1 year, from bulk foliar litter samples representing oak, maple, and pine; climatic variables, soil nutrients, dry matter loss	1,(1),(6)
III	2	Monthly counts of streptomycetes associated with mycorrhizae from planted red pine seedlings; climatic variables, soil nutrients, mycorrhiza density, seedling growth and moisture stress	1,(2),(4)
IV	2	Monthly determinations of numbers of streptomycete strains associated with Type 3 mycorrhizae from planted red pine seedlings; climatic variables, soil nutrients, mycorrhiza density, seedling growth and moisture stress	1,(2),(4)

[1] Numbers in parentheses refer to work elements in the Herbaceous Plant Cover and Trees project.

* Bold print designates the response variable; other lists are covariates.

The experimental design is a split plot in space and time. Each plot (control, antenna, and ground) is subjected to a certain level of ELF field exposure and is subdivided into two stand types (subplots). 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). Each stand type is divided into three contiguous replicates on each subplot (ELF field exposure) 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 plots 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 site follows this design with one exception. There is no pole-sized hardwood stand subplot at the ground plot because the necessary buffer strips would have resulted in the hardwood subplot stand being too distant from the grounded antenna for meaningful exposure. Thus one treatment factor (pole-sized stands) is eliminated at the ground plot. 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, the stand type treatment factor is irrelevant and falls out of the analysis. All other factors remain unchanged.

Analysis of Covariance

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 otherwise inflate the experimental error. 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 differences in response variables between years or plots.

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 variable; 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, and plant moisture stress. 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 most general and encompassing ANOVA table for the project is shown in Table 3.

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 Herbaceous Plant Cover and Tree Studies 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 3. Generalized analysis of variance table for the Litter Decomposition and Microflora project.

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	F-Ratio
Plot	2	SS_P	MS_P	$MS_P/MS_{E(S)}$
Site	2	SS_S	MS_S	$MS_S/MS_{E(S)}$
Covariates	# Covariates	SS_C	MS_C	$MS_C/MS_{E(S)}$
Error (S)	O_S[1]-4-#Covariates-1	$SS_{E(S)}$	$MS_{E(S)}$	
Stand Type	1	SS_T	MS_T	$MS_T/MS_{E(ST)}$
Site x Stand Type	2	SS_{ST}	MS_{ST}	$MS_{ST}/MS_{E(ST)}$
Covariates	# Covariates	SS_{CT}	MS_{CT}	$MS_{CT}/MS_{E(ST)}$
Error (ST)	O_T[2]-3-#Covariates-1	$SS_{E(ST)}$	$MS_{E(ST)}$	
Years	# Yrs-1	SS_Y	MS_Y	$MS_Y/MS_{E(SY)}$
Site x Years	(2)(#Yrs-1)	SS_{SY}	MS_{SY}	$MS_{SY}/MS_{E(SY)}$
Covariates	# Covariates	SS_{CY}	MS_{CY}	$MS_{CY}/MS_{E(SY)}$
Error (SY)	O_Y[3]-3(#Yrs-1)-#Covariates-1	$SS_{E(SY)}$	$MS_{E(SY)}$	
Stand Type x Year	(1)(#Yrs-1)	SS_{TY}	MS_{TY}	$MS_{TY}/MS_{E(TY)}$
Site x Stand Type x Year	(2)(1)(#Yrs-1)	SS_{STY}	MS_{STY}	$MS_{STY}/MS_{E(STY)}$
Covariates	# Covariates	SS_{CTY}	MS_{CTY}	$MS_{CTY}/MS_{E(STY)}$
Error (STY)	O_{TY}[4]-3(#yrs-1)-#Covariates-1	$SS_{E(STY)}$	$MS_{E(STY)}$	

[1] O_S = number of observations on all sites in a given year
[2] O_T = number of observations on a stand type in a given year
[3] O_Y = number of observations on all sites across all years
[4] O_{TY}= number of observations on all stand types across all years

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 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. Nutrient flux, on the other hand, provides continuously meaningful ecological information. We are also finding that mass loss characterization on the basis of individual leaves provides additional biologically meaningful 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 operating in the individual leaves comprising the bulk sample. These average rates are nevertheless essential for conversion of nutrient concentrations determined for bulk litter samples from per cent 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 sampling dates, subplots and years.

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 greatly 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 pole-stand subplots. 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.

Since the 1985 Annual Report was written, a second year's experience with red pine, northern red oak, and red maple foliar litter decomposition and nutrient flux has been gained on the antenna, ground, and control plots. The 1985-86 study represented the third year of experience with red pine on the antenna and ground plots. Experience to date supports the contention that mass loss and nutrient flux over time from freshly fallen foliar litter can be characterized with sufficient precision to detect subtle environmental perturbations.

Methods

Litter decompoeition is being quantified as percent change over time in dry matter and nutrient (N, P, K, Ca, and Mg) masses. Analysis of litter nutrient content is being conducted by the Soils Analysis Laboratory, School of Forestry and Wood Products, Michigan Technological University. Experiments are conducted annually and focus on the first year following each year's litter-fall.

A single parent litter collection, from a single location, is made for each study species in order to avoid the effects of 1) differences which might be present in substrate quality between different litter sources, and 2) differences between years in substrate quality among litter sources which might develop as a result of ELF field effects. Accommodation of the potential for either type of effect would unnecessarily complicate the experimental design and would greatly increase the number of samples required in order to maintain the power of statistical tests. We feel that the additional expense attached to expanding the experimental design to include separate litter collections from each site is not warranted at this time. Should changes in northern red oak foliar nutrient concentrations be identified and attributed to ELF fields (Herbaceous Plant Cover and Tree Studies, Annual Report 1986, Element 7. Litter Production, pages 166-173), we will reconsider our experimental design to evaluate the effect of site specific differences in foliar litter quality on litter decomposition.

Ratios of fresh to dry mass and initial nutrient content are determined for 15 random samples taken at regular intervals during field sample preparation from each of the pine, oak, and maple litter parent collections. All mass loss data (dry matter as well as nutrient masses) are based on 30°C dry masses. Preweighed samples are enclosed in nylon mesh envelopes (3 mm openings), disbursed in the field during early December, and retrieved monthly from early May to early December. All envelopes are constructed to lay flat on the ground. Snow cover at the study sites dictates early May to be the earliest possible recovery date, as samples are frozen to the ground until snowmelt is complete.

Raw data are expressed as the proportion (X) of original dry matter or nutrient mass remaining over time. Dry matter mass loss is being studied by an individual fascicle/leaf method as well as via bulk litter samples, while nutrient flux is determined solely for the bulk litter samples. Individual fascicles/leaves offer the opportunity to study decomposition of basic

foliage units. Each tethered fascicle or leaf is perfectly intact at the time of dispersal. The influence of fragmentation on individual pine fascicle decomposition is especially easy to eliminate by discarding, prior to analysis, any fascicles broken during the course of an experiment. Finally, in order to determine the influence of our envelopes on decomposition rates, tethered, unbagged individual pine fascicles and oak leaves were also placed in the field on each of the control plantation and pole-stand subplot replicates as part of the 1984-85 and 1985-86 studies.

1985-86 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 relative remoteness from interfering 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 similarly collected along the northeast edge of the control plantation subplot replicate 3.

Random subsamples from the parent litter collections were placed in replicate nylon mesh envelopes (3 mm openings). 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. Tethered pine fascicle envelopes measured 22 cm x 14 cm, while individual maple and individual oak leaf envelopes measured 22 cm x 28 cm. Each tethered pine fascicle and oak leaf envelope contained 10 entire preweighed fascicles/leaves tethered along an approximately 30 cm long section of 6 lb test nylon monofilament line. Individual maple leaf envelopes were sewn into quarters, each containing one entire, preweighed maple leaf. Experience from the 1984-85 study demonstrated that separation of individual maple leaves is necessary in order to be able to distinguish among the sample leaves upon

retrieval. Tethered, unbagged samples of pine and oak were constructed in the same manner as bagged samples, and were simply staked to the ground at both ends of their nylon tether.

The following outline describes the field disbursal and recovery of bulk litter and individual fascicle/leaf envelopes of each study species.

A. On each of the three subplot replicates at each of the three plantations:
   1. Ten bulk litter envelopes of each species were placed together at each of two locations.
      a. One of these envelopes per species was retrieved from each location on each sampling date.
   2. Ten individual fascicle/leaf envelopes of each species were placed together at one of the locations mentioned above.
      a. One of these envelopes per species was retrieved on each sampling date.

B. On each of the three subplot replicates in each of the two pole-stands:
   1. Four bulk litter envelopes of each species were placed placed together at each of five locations.
      a. One of these envelopes per species was retrieved on each sampling date from each of two locations.
   2. Two individual fascicle/leaf envelopes of each species were placed together at each of the five locations mentioned above.
      a. One of these envelopes per species was retrieved on each sampling date from one of these locations.

Each month, from early May through early December, 1986, two bulk sample envelopes and one tethered foliage envelope for each species were retrieved from each of the 15 subplot replicates (3 each in the ground, antenna and control plantation subplots, and in the antenna and control pole-stand subplots). Also, one set each of tethered, unbagged pine fascicles and oak leaves was retrieved from each control plantation and pole-stand

subplot replicate. As a result, decomposition estimates for each subplot on each sampling date are based on 6 bulk samples for each species, and as many as 30 pine fascicles (depending on fragmentation), 30 oak leaves, and 12 maple leaves.

Moisture content was again determined for most samples at the time of retrieval, in order to further compare the bulk litter and tethered fascicle methods of quantifying decomposition. In the field, each retrieved sample was placed in an air-tight plastic freezer-storage bag from which as much air as possible was then removed. When tethered samples were judged too fragile to survive air withdrawal without fragmenting, moisture content was not determined. This generally occurred only on the plantation subplots during dry weather and later in the year. In the laboratory, fresh "wet" masses were recorded prior to drying to a constant mass at 30°C. Moisture content in the field at the time of retrieval was then calculated as wet mass minus dry mass divided by dry mass. Differences in moisture content between bulk samples and individual fascicle/leaf samples will be evaluated as time permits.

Weather data collected by the Herbaceous Plant Cover and Trees project have proved useful in helping to explain decomposition progress through the year at the study plots. This data will be very helpful in explaining differences in decomposition rates between years as well. Pearson's product moment correlation analyses are being used in two ways to explore the relationships between dry matter mass loss and nutrient flux for each litter species and various temperature- and moisture-related weather variables.

1. First, decomposition progress over total elapsed time since sample disbursal to the field was correlated with running totals of mean daily temperature (°C) and air temperature degree days (4.4°C basis), soil temperature degree days (4.4°C basis, 5 cm below the soil surface), total precipitation, and the number of days with precipitation events delivering at least .01 or .10 inches of water.

2. Second, monthly progress in decomposition was correlated with weather variables reflecting three time periods:
   a. the month corresponding to that for decomposition progress,
   b. the month previous to that corresponding to decomposition progress, and
   c. both months combined.

   The weather variables analyzed were mean daily air and soil temperatures, accumulated air and soil temperature degree days, soil moisture (5 cm below the soil surface), total precipitation, and the number of precipitation events delivering at least .01 or .10 inches of water. A similar analysis for the 1985 field season will be conducted.

Sufficient samples were recovered each month to permit both 1) analysis of differences in dry matter and nutrient masses between species, dates, subplots and years by analysis of variance, with multiple range comparisons made via Tukey's Honestly Significant Difference (H.S.D., or w) procedure (Dowdy and Wearden 1983, Steel and Torrie 1980), and 2) analysis of single exponential model rate constants (k) derived by fitting the year's dry matter mass loss data for each species on each subplot to an equation of the form $Y = e^{-kt}$ (Wieder and Lang 1982). In the past, we have derived single exponential models using the program BMDPAR, designed for derivative-free nonlinear regression. Rate constants were compared statistically by calculation of confidence intervals based on asymptotic standard deviations. We are currently testing the log transformation of the single exponential model ($\ln Y = -kt$) as a desirable alternative model form. Models of this form tend to homogenize variances and are more easily expanded to incorporate covariates.

Dry matter mass loss data are transformed to the arc sine square root of X to homogenize variances prior to correlation analysis and analysis of variance (Steel and Torrie 1980). The arc sine square root of X is recommended for use with data expressed as decimal proportions less than 1.00, especially when proportions within a data set vary widely. We will compare the

log transformation with the arc sine square root of X for applicability to ANOVA on dry matter mass loss data sets. The effects of transforming mass flux data for the five nutrient elements studied are being evaluated. The log transformation is most likely to apply to the nitrogen, phosphorus, and calcium data sets, where values exceeding 100 percent are not uncommon. In all statistical analyses performed, acceptance or rejection of the null hypothesis is based on $\alpha = .05$, regardless of the statistical test employed. Differences which are significant with $P \leq .05$ are presented along with the attained significance level (P) of the test statistic, as provided by the software used.

Sufficient decomposition and weather data are now available for a substantial modeling effort. In addition, the soils at each subplot replicate have been characterized in detail by the Herbaceous Plant Cover and Trees project (Annual Report 1985). Weather and soil variables will be evaluated as covariates in 1987, for the purpose of further improving statistical power.

1986-87 Study

Fresh-fallen red pine, northern red oak, and red maple foliar litter was collected again in 1986 as described for the 1985-86 study. The same experimental design established for the 1984-85 and 1985-86 studies is being followed for bulk litter samples in the 1986-87 study. The experimental design for individual foliage units has been improved. In the past, one envelope per month per species (containing multiple tethered leaves) has been recovered from each subplot replicate. Beginning with the 1986-87 study, individual leaf envelopes each contain one pine fascicle, one oak leaf, and one 7 cm diameter disk of Whatman No. 1 filter paper. As a result, instead of collecting 3 individual leaf envelopes (one per species) from one location per subplot replicate each month, we will collect 8 envelopes (each representing pine, oak, and filter paper). Three advantages to this modified method were forseen:

1. Foliage samples of each species are more clearly independent of one another.

2. Recovery of individual leaf envelopes from 24 locations per subplot each month instead of 3 will better represent site variability on each subplot.

3. Filter paper disks might prove useful as a litter species due to their high degree of initial homogeneity, a view shared by Dr. Forest Stearns at the 1986 Technical Symposium. While the quality of pine foliar litter appears to be quite consistent from year to year, the quality of oak and maple litter parent collections varies slightly with annual differences in insect defoliator activity, etc.

In fact, as we write the final draft of this report, the validity of the first two points seems assured. However, filter paper disks do not appear (at present) to be providing any improvement over individual maple leaves as a litter species. The filter paper disk samples appear to be weathering irregularly in the field, and seem likely to provide highly variable data by the close of the 1987 field season. The Wetlands Studies project (UW-Milwaukee) has apparently also found cellulose samples unsatisfactory for study of litter decomposition. The relative value of individual maple leaves and filter paper disks as litter species will be carefully evaluated in planning for the 1987-88 study.

We do not expect that this adjustment in method will prevent comparison of individual leaf data collected in different years by the two methods. Regardless, the ability to compare antenna and ground subplots with the control subplots will be enhanced by the improvement in experimental design. It should be emphasized that the experimental design regarding bulk litter envelopes remains unaltered.

Description of Progress

1985-86 Study

Tables 4 through 10 present mean dry matter mass losses for all samples retrieved in 1986 (by sampling date and subplot), along with standard deviations and "minimum detectable differences" calculated from confidence intervals associated with the sample means. Tables 4 and 5 present the data from all five study subplots for bulk and tethered bagged pine samples, respectively; Tables 6 and 7 present corresponding data for oak, and Table 8 presents data from the control plot for tethered unbagged pine and oak samples. Tables 9 and 10 represent the bulk and individual leaf maple samples, respectively. Overall, the data show that the following shifts in bulk sample means should be detectable ($\alpha = .05$).

A. Pine
   1. Plantation Subplots - 7% (5% or less for 19 of the 21 means estimated)
   2. Pole-stand Subplots - 3%
B. Oak
   1. Plantation Subplots - 21% (6% or less through September)
   2. Pole-stand Subplots - 9% (5% or less through October)
C. Maple
   1. Plantation Subplots - 55% (less than 10% through August)
   2. Pole-stand Subplots - 7% (5% or less for 15 of the 16 means estimated)

Further, the following shifts in individual fascicle/leaf sample means should be detectable.

A. Pine
   1. Plantation Subplots - 3%
   2. Pole-stand Subplots - 3%

Table 4. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1986, for bulk red pine foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Plot					
	Plantation			Pole-stand		
	Mean	S.D.[b]	%[c]	Mean	S.D.	%
7 May	0.92	0.01	1	0.94	0.01	1
3 June	0.90	0.02	2	0.91	0.02	2
1 July	0.89	0.02	2	0.91	0.01	1
30 July	0.86	0.01	1	0.86	0.01	1
3 September	0.81	0.02	2	0.79	0.02	2
1 October	0.76	0.05	7	0.75	0.02	3
6 November	0.74	0.02	3	0.72	0.01	2
6 December				0.71	0.01	1

Table 4. (cont)

Sampling Date	Control Plot					
	Plantation			Pole-stand		
	Mean	S.D	%	Mean	S.D	%
7 May	0.90	0.01	1	0.93	0.01	1
3 June	0.87	0.05	6	0.92	0.02	2
1 July	0.87	0.02	3	0.89	0.02	2
30 July	0.84	0.02	2	0.85	0.01	1
3 September	0.78	0.02	3	0.79	0.01	2
1 October	0.76	0.03	4	0.75	0.01	1
6 November	0.70	0.03	5	0.72	0.01	2
6 December				0.73	0.02	3

Table 4. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
7 May	0.91	0.02	2
3 June	0.87	0.03	4
1 July	0.88	0.04	5
30 July	0.84	0.03	4
3 September	0.81	0.01	2
1 October	0.72	0.02	3
6 November	0.71	0.01	1
6 December			

a/ Proportion ($X = 1/M_0$), 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 $t_{0.05,3} * S.E./Mean$, and expressed as a percentage of the sample mean.

Table 5. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1986, for tethered red pine foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Plot					
	Plantation			Pole-stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
7 May	0.91	0.03	1	0.92	0.02	1
3 June	0.92	0.02	1	0.93	0.02	1
1 July	0.88	0.03	1	0.91	0.03	1
30 July	0.87	0.05	2	0.89	0.02	1
3 September	0.80	0.05	2	0.80	0.03	1
1 October	0.76	0.03	2	0.77	0.04	2
6 November	0.72	0.03	2	0.76	0.03	2
6 December				0.71	0.03	2

Table 5. (cont)

Sampling Date	Control Plot					
	Plantation			Pole-stand		
	Mean	S.D	%	Mean	S.D	%
7 May	0.92	0.02	1	0.91	0.02	1
3 June	0.90	0.03	1	0.93	0.02	1
1 July	0.88	0.02	1	0.91	0.02	1
30 July	0.86	0.02	1	0.88	0.04	2
3 September	0.79	0.02	1	0.81	0.03	1
1 October	0.77	0.04	3	0.78	0.03	2
6 November	0.73	0.04	2	0.71	0.04	2
6 December				0.74	0.03	3

Table 5. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
7 May	0.91	0.02	1
3 June	0.91	0.02	1
1 July	0.86	0.03	1
30 July	0.84	0.02	1
3 September	0.75	0.03	2
1 October	0.73	0.03	2
6 November	0.72	0.04	2
6 December			

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 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.

b/ standard deviation

c/ detectable difference: the estimated shift in each mean value 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 ($n = 30$, or less depending on fragmentation)

Table 6. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1986, for bulk northern red oak foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Plot					
	Plantation			Pole-stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
7 May	0.93	0.02	2	0.94	0.02	2
3 June	0.93	0.01	1	0.95	0.01	1
1 July	0.90	0.01	2	0.94	0.01	1
30 July	0.87	0.01	1	0.91	0.02	2
3 September	0.80	0.01	2	0.87	0.02	2
1 October	0.73	0.02	4	0.81	0.02	3
6 November	0.69	0.06	10	0.74	0.04	5
6 December				0.69	0.07	9

Table 6. (cont)

Sampling Date	Control Plot					
	Plantation			Pole-stand		
	Mean	S.D	%	Mean	S.D	%
7 May	0.94	0.01	1	0.94	0.01	1
3 June	0.92	0.01	1	0.95	0.01	1
1 July	0.90	0.01	1	0.93	0.01	1
30 July	0.87	0.02	2	0.91	0.01	2
3 September	0.83	0.02	3	0.85	0.02	3
1 October	0.76	0.04	6	0.78	0.01	1
6 November	0.68	0.08	12	0.72	0.01	2
6 December				0.73	0.01	1

Table 6. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
7 May	0.93	0.01	1
3 June	0.93	0.02	2
1 July	0.90	0.01	2
30 July	0.86	0.02	2
3 September	0.81	0.02	2
1 October	0.74	0.03	5
6 November	0.62	0.14	21
6 December			

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: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,5} * S.E./Mean$, and expressed as a percentage of the sample mean

Table 7. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1986, for tethered northern red oak foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Plot					
	Plantation			Pole-stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
7 May	0.94	0.02	1	0.94	0.03	1
3 June	0.90	0.07	3	0.94	0.03	1
1 July	0.91	0.06	2	0.94	0.03	1
30 July	0.85	0.10	4	0.90	0.05	2
3 September	0.74	0.09	5	0.82	0.05	2
1 October	0.73	0.11	6	0.79	0.06	3
6 November	0.66	0.13	7	0.70	0.09	5
6 December				0.72	0.06	3

Table 7. (cont)

Sampling Date	Control Plot					
	Plantation			Pole-stand		
	Mean	S.D	%	Mean	S.D	%
7 May	0.94	0.02	1	0.95	0.02	1
3 June	0.91	0.03	1	0.94	0.03	1
1 July	0.88	0.06	3	0.92	0.05	2
30 July	0.85	0.08	3	0.91	0.05	2
3 September	0.78	0.11	5	0.81	0.05	3
1 October	0.74	0.09	5	0.75	0.08	4
6 November	0.69	0.11	6	0.66	0.09	5
6 December				0.69	0.07	4

Table 7. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
7 May	0.94	0.02	1
3 June	0.93	0.03	1
1 July	0.90	0.04	2
30 July	0.84	0.09	4
3 September	0.74	0.10	5
1 October	0.71	0.12	7
6 November	0.69	0.08	4
6 December			

a/ Proportion ($X = 1/M_0$), where M_0 and M_t 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.

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 $t_{.05,\infty} * S.E./Mean$, and expressed as a percentage of the sample mean

Table 8. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1986, for tethered unbagged northern red oak and tethered unbagged red pine foliar litter samples disbursed at the control plot in early December, 1985.

	Northern Red Oak					
	Plantation			Pole-stand		
Sampling Date	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
7 May	0.92	0.02	1	0.94	0.03	2
3 June	0.92	0.02	2	0.96	0.02	1
1 July	0.88	0.03	2	0.91	0.02	1
30 July	0.83	0.07	5	0.89	0.05	3
3 September	0.68	0.11	9	0.84	0.04	3
1 October	0.69	0.07	6	0.74	0.05	4
6 November	0.65	0.13	11	0.61	0.07	6
6 December				0.52	0.14	34

Table 8. (cont)

	Red Pine					
	Plantation			Pole-stand		
Sampling Date	Mean	S.D	%	Mean	S.D	%
7 May	0.92	0.01	2	0.92	0.03	2
3 June	0.90	0.03	3	0.93	0.02	1
1 July	0.88	0.03	2	0.88	0.04	3
30 July	0.86	0.03	3	0.85	0.04	2
3 September	0.81	0.04	4	0.80	0.05	4
1 October	0.78	0.03	3	0.74	0.09	7
6 November	0.75	0.03	2	0.72	0.05	4
6 December				0.67	0.02	8

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 masses 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.

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 $t_{.05,n} * S.E./Mean$, and expressed as a percentage of the sample mean (n = 30, or less depending on fragmentation)

Table 9. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1986, for bulk red maple foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Plot: Plantation Mean[a]	S.D.[b]	%[c]	Antenna Plot: Pole-stand Mean	S.D.	%
7 May	0.82	0.03	3	0.86	0.01	1
3 June	0.82	0.02	2	0.85	0.02	2
1 July	0.75	0.03	4	0.84	0.03	4
30 July	0.68	0.02	3	0.78	0.03	4
3 September	0.62	0.05	8	0.76	0.03	5
1 October	0.52	0.03	6	0.71	0.04	7
6 November	0.44	0.10	23	0.63	0.03	5
6 December				0.64	0.04	5

Table 9. (cont)

Sampling Date	Control Plot: Plantation Mean	S.D	%	Control Plot: Pole-stand Mean	S.D	%
7 May	0.82	0.02	2	0.84	0.02	3
3 June	0.81	0.02	3	0.85	0.01	1
1 July	0.76	0.02	3	0.82	0.03	3
30 July	0.69	0.02	3	0.77	0.03	4
3 September	0.68	0.05	8	0.75	0.02	2
1 October	0.59	0.13	26	0.69	0.03	5
6 November	0.57	0.06	12	0.63	0.03	4
6 December				0.64	0.02	3

Table 9. (cont)

Sampling Date	Ground Plot: Plantation Mean	S.D.	%
7 May	0.80	0.03	4
3 June	0.80	0.03	4
1 July	0.76	0.02	2
30 July	0.70	0.04	5
3 September	0.61	0.04	8
1 October	0.54	0.06	11
6 November	0.36	0.19	55
6 December			

a/ Proportion ($X = 1/M_0$), 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 $t_{.05,5} * S.E./Mean$, and expressed as a percentage of the sample mean

Table 10. Mean proportion[a] of initial dry matter mass (30°C) remaining at different times in 1986, for tethered red maple foliar litter samples disbursed in early December, 1985.

Sampling Date	Antenna Plot: Plantation Mean[a]	S.D.[b]	%[c]	Antenna Plot: Pole-stand Mean	S.D.	%
7 May	0.78	0.05	4	0.83	0.06	5
3 June	0.72	0.09	8	0.81	0.07	5
1 July	0.63	0.10	10	0.82	0.07	6
30 July	0.47	0.13	17	0.70	0.06	6
3 September	0.41	0.13	24	0.71	0.06	6
1 October	0.33	0.15	39	0.62	0.09	9
6 November	0.30	0.12	29	0.45	0.20	28
6 December				0.60	0.07	10

Table 10. (cont)

Sampling Date	Control Plot: Plantation Mean	S.D	%	Control Plot: Pole-stand Mean	S.D	%
7 May	0.77	0.06	5	0.79	0.06	5
3 June	0.74	0.09	8	0.80	0.06	4
1 July	0.61	0.10	10	0.76	0.04	3
30 July	0.55	0.10	12	0.73	0.07	6
3 September	0.57	0.11	12	0.69	0.08	7
1 October	0.39	0.16	25	0.64	0.09	9
6 November	0.28	0.08	46	0.54	0.11	12
6 December				0.62	0.09	9

Table 10. (cont)

Sampling Date	Ground Plot: Plantation Mean	S.D.	%
7 May	0.78	0.07	5
3 June	0.74	0.06	6
1 July	0.55	0.09	11
30 July	0.46	0.09	13
3 September	0.40	0.17	39
1 October	0.26	0.14	89
6 November	0.53	0.10	48
6 December			

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.

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 $t_{.05,11} * S.E./Mean$, and expressed as a percentage of the sample mean

B. Oak
   1. Plantation Subplots - 7% (5% or less through August)
   2. Pole-stand Subplots - 5% (3% or less for 12 of the 16 means estimated)

C. Maple
   1. Plantation Subplots - 89% (17% or less through July)
   2. Pole-stand Subplots - 28% (less than 10% through September)

The individual bagged pine fascicle and oak leaf samples provided smaller minimum detectable difference estimates than did bulk pine and oak samples. This was due to the greater sample size associated with individual pine fascicles and oak leaves, and in spite of slightly larger variances for the individual fascicles/leaves. The opposite was the case with maple, however, due to greater sample variances and the smaller sample size for individual maple leaves than for tethered pine fascicles and oak leaves. Both bulk and individual fascicle/leaf samples for all three litter species provided smaller detectable differences in the pole-stand subplots than in the plantation subplots. Detectable differences in the plantations often increased markedly in September and/or October, in contrast to the stabler level of precision obtained with the pole-stand subplots.

Bulk envelope dry matter mass loss sample means (with corresponding confidence intervals) are presented graphically in Figures 1 through 5 for all three species on each sampling date at each of the five study subplots. Figures 6 through 10 present analogous data for the bagged individual fascicle/leaf samples representing all three species at all five subplots, and Figures 11 and 12 present the unbagged tethered fascicle/leaf data for pine and oak at the two control subplots.

Comparisons between dry matter mass loss sample means (with corresponding confidence intervals) for bulk as well as bagged and unbagged tethered pine fascicle samples are presented graphically for the 1984-85 and 1985-86 studies at the control plantation and pole-stand subplots in Figures 13 through 16. There is little or no evidence to suggest either 1) that our envelopes

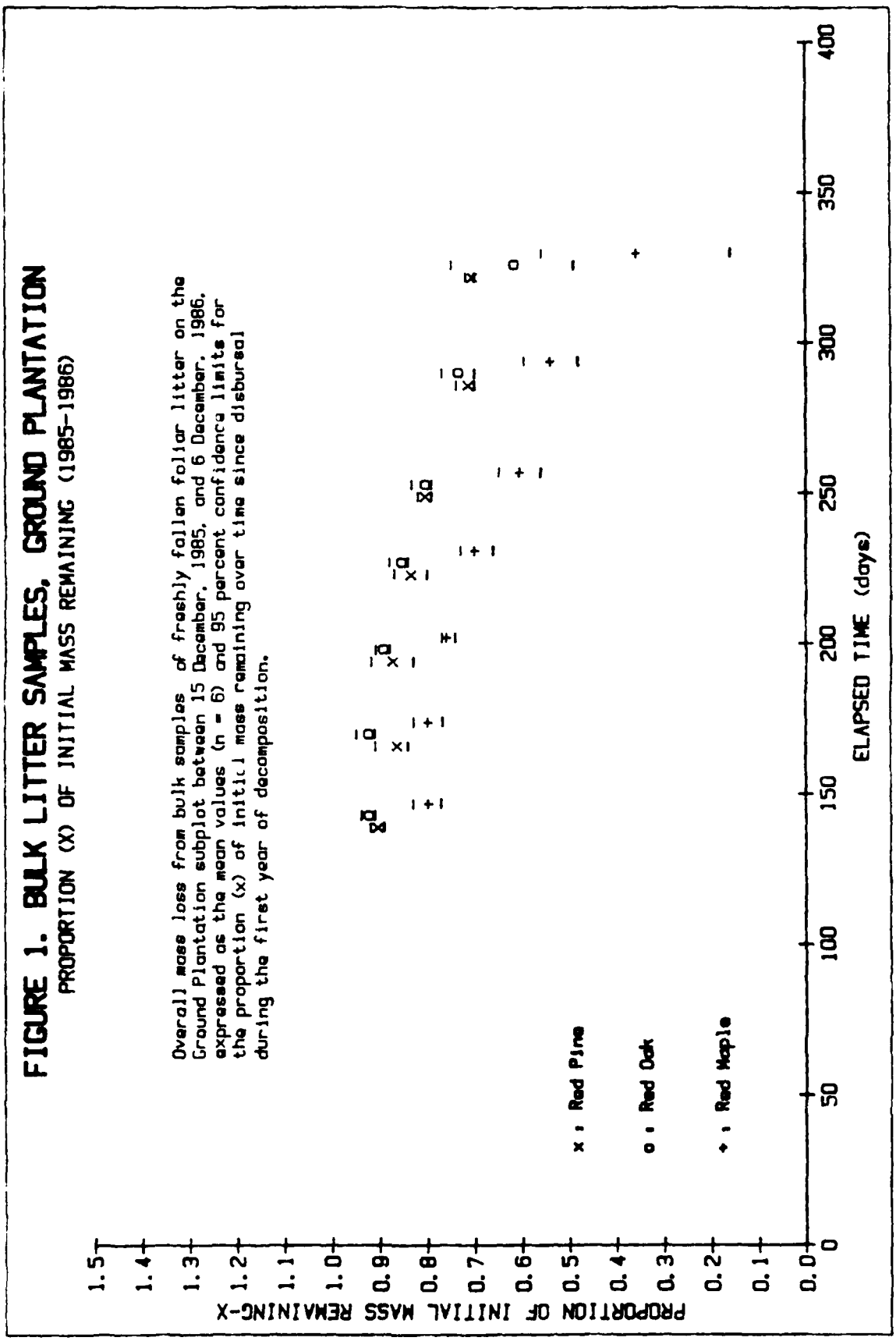


FIGURE 1. BULK LITTER SAMPLES, GROUND PLANTATION
PROPORTION (X) OF INITIAL MASS REMAINING (1985-1986)
Overall mass loss from bulk samples of freshly fallen foliar litter on the Ground Plantation subplot between 15 December, 1985, and 6 December, 1986, expressed as the mean values (n = 6) and 95 percent confidence limits for the proportion (x) of initial mass remaining over time since disbursal during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
x : Red Pine
o : Red Oak
+ : Red Maple

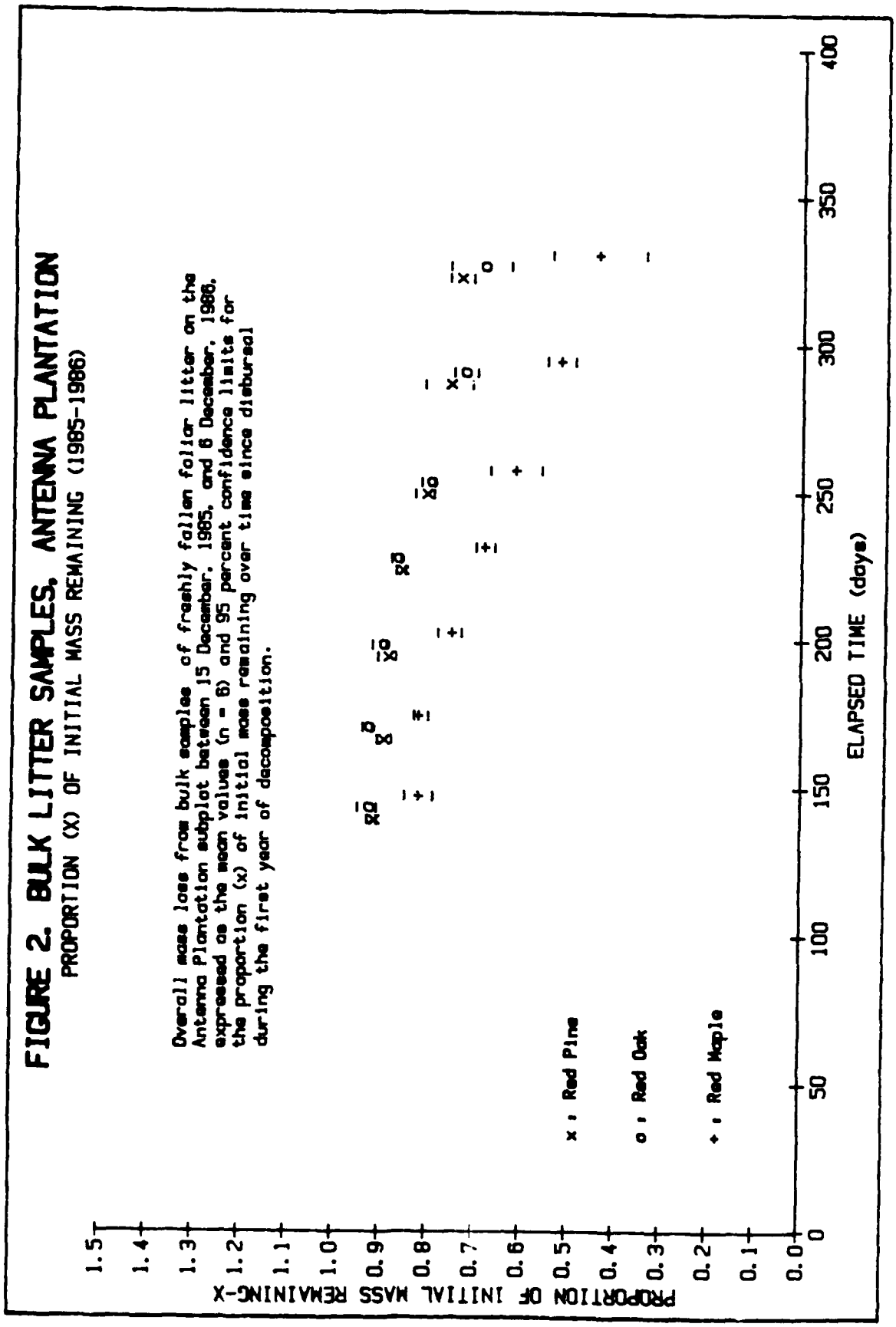
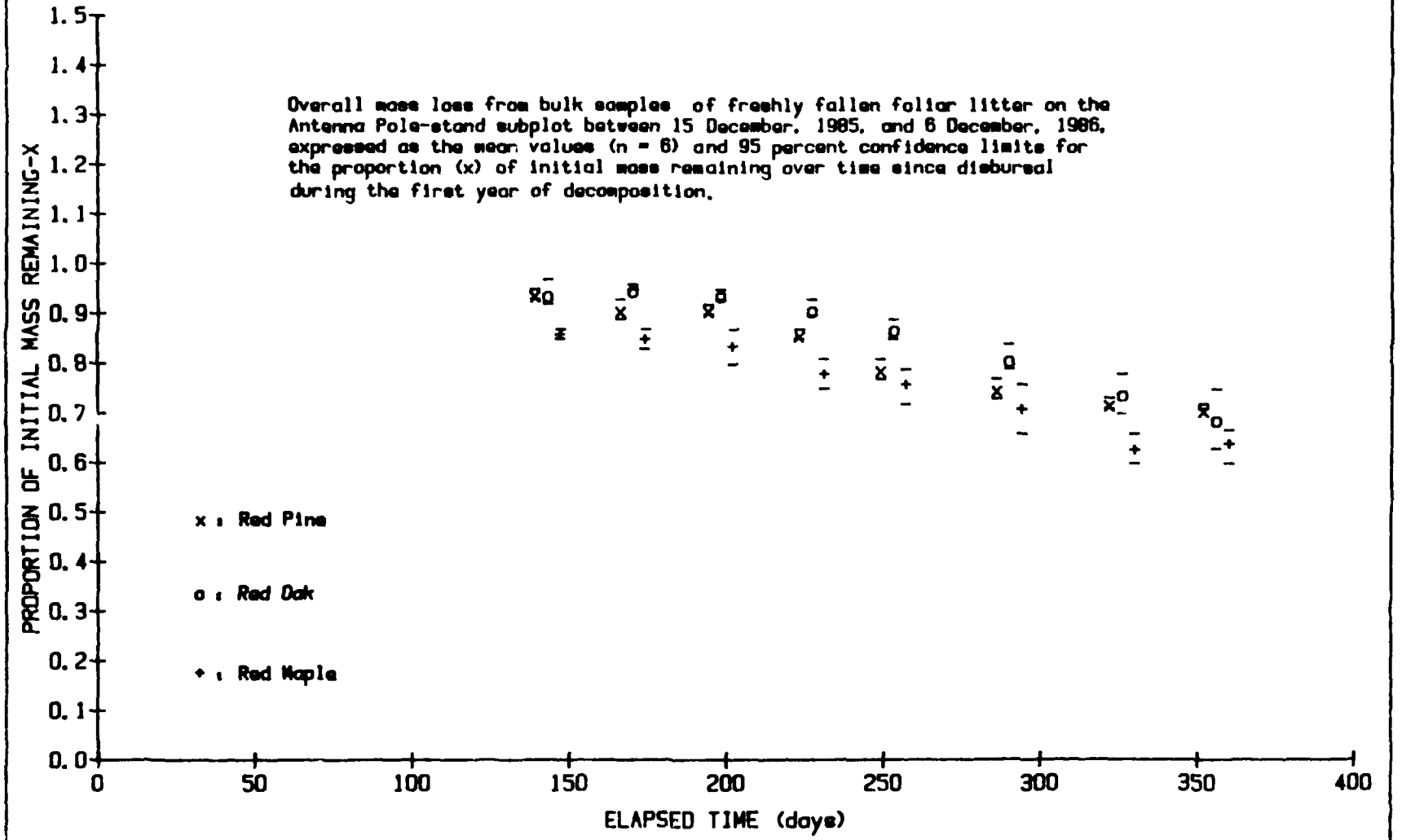


FIGURE 2. BULK LITTER SAMPLES, ANTENNA PLANTATION
PROPORTION (X) OF INITIAL MASS REMAINING (1985-1986)
Overall mass loss from bulk samples of freshly fallen foliar litter on the Antenna Plantation subplot between 15 December, 1985, and 6 December, 1986, expressed as the mean values (n = 8) and 95 percent confidence limits for the proportion (x) of initial mass remaining over time since disbursal during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
x : Red Pine
o : Red Oak
+ : Red Maple

FIGURE 3. BULK LITTER SAMPLES, ANTENNA POLE-STAND

PROPORTION (X) OF INITIAL MASS REMAINING (1985-1986)



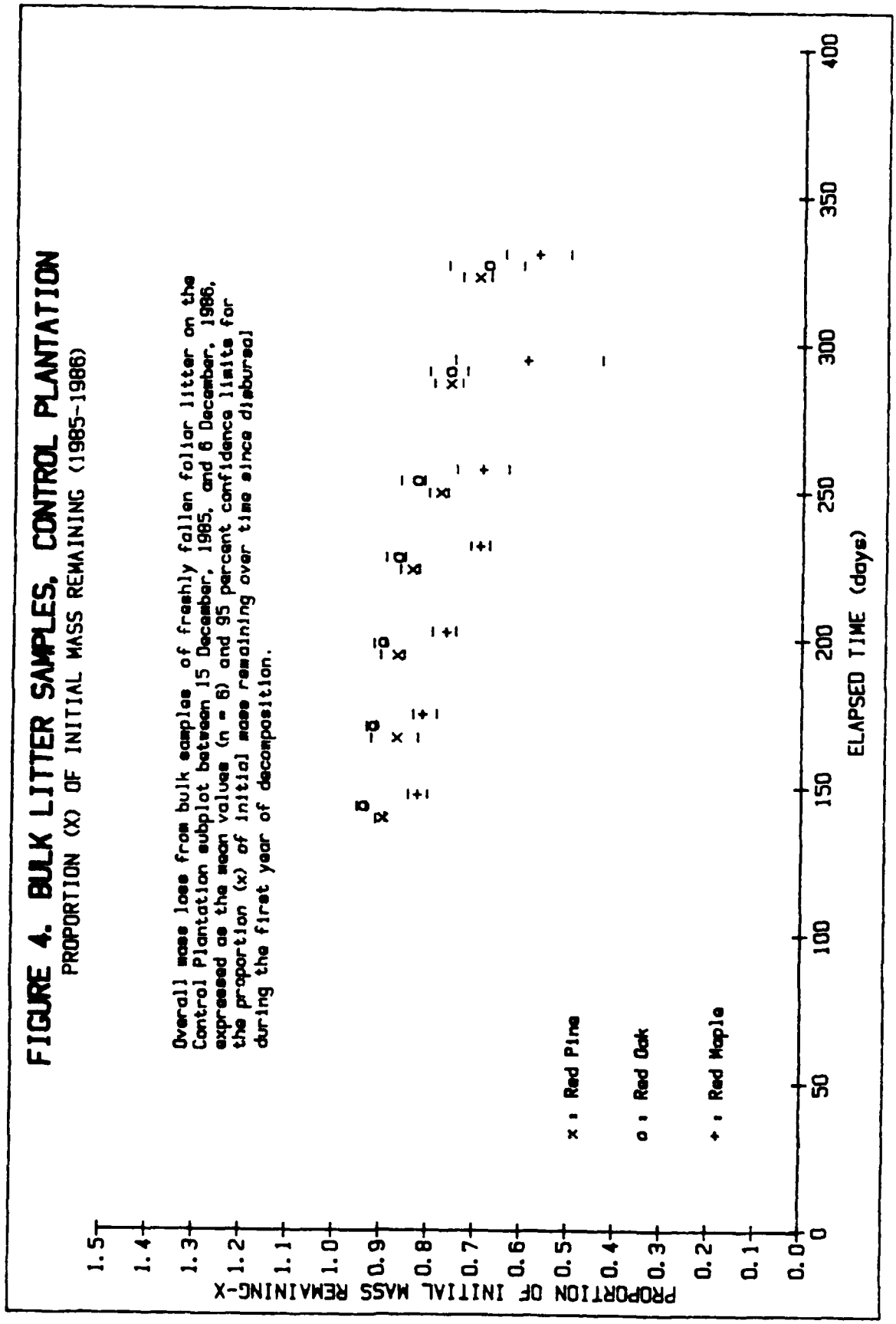


FIGURE 4. BULK LITTER SAMPLES, CONTROL PLANTATION
PROPORTION (X) OF INITIAL MASS REMAINING (1985-1986)
Overall mass loss from bulk samples of freshly fallen foliar litter on the Control Plantation subplot between 15 December, 1985, and 6 December, 1986, expressed as the mean values (n = 6) and 95 percent confidence limits for the proportion (x) of initial mass remaining over time since disbursal during the first year of decomposition.
x : Red Pine
o : Red Oak
+ : Red Maple
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
0
50
100
150
200
250
300
350
400

FIGURE 5. BULK LITTER SAMPLES, CONTROL POLE-STAND

PROPORTION (X) OF INITIAL MASS REMAINING (1985-1986)

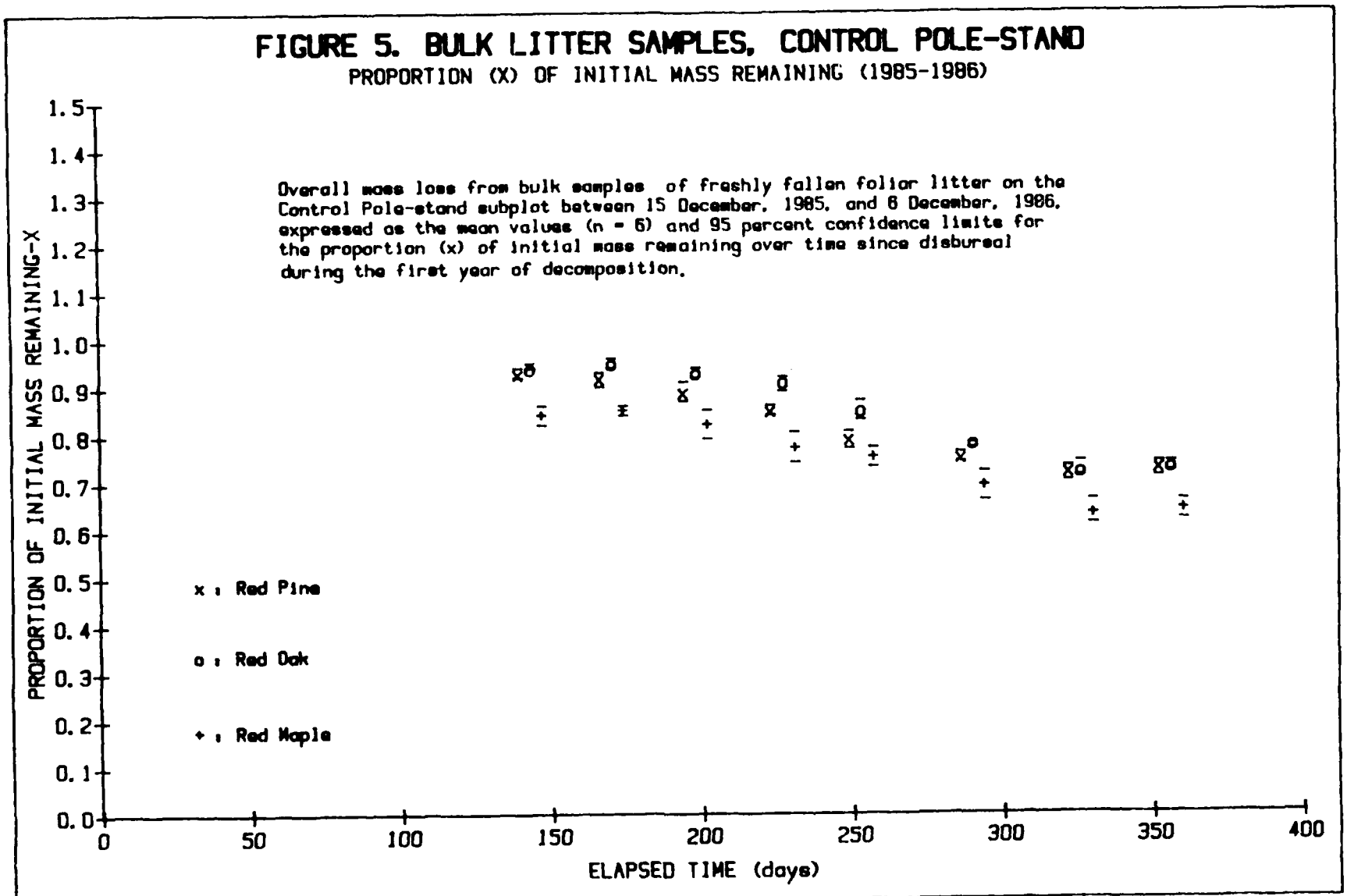
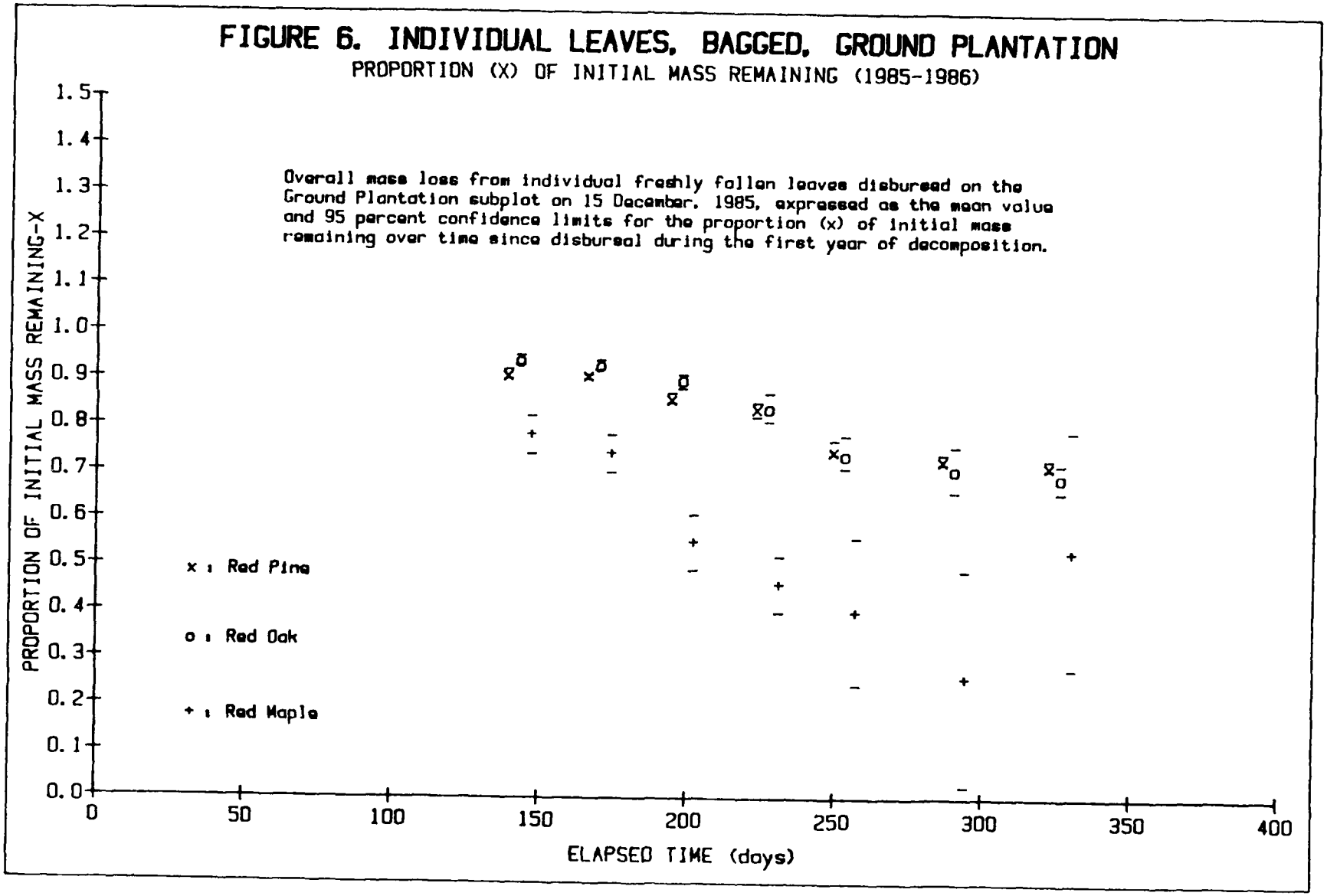


FIGURE 6. INDIVIDUAL LEAVES, BAGGED, GROUND PLANTATION

PROPORTION (X) OF INITIAL MASS REMAINING (1985-1986)



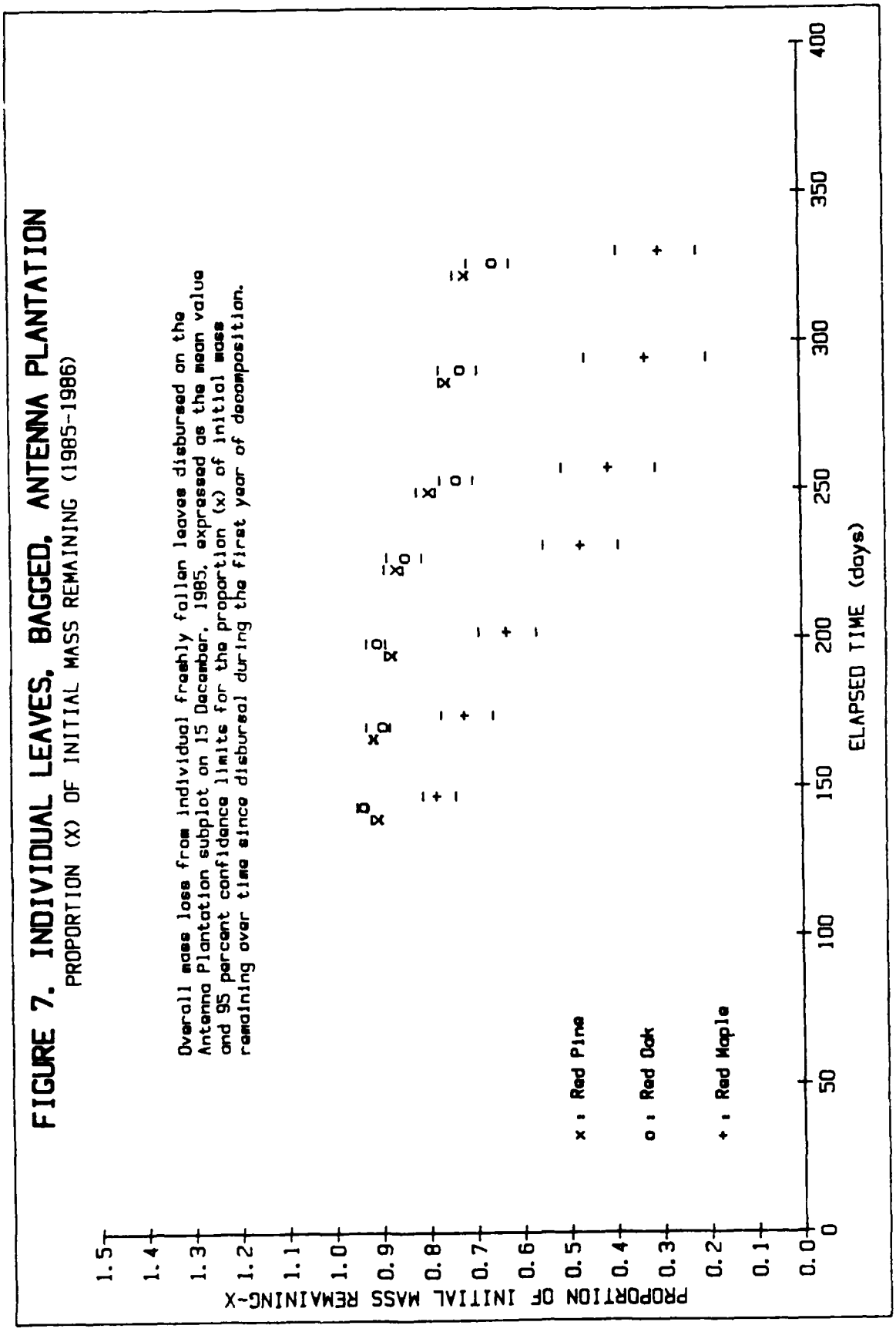


FIGURE 7. INDIVIDUAL LEAVES, BAGGED, ANTENNA PLANTATION
PROPORTION (X) OF INITIAL MASS REMAINING (1985-1986)
Overall mass loss from individual freshly fallen leaves disbursed on the Antenna Plantation subplot on 15 December, 1985, expressed as the mean value and 95 percent confidence limits for the proportion (x) of initial mass remaining over time since disbursal during the first year of decomposition.
x : Red Pine
o : Red Oak
+ : Red Maple
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
0
50
100
150
200
250
300
350
400

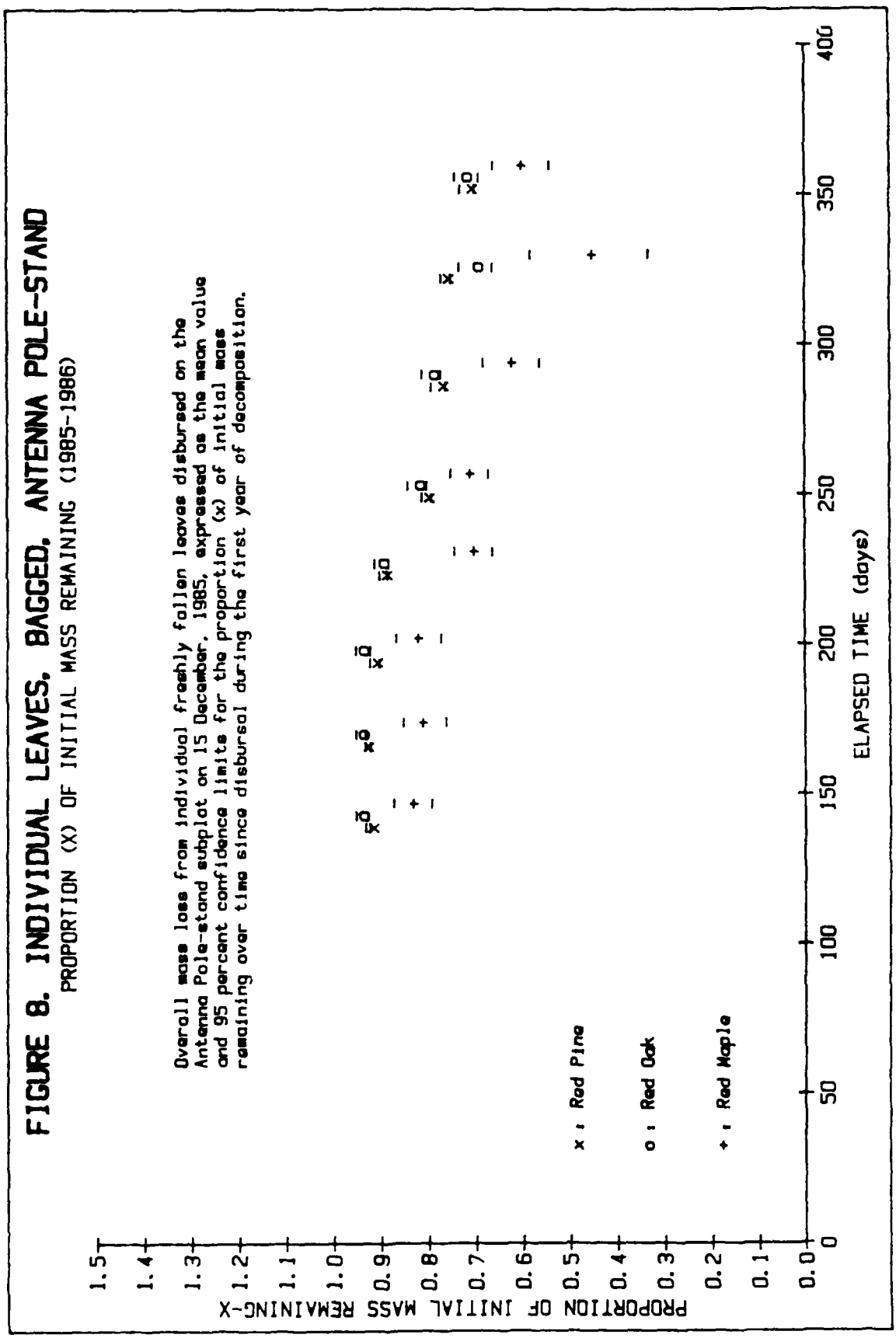
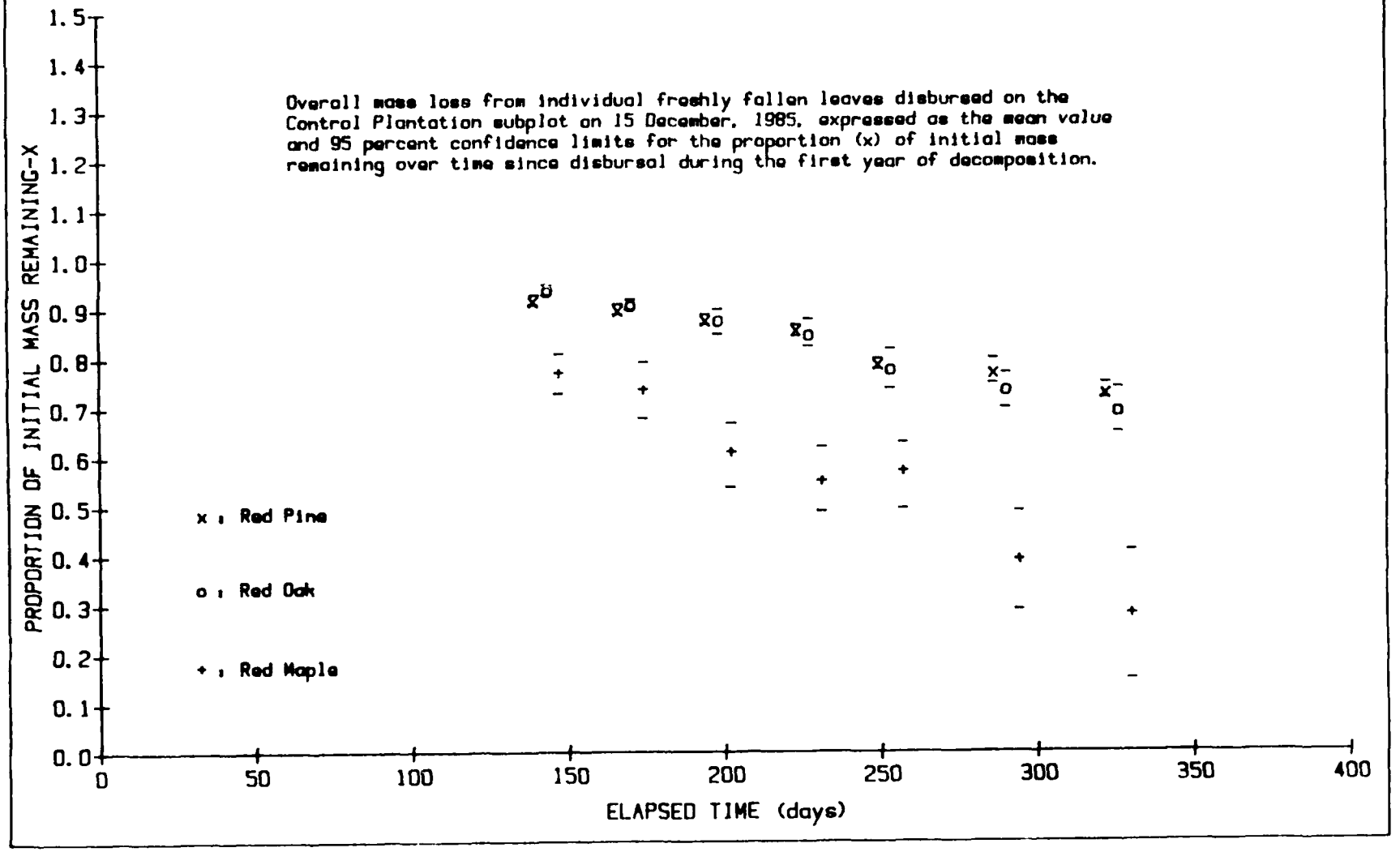


FIGURE 8. INDIVIDUAL LEAVES, BAGGED, ANTENNA POLE-STAND
PROPORTION (X) OF INITIAL MASS REMAINING (1985-1986)
Overall mass loss from individual freshly fallen leaves disbursed on the Antenna Pole-stand subplot on 15 December, 1985, expressed as the mean value and 95 percent confidence limits for the proportion (x) of initial mass remaining over time since disbursal during the first year of decomposition.
x : Red Pine
o : Red Oak
+ : Red Maple
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
0
50
100
150
200
250
300
350
400

FIGURE 9. INDIVIDUAL LEAVES, BAGGED, CONTROL PLANTATION

PROPORTION (X) OF INITIAL MASS REMAINING (1985-1986)



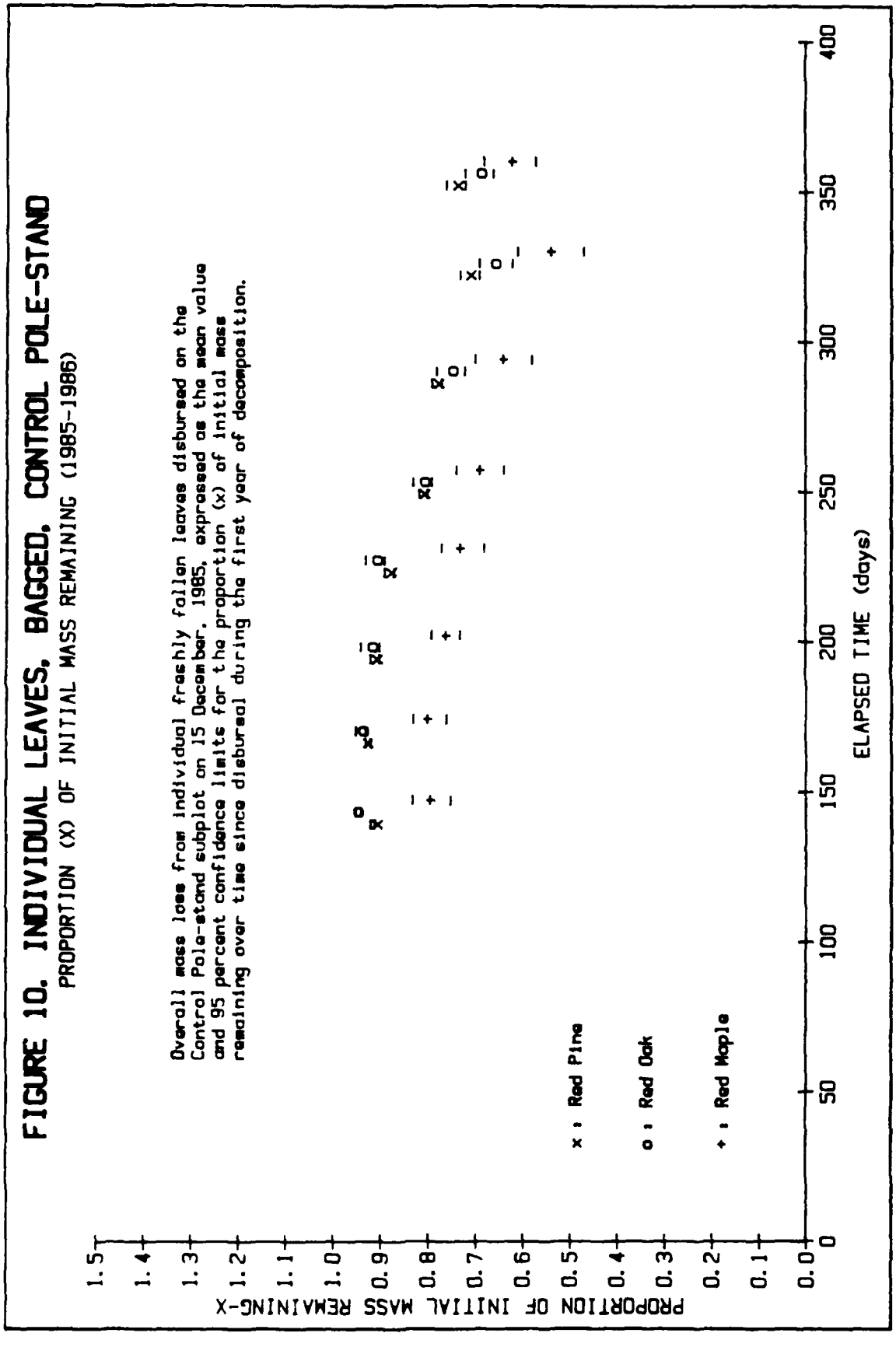


FIGURE 10. INDIVIDUAL LEAVES, BAGGED, CONTROL POLE-STAND
PROPORTION (X) OF INITIAL MASS REMAINING (1985-1986)
Overall mass loss from individual freshly fallen leaves disbursed on the Control Pole-stand subplot on 15 December, 1985, expressed as the mean value and 95 percent confidence limits for the proportion (x) of initial mass remaining over time since disbursal during the first year of decomposition.
x : Red Pine
o : Red Oak
+ : Red Maple
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
0
50
100
150
200
250
300
350
400

FIGURE 11. INDIVIDUAL LEAVES, UNBAGGED, CONTROL PLANTATION

PROPORTION (X) OF INITIAL MASS REMAINING (1985-1986)

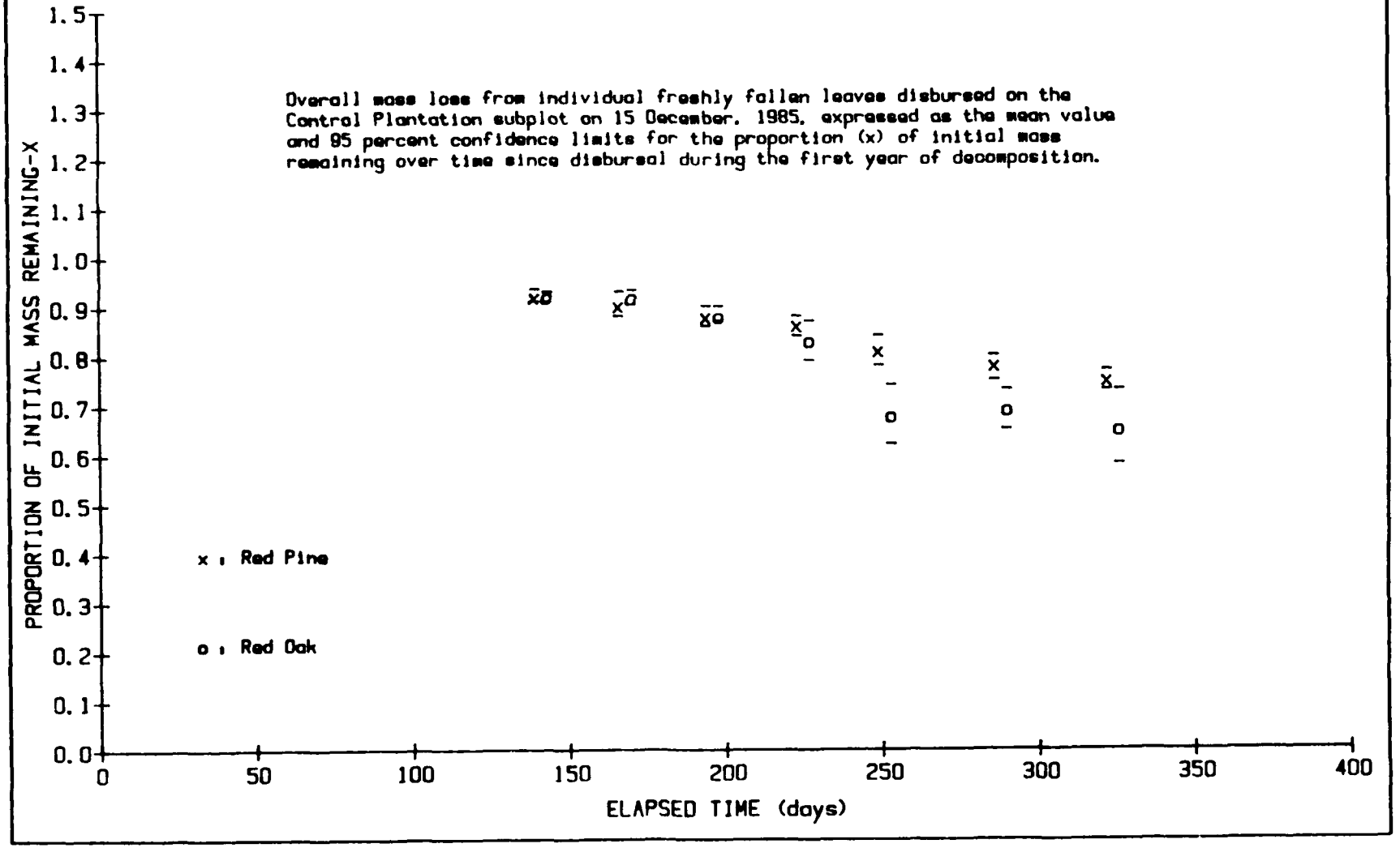


FIGURE 12. INDIVIDUAL LEAVES, UNBAGGED, CONTROL POLE-STAND

PROPORTION (X) OF INITIAL MASS REMAINING (1985-1986)

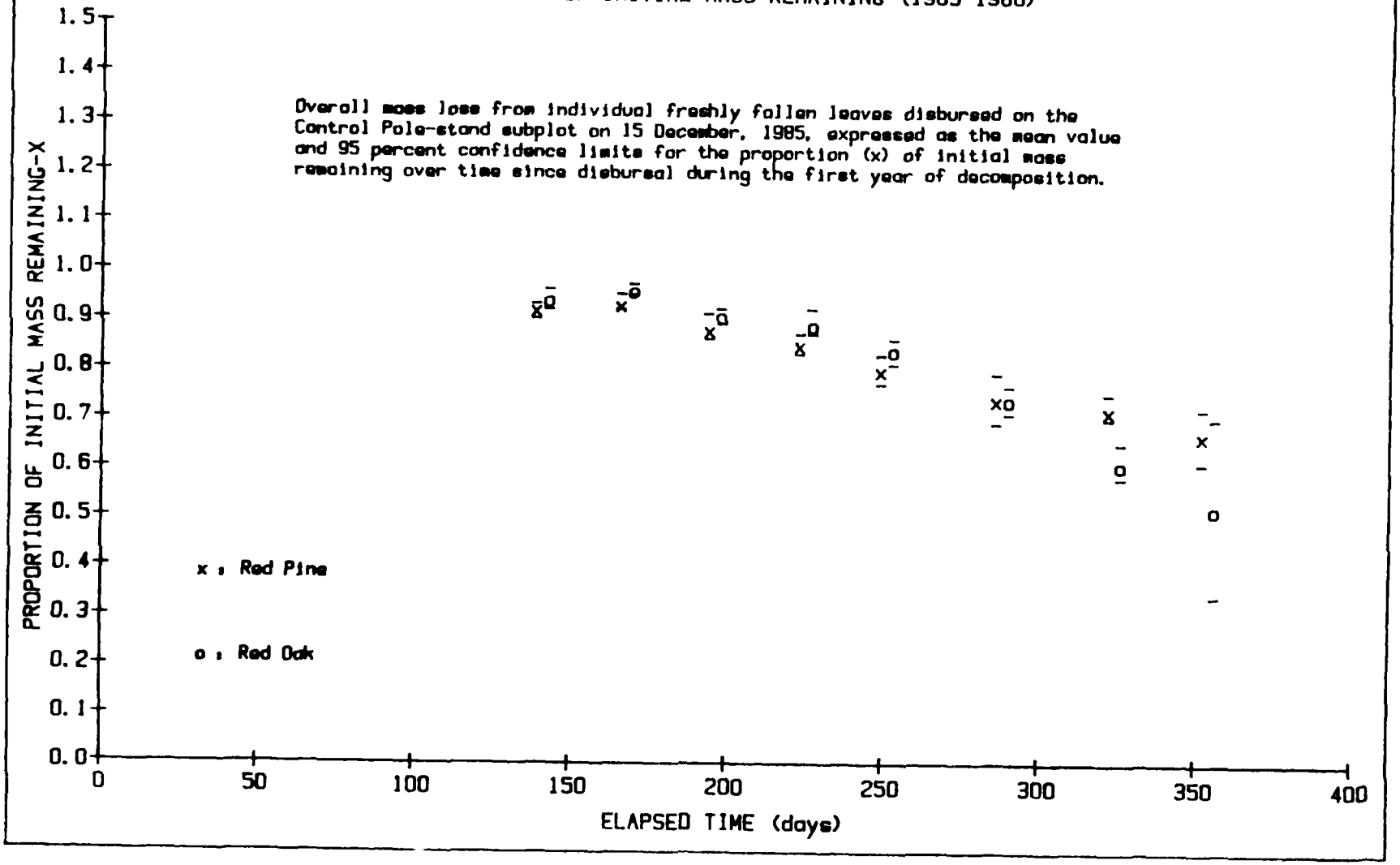
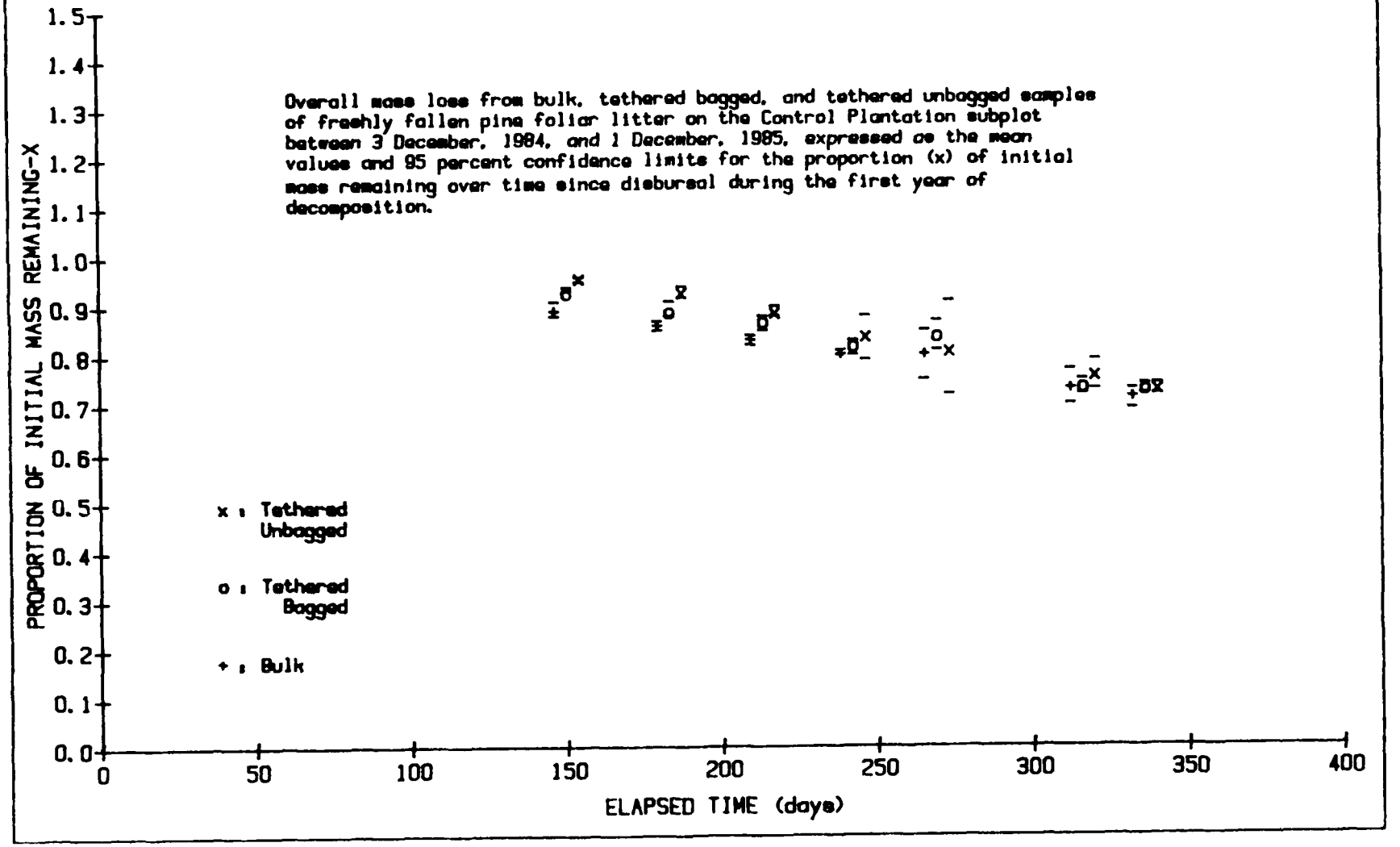


FIGURE 13. COMPARISON OF PINE SAMPLES, CONTROL PLANTATION

PROPORTION (X) OF INITIAL MASS REMAINING (1984-1985)



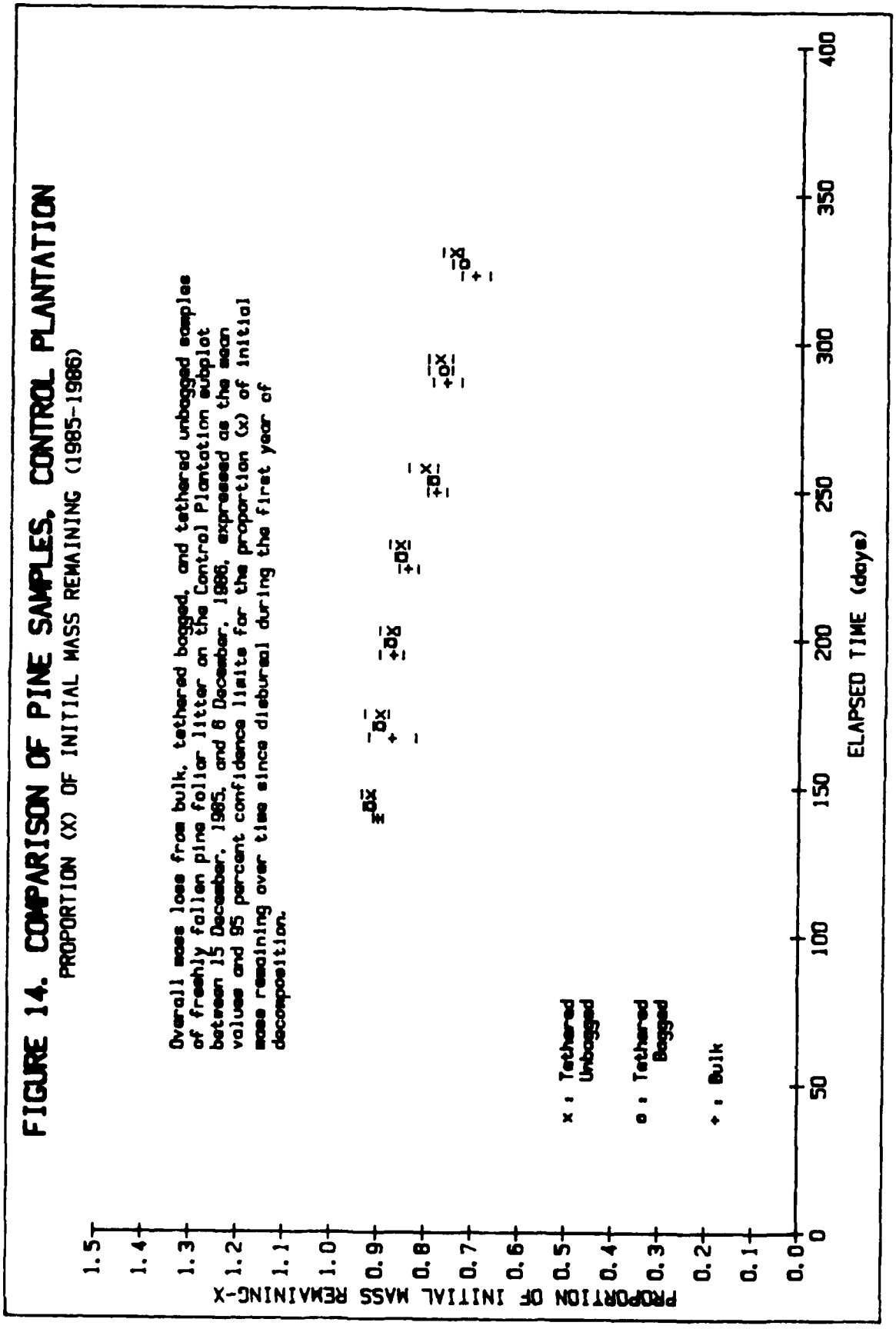
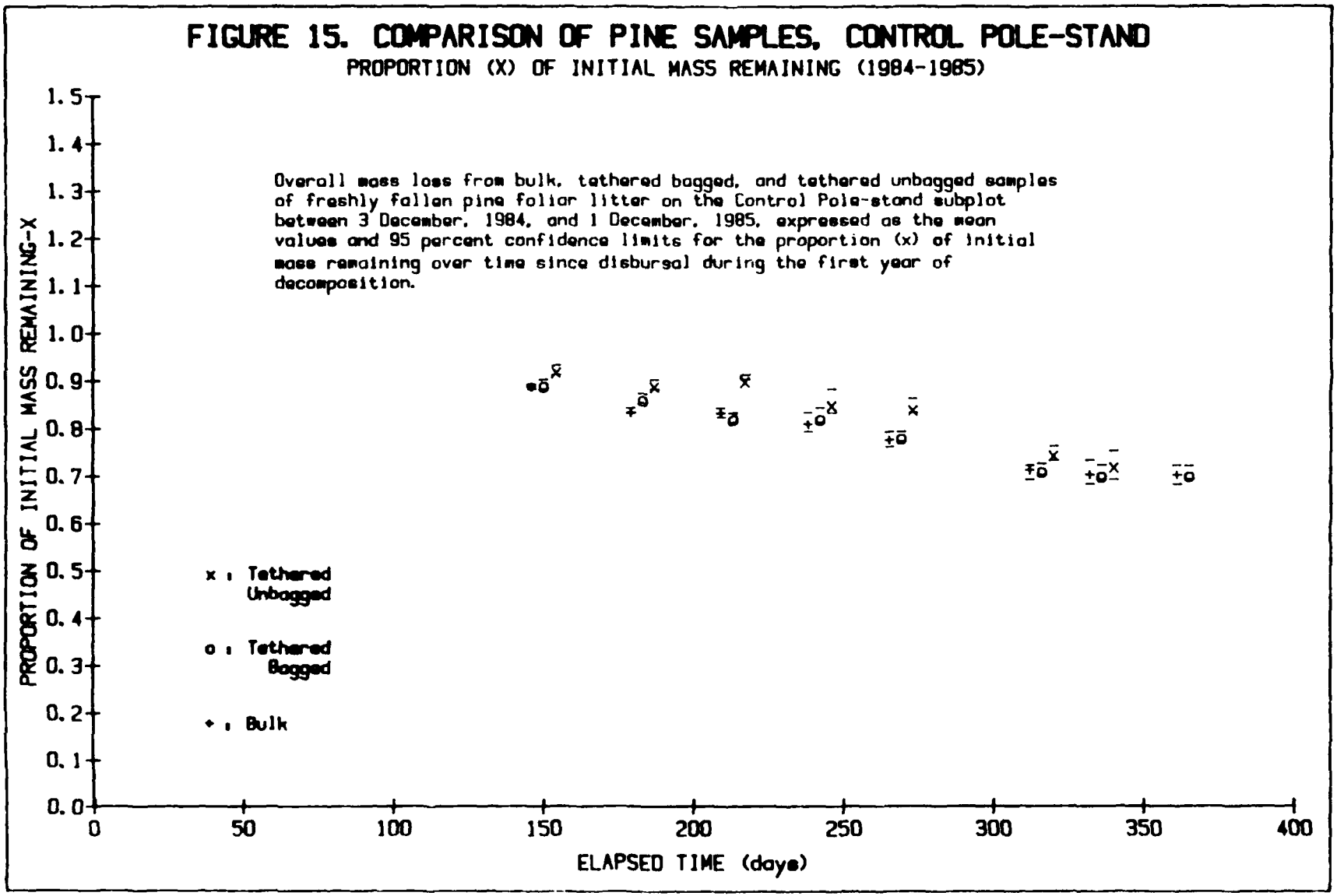


FIGURE 14. COMPARISON OF PINE SAMPLES, CONTROL PLANTATION
PROPORTION (X) OF INITIAL MASS REMAINING (1985-1986)
Overall mass loss from bulk, tethered bagged, and tethered unbagged samples of freshly fallen pine foliar litter on the Control Plantation subplot between 15 December, 1985, and 8 December, 1986, expressed as the mean values and 95 percent confidence limits for the proportion (x) of initial mass remaining over time since disbural during the first year of decomposition.
x : Tethered Unbagged
o : Tethered Bagged
+ : Bulk
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
0
50
100
150
200
250
300
350
400

FIGURE 15. COMPARISON OF PINE SAMPLES, CONTROL POLE-STAND

PROPORTION (X) OF INITIAL MASS REMAINING (1984-1985)



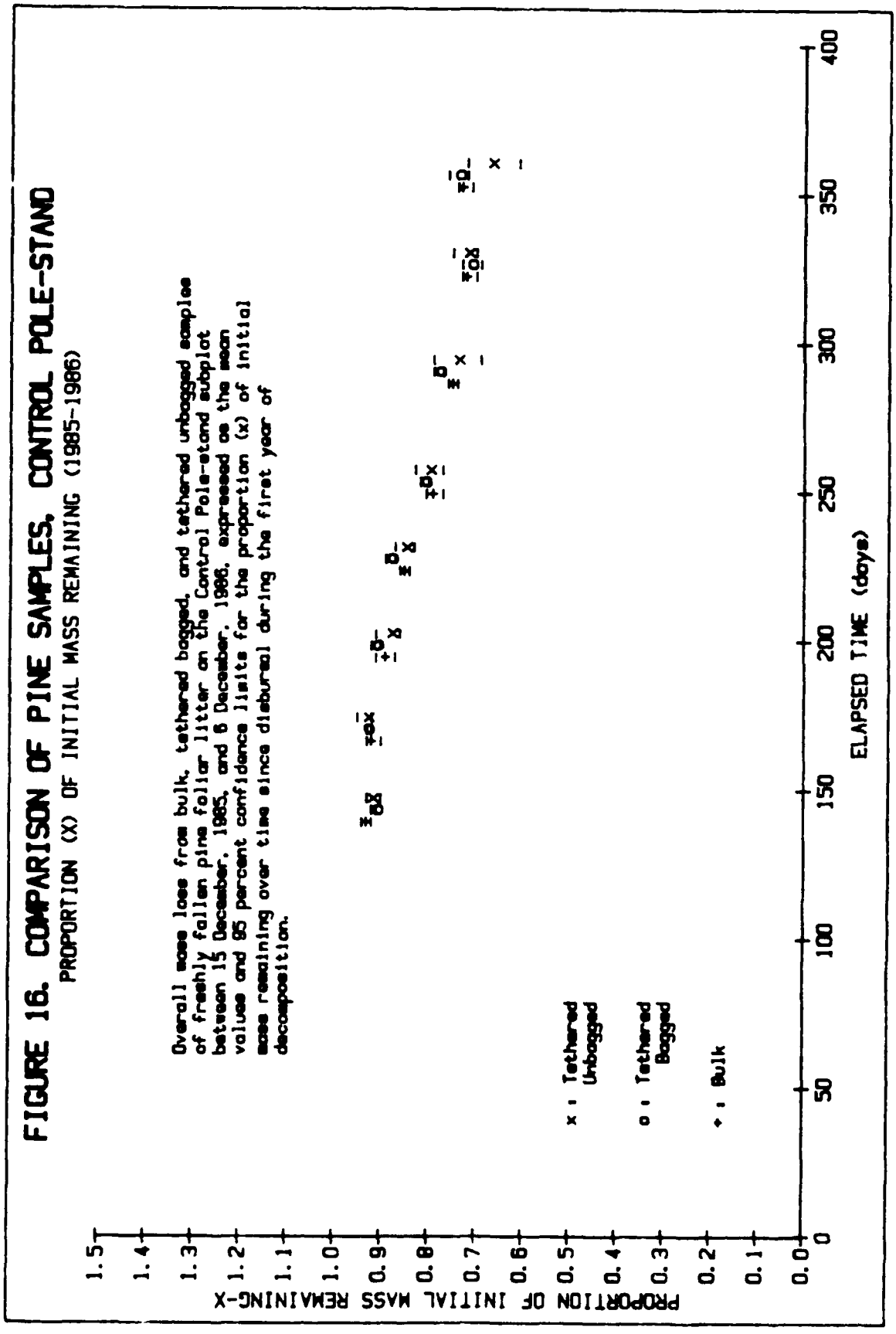


FIGURE 16. COMPARISON OF PINE SAMPLES, CONTROL POLE-STAND

PROPORTION (X) OF INITIAL MASS REMAINING (1985-1986)

Overall mass loss from bulk, tethered bagged, and tethered unbagged samples of freshly fallen pine foliar litter on the Control Pole-stand subplot between 15 December, 1985, and 6 December, 1986, expressed as the mean value and 95 percent confidence limits for the proportion (x) of initial mass remaining over time since disburial during the first year of decomposition.

significantly influenced pine sample decomposition rate or 2) that our individual fascicle samples decomposed at a significantly different rate than our bulk pine samples. Analogous comparisons between oak sample types are presented in Figures 17 through 20. Again, there seem to be no meaningful differences between bulk and individual leaf sample decomposition rates, and our envelopes had no significant effect on sample decomposition rate. Analogous data for bulk and bagged individual leaf maple samples are displayed in Figures 21 through 24. The only case of a significant difference between the decomposition rates of bulk and individual leaf samples occurred in the control plantation, where bulk maple sample decomposition slowed down relative to individual maple leaves from June of 1986 to the end of the season. Overall, it appears that our envelopes have negligible influence on the rate at which enclosed litter samples decompose. It also appears that bulk and individual fascicle/leaf samples generally decompose at similar rates, though in two cases (one case each with oak and maple) bulk samples decomposed less by the end of the field season than did individual leaf samples.

The transformed dry matter mass loss data (arc sine square root of "X", the proportion of original sample mass remaining) have been analyzed using the SPSS subprogram ANOVA for two-way analysis of variance, Tukey's H.S.D. test for multiple comparisons, and the Bartlett-Box F test for homogeneity of variances (Dowdy and Wearden 1983). The arc sine square root transformation reduces the heterogeneity of sample variances generally to insignificance. As a result, we have found that our dry matter mass loss data are sufficiently precise to detect very slight shifts in decomposition rates between years at a given subplot or among subplots during a given year. Tables 11 through 15 present two-way ANOVA tables comparing dry matter mass loss from bulk pine samples between years and monthly sampling dates for each of the five study subplots. Figures 25 through 29 represent the same data graphically as comparisons between years, at each of the five study subplots, of dry matter mass loss sample means (with 95 percent confidence intervals). Corresponding ANOVA

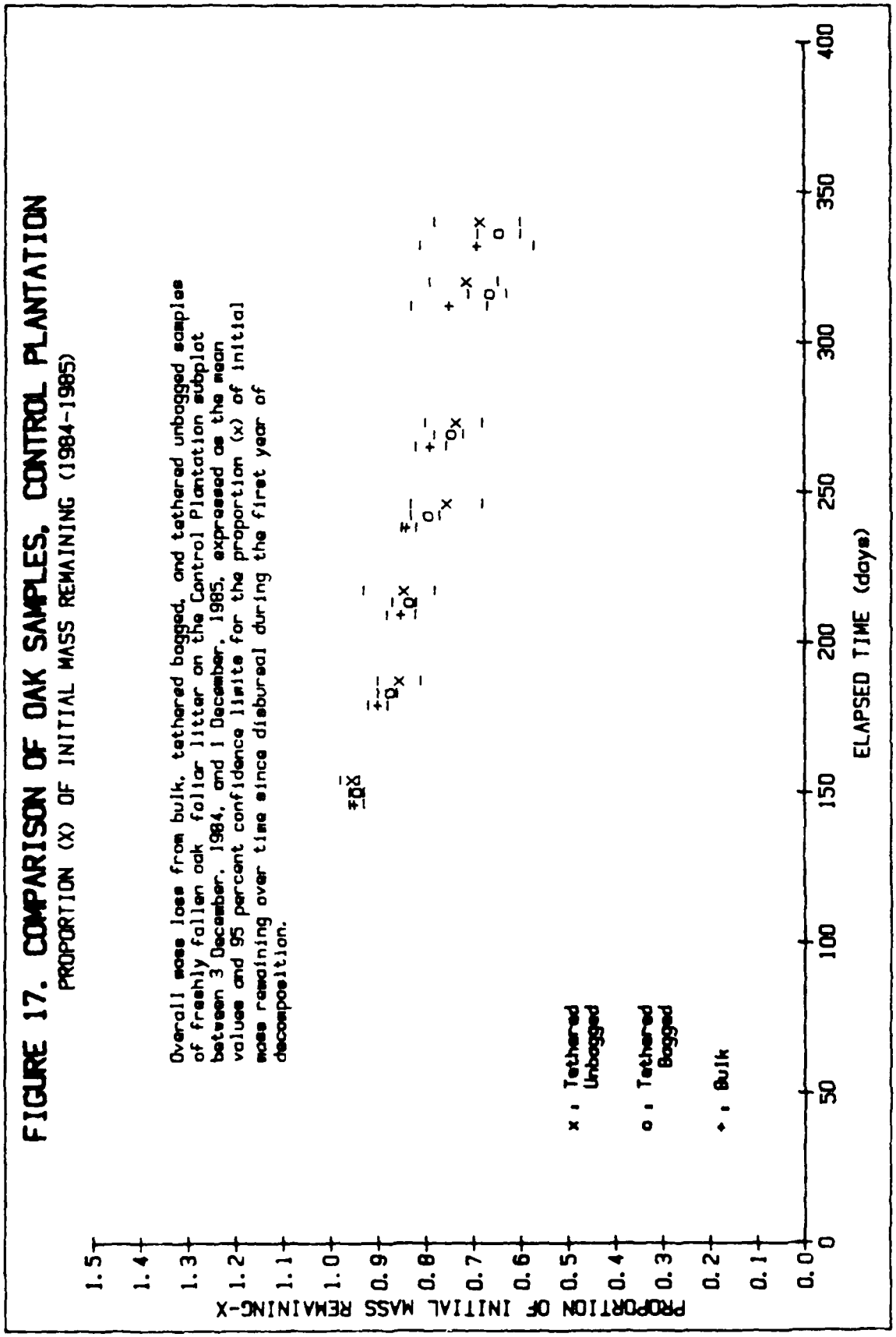
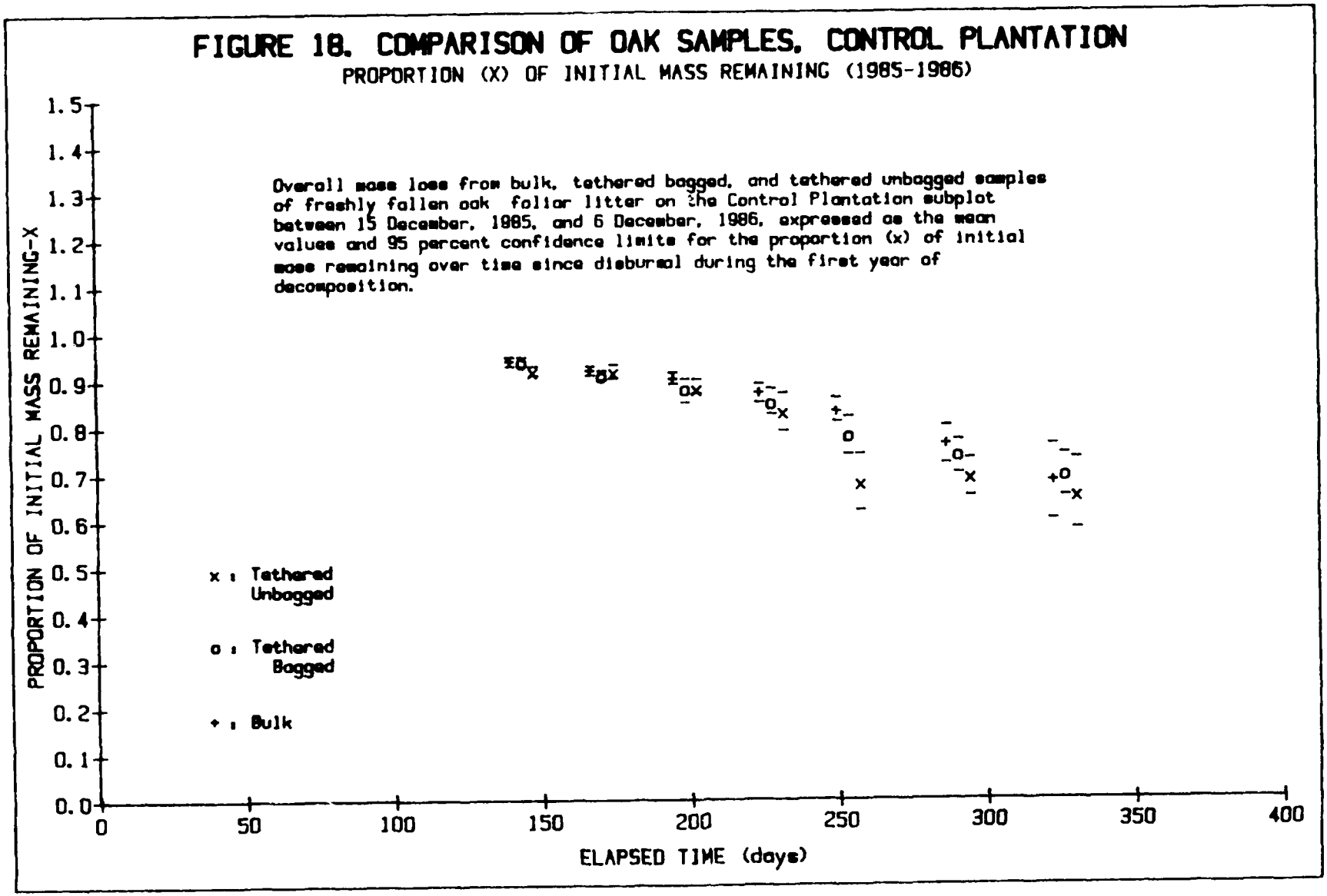


FIGURE 17. COMPARISON OF OAK SAMPLES, CONTROL PLANTATION
PROPORTION (X) OF INITIAL MASS REMAINING (1984-1985)
Overall mass loss from bulk, tethered bagged, and tethered unbagged samples of freshly fallen oak foliar litter on the Control Plantation subplot between 3 December, 1984, and 1 December, 1985, expressed as the mean values and 95 percent confidence limits for the proportion (x) of initial mass remaining over time since disbursal during the first year of decomposition.
x : Tethered Unbagged
o : Tethered Bagged
+ : Bulk
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
0
50
100
150
200
250
300
350
400

FIGURE 18. COMPARISON OF OAK SAMPLES, CONTROL PLANTATION

PROPORTION (X) OF INITIAL MASS REMAINING (1985-1986)



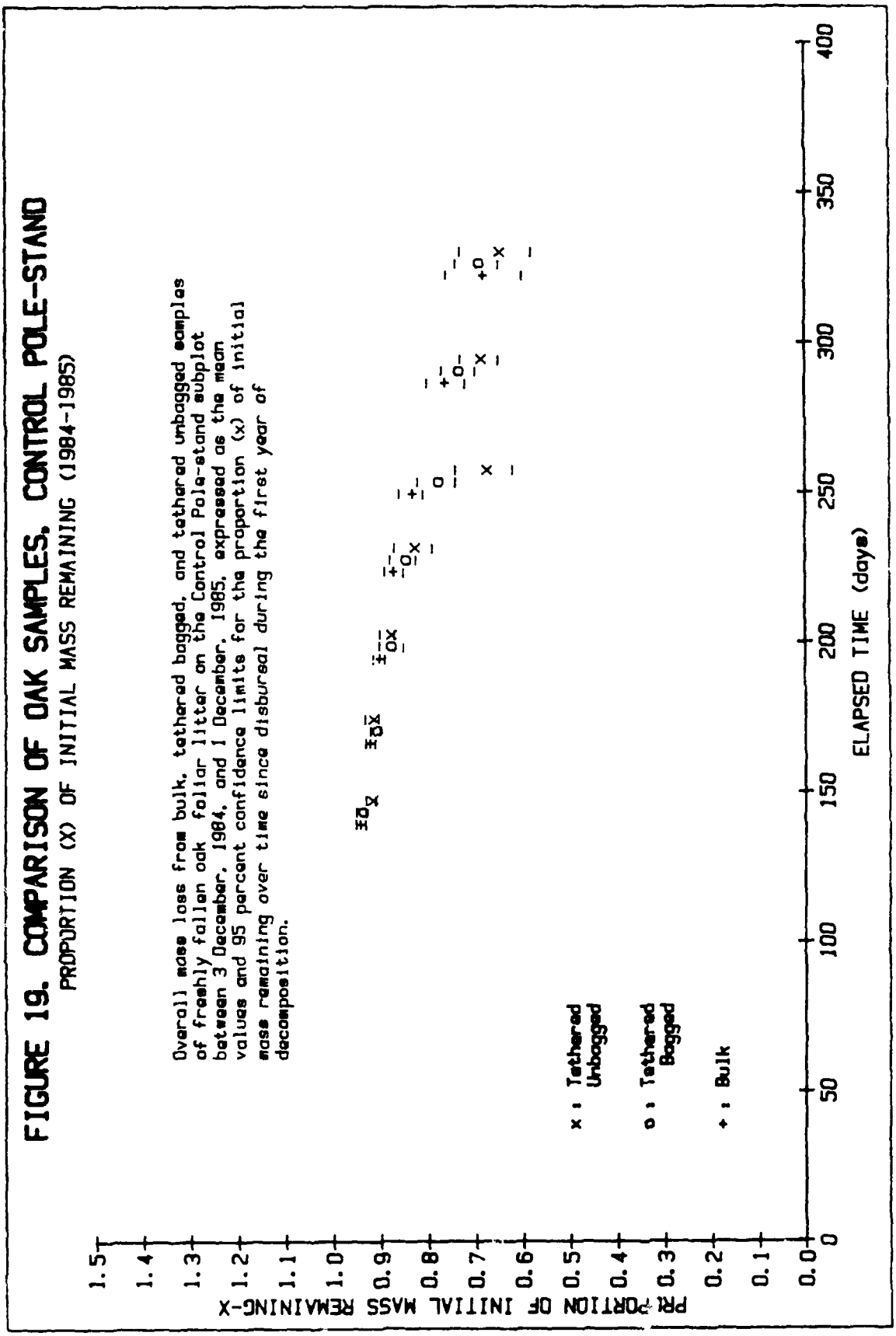


FIGURE 19. COMPARISON OF OAK SAMPLES, CONTROL POLE-STAND
PROPORTION (X) OF INITIAL MASS REMAINING (1984-1985)
Overall mass loss from bulk, tethered bagged, and tethered unbagged samples of freshly fallen oak foliar litter on the Control Pole-stand subplot between 3 December, 1984, and 1 December, 1985, expressed as the mean values and 95 percent confidence limits for the proportion (x) of initial mass remaining over time since disbursal during the first year of decomposition.
x : Tethered Unbagged
o : Tethered Bagged
+ : Bulk
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
0
50
100
150
200
250
300
350
400

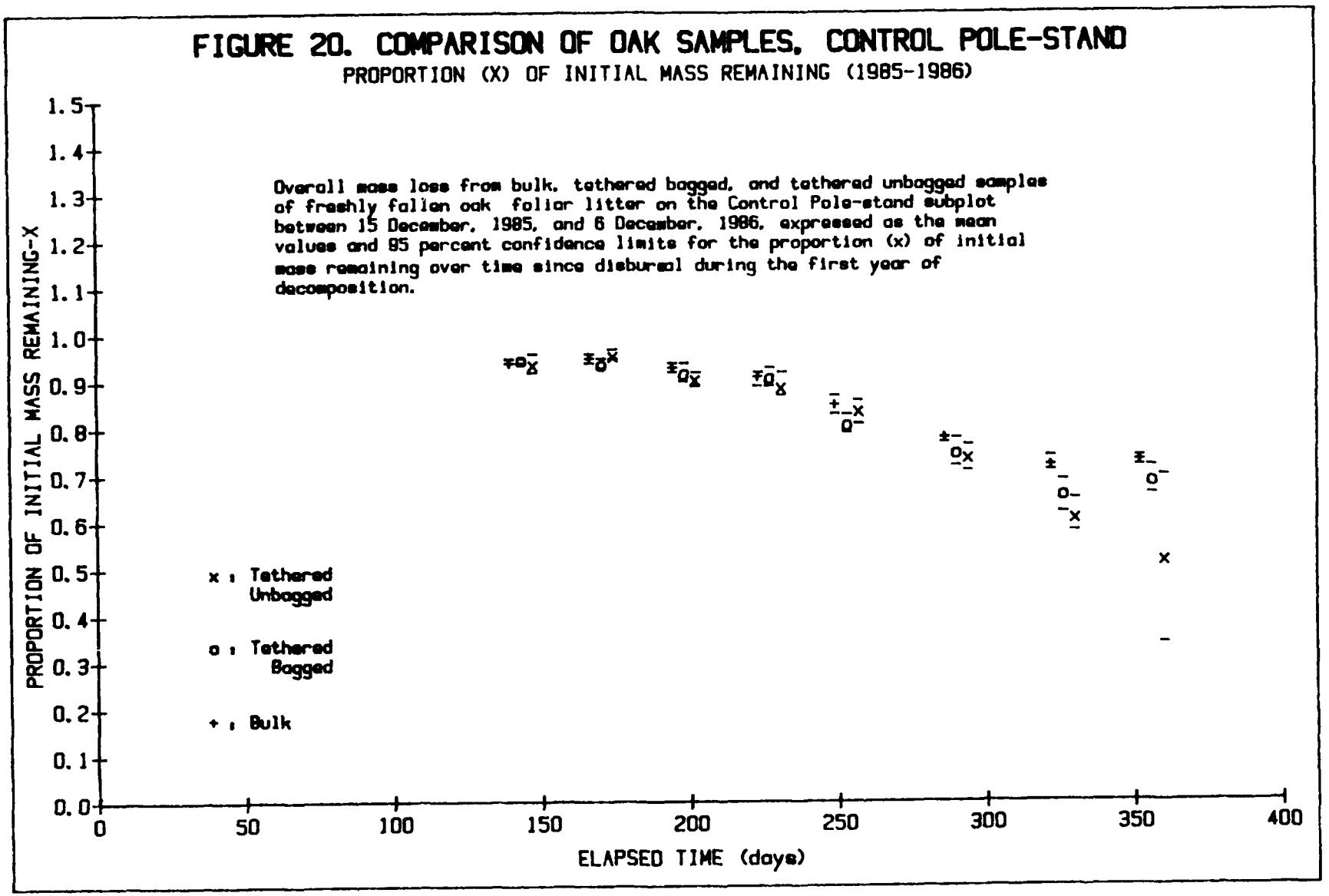


FIGURE 20. COMPARISON OF OAK SAMPLES, CONTROL POLE-STAND
PROPORTION (X) OF INITIAL MASS REMAINING (1985-1986)
Overall mass loss from bulk, tethered bagged, and tethered unbagged samples of freshly fallen oak foliar litter on the Control Pole-stand subplot between 15 December, 1985, and 6 December, 1986, expressed as the mean values and 95 percent confidence limits for the proportion (x) of initial mass remaining over time since disbursal during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING-X
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
x : Tethered Unbagged
o : Tethered Bagged
+ : Bulk
0
50
100
150
200
250
300
350
400
ELAPSED TIME (days)

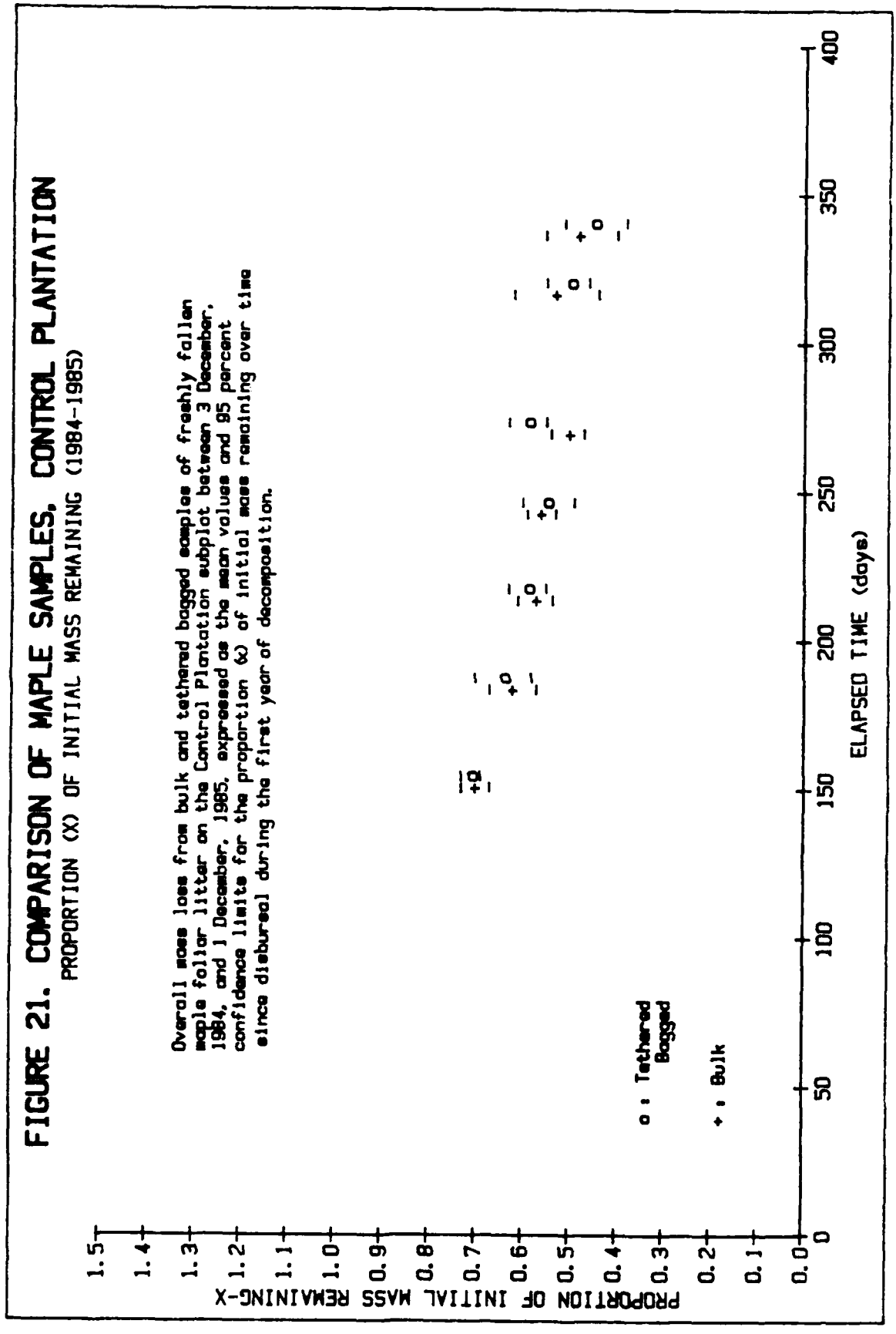


FIGURE 21. COMPARISON OF MAPLE SAMPLES, CONTROL PLANTATION
PROPORTION (X) OF INITIAL MASS REMAINING (1984-1985)
Overall mass loss from bulk and tethered bagged samples of freshly fallen maple foliar litter on the Control Plantation subplot between 3 December, 1984, and 1 December, 1985, expressed as the mean values and 95 percent confidence limits for the proportion (X) of initial mass remaining over time since disbursal during the first year of decomposition.
o : Tethered Bagged
+ : Bulk
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
0
50
100
150
200
250
300
350
400

FIGURE 22. COMPARISON OF MAPLE SAMPLES, CONTROL PLANTATION

PROPORTION (X) OF INITIAL MASS REMAINING (1985-1986)

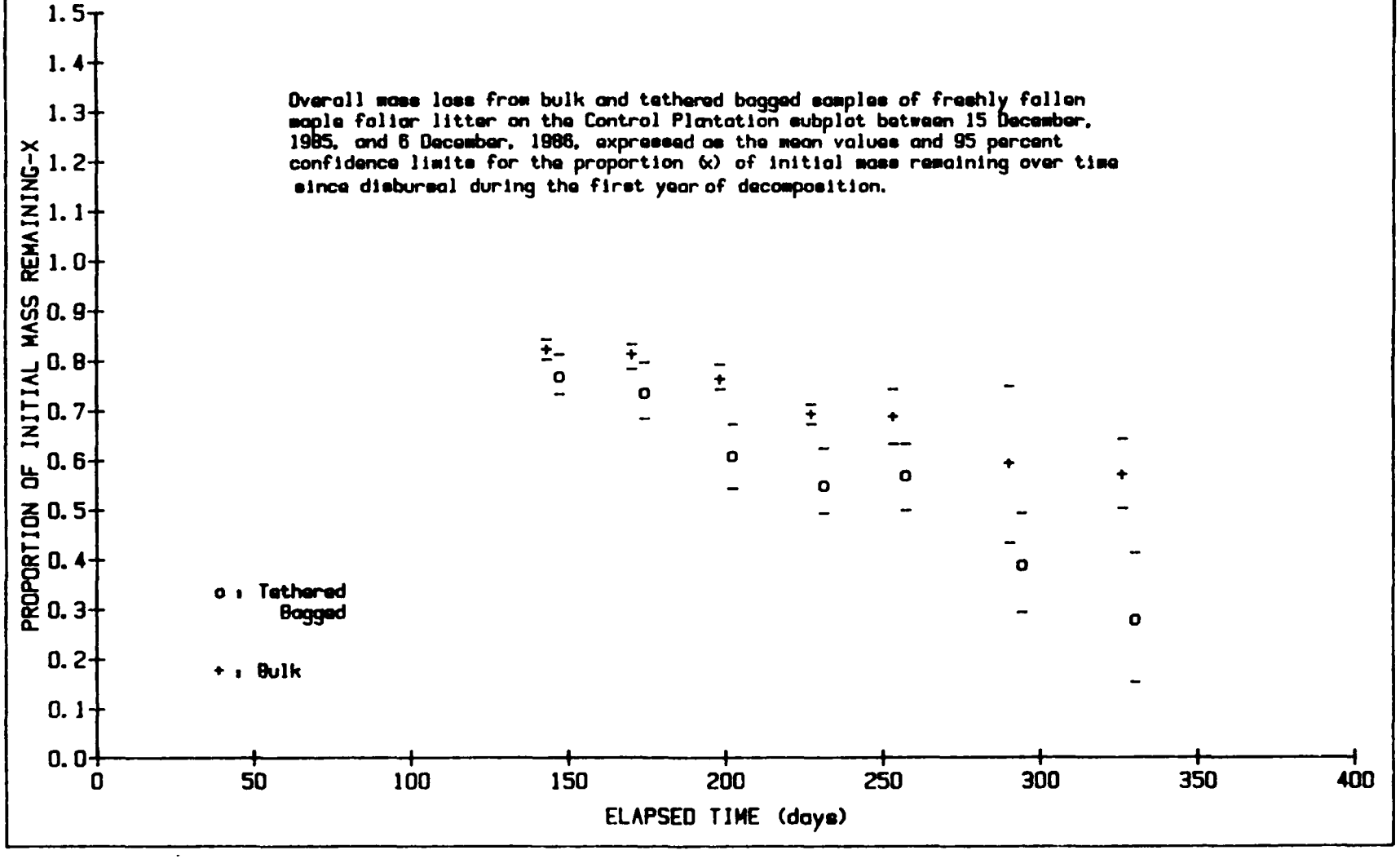


FIGURE 23. COMPARISON OF MAPLE SAMPLES, CONTROL POLE-STAND

PROPORTION (X) OF INITIAL MASS REMAINING (1984-1985)

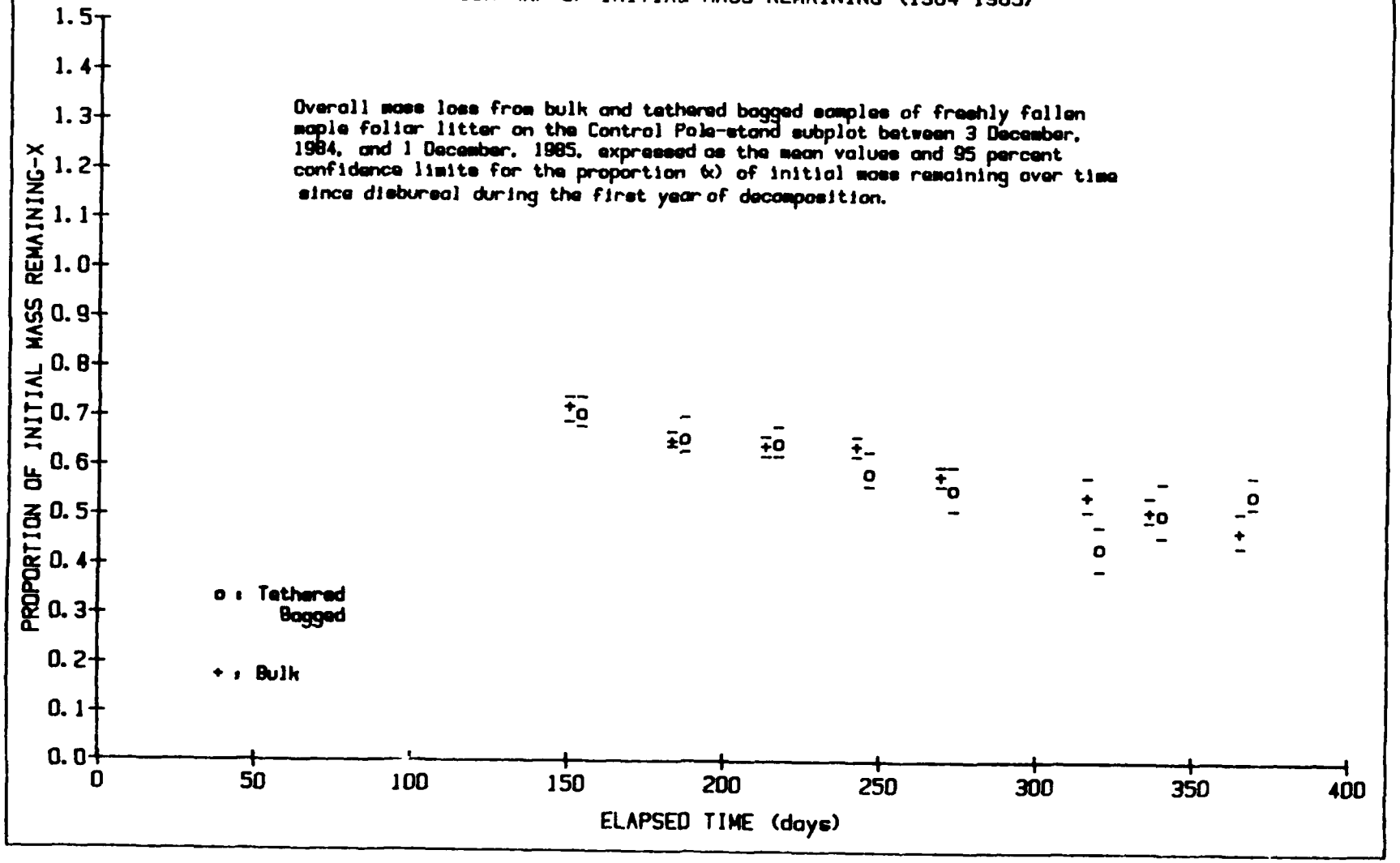


FIGURE 24. COMPARISON OF MAPLE SAMPLES, CONTROL POLE-STAND

PROPORTION (X) OF INITIAL MASS REMAINING (1985-1986)

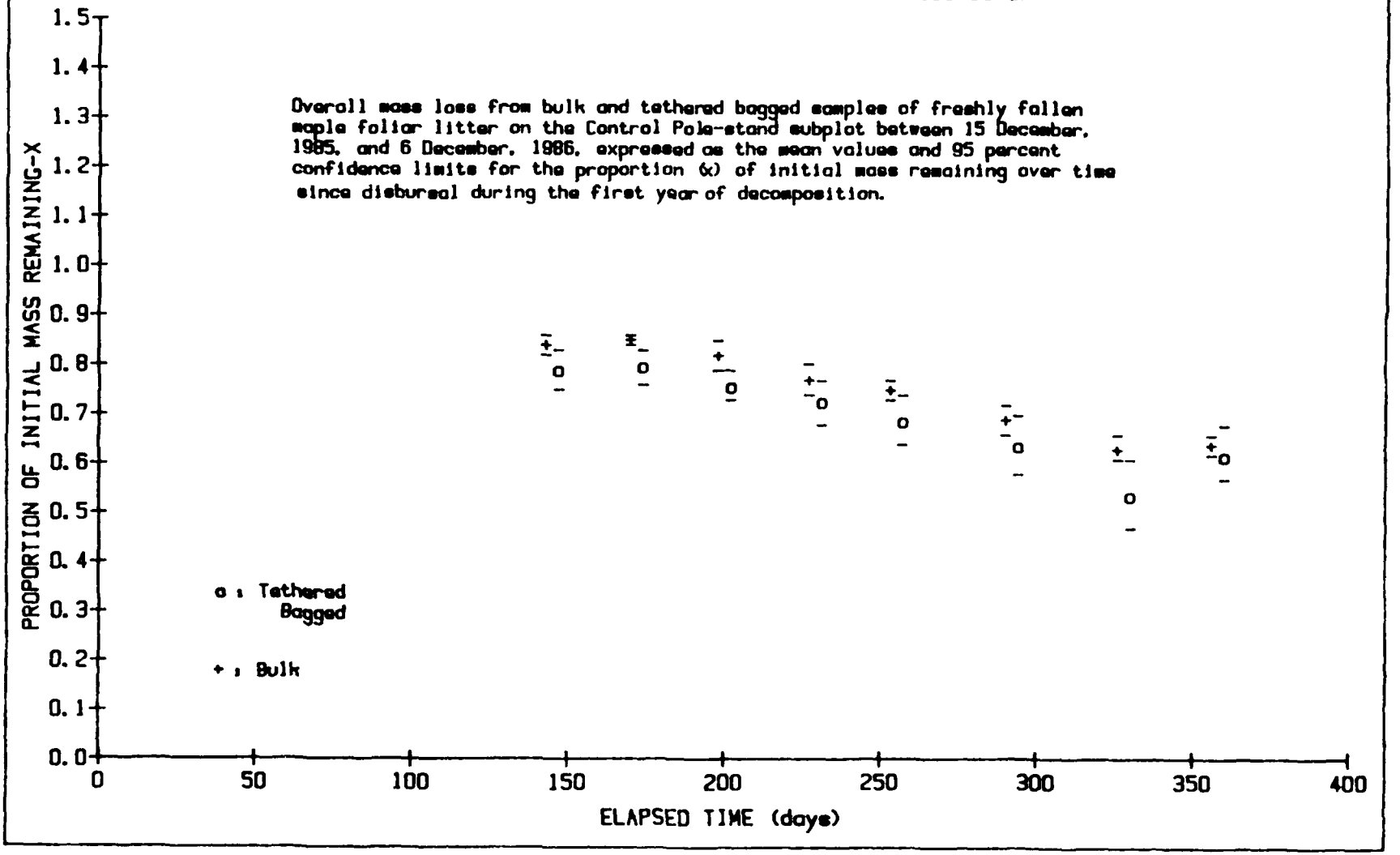


Table 11. Two-way ANOVA table for analysis of differences in dry matter mass loss (transformed to the arcsin square root of X) from bulk pine samples on the ground plantation subplot, by year and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	8	.157	143.414	0.0
Year	2	.053	47.921	0.0
Date	6	.176	160.326	0.0
Two-way Interactions	12	.002	1.960	.035
Year x Date	12	.002	1.960	.035
Explained	20	.064	58.541	0.0
Residual	112	.001		
Total	132	.011		

Table 12. Two-way ANOVA table for analysis of differences in dry matter mass loss (transformed to the arcsin square root of X) from bulk pine samples on the antenna plantation subplot, by year and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	8	.142	203.334	0.0
Year	2	.020	28.657	0.0
Date	6	.174	249.871	0.0
Two-way Interactions	12	.002	2.862	.002
Year x Date	12	.002	2.862	.002
Explained	20	.058	83.051	0.0
Residual	111	.001		
Total	131	.009		

Table 13. Two-way ANOVA table for analysis of differences in dry matter mass loss (transformed to the arcsin square root of X) from bulk pine samples on the antenna pole-stand subplot, by year and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	8	.141	247.519	0.0
Year	2	.052	91.604	0.0
Date	6	.172	303.321	0.0
Two-way Interactions	12	.004	7.483	0.0
Year x Date	12	.004	7.483	0.0
Explained	20	.059	103.498	0.0
Residual	107	.001		
Total	127	.010		

Table 14. Two-way ANOVA table for analysis of differences in dry matter mass loss (transformed to the arcsin square root of X) from bulk pine samples on the control plantation subplot, by year and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	7	.081	65.832	.000
Year	1	.007	6.010	.017
Date	6	.093	75.802	.000
Two-way Interactions	6	.003	2.548	.027
Year x Date	6	.003	2.548	.027
Explained	13	.045	36.624	.000
Residual	70	.001		
Total	83	.008		

Table 15. Two-way ANOVA table for analysis of differences in dry matter mass loss (transformed to the arcsin square root of X) from bulk pine samples on the control pole-stand subplot, by year and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	7	.108	284.928	0.0
Year	1	.079	207.864	0.0
Date	6	.114	299.005	.000
Two-way Interactions	6	.004	11.600	.000
Year x Date	6	.004	11.600	.000
Explained	13	.060	158.777	0.0
Residual	68	.000		
Total	81	.010		

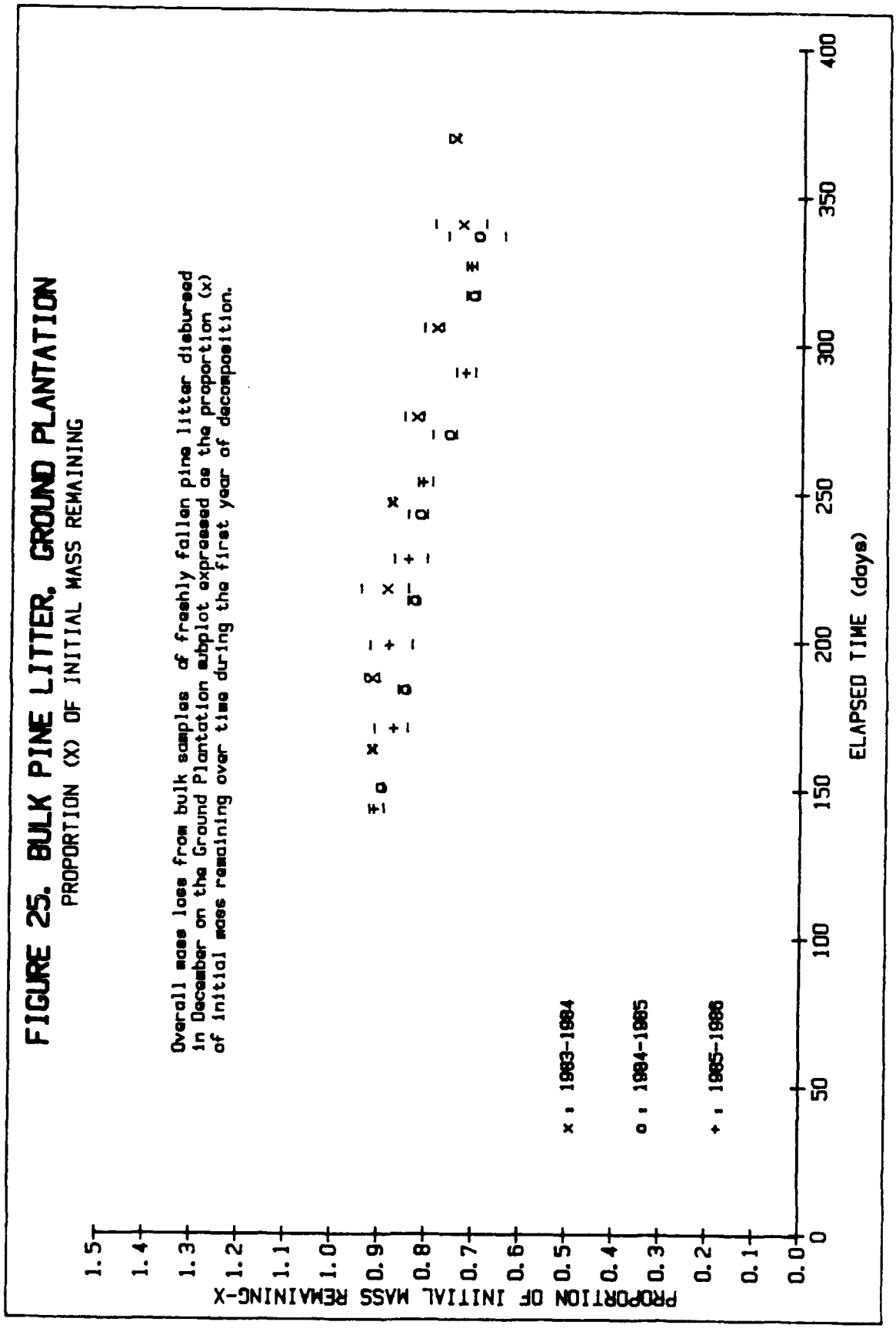
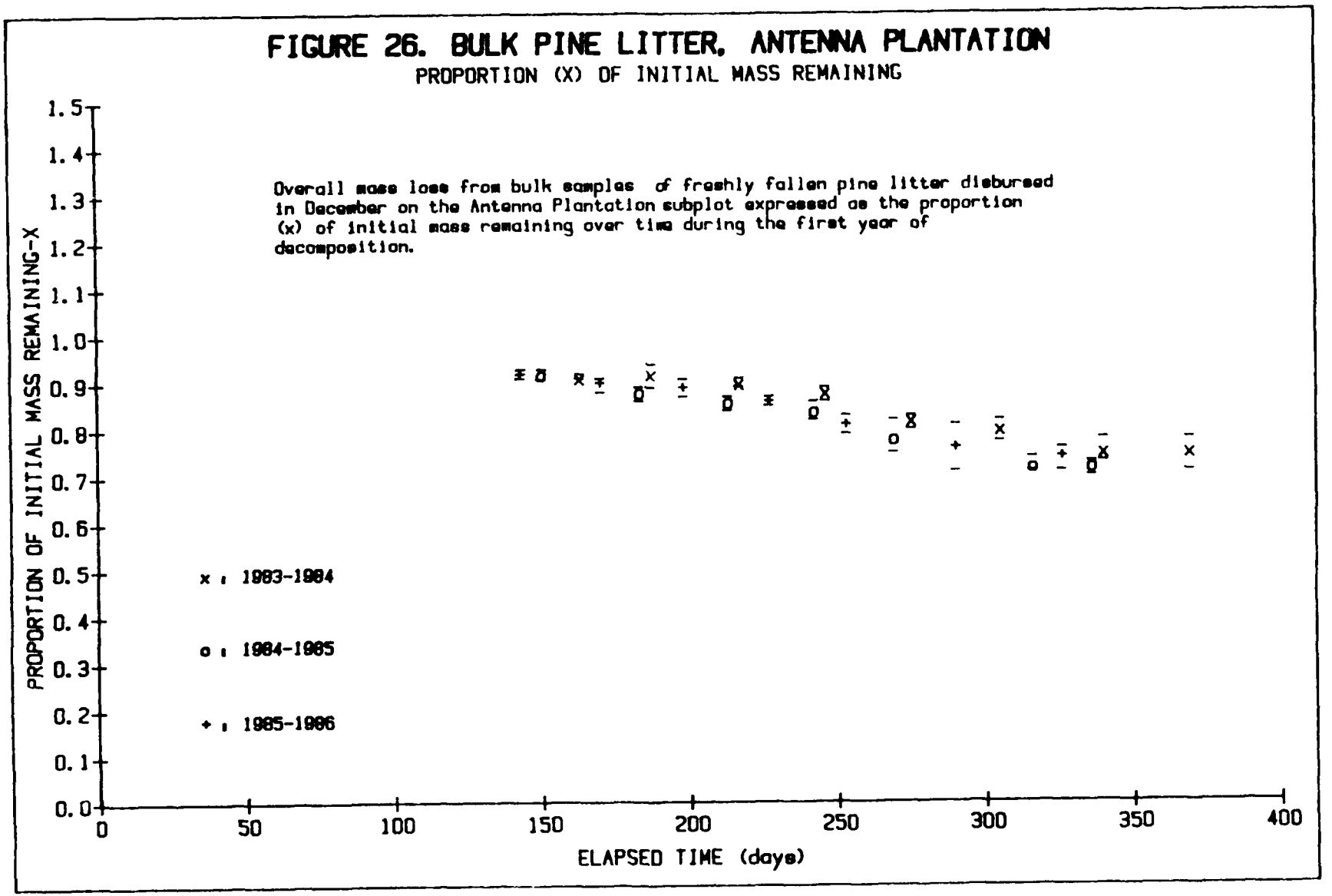


FIGURE 25. BULK PINE LITTER, GROUND PLANTATION
PROPORTION (X) OF INITIAL MASS REMAINING
Overall mass loss from bulk samples of freshly fallen pine litter disbursed in December on the Ground Plantation subplot expressed as the proportion (x) of initial mass remaining over time during the first year of decomposition.
x : 1983-1984
o : 1984-1985
+ : 1985-1986
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
0
50
100
150
200
250
300
350
400

FIGURE 26. BULK PINE LITTER, ANTENNA PLANTATION

PROPORTION (X) OF INITIAL MASS REMAINING



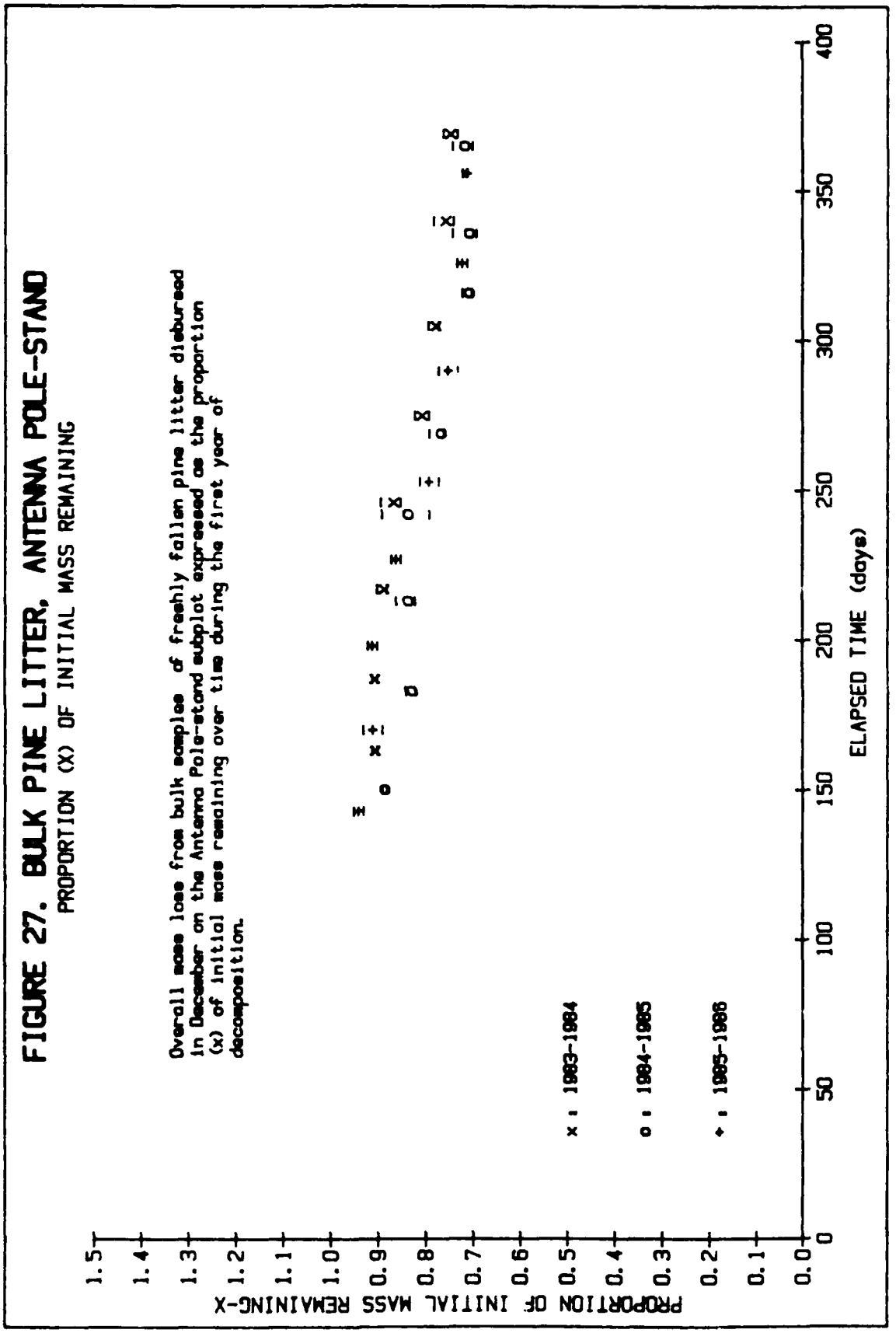


FIGURE 27. BULK PINE LITTER, ANTENNA POLE-STAND
PROPORTION (X) OF INITIAL MASS REMAINING
Overall mass loss from bulk samples of freshly fallen pine litter disbursed in December on the Antenna Pole-stand subplot expressed as the proportion (x) of initial mass remaining over time during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
x : 1983-1984
o : 1984-1985
+ : 1985-1986
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
0
50
100
150
200
250
300
350
400

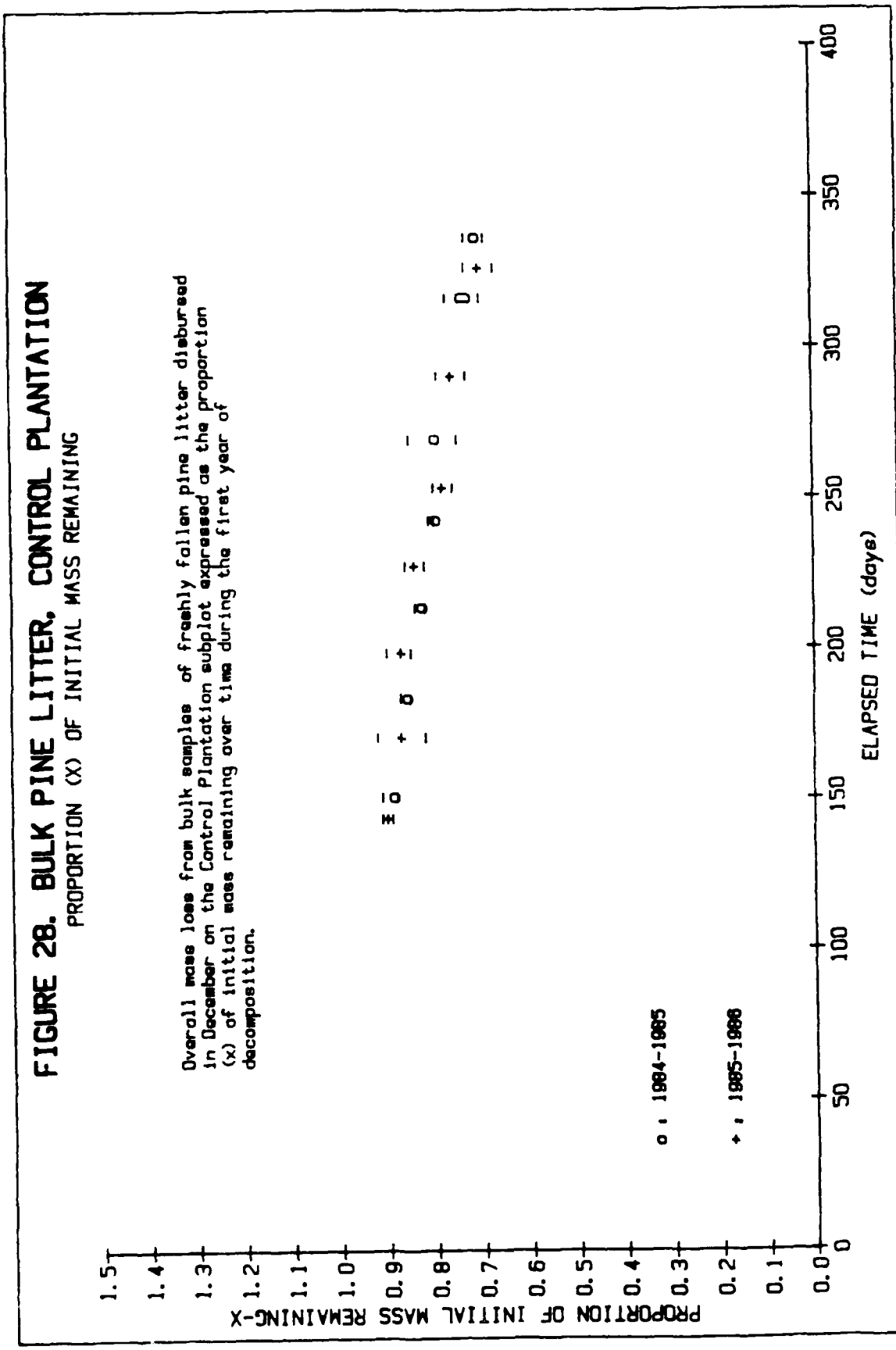


FIGURE 28. BULK PINE LITTER, CONTROL PLANTATION
PROPORTION (X) OF INITIAL MASS REMAINING
Overall mass loss from bulk samples of freshly fallen pine litter disbursed in December on the Control Plantation subplot expressed as the proportion (x) of initial mass remaining over time during the first year of decomposition.
o : 1984-1985
+ : 1985-1986
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
0
50
100
150
200
250
300
350
400

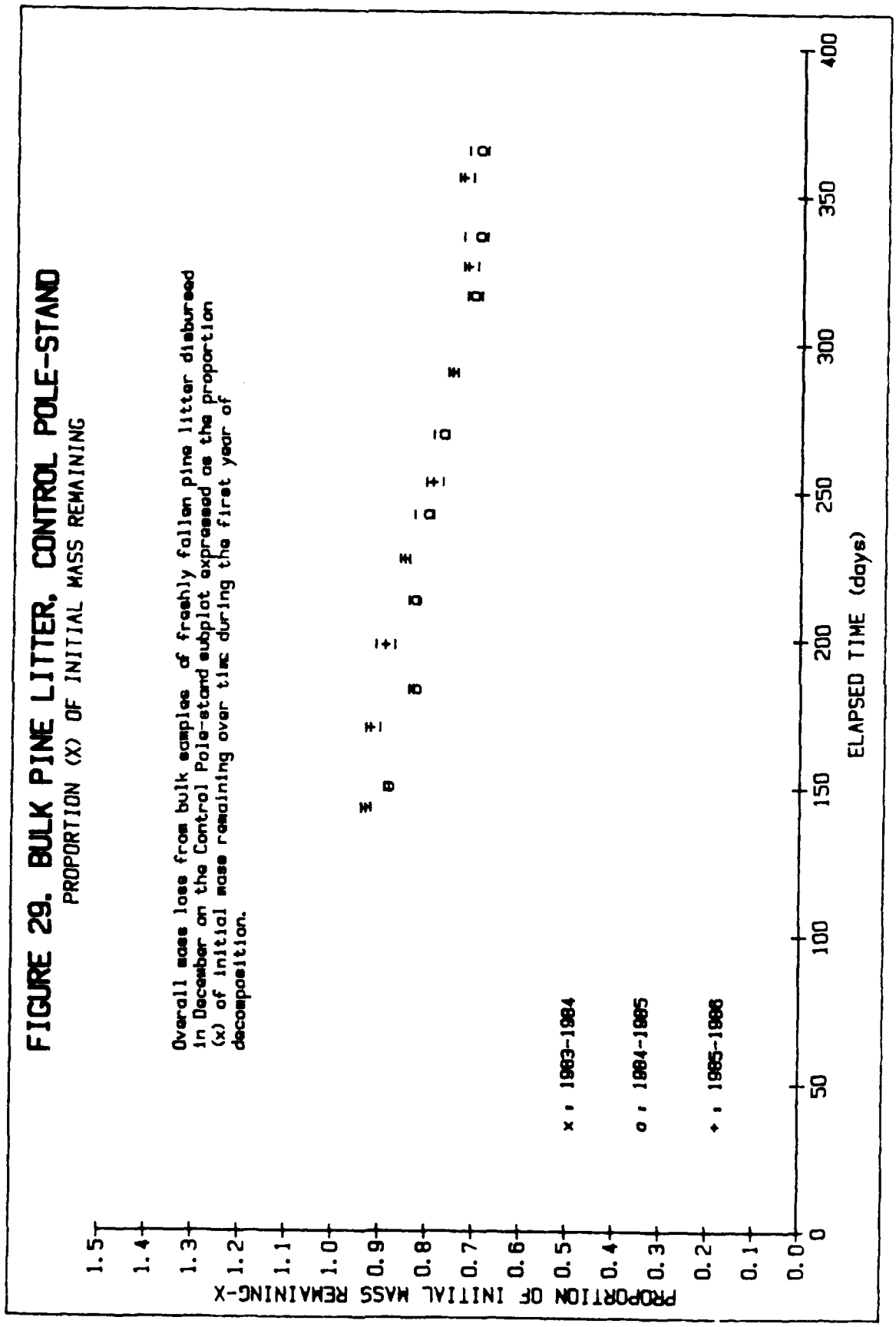


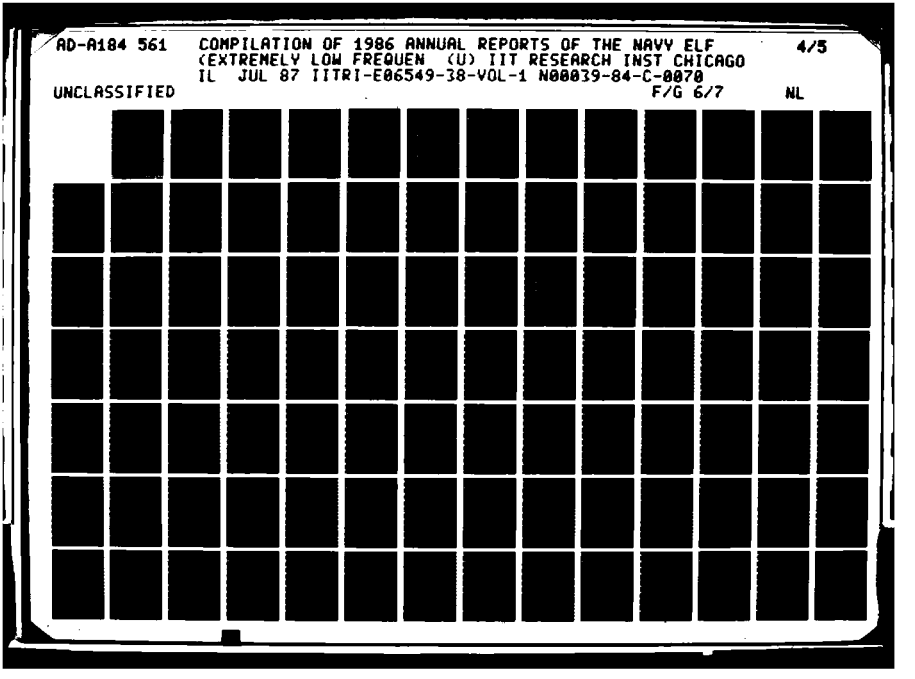
FIGURE 29. BULK PINE LITTER, CONTROL POLE-STAND
PROPORTION (X) OF INITIAL MASS REMAINING
Overall mass loss from bulk samples of freshly fallen pine litter disbursed in December on the Control Pole-stand subplot expressed as the proportion (x) of initial mass remaining over time during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
x : 1983-1984
o : 1984-1985
+ : 1985-1986

tables for bulk oak samples are presented as Tables 16 through 20, and the bulk oak data is represented in Figures 30 through 34. Analogous ANOVA tables for bulk maple samples are presented as Tables 21 through 25; the bulk maple data is represented in Figures 35 through 39. Bulk samples of all three species at all five study subplots decomposed significantly faster in 1985 than in 1986. However, the difference between years was remarkable only for maple, and especially so at the two pole-stand subplots. By the end of the 1986 field season, maple litter decomposition at each of the three plantation subplots caught up to the level achieved by the end of the 1985 field season.

Differences in dry matter mass loss pattern among the five study subplots and between sampling dates are being investigated. Two-way ANOVA tables representing bulk sample dry matter mass loss are presented for each year and species studied (Tables 26 and 27 for pine, Tables 28 and 29 for oak, and Tables 30 and 31 for maple). Significant differences between subplots developed during 1985 and 1986 for each litter species. Significant differences did not develop between subplots in the 1984 pine study, probably because 1) all samples were incubated in the antenna pole-stand subplot until establishment of the antenna and grou plantations in late June and 2) there were only three subplots compare since the control site had not been selected in time receive samples in December of 1983. ANOVA revealed the f ing points of interest.

A. Subplots

1. In 1986, bulk litter samples of all three spe posed significantly faster on the plantati on the pole-stand subplots (with the single e pine litter did not decompose faster tion subplot than on either pole stand


AD-A184 561 COMPILATION OF 1986 ANNUAL REPORTS OF THE NAVY ELF (EXTREMELY LOW FREQUEN (U) IIT RESEARCH INST CHICAGO IL JUL 87 IITRI-E06549-38-VOL-1 N00039-84-C-0070
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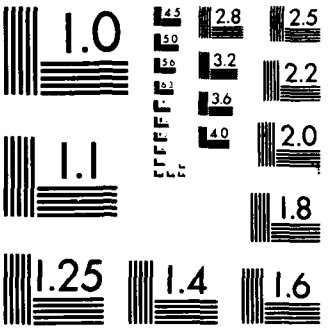


Table 16. Two-way ANOVA table for analysis of differences in dry matter mass loss (transformed to the arcsin square root of X) from bulk oak samples on the ground plantation subplot, by year and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	7	.184	68.298	.000
Year	1	.044	16.198	.000
Date	6	.209	77.495	.000
Two-way Interactions	6	.009	3.282	.007
Year x Date	6	.009	3.282	.007
Explained	13	.103	38.291	.000
Residual	71	.003		
Total	84	.018		

Table 17. Two-way ANOVA table for analysis of differences in dry matter mass loss (transformed to the arcsin square root of X) from bulk oak samples on the antenna plantation subplot, by year and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	7	.144	75.723	.000
Year	1	.028	14.560	.000
Date	6	.163	85.916	.000
Two-way Interactions	6	.007	3.554	.004
Year x Date	6	.007	3.554	.004
Explained	13	.080	42.414	.000
Residual	70	.002		
Total	83	.014		

Table 18. Two-way ANOVA table for analysis of differences in dry matter mass loss (transformed to the arcsin square root of X) from bulk oak samples on the antenna pole-stand subplot, by year and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	7	.121	55.623	.000
Year	1	.089	40.727	.000
Date	6	.127	58.105	.000
Two-way Interactions	6	.012	5.559	.000
Year x Date	6	.012	5.559	.000
Explained	13	.071	32.516	.000
Residual	70	.002		
Total	83	.013		

Table 19. Two-way ANOVA table for analysis of differences in dry matter mass loss (transformed to the arcsin square root of X) from bulk oak samples on the control plantation subplot, by year and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	7	.155	52.487	.000
Year	1	.178	6.015	.000
Date	6	.018	60.233	.017
Two-way Interactions	6	.004	1.508	.188
Year x Date	6	.004	1.508	.188
Explained	13	.086	28.958	.000
Residual	70	.003		
Total	83	.016		

Table 20. Two-way ANOVA table for analysis of differences in dry matter mass loss (transformed to the arcsin square root of X) from bulk oak samples on the control polestand subplot, by year and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	7	.183	221.582	0.0
Year	1	.099	119.504	0.0
Date	6	.197	238.595	.000
Two-way Interactions	6	.002	2.955	.013
Year x Date	6	.002	2.955	.013
Explained	13	.100	120.677	0.0
Residual	70	.001		
Total	83	.016		

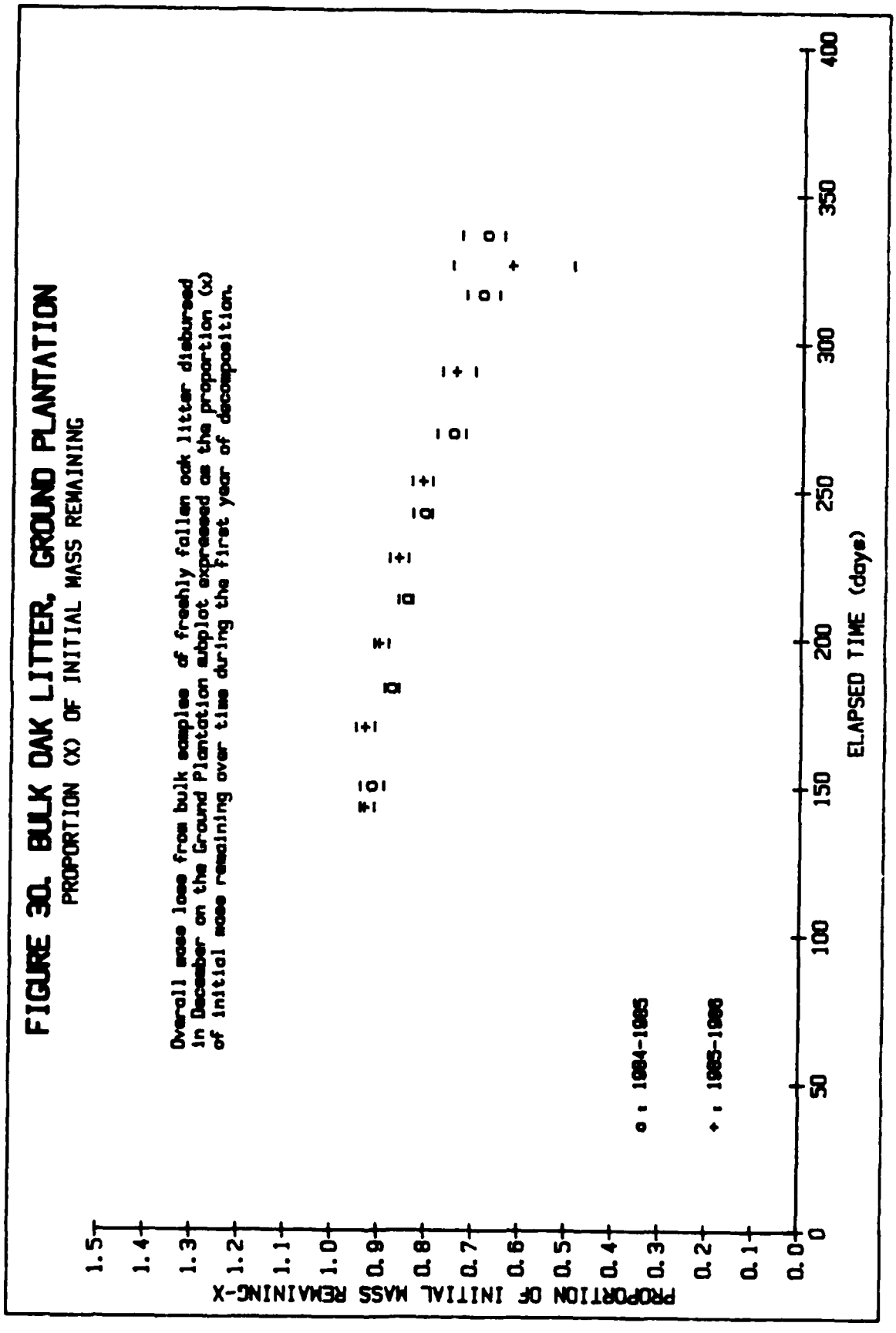


FIGURE 30. BULK OAK LITTER, GROUND PLANTATION
PROPORTION (X) OF INITIAL MASS REMAINING
Overall mass loss from bulk samples of freshly fallen oak litter disbursed in December on the Ground Plantation subplot expressed as the proportion (x) of initial mass remaining over time during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
o : 1984-1985
+ : 1985-1986

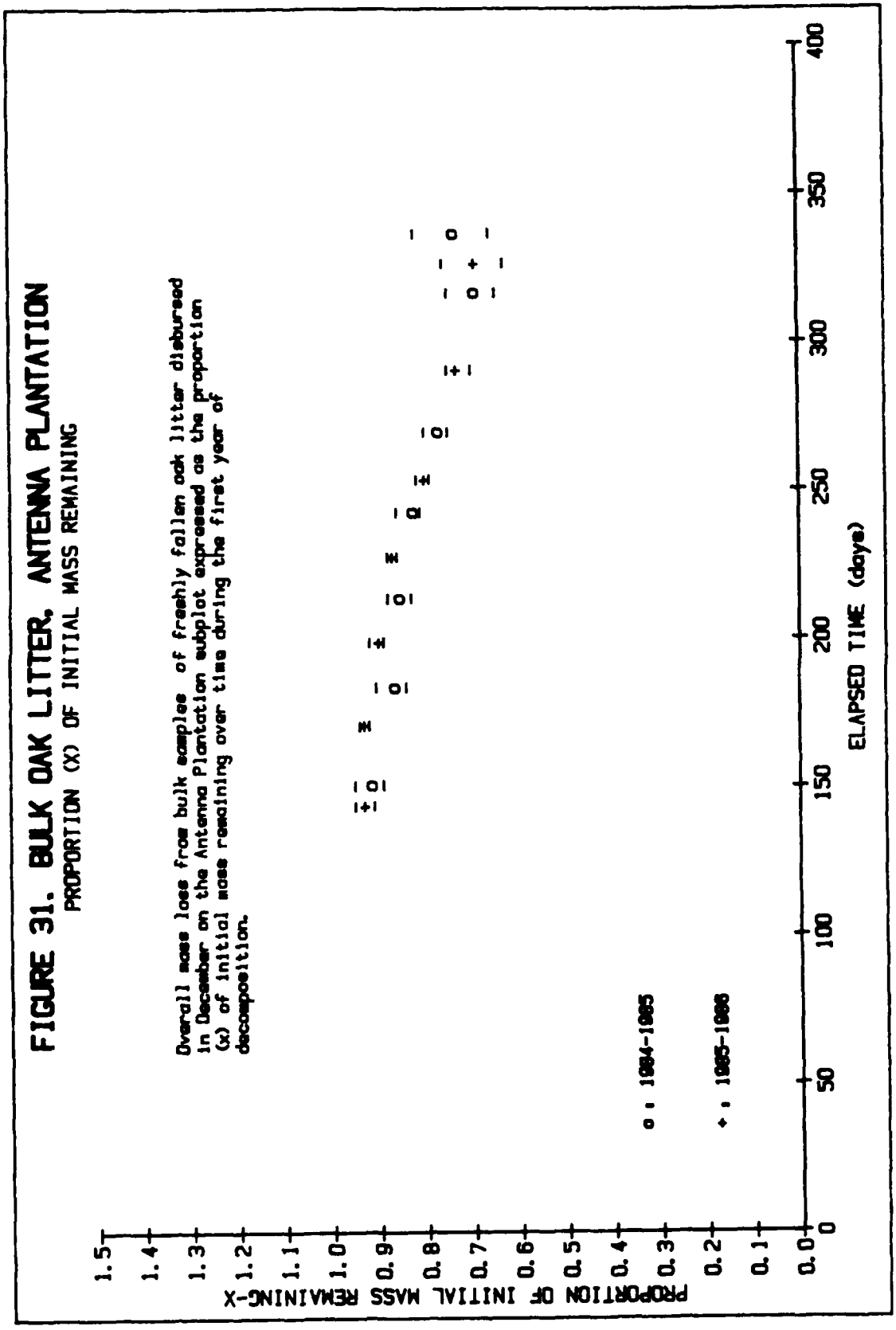


FIGURE 31. BULK OAK LITTER, ANTENNA PLANTATION
PROPORTION (X) OF INITIAL MASS REMAINING
Overall mass loss from bulk samples of freshly fallen oak litter disbursed in December on the Antenna Plantation subplot expressed as the proportion (x) of initial mass remaining over time during the first year of decomposition.
o : 1984-1985
+ : 1985-1986
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
0
50
100
150
200
250
300
350
400

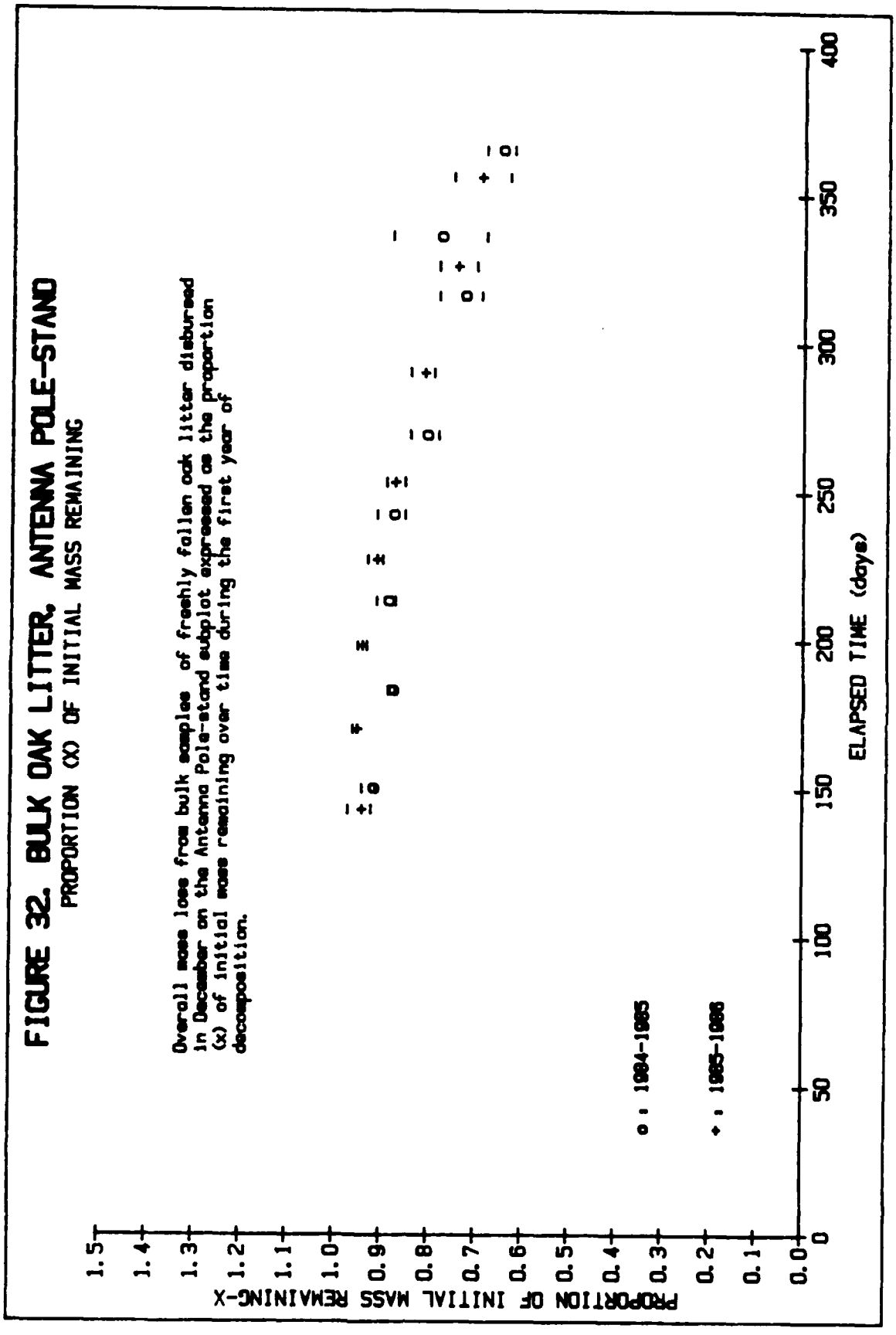


FIGURE 32. BULK OAK LITTER, ANTENNA POLE-STAND
PROPORTION (X) OF INITIAL MASS REMAINING
Overall mass loss from bulk samples of freshly fallen oak litter disbursed in December on the Antenna Pole-stand subplot expressed as the proportion (x) of initial mass remaining over time during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
o : 1984-1985
+ : 1985-1986
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
0
50
100
150
200
250
300
350
400

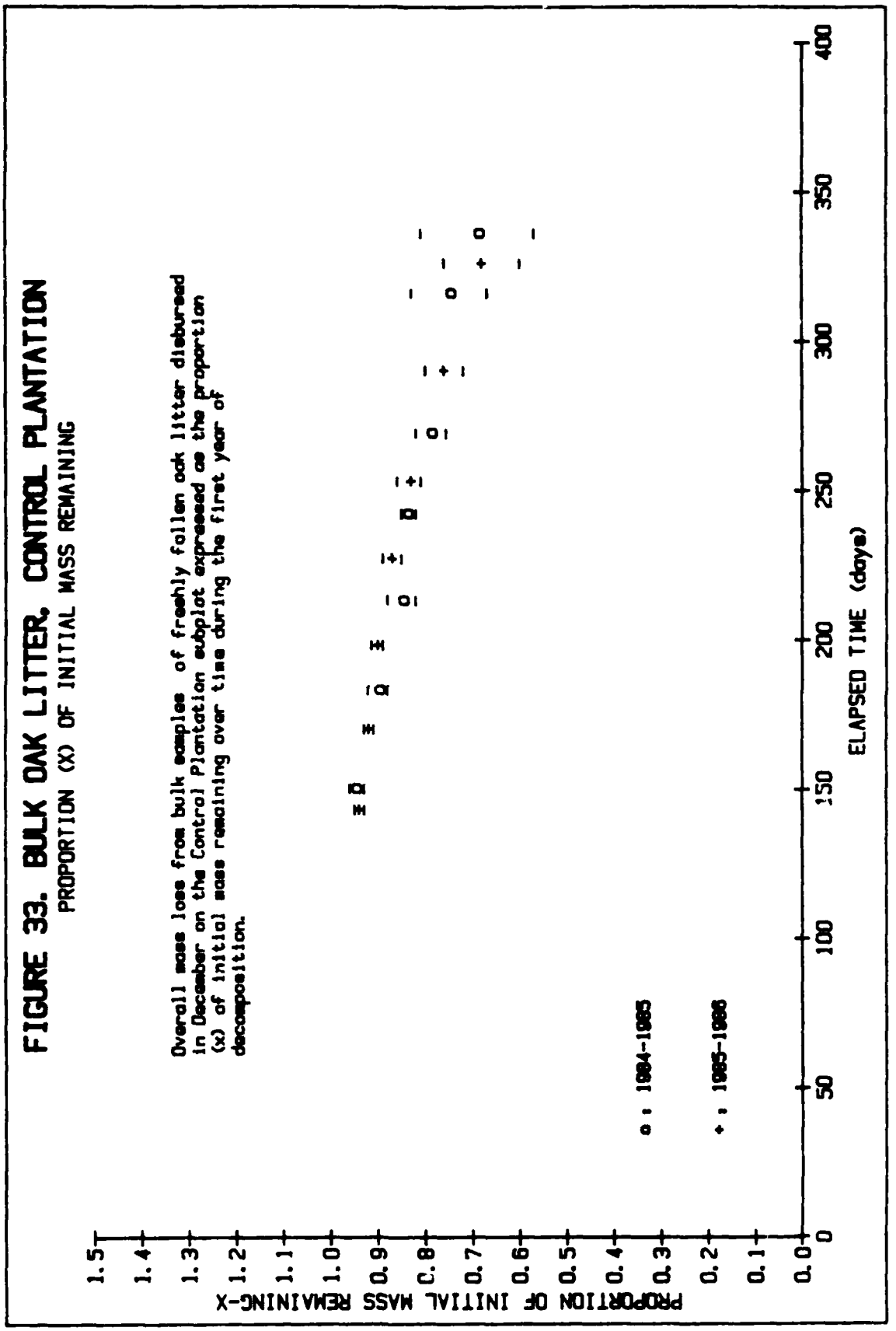


FIGURE 33. BULK OAK LITTER, CONTROL PLANTATION
PROPORTION (X) OF INITIAL MASS REMAINING
Overall mass loss from bulk samples of freshly fallen oak litter disbursed in December on the Control Plantation subplot expressed as the proportion (x) of initial mass remaining over time during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
o : 1984-1985
+ : 1985-1986
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
0
50
100
150
200
250
300
350
400

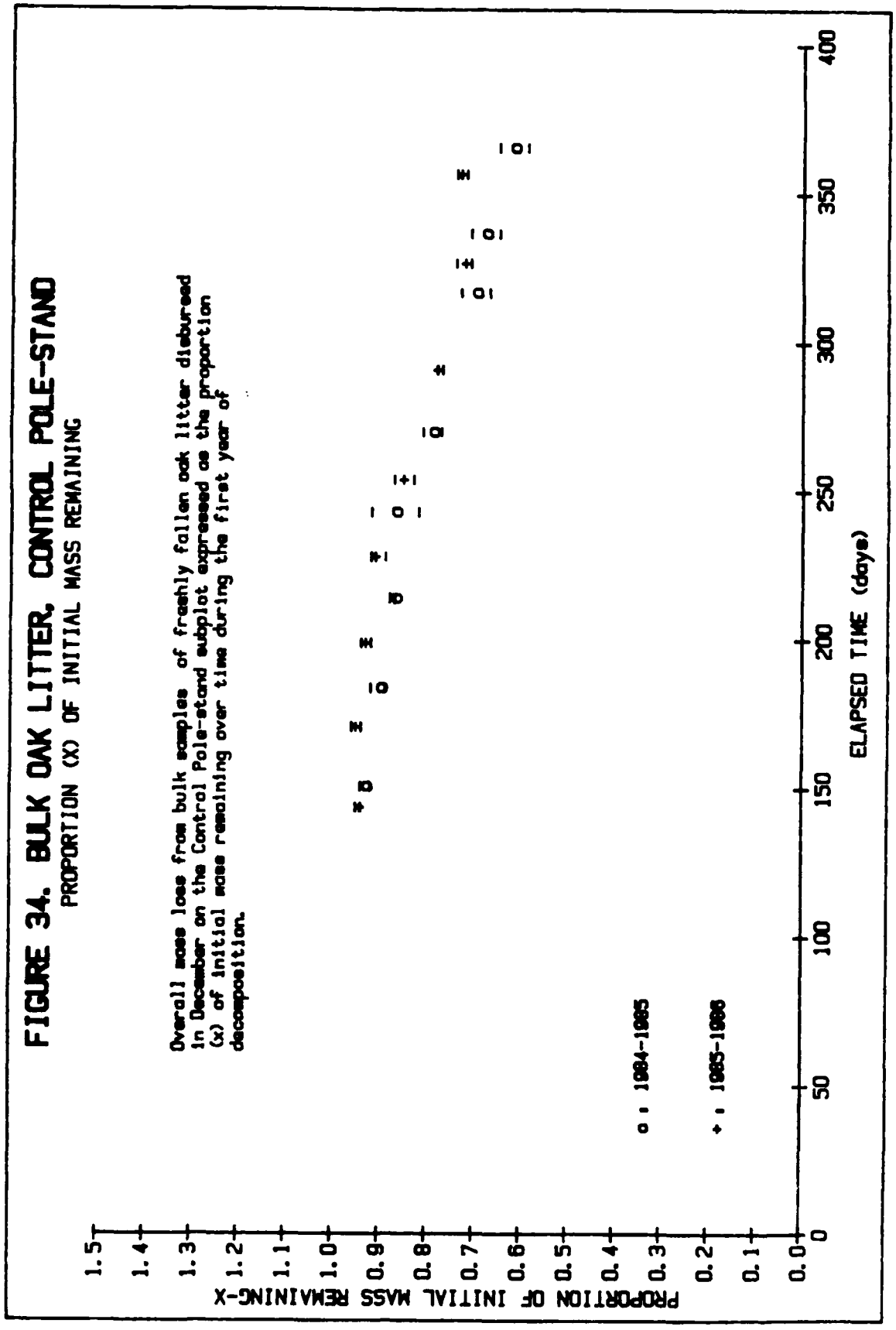


FIGURE 34. BULK OAK LITTER, CONTROL POLE-STAND
PROPORTION (X) OF INITIAL MASS REMAINING
Overall mass loss from bulk samples of freshly fallen oak litter disbursed in December on the Control Pole-stand subplot expressed as the proportion (x) of initial mass remaining over time during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
o : 1984-1985
+ : 1985-1986
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
0
50
100
150
200
250
300
350
400

Table 21. Two-way ANOVA table for analysis of differences in dry matter mass loss (transformed to the arcsin square root of X) from bulk maple samples on the ground plantation subplot, by year and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	7	.248	44.586	.000
Year	1	.495	88.811	.000
Date	6	.207	37.215	.000
Two-way Interactions	6	.028	4.953	.000
Year x Date	6	.028	4.953	.000
Explained	13	.146	26.294	.000
Residual	70	.006		
Total	83	.028		

Table 22. Two-way ANOVA table for analysis of differences in dry matter mass loss (transformed to the arcsin square root of X) from bulk maple samples on the antenna plantation subplot, by year and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	7	.190	73.249	.000
Year	1	.277	106.436	.000
Date	6	.176	67.718	.000
Two-way Interactions	6	.019	7.218	.000
Year x Date	6	.019	7.218	.000
Explained	13	.111	42.773	.000
Residual	70	.003		
Total	83	.020		

Table 23. Two-way ANOVA table for analysis of differences in dry matter mass loss (transformed to the arcsin square root of X) from bulk maple samples on the antenna pole-stand subplot, by year and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	7	.157	148.404	0.0
Year	1	.611	76.683	.000
Date	6	.081	578.727	.000
Two-way Interactions	6	.007	6.556	.000
Year x Date	6	.007	6.556	.000
Explained	13	.088	82.936	0.0
Residual	70	.001		
Total	83	.015		

Table 24. Two-way ANOVA table for analysis of differences in dry matter mass loss (transformed to the arcsin square root of X) from bulk maple samples on the control plantation subplot, by year and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	7	.150	49.594	.000
Year	1	.458	150.952	.000
Date	6	.097	32.039	.000
Two-way Interactions	6	.009	3.023	.011
Year x Date	6	.009	3.023	.011
Explained	13	.085	28.100	.000
Residual	69	.003		
Total	82	.016		

Table 25. Two-way ANOVA table for analysis of differences in dry matter mass loss (transformed to the arcsin square root of X) from bulk maple samples on the control pole-stand subplot, by year and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	7	.154	236.909	0.0
Year	1	.594	913.319	0.0
Date	6	.078	119.650	.000
Two-way Interactions	6	.004	6.497	.000
Year x Date	6	.004	6.497	.000
Explained	13	.085	130.565	0.0
Residual	69	.001		
Total	82	.014		

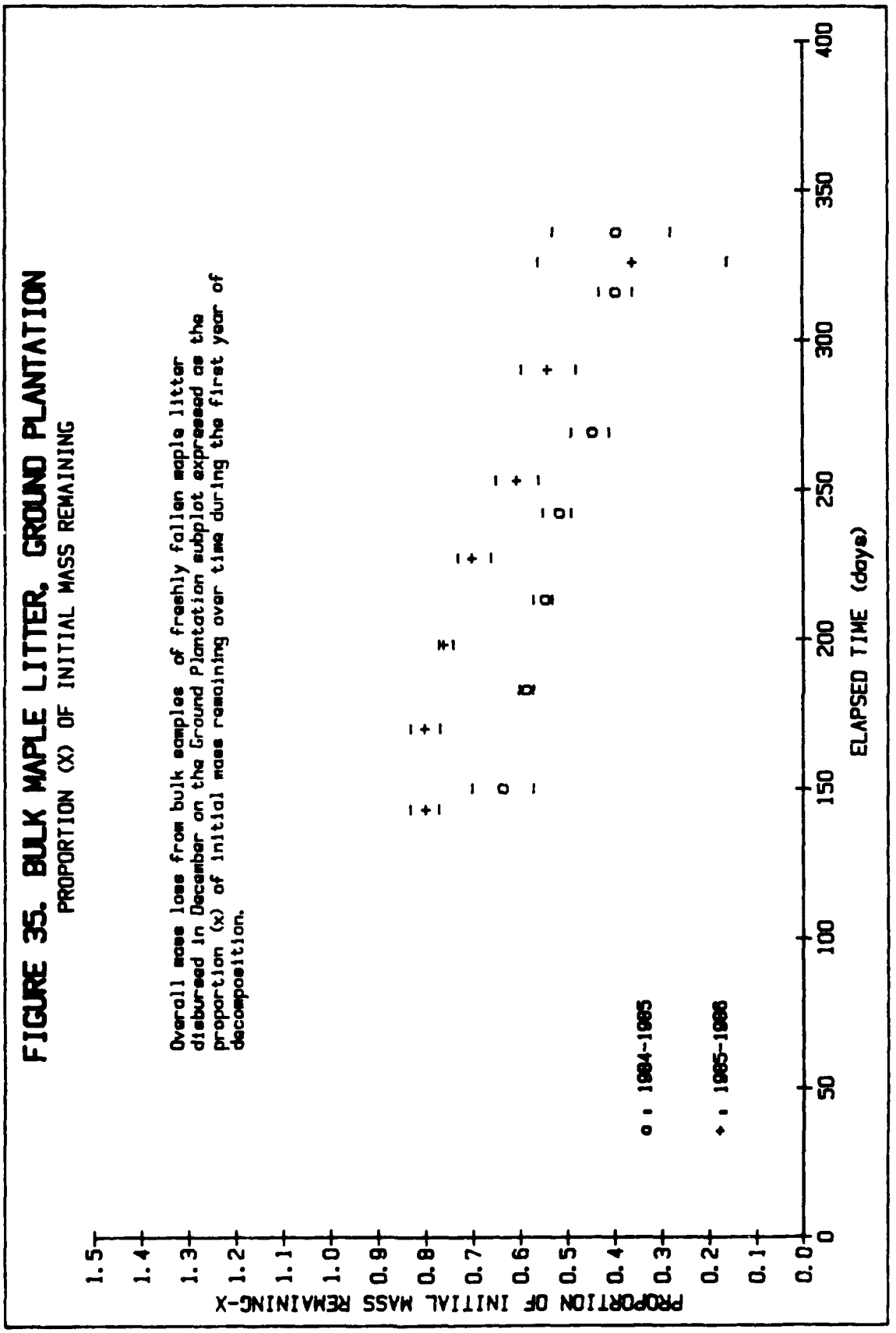


FIGURE 35. BULK MAPLE LITTER, GROUND PLANTATION
PROPORTION (X) OF INITIAL MASS REMAINING
Overall mass loss from bulk samples of freshly fallen maple litter disbursed in December on the Ground Plantation subplot expressed as the proportion (x) of initial mass remaining over time during the first year of decomposition.
o : 1984-1985
+ : 1985-1986
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
0
50
100
150
200
250
300
350
400

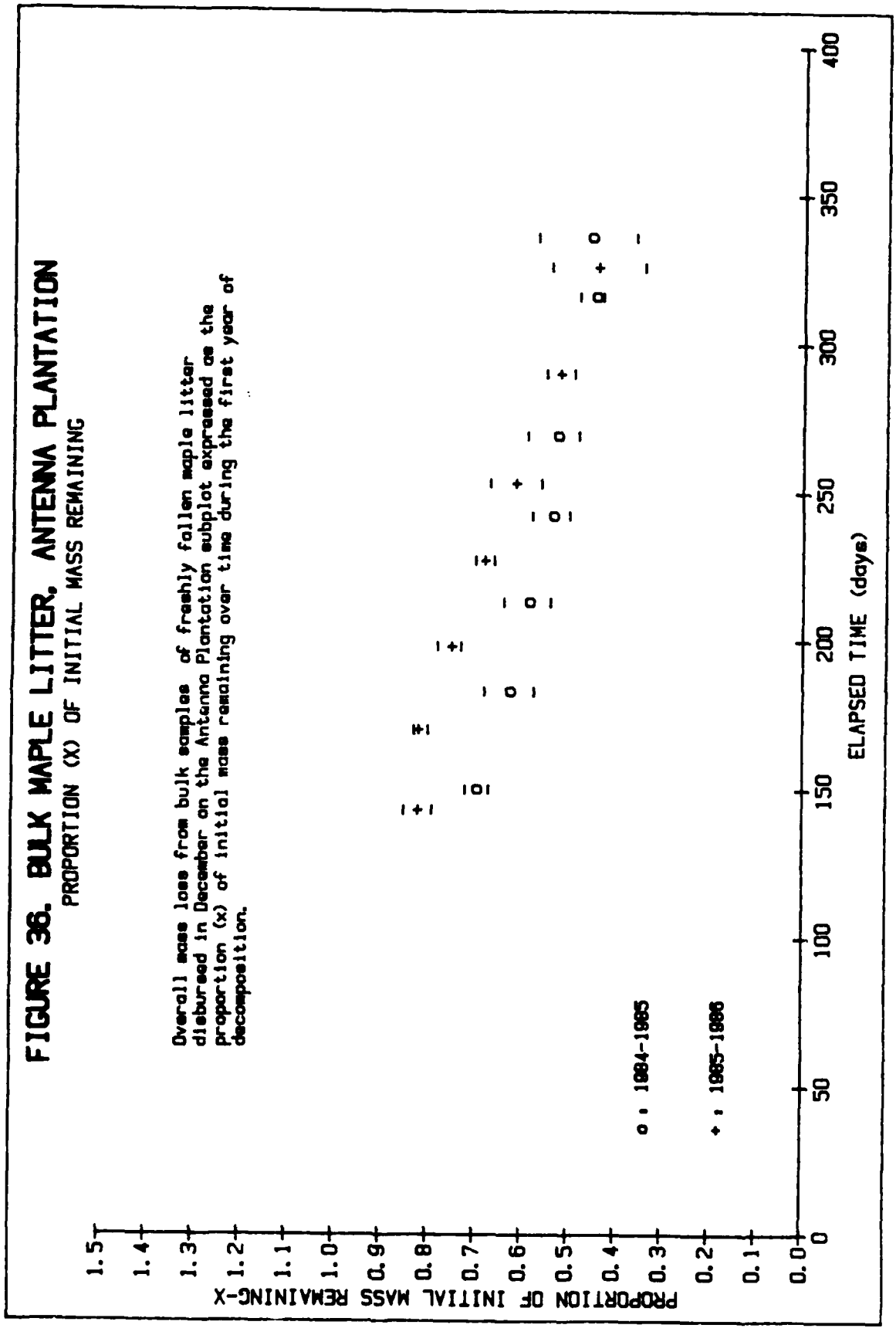


FIGURE 36. BULK MAPLE LITTER, ANTENNA PLANTATION
PROPORTION (X) OF INITIAL MASS REMAINING
Overall mass loss from bulk samples of freshly fallen maple litter disbursed in December on the Antenna Plantation subplot expressed as the proportion (x) of initial mass remaining over time during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
o : 1984-1985
+ : 1985-1986

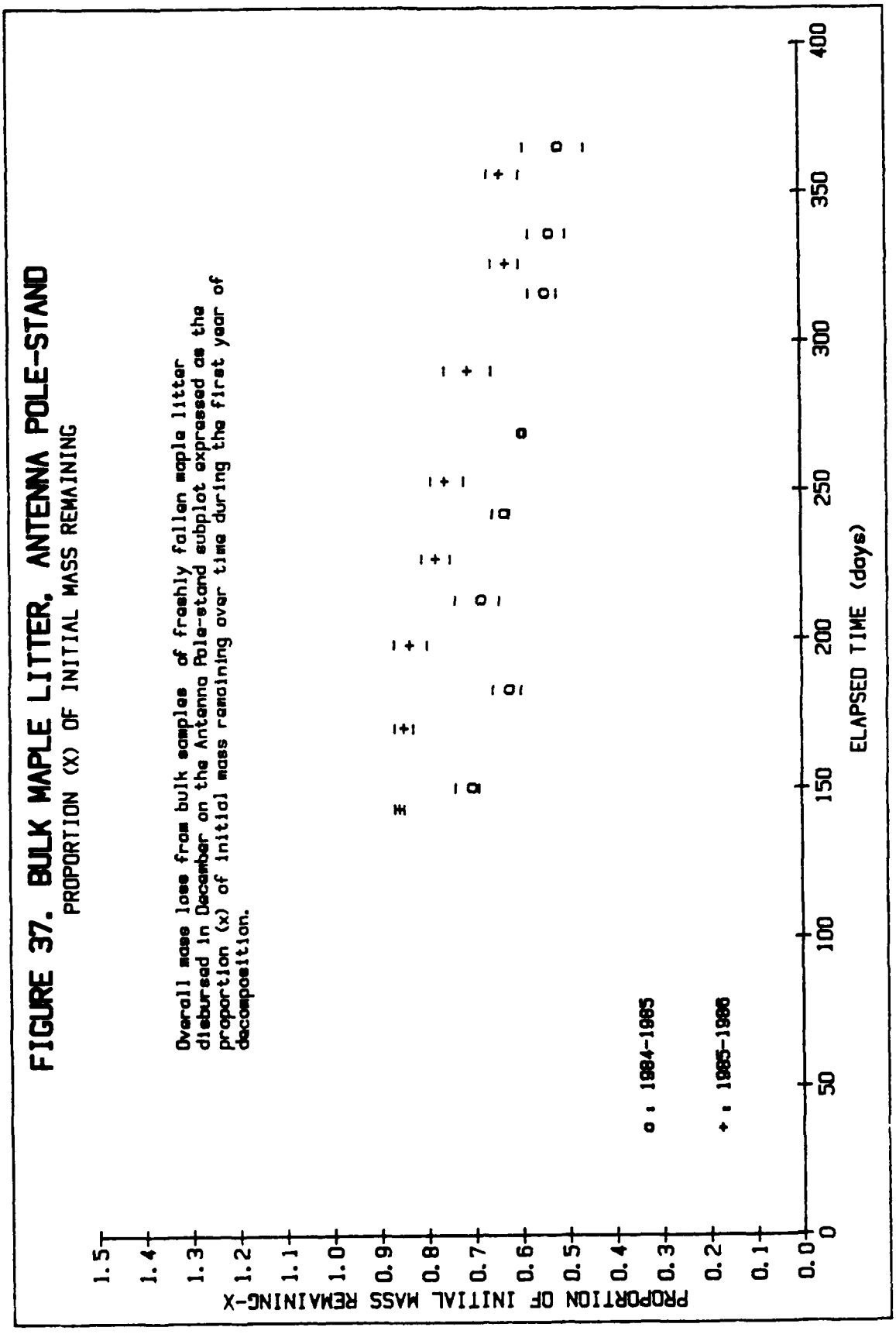


FIGURE 37. BULK MAPLE LITTER, ANTENNA POLE-STAND

PROPORTION (X) OF INITIAL MASS REMAINING

Overall mass loss from bulk samples of freshly fallen maple litter disbursed in December on the Antenna Pole-stand subplot expressed as the proportion (x) of initial mass remaining over time during the first year of decomposition.

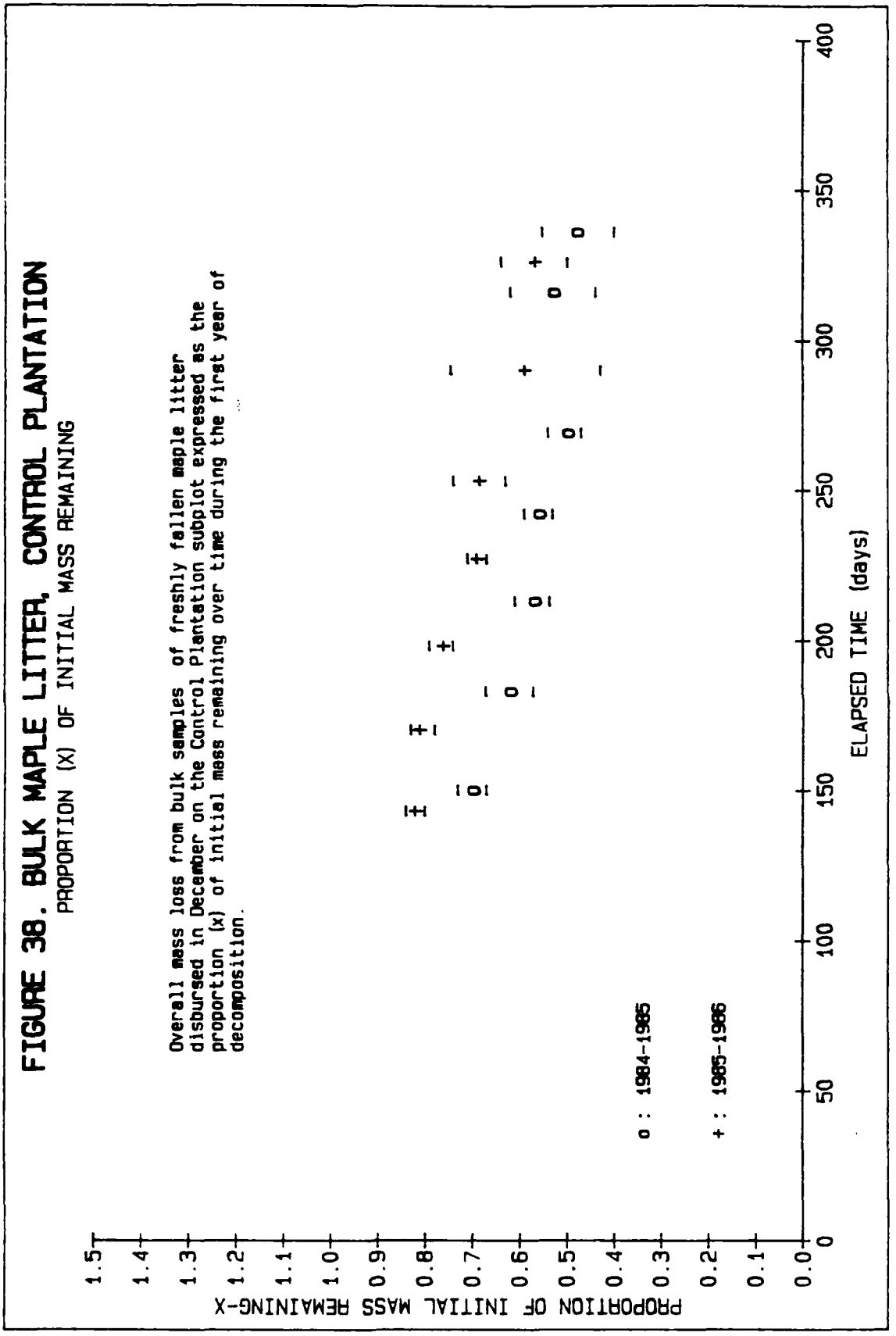


FIGURE 38. BULK MAPLE LITTER, CONTROL PLANTATION
PROPORTION (X) OF INITIAL MASS REMAINING
Overall mass loss from bulk samples of freshly fallen maple litter disbursed in December on the Control Plantation subplot expressed as the proportion (x) of initial mass remaining over time during the first year of decomposition.
o : 1984-1985
+ : 1985-1986
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
0
50
100
150
200
250
300
350
400

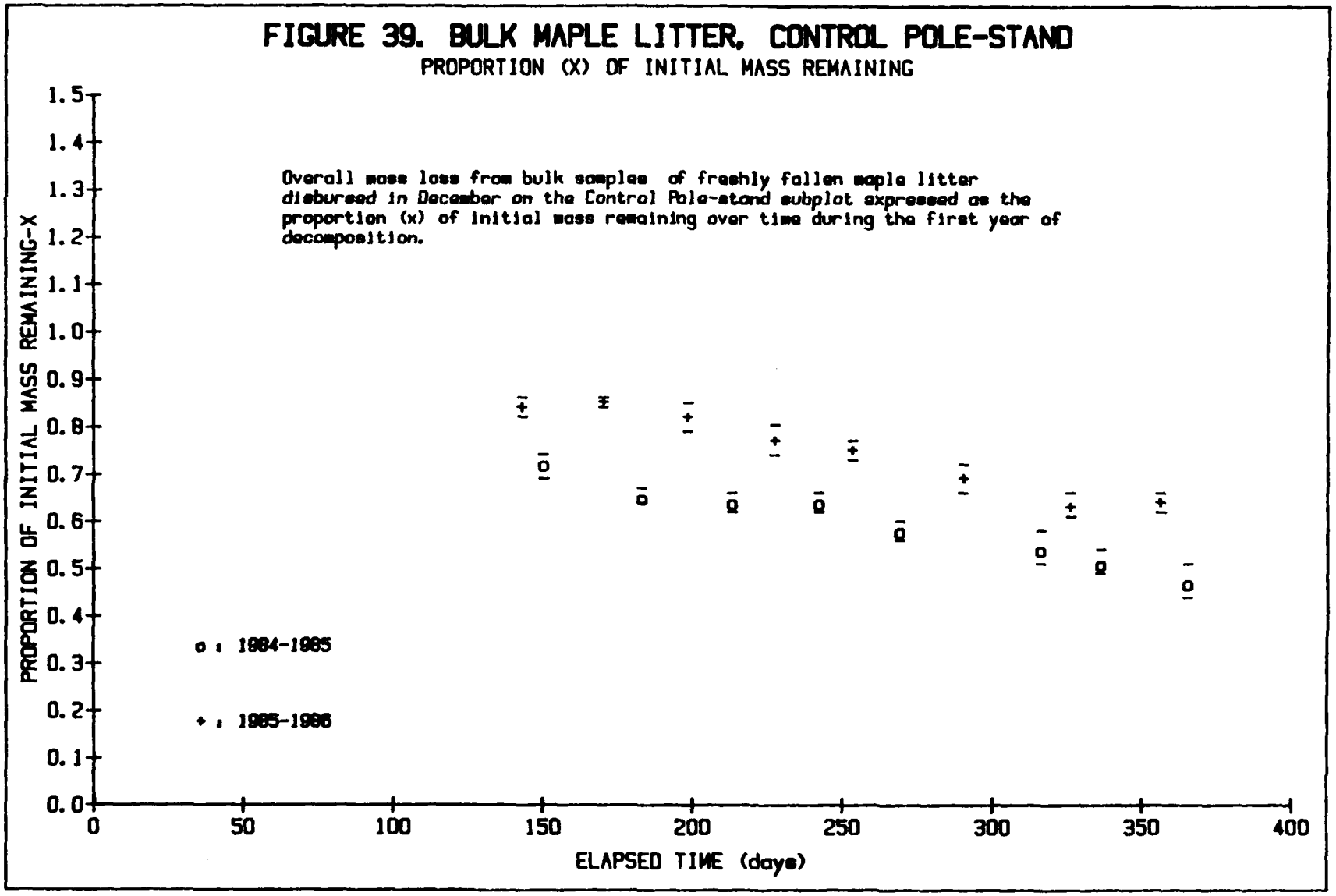


FIGURE 39. BULK MAPLE LITTER, CONTROL POLE-STAND
PROPORTION (X) OF INITIAL MASS REMAINING
Overall mass loss from bulk samples of freshly fallen maple litter disbursed in December on the Control Pole-stand subplot expressed as the proportion (x) of initial mass remaining over time during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING-X
1.5
1.4
1.3
1.2
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
o : 1984-1985
+ : 1985-1986
0
50
100
150
200
250
300
350
400
ELAPSED TIME (days)

Table 26. Two-way ANOVA table for analysis of differences in dry matter mass loss (transformed to the arcsin square root of X) from bulk pine samples, by subplot and sampling date during 1986.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	10	.205	221.087	0.0
Subplot	4	.010	11.026	.000
Date	6	.334	360.254	0.0
Two-way Interactions	24	.002	1.688	.030
Subplot x Date	24	.002	1.688	.030
Explained	34	.061	66.217	0.0
Residual	176	.001		
Total	210	.011		

Table 27. Two-way ANOVA table for analysis of differences in dry matter mass loss (transformed to the arcsin square root of X) from bulk pine samples, by subplot and sampling date during 1985.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	10	.142	174.208	0.0
Subplot	4	.008	9.496	.000
Date	6	.232	284.309	0.0
Two-way Interactions	24	.001	1.649	.036
Subplot x Date	24	.001	1.649	.036
Explained	34	.043	52.402	0.0
Residual	173	.001		
Total	207	.008		

Table 28. Two-way ANOVA table for analysis of differences in dry matter mass loss (transformed to the arcsin square root of X) from bulk oak samples, by subplot and sampling date during 1986.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	10	.329	193.399	0.0
Subplot	4	.048	27.987	0.0
Date	6	.514	302.152	0.0
Two-way Interactions	24	.002	.907	.593
Subplot x Date	24	.002	.907	.593
Explained	34	.098	57.522	0.0
Residual	176	.002		
Total	210	.017		

Table 29. Two-way ANOVA table for analysis of differences in dry matter mass loss (transformed to the arcsin square root of X) from bulk oak samples, by subplot and sampling date during 1985.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	10	.231	91.335	0.0
Subplot	4	.021	8.344	.000
Date	6	.371	146.662	0.0
Two-way Interactions	24	.004	1.750	.022
Subplot x Date	24	.004	1.750	.022
Explained	34	.071	28.098	0.0
Residual	175	.003		
Total	209	.014		

Table 30. Two-way ANOVA table for analysis of differences in dry matter mass loss (transformed to the arcsin square root of X) from bulk maple samples, by subplot and sampling date during 1986.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	10	.351	114.133	0.0
Subplot	4	.165	53.736	.000
Date	6	.475	154.512	0.0
Two-way Interactions	24	.010	3.140	.000
Subplot x Date	24	.010	3.140	.000
Explained	34	.110	35.785	0.0
Residual	174	.003		
Total	208	.021		

Table 31. Two-way ANOVA table for analysis of differences in dry matter mass loss (transformed to the arcsin square root of X) from bulk maple samples, by subplot and sampling date during 1985.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	10	.146	69.428	0.0
Subplot	4	.098	46.875	.000
Date	6	.179	85.239	0.0
Two-way Interactions	24	.003	1.629	.040
Subplot x Date	24	.003	1.629	.040
Explained	34	.045	21.570	0.0
Residual	174	.002		
Total	208	.009		

2. In 1985, maple litter decomposed fastest on the ground plantation, and faster on all three of the plantation subplots than in either pole-stand subplot. Oak litter decomposed faster on the ground plantation than anywhere else except the antenna plantation, and slower in the antenna pole-stand than anywhere else except the two control subplots. Pine litter, however, decomposed most slowly on the antenna plantation, and faster in the control pole-stand than in the control plantation.

B. Sampling Dates

1. In 1986, pine litter decomposition failed to progress significantly in June, oak litter decomposition failed to progress in May, and maple decomposition failed to progress significantly during May and October.
2. In 1985, pine litter failed to decompose significantly during June and October, oak litter during July and October, and maple during June and October.

While the results of multiple comparison testing between subplots for the 1984-85 and 1985-86 studies appear to be contradictory for pine (and to a lesser extent for oak), Figures 25-29 and 30-34 (for pine and oak respectively) demonstrate the striking similarity in decomposition progress for each species across both years at each of the five subplots. In fact, there appears to be little, if any, meaningful difference in the progress of either pine or oak litter decomposition, either between the two years or among the five study subplots. The detection of significant differences between subplots is due in part to the precision achieved by the method, but is probably also due to the fact that minor differences which develop between subplots tend to be carried for several months during which no differential adjustments occur. Only maple demonstrated apparently meaningful differences in decomposition progress between years and among subplots (Figures 35-39). Interestingly, the striking differences in maple decomposition between the two years dissipated by November at each of the plantation subplots, whereas the same differences

between years were maintained at the pole-stands into December.

Nutrient flux involved with bulk sample decomposition for each litter species has been determined for the 1984-85 study. For analysis, the nitrogen, phosphorus, potassium, calcium and magnesium content of retrieved litter samples are expressed as the proportion (X) of their original mass remaining at the time of sample retrieval. Bulk samples from the 1985-86 study currently await analysis. The nitrogen flux data for pine, oak and maple in the 1984-85 study are presented in Tables 32-34; analogous data for phosphorus are presented in Tables 35-37, for potassium in Tables 38-40, for calcium in Tables 41-43, and for magnesium in Tables 44-46. The nitrogen flux patterns for each species are compared for each subplot in Figures 40-44; analogous representations of the data for the other elements are presented in Figures 45-49 for phosphorus, 50-54 for potassium, 55-59 for calcium, and 60-64 for magnesium.

Preliminary analyses of nutrient flux data for this report were conducted on the untransformed raw data as presented in Tables 32-46. Two-way ANOVA tables representing analyses of nitrogen, phosphorus, potassium, calcium and magnesium flux from bulk pine samples at the antenna pole-stand by year (1984 vs 1985 field seasons) and sampling date (early May through early November) are presented in Tables 47-51. Pine was the only litter species included in the 1983-84 study. Also, the antenna pole-stand is the only appropriate subplot for comparison between the 1984 and 1985 field seasons, because the plantation subplots were not cleared until June of 1984 and the control site was not finally selected until the winter of 1983-84. Because the nitrogen data set for the 1983-84 study is incomplete (lacking data for May through July, 1984), the nitrogen ANOVA covers the period from early August through early November. Two points stand out in this analysis of between-year differences in pine litter nutrient flux.

Table 32. Mean proportion[a] of initial total nitrogen mass remaining at different times in 1985, for bulk red pine foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot					
	Plantation			Pole-stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
30 April	1.01	0.05	5	1.06	0.14	13
2 June	1.00	0.05	5	1.05	0.07	7
2 July	1.09	0.08	8	1.22	0.08	7
31 July	1.01	0.07	7	1.17	0.14	12
27 August	1.10	0.05	5	1.01	0.06	7
12 October	1.21	0.13	11	1.17	0.18	16
2 November	0.63	0.49	82	1.06	0.11	11
1 December				1.13	0.14	13

Table 32. (cont)

Sampling Date	Control Plot					
	Plantation			Pole-stand		
	Mean	S.D	%	Mean	S.D	%
30 April	1.15	0.17	15	0.98	0.08	8
2 June	1.09	0.08	8	0.97	0.15	19
2 July	1.13	0.07	7	1.07	0.09	9
31 July	1.18	0.11	9	1.01	0.08	9
27 August	1.60	0.32	21	1.30	0.20	16
12 October	1.43	0.22	16	1.06	0.14	14
2 November	1.30	0.08	6	1.15	0.09	10
1 December				1.22	0.13	12

Table 32. (cont)

Sampling Date	Ground		
	Plantation		
	Mean	S.D.	%
30 April	0.98	0.07	
2 June	0.96	0.09	10
2 July	1.14	0.10	9
31 July	0.99	0.07	7
27 August	1.03	0.06	6
12 October	1.27	0.13	11
2 November	0.45	0.20	48
1 December			

a/ Proportion ($X = 1/M_0$), where M_0 and M_1 are the percent N content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.
b/ standard deviation
c/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,5} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 33. Mean proportion[a] of initial total nitrogen mass remaining at different times in 1985, for bulk red oak foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot					
	Plantation			Pole-stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
30 April	1.09	0.08	7	1.19	0.12	11
2 June	1.22	0.16	14	1.28	0.10	8
2 July	1.20	0.13	11	1.35	0.13	10
31 July	1.17	0.04	4	1.22	0.06	5
27 August	0.94	0.07	7	0.94	0.09	10
12 October	0.84	0.30	38	1.07	0.59	58
2 November	1.08	0.12	11	1.23	0.14	12
1 December				0.94	0.14	16

Table 33. (cont)

Sampling Date	Control Plot					
	Plantation			Pole-stand		
	Mean	S.D	%	Mean	S.D	%
30 April	1.13	0.12	11	1.17	0.12	11
2 June	1.11	0.07	6	1.13	0.12	11
2 July	1.18	0.06	5	1.30	0.04	3
31 July	1.23	0.07	6	1.23	0.10	9
27 August	1.02	0.06	6	1.04	0.07	7
12 October	1.10	0.46	44	1.50	0.34	24
2 November	1.02	0.15	15	1.00	0.08	9
1 December				0.89	0.07	9

Table 33. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
30 April	1.11	0.08	8
2 June	1.09	0.03	3
2 July	1.17	0.09	8
31 July	1.28	0.19	16
27 August	0.95	0.09	10
12 October	0.76	0.23	32
2 November	1.07	0.11	11
1 December			

a/ Proportion ($X = 1/M_0$), where M_0 and M_1 are the percent N content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.
b/ standard deviation
c/ detectable difference: the estimated shift in each mean value 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 ($n = 6$)

Table 34. Mean proportion[a] of initial total nitrogen mass remaining at different times in 1985, for bulk red maple foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot					
	Plantation			Pole-stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
30 April	0.93	0.10	11	1.13	0.14	13
2 June	1.04	0.11	11	1.17	0.09	8
2 July	1.08	0.14	14	1.24	0.09	7
31 July	0.96	0.12	13	1.18	0.09	8
27 August	0.98	0.15	16	1.32	0.30	24
12 October	0.97	0.18	19	1.24	0.06	5
2 November	1.28	0.35	29	1.31	0.14	11
1 December				1.29	0.32	27

Table 34. (cont)

Sampling Date	Control Plot					
	Plantation			Pole-stand		
	Mean	S.D	%	Mean	S.D	%
30 April	1.06	0.14	14	1.04	0.05	6
2 June	1.13	0.11	10	1.18	0.10	9
2 July	1.12	0.07	6	1.25	0.07	6
31 July	1.13	0.11	10	1.20	0.07	6
27 August	1.14	0.11	10	1.49	0.06	4
12 October	1.42	0.10	8	1.38	0.21	16
2 November	1.57	0.29	19	1.51	0.26	18
1 December				1.21	0.12	10

Table 34. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
30 April	0.94	0.05	6
2 June	0.91	0.08	9
2 July	0.96	0.08	9
31 July	0.95	0.07	8
27 August	0.99	0.12	13
12 October	0.99	0.09	10
2 November	1.18	0.28	25
1 December			

a/ Proportion ($X = 1/M_0$), where M_0 and M_t are the percent N content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.
b/ standard deviation
c/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,5} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 35. Mean proportion[a] of initial total phosphorus mass remaining at different times in 1985, for bulk red pine foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot					
	Plantation			Pole-stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
30 April	1.13	0.03	3	1.13	0.15	13
2 June	1.09	0.05	5	1.09	0.08	8
2 July	0.97	0.06	7	1.16	0.12	11
31 July	0.98	0.08	8	1.20	0.16	14
27 August	0.94	0.10	11	0.89	0.09	10
12 October	1.58	0.11	8	1.64	0.12	7
2 November	1.48	0.59	42	1.45	0.12	8
1 December				1.43	0.17	12

Table 35. (cont)

Sampling Date	Control Plot					
	Plantation			Pole-stand		
	Mean	S.D	%	Mean	S.D	%
30 April	1.26	0.08	7	0.97	0.12	13
2 June	1.09	0.11	11	0.93	0.19	25
2 July	1.03	0.04	4	0.97	0.07	8
31 July	1.09	0.12	12	0.99	0.15	16
27 August	1.38	0.35	27	1.28	0.18	15
12 October	1.84	0.20	11	1.47	0.12	9
2 November	1.44	0.07	5	1.50	0.06	5
1 December				1.70	0.14	8

Table 35. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
30 April	1.00	0.07	7
2 June	0.91	0.09	10
2 July	0.97	0.10	11
31 July	0.97	0.06	6
27 August	0.84	0.08	10
12 October	1.12	0.19	18
2 November	0.94	0.41	45
1 December			

a/ Proportion ($X = 1/M_0$), where M_0 and M_1 are the percent P content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.
b/ standard deviation
c/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,5} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 36. Mean proportion[a] of initial total phosphorus mass remaining at different times in 1985, for bulk red oak foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot					
	Plantation			Pole-stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
30 April	0.54	0.12	24	0.79	0.07	10
2 June	0.58	0.19	34	0.78	0.07	9
2 July	0.61	0.19	32	0.78	0.13	18
31 July	0.57	0.08	14	0.72	0.08	12
27 August	0.77	0.13	18	1.00	0.14	14
12 October	0.57	0.24	45	1.10	0.42	41
2 November	0.67	0.07	12	1.01	0.16	16
1 December				0.79	0.14	19

Table 36. (cont)

Sampling Date	Control Plot					
	Plantation			Pole-stand		
	Mean	S.D	%	Mean	S.D	%
30 April	0.69	0.06	10	0.79	0.04	6
2 June	0.62	0.07	12	0.75	0.08	11
2 July	0.58	0.04	7	0.76	0.07	9
31 July	0.69	0.03	4	0.73	0.04	6
27 August	0.92	0.04	5	0.86	0.21	25
12 October	1.04	0.32	33	1.16	0.17	15
2 November	0.93	0.30	34	1.12	0.16	15
1 December				0.87	0.07	8

Table 36. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
30 April	0.57	0.10	18
2 June	0.58	0.08	15
2 July	0.58	0.05	8
31 July	0.71	0.08	12
27 August	0.90	0.15	17
12 October	0.54	0.06	12
2 November	0.65	0.06	10
1 December			

a/ Proportion ($X = 1/M_0$), where M_0 and M_1 are the percent P content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.
b/ standard deviation
c/ detectable difference: the estimated shift in each mean value 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 ($n = 6$)

Table 37. Mean proportion[a] of initial total phosphorus mass remaining at different times in 1985, for bulk red maple foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot					
	Plantation			Pole-stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
30 April	0.51	0.11	23	0.73	0.10	14
2 June	0.56	0.08	15	0.70	0.06	9
2 July	0.51	0.07	15	0.69	0.07	11
31 July	0.51	0.08	16	0.68	0.06	9
27 August	0.57	0.20	36	0.82	0.14	18
12 October	0.50	0.10	21	0.78	0.06	8
2 November	0.64	0.16	27	0.90	0.16	19
1 December				0.81	0.20	26

Table 37. (cont)

Sampling Date	Control Plot					
	Plantation			Pole-stand		
	Mean	S.D	%	Mean	S.D	%
30 April	0.67	0.16	24	0.76	0.05	9
2 June	0.66	0.12	18	0.75	0.11	15
2 July	0.55	0.05	9	0.81	0.09	12
31 July	0.59	0.06	11	0.78	0.08	10
27 August	0.71	0.08	11	0.98	0.12	12
12 October	0.88	0.14	16	0.96	0.17	18
2 November	0.97	0.19	21	1.07	0.10	10
1 December				0.81	0.07	9

Table 37. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
30 April	0.48	0.05	11
2 June	0.47	0.06	14
2 July	0.50	0.04	9
31 July	0.51	0.02	5
27 August	0.65	0.06	9
12 October	0.56	0.08	15
2 November	0.68	0.24	37
1 December			

a/ Proportion ($X = M_1/M_0$), where M_0 and M_1 are the percent P content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.
b/ standard deviation
c/ detectable difference: the estimated shift in each mean value 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 ($n = 6$)

Table 38. Mean proportion[a] of initial total potassium mass remaining at different times in 1985, for bulk red pine foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot					
	Plantation			Pole-stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
30 April	0.62	0.06	10	0.60	0.07	13
2 June	0.49	0.06	13	0.52	0.03	6
2 July	0.49	0.10	23	0.68	0.05	8
31 July	0.51	0.11	22	0.67	0.09	15
27 August	0.46	0.10	22	0.44	0.02	5
12 October	0.34	0.06	19	0.37	0.04	11
2 November	0.31	0.08	26	0.42	0.07	18
1 December				0.44	0.09	20

Table 38. (cont)

Sampling Date	Control Plot					
	Plantation			Pole-stand		
	Mean	S.D	%	Mean	S.D	%
30 April	0.70	0.11	17	0.72	0.09	14
2 June	0.52	0.07	15	0.59	0.10	22
2 July	0.48	0.04	9	0.56	0.06	11
31 July	0.50	0.09	19	0.64	0.22	36
27 August	0.43	0.06	14	0.42	0.06	16
12 October	0.51	0.12	25	0.48	0.06	12
2 November	0.52	0.21	44	0.57	0.10	23
1 December				0.58	0.14	25

Table 38. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
30 April	0.48	0.06	12
2 June	0.35	0.03	9
2 July	0.40	0.05	12
31 July	0.37	0.04	11
27 August	0.38	0.10	27
12 October	0.47	0.14	33
2 November	0.55	0.21	40
1 December			

a/ Proportion ($X = 1/M_0$), where M_0 and M_1 are the percent K content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.
b/ standard deviation
c/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,5} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 39. Mean proportion[a] of initial total potassium mass remaining at different times in 1985, for bulk red oak foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot					
	Plantation			Pole-stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
30 April	0.35	0.13	39	0.57	0.06	12
2 June	0.41	0.13	33	0.57	0.21	38
2 July	0.54	0.09	17			
31 July	0.30	0.07	26	0.47	0.08	18
27 August	0.47	0.13	29	0.69	0.07	11
12 October	0.52	0.14	28	0.98	0.06	6
2 November	0.53	0.08	16	0.72	0.13	18
1 December				0.62	0.10	18

Table 39. (cont)

Sampling Date	Control Plot					
	Plantation			Pole-stand		
	Mean	S.D	%	Mean	S.D	%
30 April	0.48	0.08	18	0.62	0.10	17
2 June	0.47	0.04	9	0.66	0.05	8
2 July	0.55	0.05	10	0.72	0.14	21
31 July	0.42	0.03	8	0.52	0.10	19
27 August	0.58	0.05	9	0.62	0.10	17
12 October	1.21	0.59	51	1.03	0.09	9
2 November	0.64	0.12	20	0.89	0.13	15
1 December				0.69	0.09	13

Table 39. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
30 April	0.40	0.12	31
2 June	0.48	0.04	9
2 July	0.50	0.03	6
31 July	0.64	0.32	53
27 August	0.48	0.14	31
12 October	0.51	0.09	18
2 November	0.57	0.11	21
1 December			

a/ Proportion ($X = 1/M_0$), where M_0 and M_t are the percent K content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.
b/ standard deviation
c/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,5} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 40. Mean proportion[a] of initial total potassium mass remaining at different times in 1985, for bulk red maple foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot					
	Plantation			Pole-stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
30 April	0.09	0.03	38	0.16	0.02	13
2 June	0.08	0.02	19	0.12	0.01	9
2 July	0.07	0.01	21	0.17	0.03	17
31 July	0.06	0.01	15	0.12	0.01	13
27 August	0.06	0.01	8	0.10	0.01	13
12 October	0.07	0.02	25	0.11	0.01	11
2 November	0.08	0.04	53	0.09	0.02	26
1 December				0.08	0.03	36

Table 40. (cont)

Sampling Date	Control Plot					
	Plantation			Pole-stand		
	Mean	S.D	%	Mean	S.D	%
30 April	0.11	0.02	18	0.22	0.04	22
2 June	0.09	0.02	21	0.15	0.01	7
2 July	0.08	0.01	16	0.17	0.04	24
31 July	0.10	0.03	31	0.15	0.03	20
27 August	0.10	0.03	36	0.13	0.02	18
12 October	0.16	0.07	49	0.12	0.02	21
2 November	0.12	0.04	37	0.16	0.01	6
1 December				0.10	0.01	12

Table 40. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
30 April	0.09	0.02	18
2 June	0.08	0.01	15
2 July	0.07	0.01	10
31 July	0.10	0.04	41
27 August	0.06	0.01	15
12 October	0.08	0.02	26
2 November	0.08	0.02	33
1 December			

a/ Proportion ($X = 1/M_0$), where M_0 and M_1 are the percent K content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.
b/ standard deviation
c/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,5} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 41. Mean proportion[a] of initial total calcium mass remaining at different times in 1985, for bulk red pine foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot					
	Plantation			Pole-stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
30 April	1.14	0.06	6	1.10	0.06	6
2 June	1.02	0.03	3	0.96	0.05	5
2 July	0.99	0.06	7	0.96	0.05	5
31 July	0.98	0.07	8	0.99	0.06	6
27 Auguet	0.96	0.10	11	1.07	0.05	5
12 October	0.99	0.09	9	1.04	0.06	6
2 November	0.98	0.08	9	1.10	0.05	5
1 December				1.04	0.05	5

Table 41. (cont)

Sampling Date	Control Plot					
	Plantation			Pole-stand		
	Mean	S.D	%	Mean	S.D	%
30 April	1.05	0.07	7	0.97	0.10	10
2 June	0.92	0.09	10	0.89	0.09	13
2 July	0.97	0.07	8	0.89	0.11	13
31 July	0.95	0.04	4	0.87	0.09	11
27 August	1.01	0.06	6	0.91	0.05	6
12 October	0.98	0.05	5	0.94	0.06	7
2 November	0.91	0.05	6	0.96	0.09	12
1 December				0.99	0.02	2

Table 41. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
30 April	1.12	0.06	5
2 June	1.10	0.06	6
2 July	0.97	0.08	9
31 July	1.04	0.06	6
27 August	1.04	0.05	5
12 October	1.00	0.03	3
2 November	1.04	0.11	11
1 December			

a/ Proportion ($X = 1/M_0$), where M_0 and M_1 are the percent Ca content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.
b/ standard deviation
c/ detectable difference: the estimated shift in each mean value 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 ($n = 6$)

Table 42. Mean proportion[a] of initial total calcium mass remaining at different times in 1985, for bulk red oak foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot: Plantation Mean[a]	S.D.[b]	%[c]	Antenna Plot: Pole-stand Mean	S.D.	%
30 April	0.97	0.11	12	0.99	0.05	5
2 June	0.95	0.06	6	1.01	0.07	7
2 July	0.95	0.03	3			
31 July	0.98	0.11	12	1.06	0.06	5
27 August	0.88	0.08	10	0.97	0.03	4
12 October	0.83	0.09	11	0.92	0.03	4
2 November	0.79	0.05	7	0.89	0.04	4
1 December				0.79	0.08	11

Table 42. (cont)

Sampling Date	Control Plot: Plantation Mean	S.D	%	Control Plot: Pole-stand Mean	S.D	%
30 April	0.97	0.04	5	0.97	0.05	6
2 June	1.00	0.06	6	1.00	0.06	7
2 July	1.01	0.04	4	1.00	0.04	4
31 July	1.02	0.05	5	1.07	0.05	5
27 August	0.92	0.06	7	0.85	0.10	12
12 October	0.91	0.07	8	0.92	0.07	8
2 November	0.80	0.13	17	0.84	0.04	5
1 December				0.84	0.06	8

Table 42. (cont)

Sampling Date	Ground Plot: Plantation Mean	S.D.	%
30 April	0.97	0.04	4
2 June	1.02	0.05	5
2 July	0.96	0.06	6
31 July	0.98	0.06	6
27 August	0.99	0.23	25
12 October	0.86	0.06	7
2 November	0.83	0.10	12
1 December			

a/ Proportion ($X = 1/M_0$), where M_0 and M_t are the percent Ca content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.
b/ standard deviation
c/ detectable difference: the estimated shift in each mean value 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 ($n = 6$)

Table 43. Mean proportion[a] of initial total calcium mass remaining at different times in 1985, for bulk red maple foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot					
	Plantation			Pole-stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
30 April	1.04	0.13	13	1.03	0.04	4
2 June	0.81	0.08	11	0.86	0.04	5
2 July	0.81	0.09	12	0.91	0.04	4
31 July	0.69	0.08	12	0.86	0.06	8
27 August	0.71	0.09	14	0.81	0.02	3
12 October	0.56	0.10	18	0.70	0.05	8
2 November	0.57	0.09	16	0.68	0.05	8
1 December				0.69	0.11	16

Table 43. (cont)

Sampling Date	Control Plot					
	Plantation			Pole-stand		
	Mean	S.D	%	Mean	S.D	%
30 April	0.86	0.07	9	0.70	0.03	6
2 June	0.77	0.11	15	0.68	0.03	4
2 July	0.68	0.13	20	0.65	0.02	4
31 July	0.69	0.12	18	0.66	0.03	5
27 August	0.61	0.15	26	0.63	0.10	16
12 October	0.56	0.07	13	0.65	0.15	29
2 November	0.56	0.09	16	0.59	0.08	14
1 December				0.59	0.09	16

Table 43. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
30 April	0.97	0.08	9
2 June	0.75	0.04	6
2 July	0.75	0.03	5
31 July	0.72	0.05	8
27 August	0.64	0.07	11
12 October	0.53	0.04	9
2 November	0.55	0.08	19
1 December			

a/ Proportion ($X = 1/M_0$), where M_0 and M_t are the percent Ca content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.
b/ standard deviation
c/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,5} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 44. Mean proportion[a] of initial total magnesium mass remaining at different times in 1985, for bulk red pine foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot: Plantation Mean[a]	S.D.[b]	%[c]	Pole-stand Mean	S.D.	%
30 April	1.00	0.08	8	0.97	0.06	6
2 June	0.82	0.07	8	0.79	0.05	7
2 July	0.77	0.07	9	0.76	0.03	4
31 July	0.72	0.09	13	0.80	0.07	9
27 August	0.61	0.09	16	0.68	0.03	4
12 October	0.50	0.08	16	0.56	0.06	11
2 November	0.44	0.09	21	0.63	0.06	9
1 December				0.59	0.07	12

Table 44. (cont)

Sampling Date	Control Plot: Plantation Mean	S.D	%	Pole-stand Mean	S.D	%
30 April	0.98	0.05	5	1.01	0.05	5
2 June	0.80	0.06	8	0.84	0.05	7
2 July	0.70	0.05	8	0.74	0.04	6
31 July	0.65	0.06	10	0.77	0.11	14
27 August	0.68	0.10	16	0.67	0.02	3
12 October	0.55	0.11	21	0.54	0.03	7
2 November	0.54	0.06	12	0.61	0.14	29
1 December				0.57	0.02	5

Table 44. (cont)

Sampling Date	Ground Plot: Plantation Mean	S.D.	%
30 April	1.01	0.04	4
2 June	0.81	0.05	7
2 July	0.71	0.03	5
31 July	0.61	0.04	7
27 August	0.59	0.13	23
12 October	0.52	0.05	9
2 November	0.58	0.09	16
1 December			

a/ Proportion ($X = 1/M_0$), where M_0 and M_1 are the percent Mg content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.
b/ standard deviation
c/ detectable difference: the estimated shift in each mean value 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 ($n = 6$)

Table 45. Mean proportion[a] of initial total magnesium mass remaining at different times in 1985, for bulk red oak foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot					
	Plantation			Pole-stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
30 April	0.74	0.15	21	0.80	0.05	6
2 June	0.58	0.09	17	0.67	0.09	15
2 July	0.58	0.05	9			
31 July	0.58	0.09	16	0.76	0.10	14
27 August	0.42	0.10	24	0.59	0.07	12
12 October	0.40	0.13	34	0.54	0.06	13
2 November	0.42	0.13	32	0.57	0.08	14
1 December				0.54	0.12	23

Table 45. (cont)

Sampling Date	Control Plot					
	Plantation			Pole-stand		
	Mean	S.D	%	Mean	S.D	%
30 April	0.80	0.08	10	0.86	0.05	6
2 June	0.68	0.04	6	0.86	0.07	9
2 July	0.62	0.09	15	0.76	0.09	13
31 July	0.63	0.10	17	0.77	0.07	10
27 August	0.50	0.02	5	0.53	0.07	14
12 October	0.62	0.16	27	0.51	0.07	14
2 November	0.54	0.09	17	0.53	0.06	12
1 December				0.51	0.06	12

Table 45. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
30 April	0.80	0.06	8
2 June	0.68	0.05	8
2 July	0.59	0.04	6
31 July	0.57	0.08	14
27 August	0.51	0.19	40
12 October	0.47	0.04	10
2 November	0.47	0.12	27
1 December			

a/ Proportion ($X = 1/M_0$), where M_0 and M_1 are the percent Mg content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.
b/ standard deviation
c/ detectable difference: the estimated shift in each mean value which would be detected 95 percent of the time ($\alpha = .05$), calculated as $t_{.05,5} * S.E./Mean$, and expressed as a percentage of the sample mean ($n = 6$)

Table 46. Mean proportion[a] of initial total magnesium mass remaining at different times in 1985, for bulk red maple foliar litter samples disbursed in early December, 1984.

Sampling Date	Antenna Plot					
	Plantation			Pole-stand		
	Mean[a]	S.D.[b]	%[c]	Mean	S.D.	%
30 April	0.54	0.05	9	0.60	0.02	4
2 June	0.33	0.06	19	0.43	0.02	5
2 July	0.28	0.04	14	0.54	0.07	13
31 July	0.22	0.05	24	0.44	0.05	11
27 August	0.20	0.04	19	0.40	0.02	5
12 October	0.18	0.06	35	0.40	0.10	26
2 November	0.19	0.09	50	0.38	0.07	19
1 December				0.40	0.06	17

Table 46. (cont)

Sampling Date	Control Plot					
	Plantation			Pole-stand		
	Mean	S.D	%	Mean	S.D	%
30 April	0.50	0.06	12	0.47	0.03	7
2 June	0.34	0.05	15	0.40	0.04	10
2 July	0.27	0.05	21	0.39	0.05	13
31 July	0.27	0.03	14	0.40	0.04	10
27 August	0.23	0.07	29	0.37	0.06	17
12 October	0.32	0.08	26	0.36	0.10	33
2 November	0.33	0.07	21	0.38	0.04	11
1 December				0.36	0.03	10

Table 46. (cont)

Sampling Date	Ground Plot		
	Plantation		
	Mean	S.D.	%
30 April	0.48	0.05	11
2 June	0.34	0.03	10
2 July	0.31	0.02	7
31 July	0.28	0.05	18
27 August	0.20	0.03	17
12 October	0.20	0.04	21
2 November	0.25	0.07	36
1 December			

a/ Proportion ($X = M_1/M_0$), where M_0 and M_1 are the percent Mg content (m/m, 30°C) multiplied by total dry matter mass (30°C) for time 0 and time 1, respectively.
b/ standard deviation
c/ detectable difference: the estimated shift in each mean value 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 ($n = 6$)

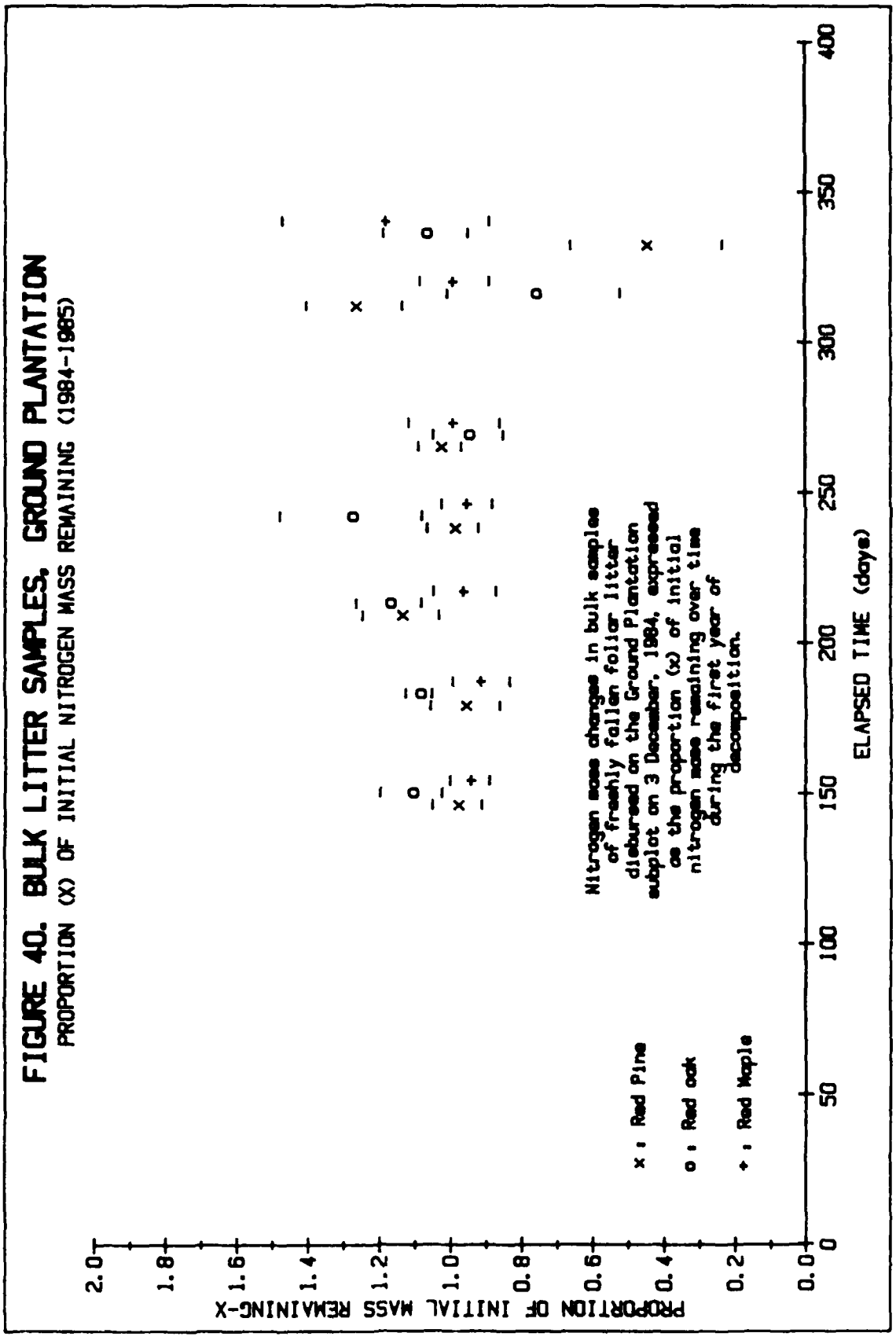


FIGURE 40. BULK LITTER SAMPLES, GROUND PLANTATION
PROPORTION (X) OF INITIAL NITROGEN MASS REMAINING (1984-1985)
Nitrogen mass changes in bulk samples of freshly fallen foliar litter disbursed on the Ground Plantation subplot on 3 December, 1984, expressed as the proportion (x) of initial nitrogen mass remaining over time during the first year of decomposition.
x : Red Pine
o : Red oak
+ : Red Maple
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0
50
100
150
200
250
300
350
400

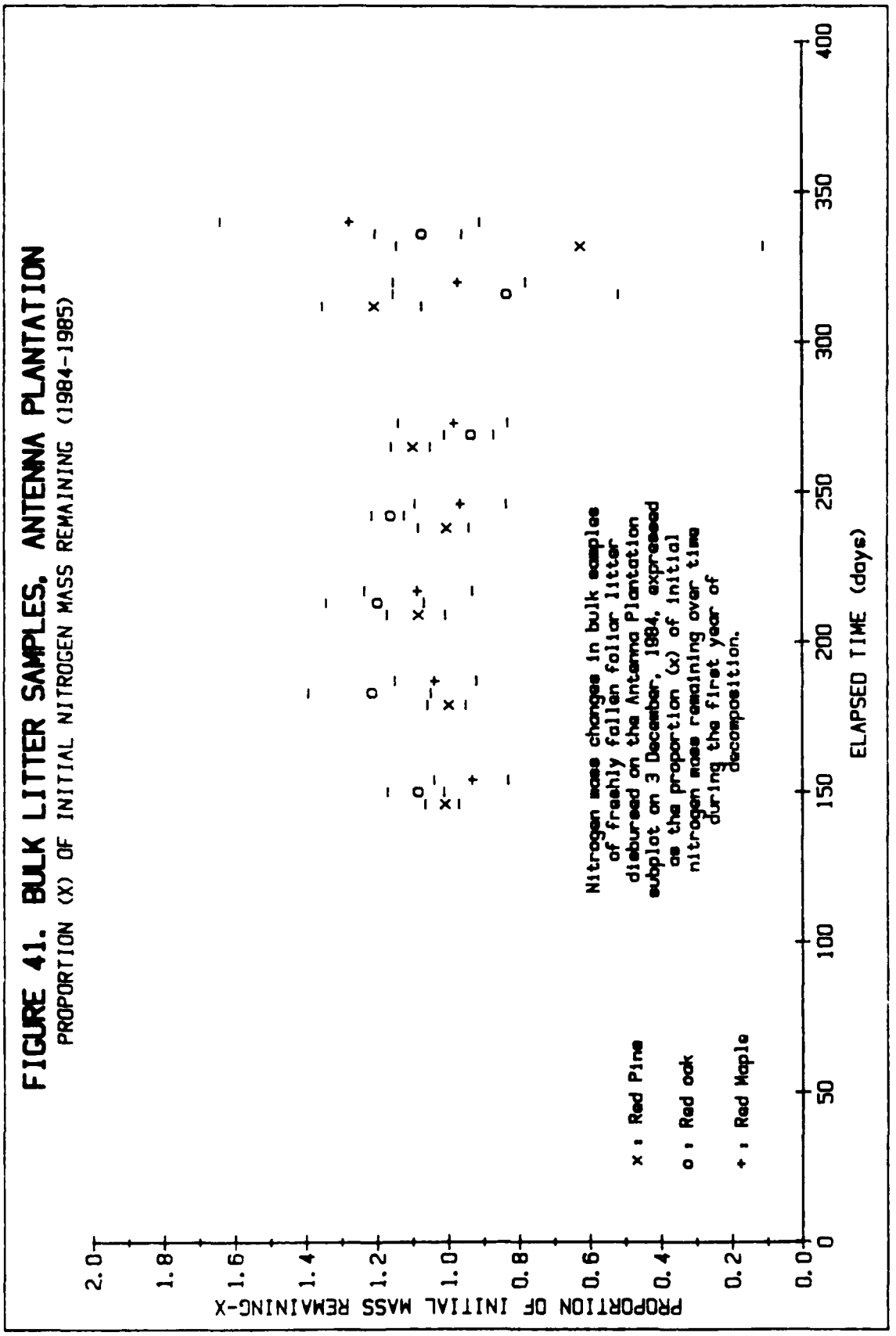


FIGURE 41. BULK LITTER SAMPLES, ANTENNA PLANTATION
PROPORTION (X) OF INITIAL NITROGEN MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0
50
100
150
200
250
300
350
400
Nitrogen mass changes in bulk samples of freshly fallen foliar litter disbursed on the Antenna Plantation subplot on 3 December, 1984, expressed as the proportion (x) of initial nitrogen mass remaining over time during the first year of decomposition.
x : Red Pine
o : Red oak
+ : Red Maple

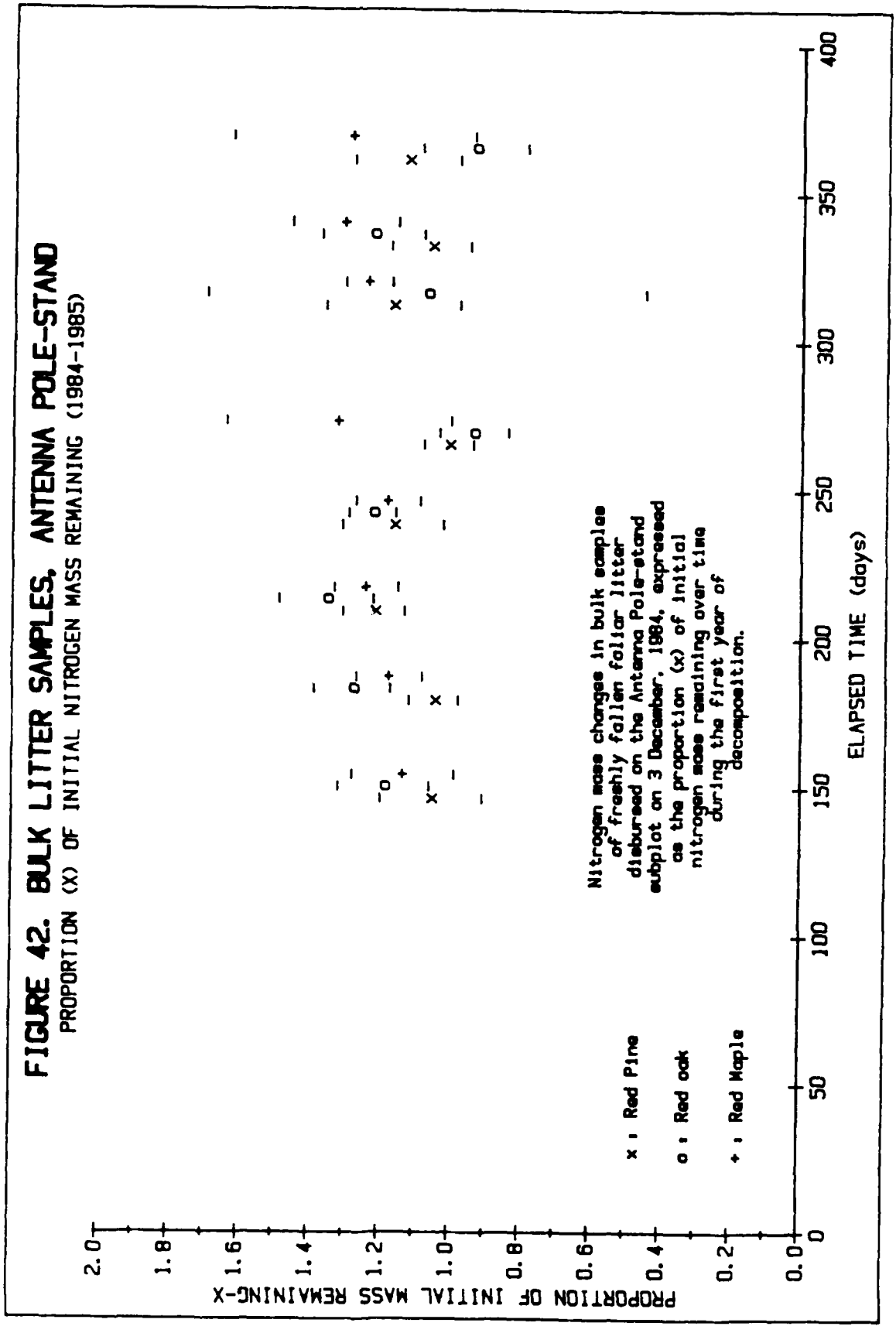


FIGURE 42. BULK LITTER SAMPLES, ANTENNA POLE-STAND
PROPORTION (X) OF INITIAL NITROGEN MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0
50
100
150
200
250
300
350
400
Nitrogen mass changes in bulk samples of freshly fallen foliar litter disbursed on the Antenna Pole-stand subplot on 3 December, 1984, expressed as the proportion (x) of initial nitrogen mass remaining over time during the first year of decomposition.
x : Red Pine
o : Red oak
+ : Red Maple

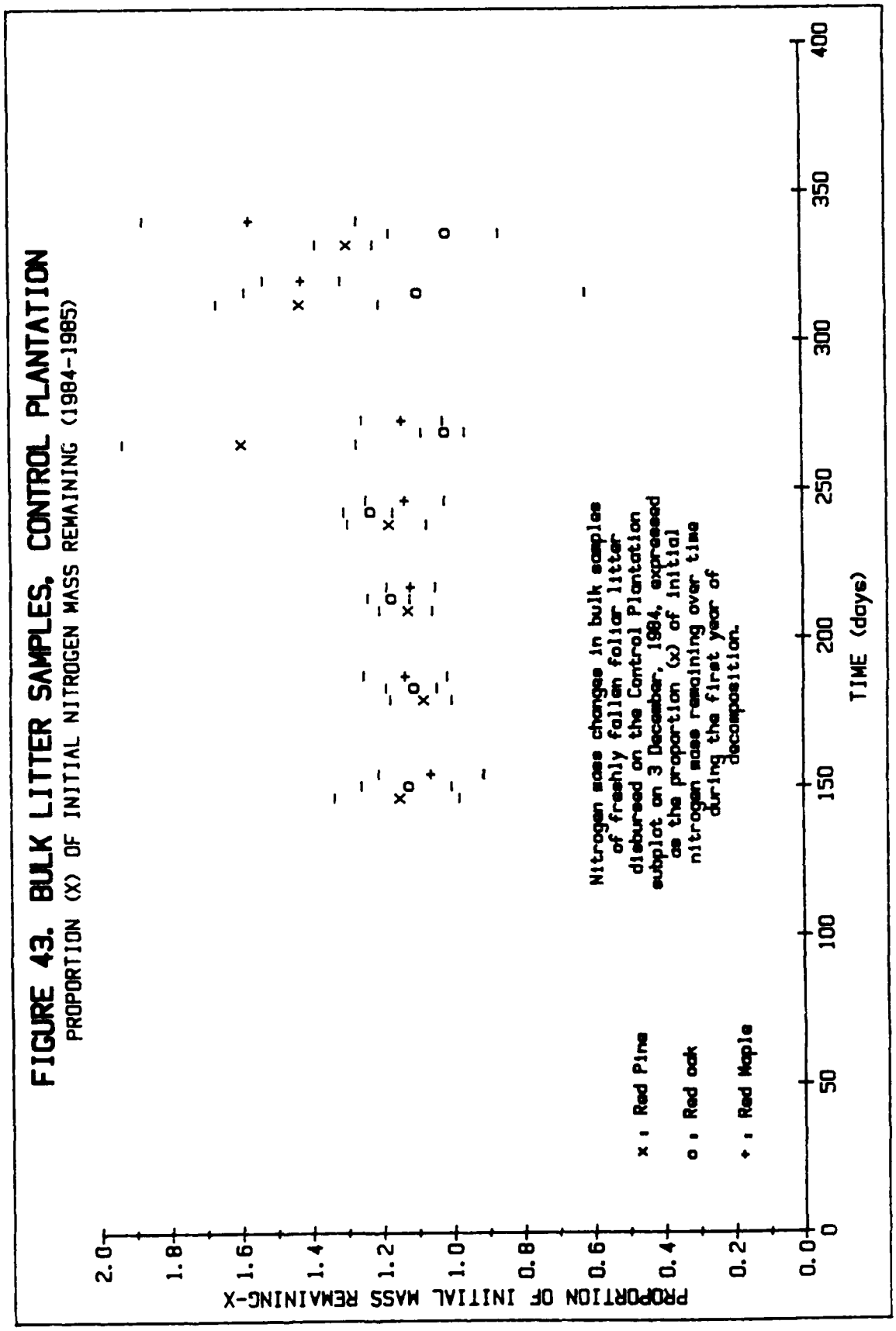


FIGURE 43. BULK LITTER SAMPLES, CONTROL PLANTATION
PROPORTION (X) OF INITIAL NITROGEN MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING-X
TIME (days)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0
50
100
150
200
250
300
350
400
Nitrogen mass changes in bulk samples of freshly fallen foliar litter disbursed on the Control Plantation subplot on 3 December, 1984, expressed as the proportion (x) of initial nitrogen mass remaining over time during the first year of decomposition.
x : Red Pine
o : Red oak
+ : Red Maple

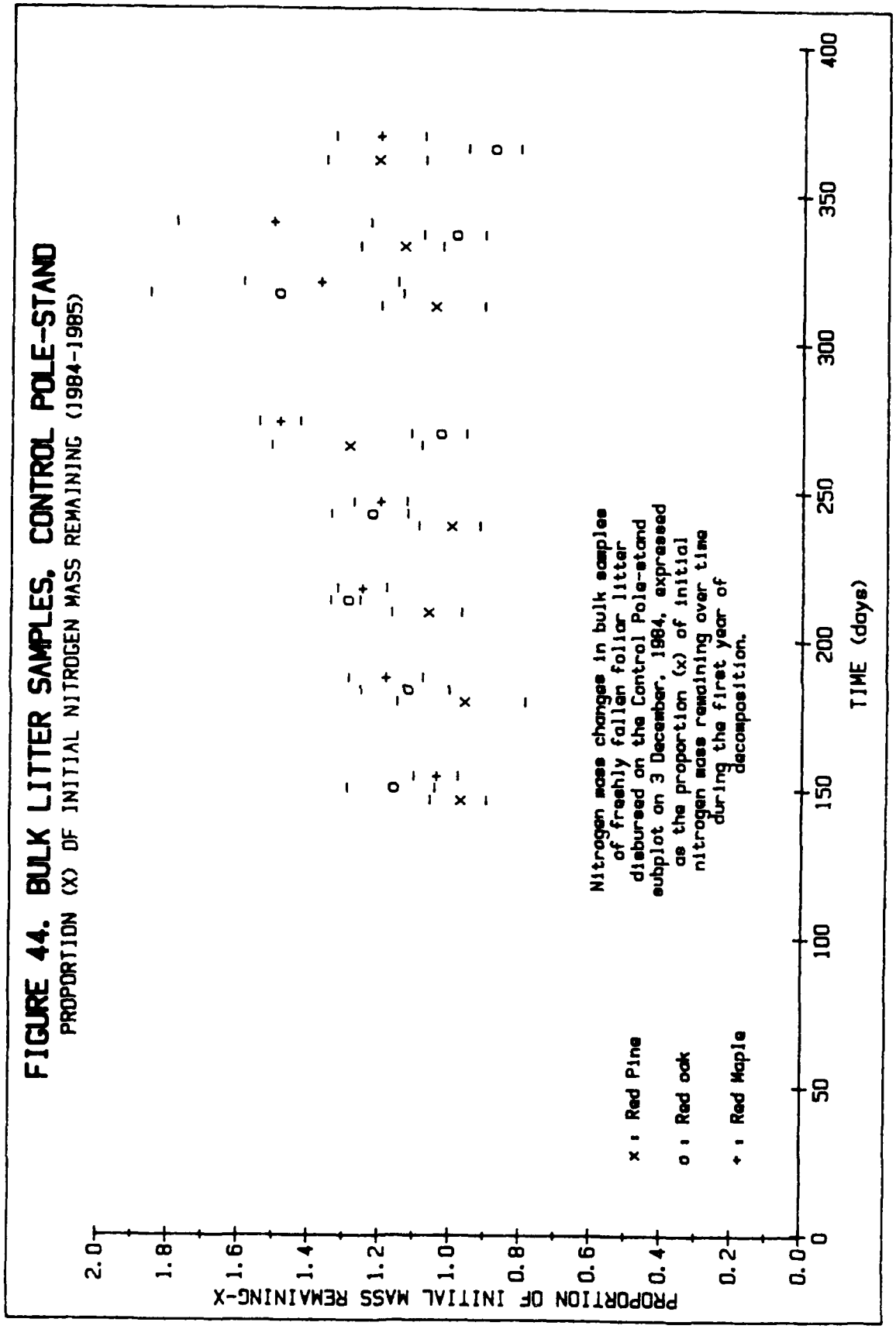
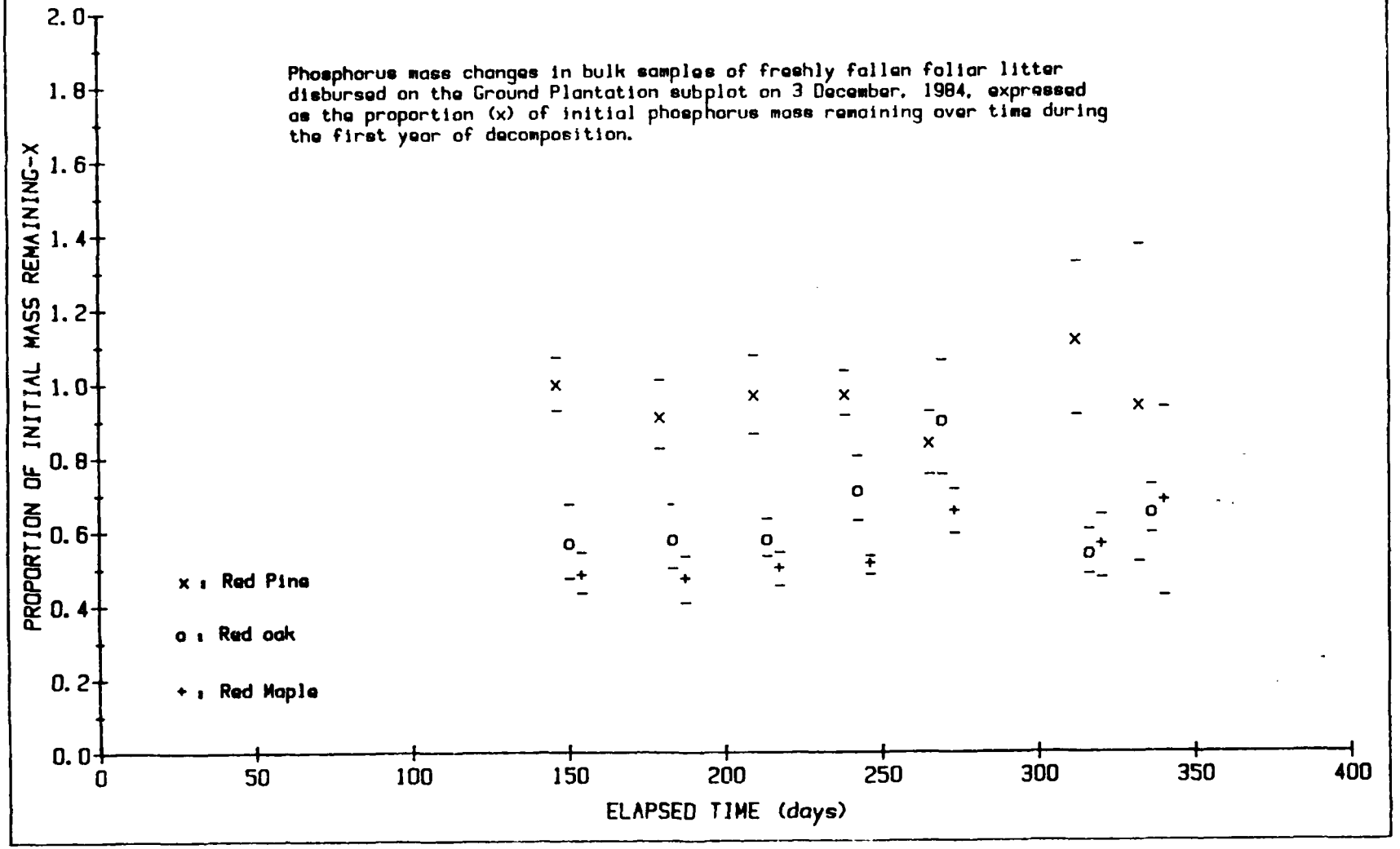


FIGURE 44. BULK LITTER SAMPLES, CONTROL POLE-STAND
PROPORTION (X) OF INITIAL NITROGEN MASS REMAINING (1984-1985)
PROPORTION OF INITIAL MASS REMAINING-X
TIME (days)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
300
350
400
x : Red Pine
o : Red oak
+ : Red Maple
Nitrogen mass changes in bulk samples of freshly fallen foliar litter disbursed on the Control Pole-stand subplot on 3 December, 1984, expressed as the proportion (x) of initial nitrogen mass remaining over time during the first year of decomposition.

FIGURE 45. BULK LITTER SAMPLES, GROUND PLANTATION

PROPORTION (X) OF INITIAL PHOSPHORUS MASS REMAINING (1984-1985)

Phosphorus mass changes in bulk samples of freshly fallen foliar litter disbursed on the Ground Plantation subplot on 3 December, 1984, expressed as the proportion (x) of initial phosphorus mass remaining over time during the first year of decomposition.



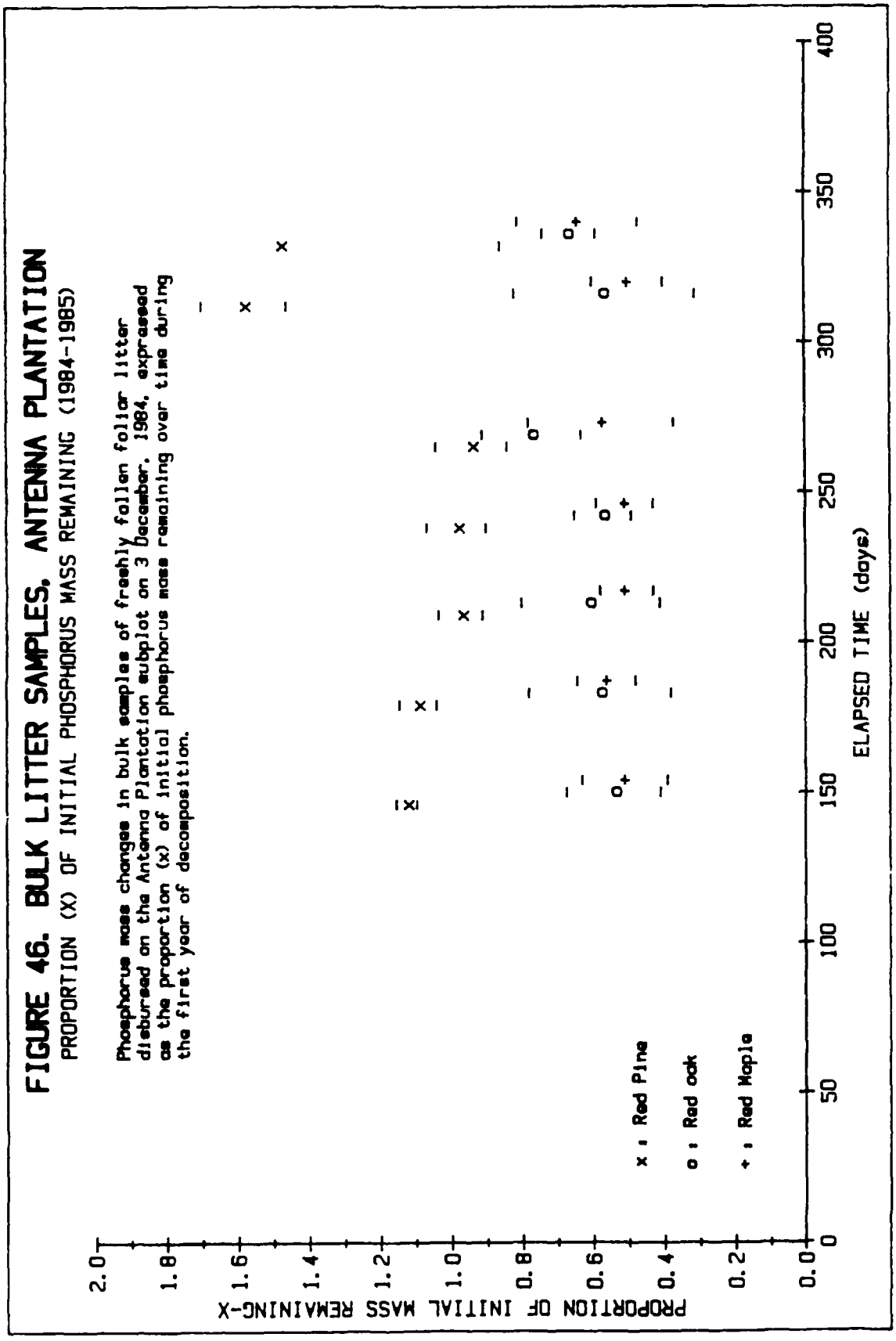


FIGURE 46. BULK LITTER SAMPLES, ANTENNA PLANTATION
PROPORTION (X) OF INITIAL PHOSPHORUS MASS REMAINING (1984-1985)
Phosphorus mass changes in bulk samples of freshly fallen foliar litter disbursed on the Antenna Plantation subplot on 3 December, 1984, expressed as the proportion (x) of initial phosphorus mass remaining over time during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
x : Red Pine
o : Red oak
+ : Red Maple
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0
50
100
150
200
250
300
350
400

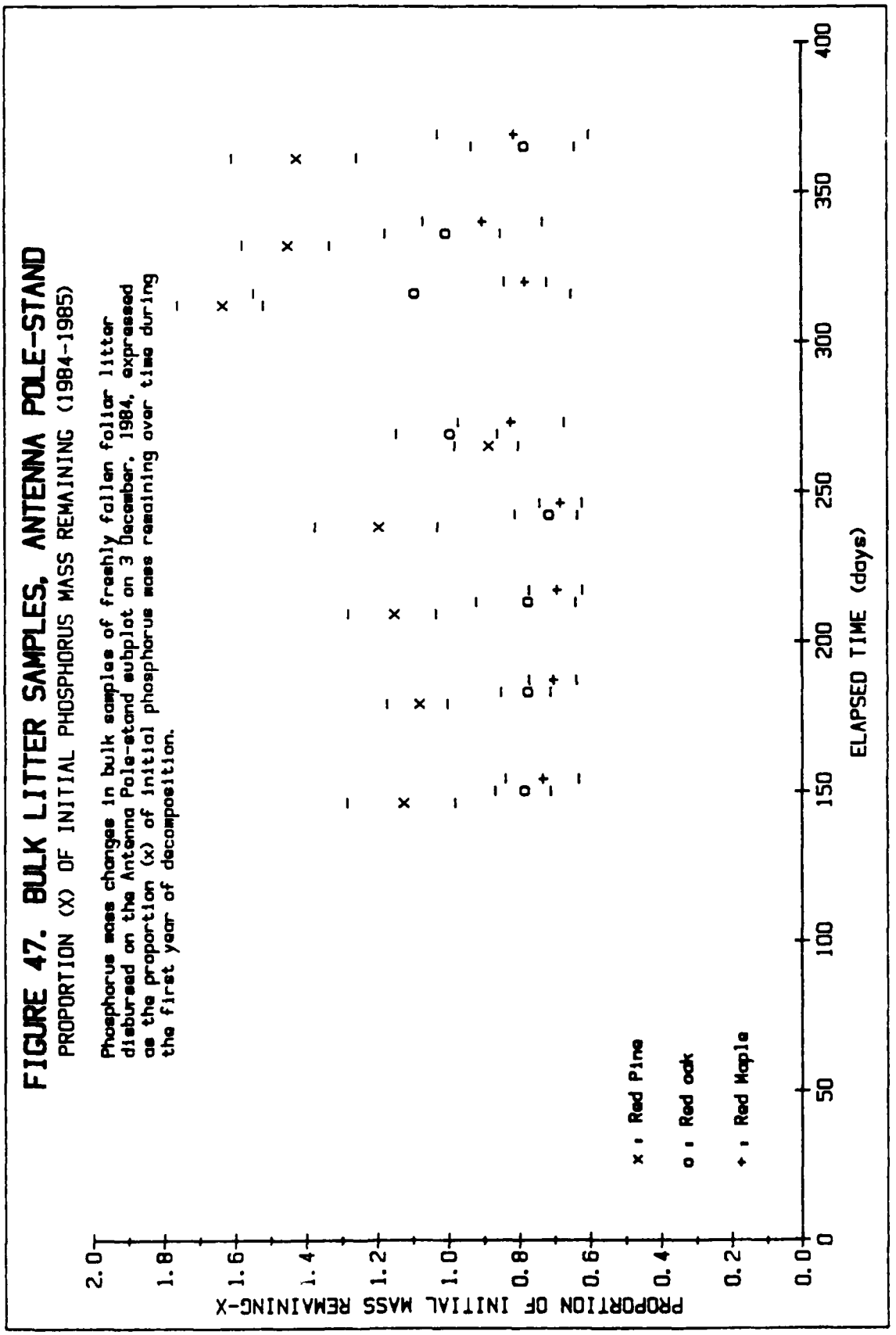


FIGURE 47. BULK LITTER SAMPLES, ANTENNA POLE-STAND
PROPORTION (X) OF INITIAL PHOSPHORUS MASS REMAINING (1984-1985)
Phosphorus mass changes in bulk samples of freshly fallen foliar litter disbursed on the Antenna Pole-stand subplot on 3 December, 1984, expressed as the proportion (x) of initial phosphorus mass remaining over time during the first year of decomposition.
x : Red Pine
o : Red oak
+ : Red Maple
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0
50
100
150
200
250
300
350
400

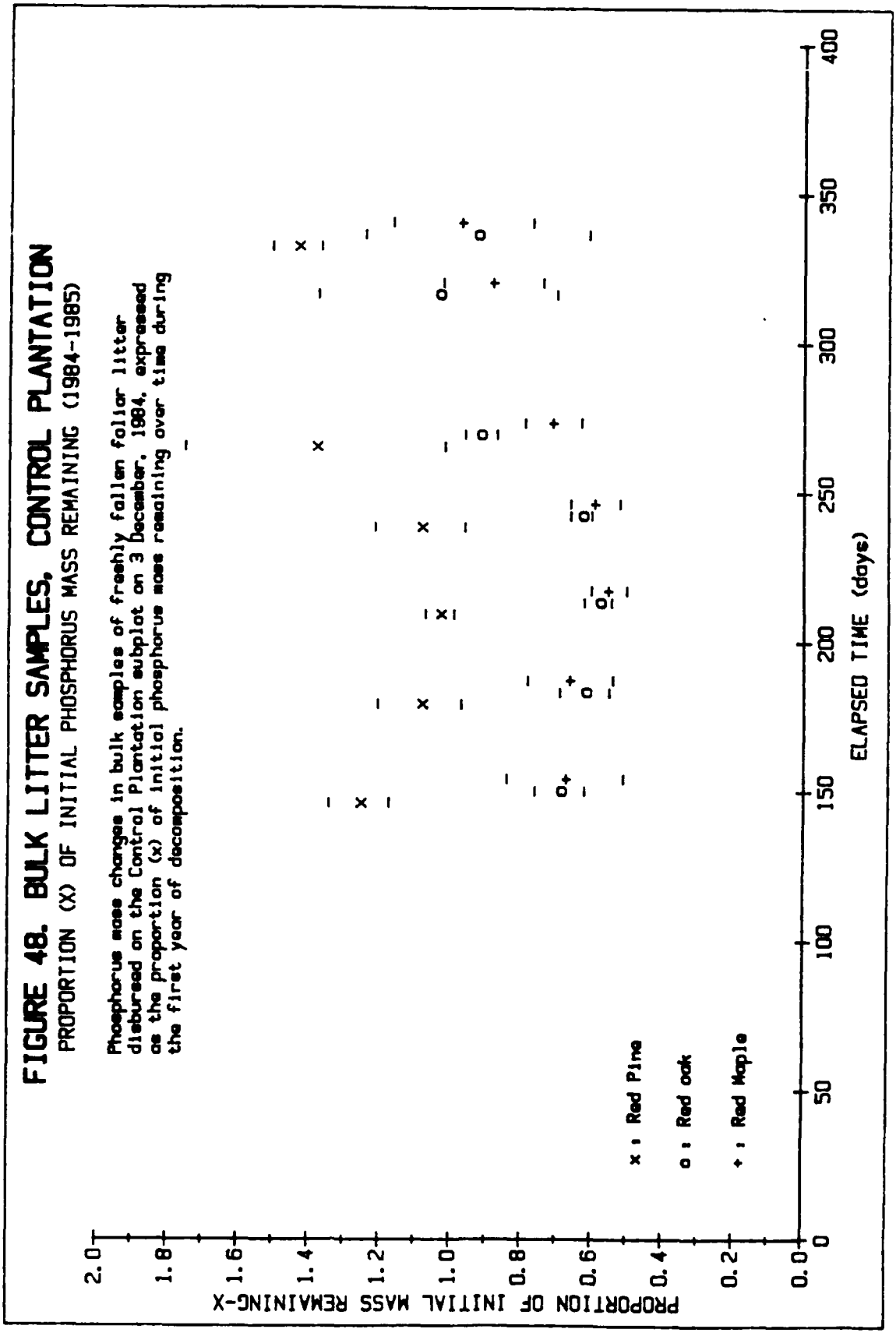


FIGURE 48. BULK LITTER SAMPLES, CONTROL PLANTATION
PROPORTION (X) OF INITIAL PHOSPHORUS MASS REMAINING (1984-1985)
Phosphorus mass changes in bulk samples of freshly fallen foliar litter disbursed on the Control Plantation subplot on 3 December, 1984, expressed as the proportion (x) of initial phosphorus mass remaining over time during the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
x : Red Pine
o : Red oak
+ : Red Maple
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0
50
100
150
200
250
300
350
400

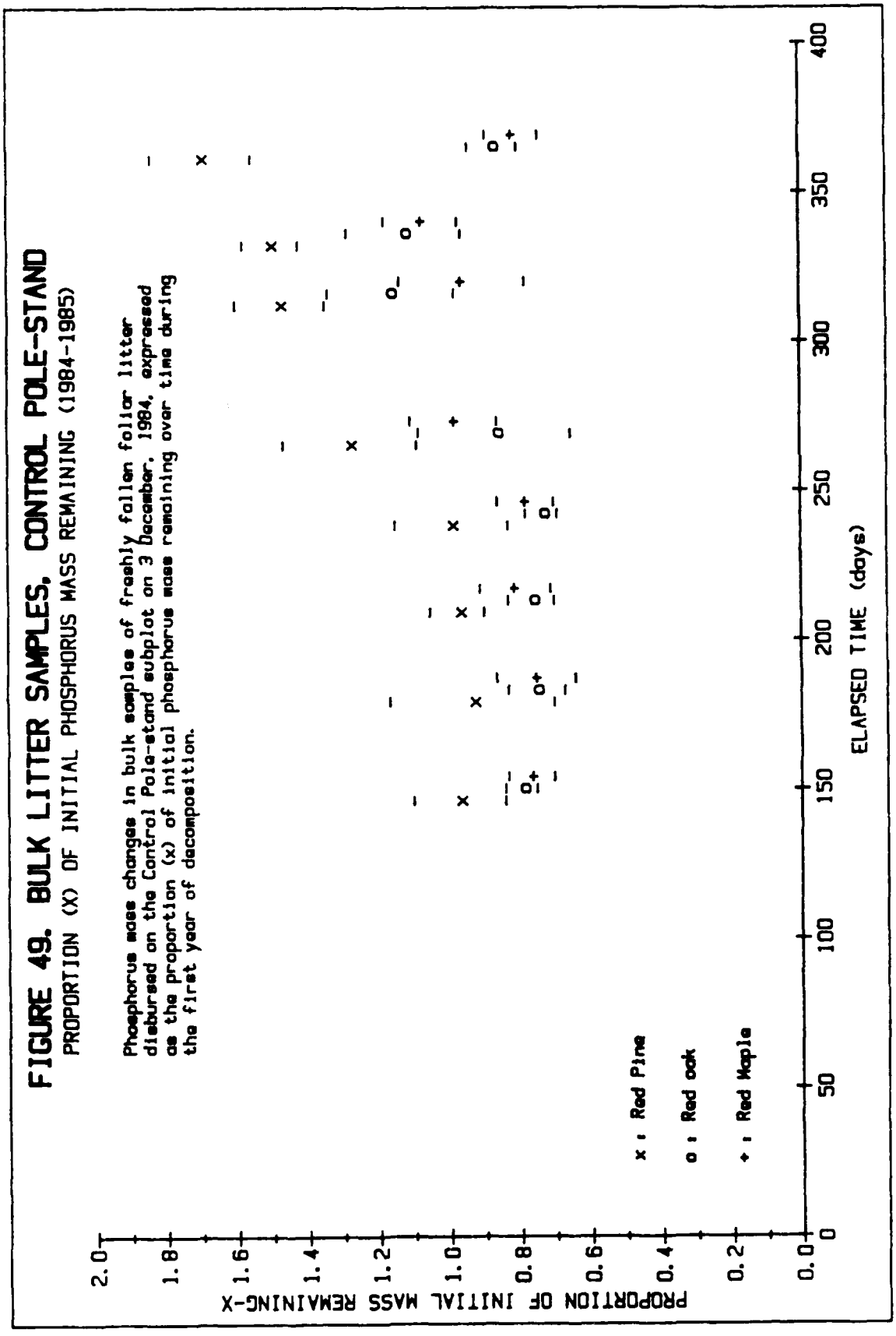


FIGURE 49. BULK LITTER SAMPLES, CONTROL POLE-STAND
PROPORTION (X) OF INITIAL PHOSPHORUS MASS REMAINING (1984-1985)
Phosphorus mass changes in bulk samples of freshly fallen foliar litter disbursed on the Control Pole-stand subplot on 3 December, 1984, expressed as the proportion (x) of initial phosphorus mass remaining over time during the first year of decomposition.
x : Red Pine
o : Red oak
+ : Red Maple
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0
50
100
150
200
250
300
350
400

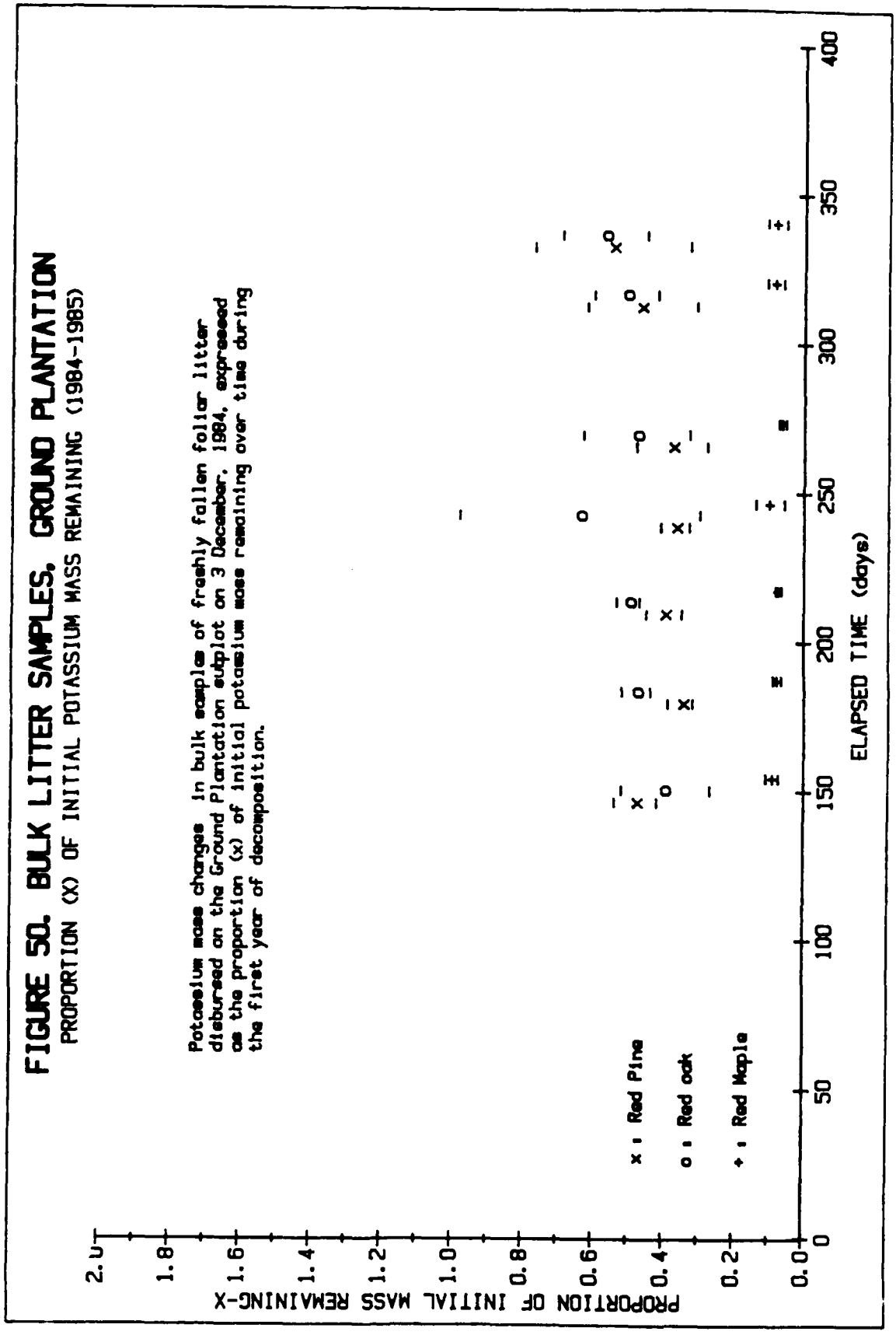
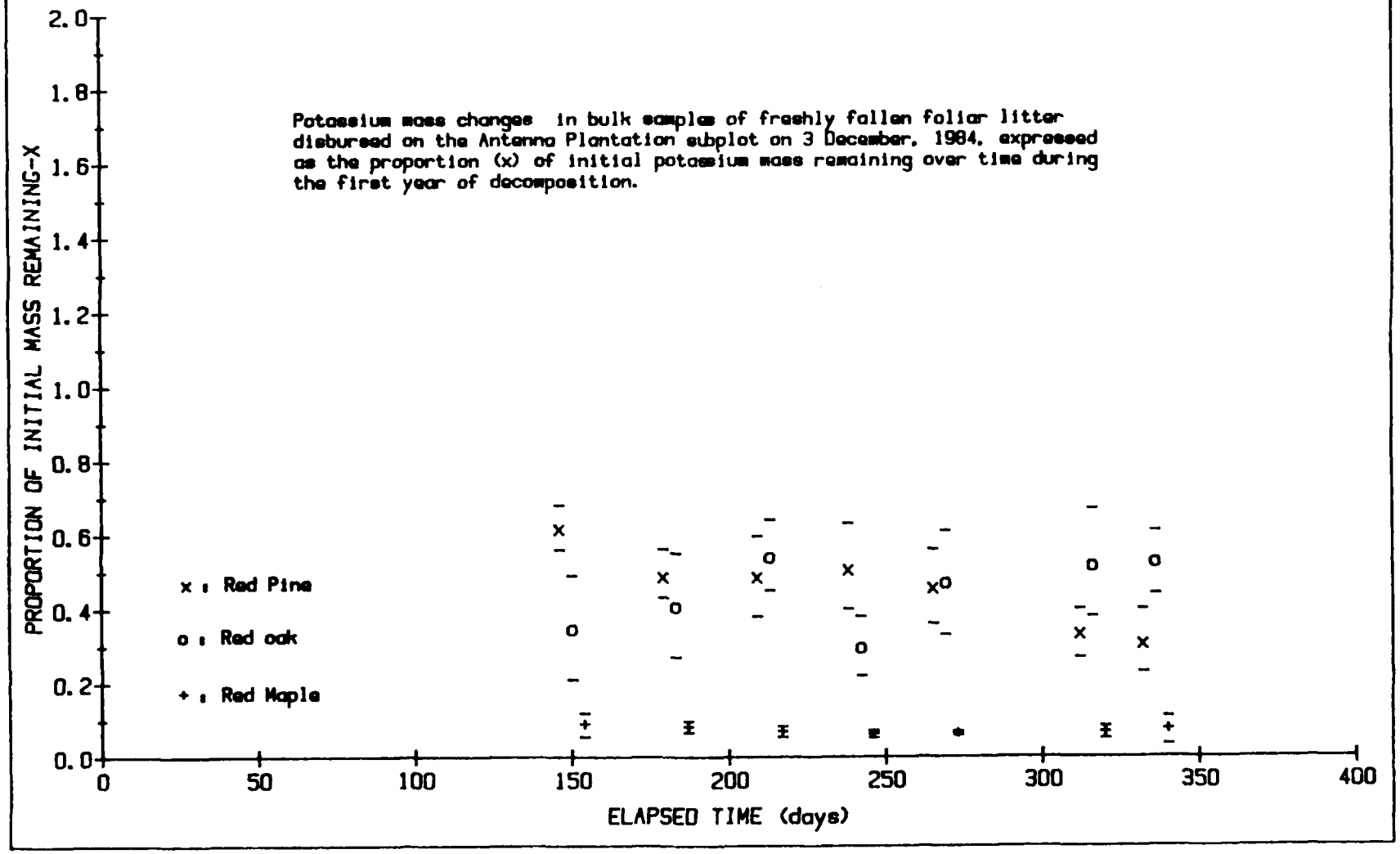


FIGURE 50. BULK LITTER SAMPLES, GROUND PLANTATION
PROPORTION (X) OF INITIAL POTASSIUM MASS REMAINING (1984-1985)
Potassium mass changes in bulk samples of freshly fallen foliar litter disbursed on the Ground Plantation subplot on 3 December, 1984, expressed as the proportion (x) of initial potassium mass remaining over time during the first year of decomposition.
x : Red Pine
o : Red oak
+ : Red Maple
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
300
350
400

FIGURE 51. BULK LITTER SAMPLES, ANTENNA PLANTATION

PROPORTION (X) OF INITIAL POTASSIUM MASS REMAINING (1984-1985)



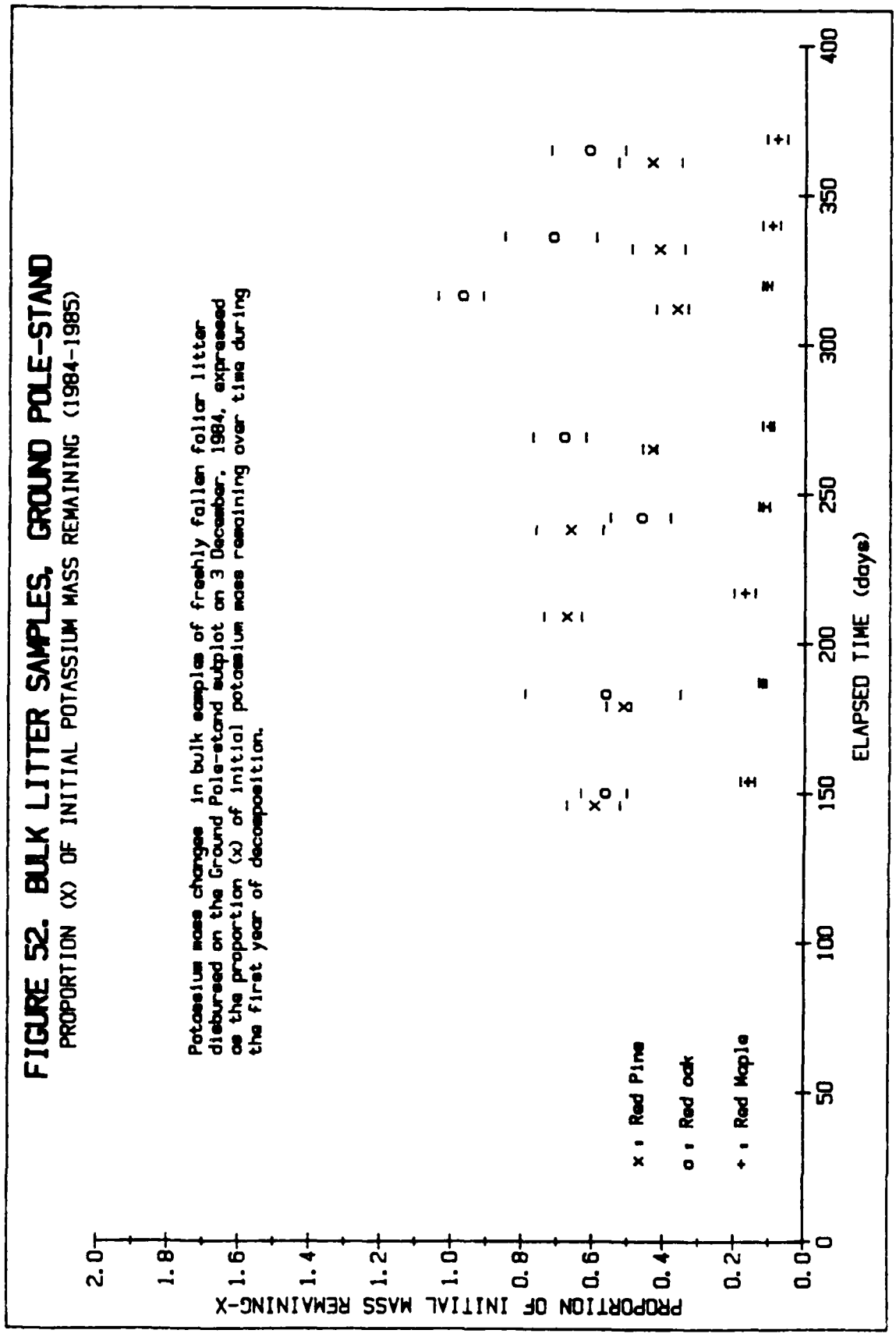
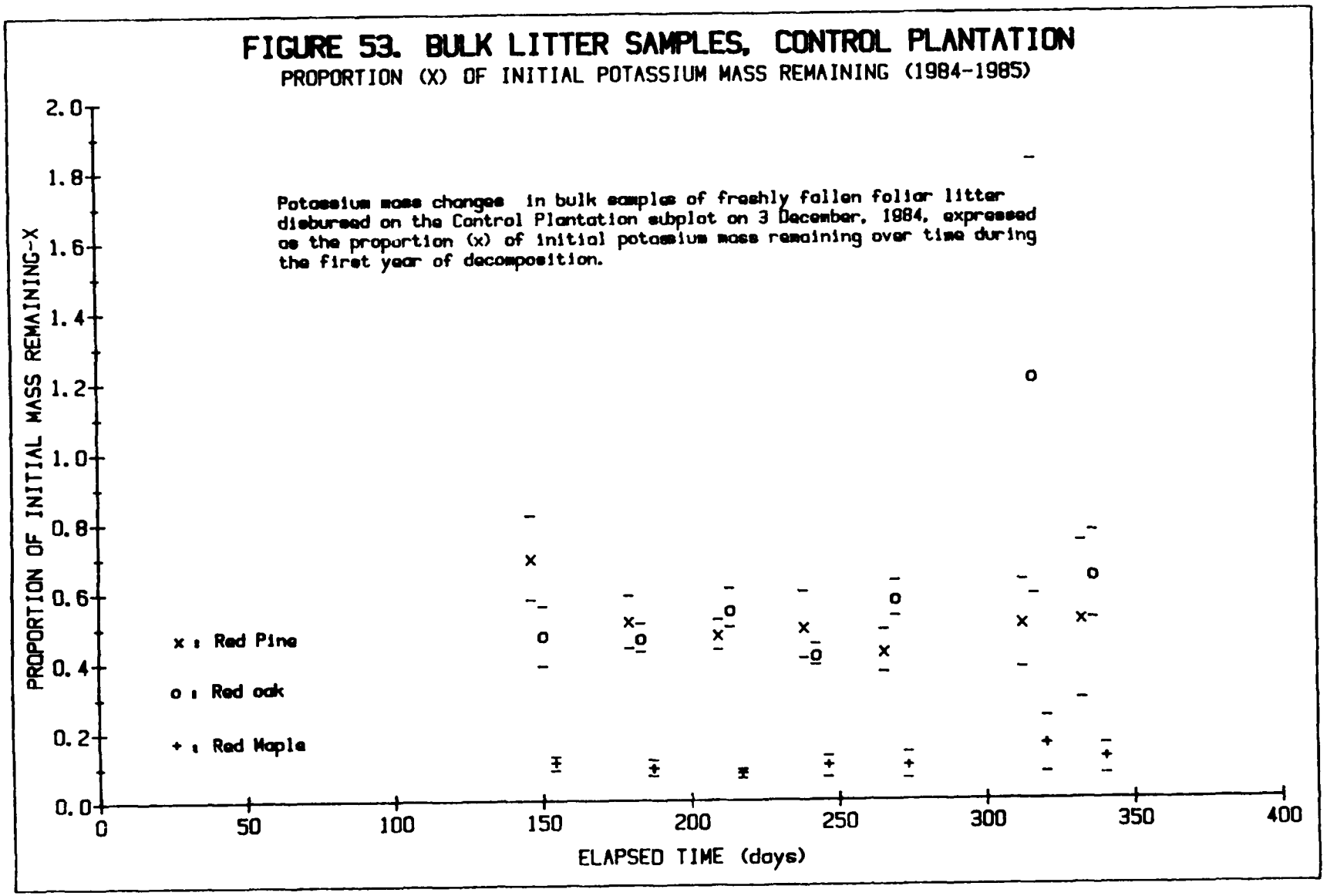


FIGURE 52. BULK LITTER SAMPLES, GROUND POLE-STAND
PROPORTION (X) OF INITIAL POTASSIUM MASS REMAINING (1984-1985)
Potassium mass changes in bulk samples of freshly fallen foliar litter disbursed on the Ground Pole-stand subplot on 3 December, 1984, expressed as the proportion (x) of initial potassium mass remaining over time during the first year of decomposition.
x : Red Pine
o : Red oak
+ : Red Maple
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0
50
100
150
200
250
300
350
400

FIGURE 53. BULK LITTER SAMPLES, CONTROL PLANTATION

PROPORTION (X) OF INITIAL POTASSIUM MASS REMAINING (1984-1985)



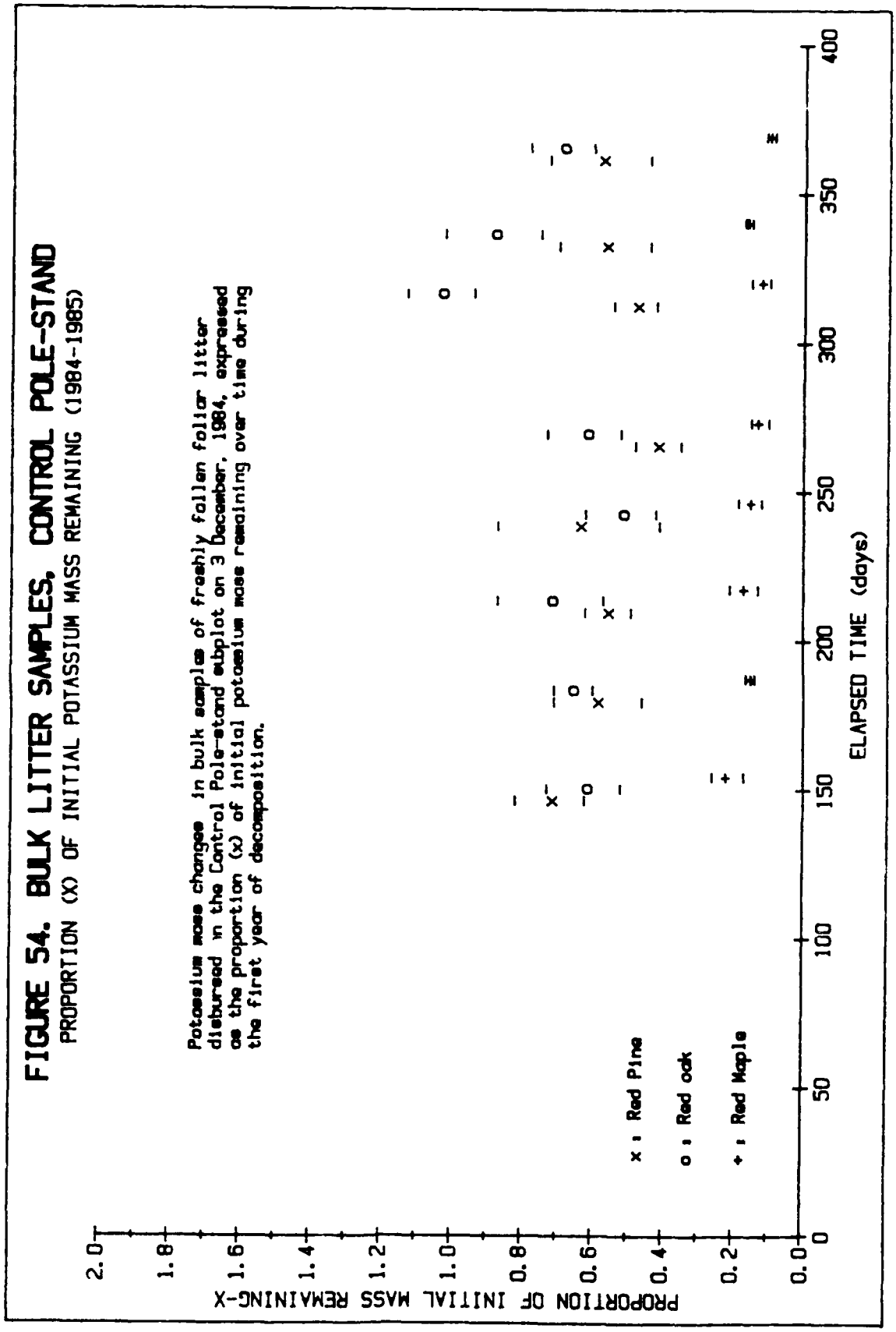
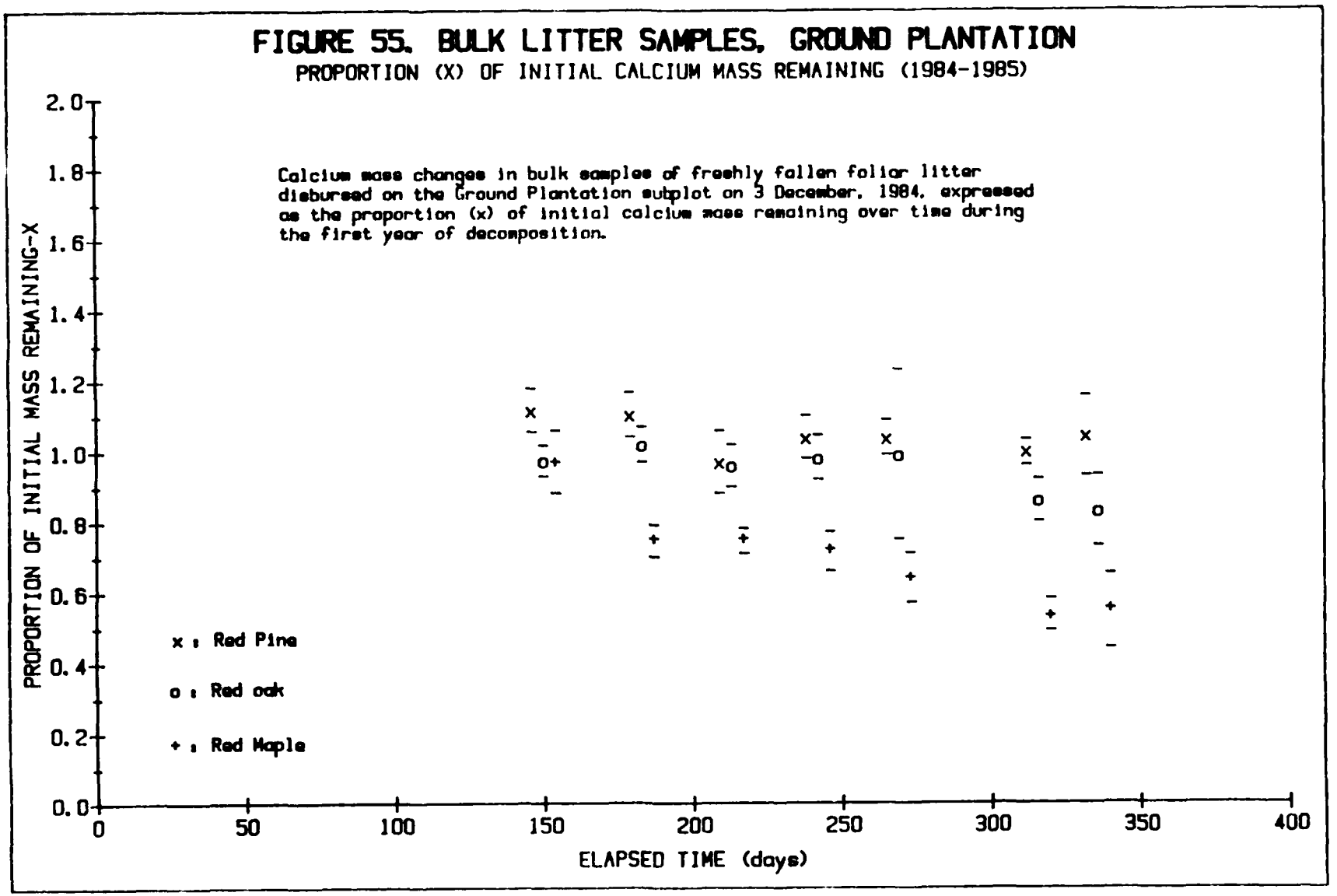


FIGURE 54. BULK LITTER SAMPLES, CONTROL POLE-STAND
PROPORTION (X) OF INITIAL POTASSIUM MASS REMAINING (1984-1985)
Potassium mass changes in bulk samples of freshly fallen foliar litter disbursed in the Control Pole-stand subplot on 3 December, 1984, expressed as the proportion (x) of initial potassium mass remaining over time during the first year of decomposition.
x : Red Pine
o : Red oak
+ : Red Maple
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0
50
100
150
200
250
300
350
400

FIGURE 55. BULK LITTER SAMPLES, GROUND PLANTATION

PROPORTION (X) OF INITIAL CALCIUM MASS REMAINING (1984-1985)



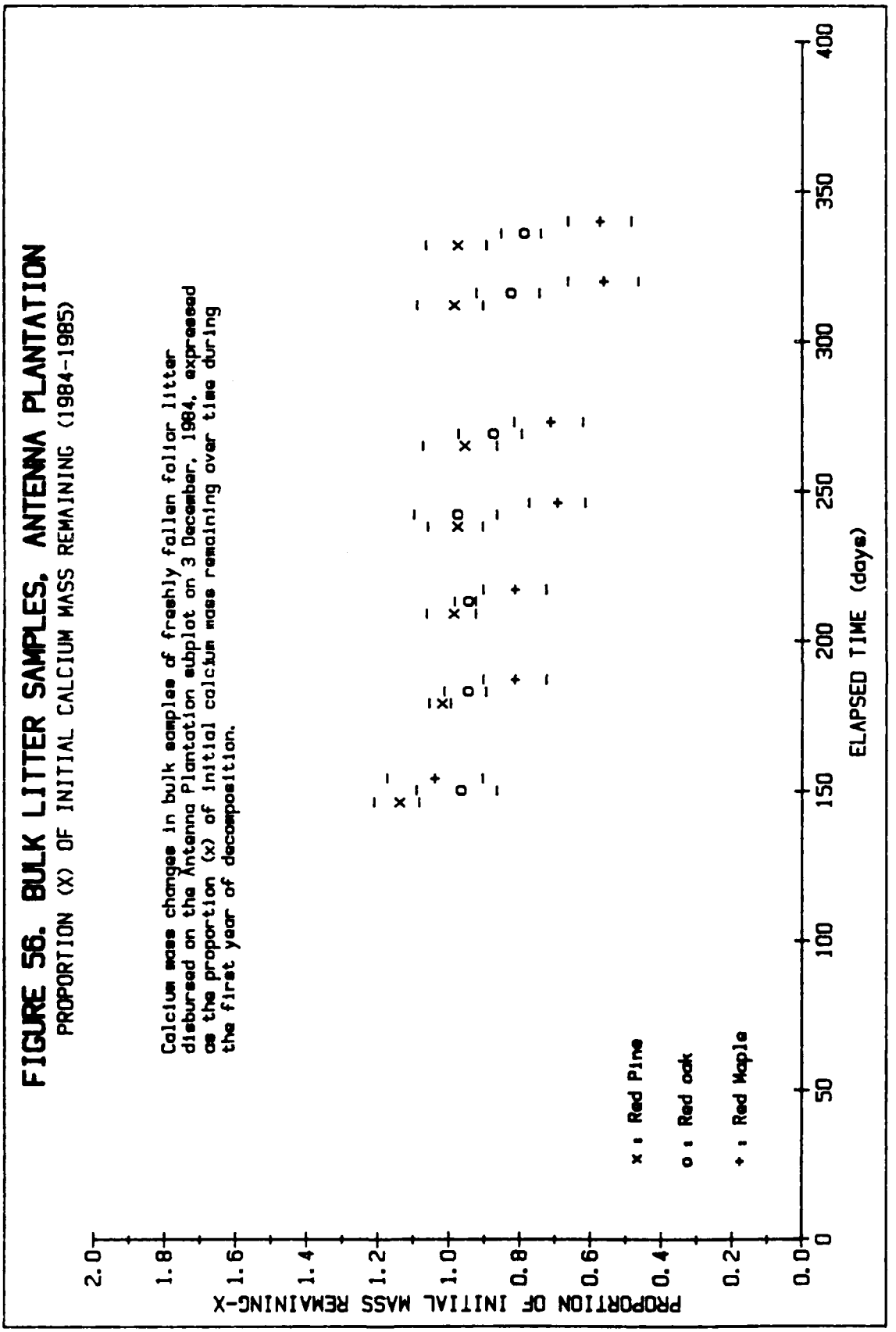
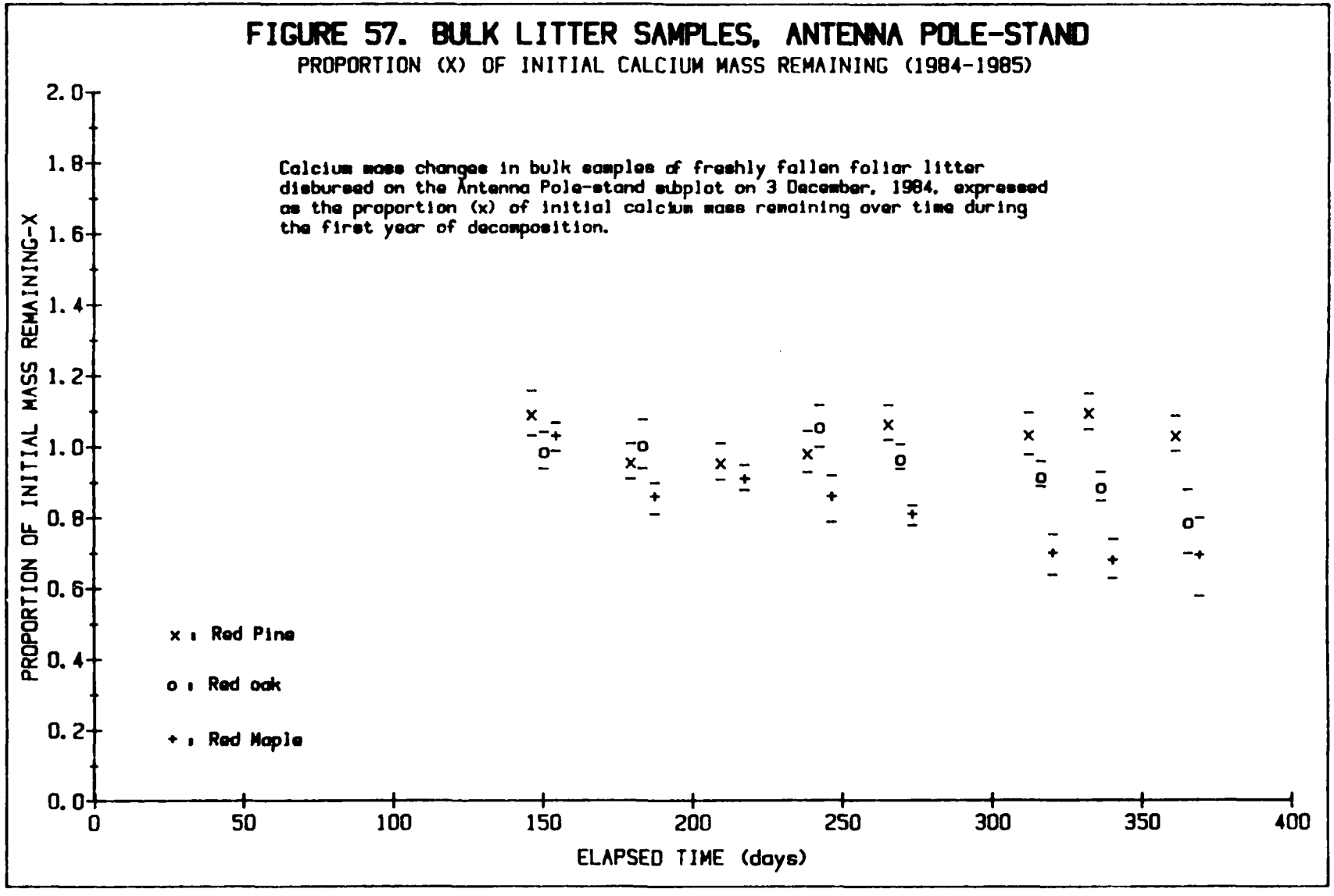


FIGURE 56. BULK LITTER SAMPLES, ANTENNA PLANTATION
PROPORTION (X) OF INITIAL CALCIUM MASS REMAINING (1984-1985)
Calcium mass changes in bulk samples of freshly fallen foliar litter disbursed on the Antenna Plantation subplot on 3 December, 1984, expressed as the proportion (x) of initial calcium mass remaining over time during the first year of decomposition.
x : Red Pine
o : Red oak
+ : Red Maple
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0
50
100
150
200
250
300
350
400

FIGURE 57. BULK LITTER SAMPLES, ANTENNA POLE-STAND

PROPORTION (X) OF INITIAL CALCIUM MASS REMAINING (1984-1985)



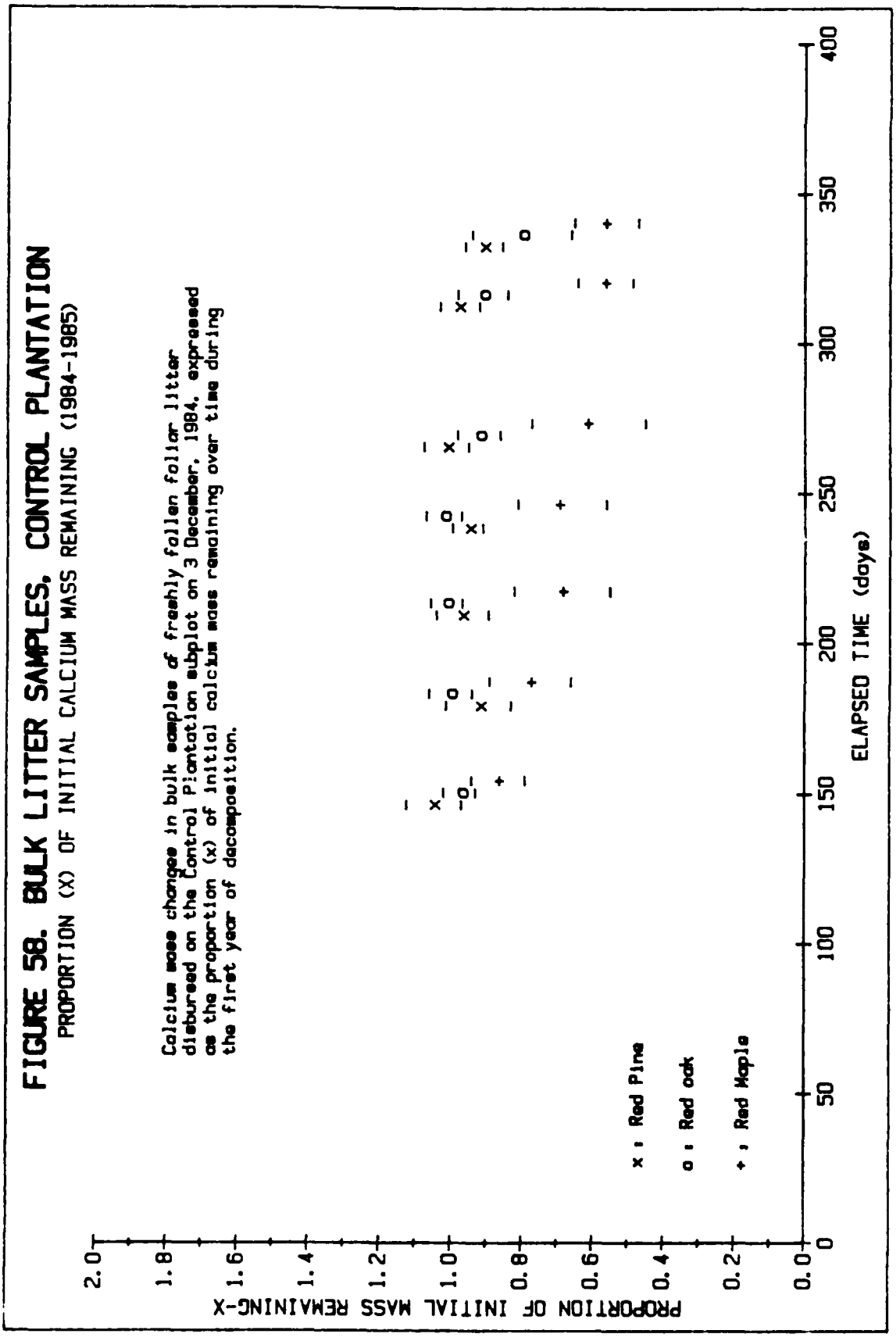
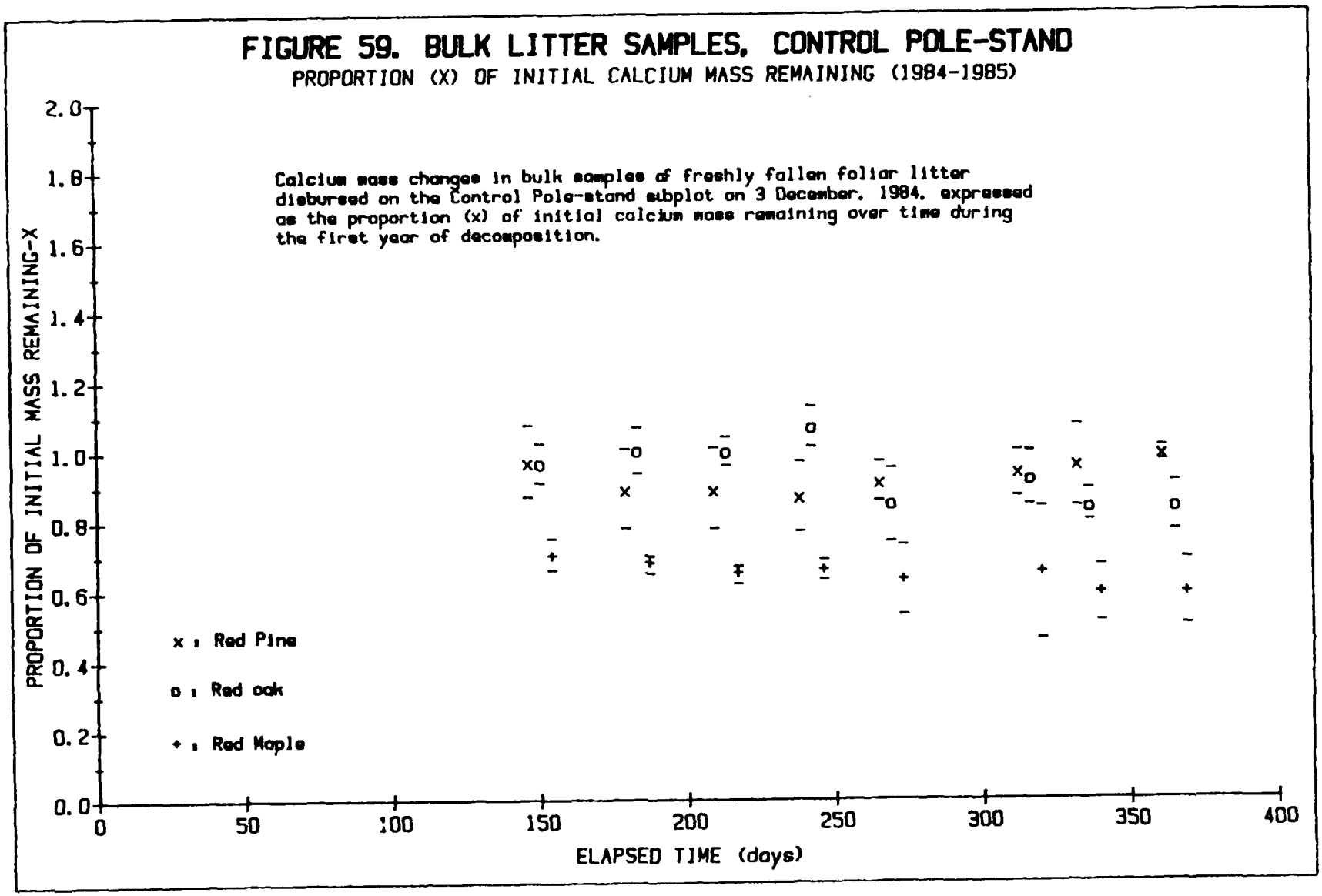


FIGURE 58. BULK LITTER SAMPLES, CONTROL PLANTATION
PROPORTION (X) OF INITIAL CALCIUM MASS REMAINING (1984-1985)
Calcium mass changes in bulk samples of freshly fallen foliar litter
disbursed on the Control Plantation subplot on 3 December, 1984, expressed
as the proportion (x) of initial calcium mass remaining over time during
the first year of decomposition.
PROPORTION OF INITIAL MASS REMAINING-X
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
300
350
400
ELAPSED TIME (days)
x : Red Pine
o : Red oak
+ : Red Maple

FIGURE 59. BULK LITTER SAMPLES, CONTROL POLE-STAND

PROPORTION (X) OF INITIAL CALCIUM MASS REMAINING (1984-1985)



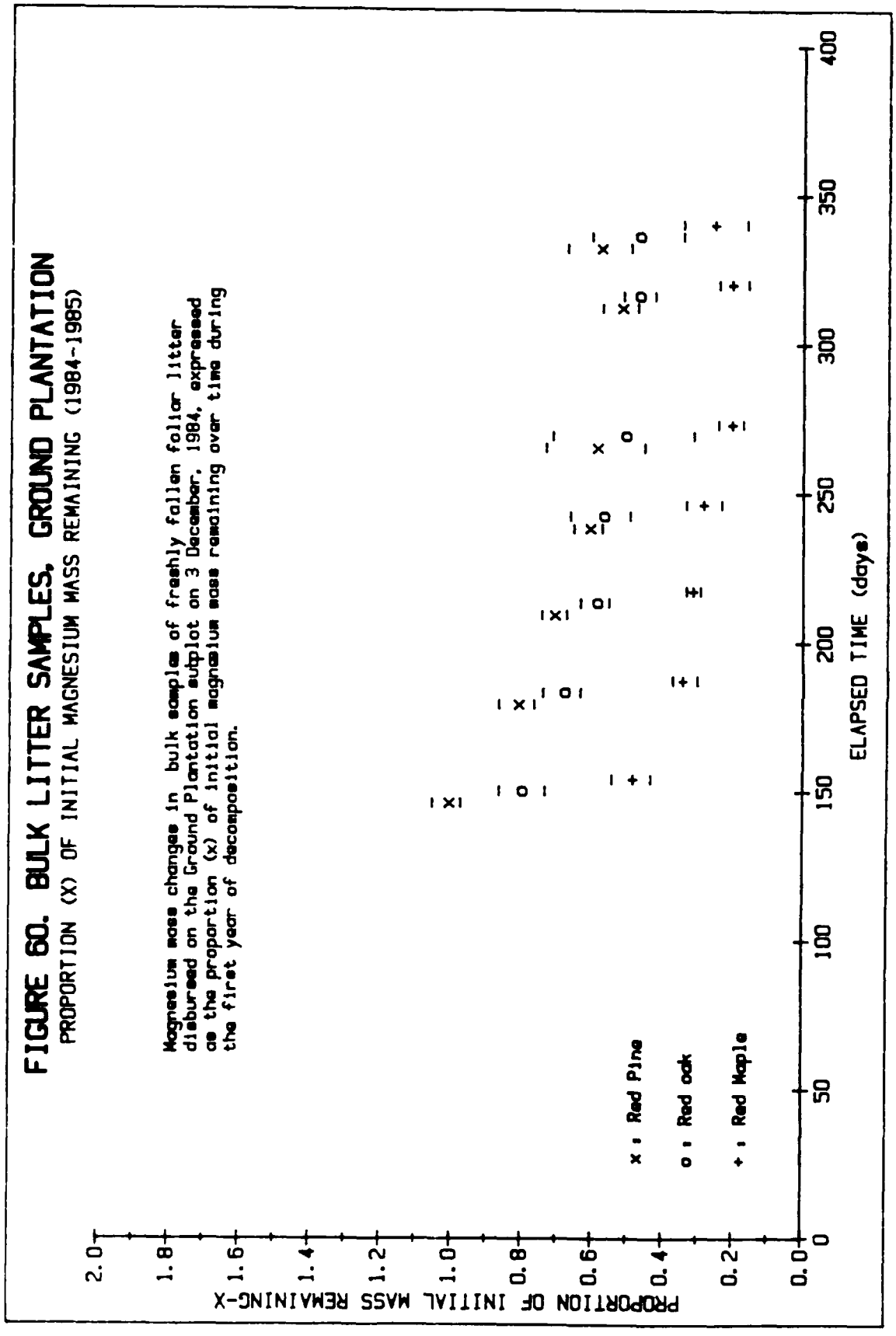
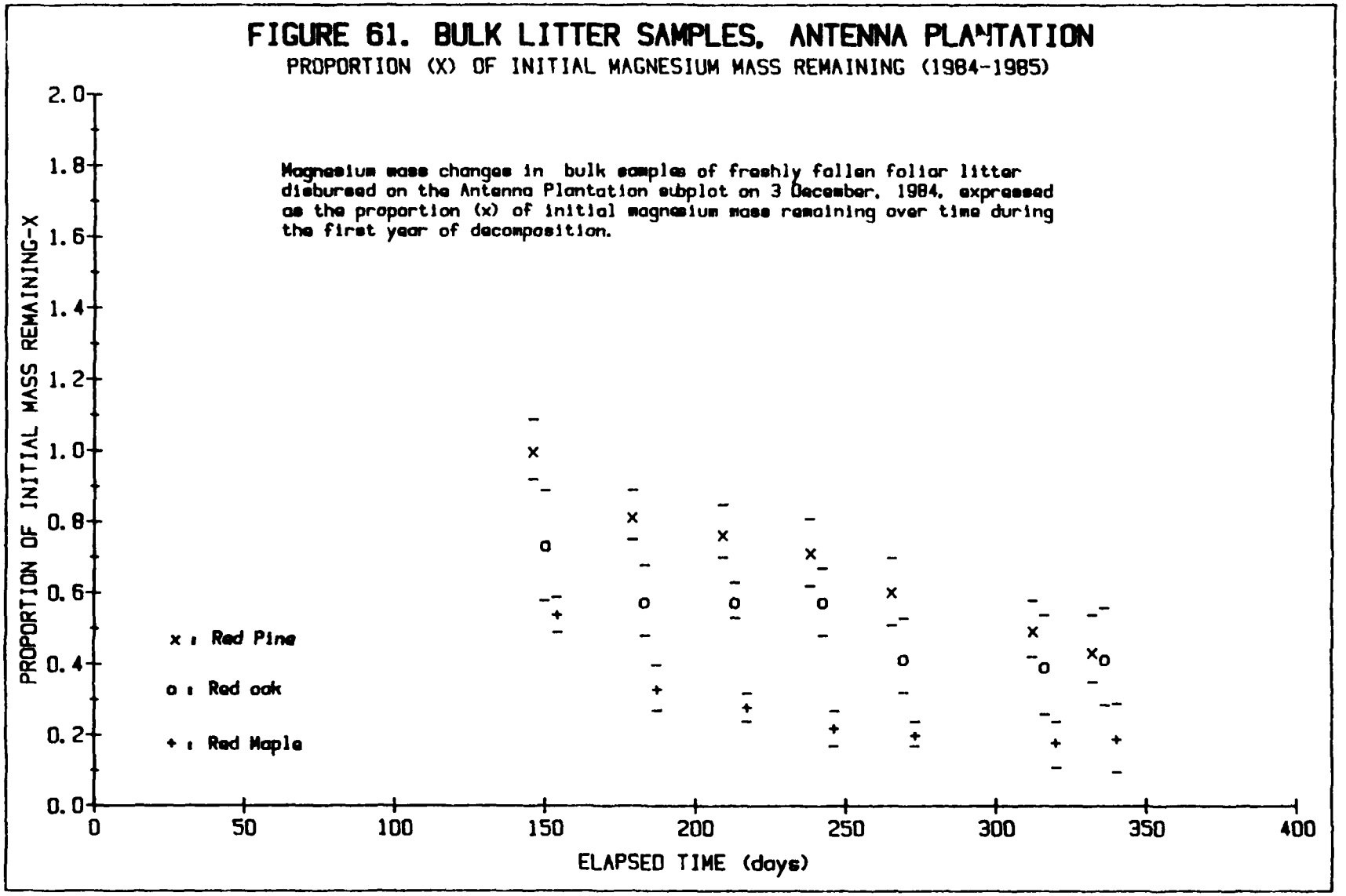


FIGURE 60. BULK LITTER SAMPLES, GROUND PLANTATION
PROPORTION (X) OF INITIAL MAGNESIUM MASS REMAINING (1984-1985)
Magnesium mass changes in bulk samples of freshly fallen foliar litter disbursed on the Ground Plantation subplot on 3 December, 1984, expressed as the proportion (x) of initial magnesium mass remaining over time during the first year of decomposition.
x : Red Pine
o : Red oak
+ : Red Maple
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0
50
100
150
200
250
300
350
400

FIGURE 61. BULK LITTER SAMPLES, ANTENNA PLANTATION

PROPORTION (X) OF INITIAL MAGNESIUM MASS REMAINING (1984-1985)



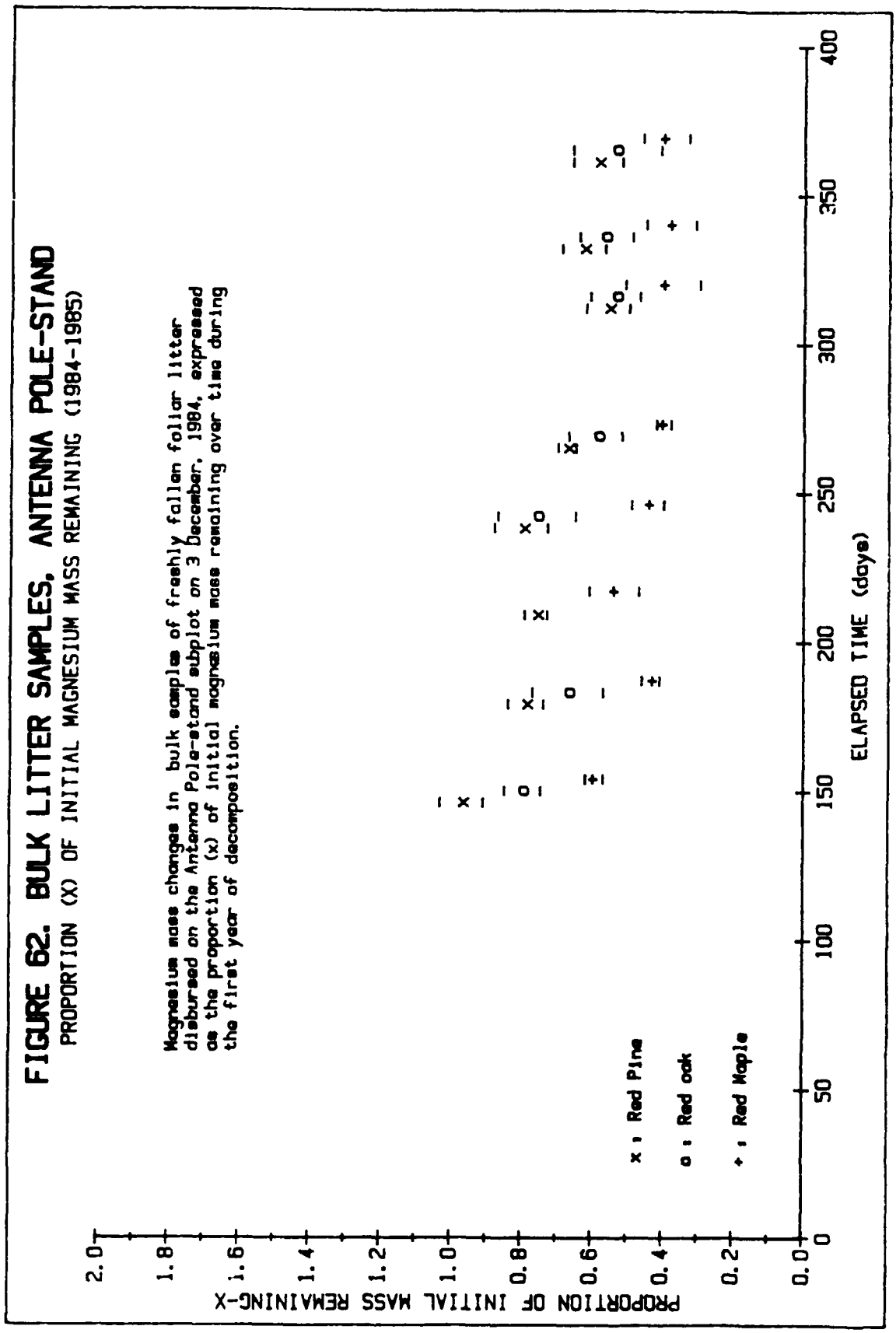


FIGURE 62. BULK LITTER SAMPLES, ANTENNA POLE-STAND
PROPORTION (X) OF INITIAL MAGNESIUM MASS REMAINING (1984-1985)
Magnesium mass changes in bulk samples of freshly fallen foliar litter disbursed on the Antenna Pole-stand subplot on 3 December, 1984, expressed as the proportion (x) of initial magnesium mass remaining over time during the first year of decomposition.
x : Red Pine
o : Red oak
+ : Red Maple
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0
50
100
150
200
250
300
350
400

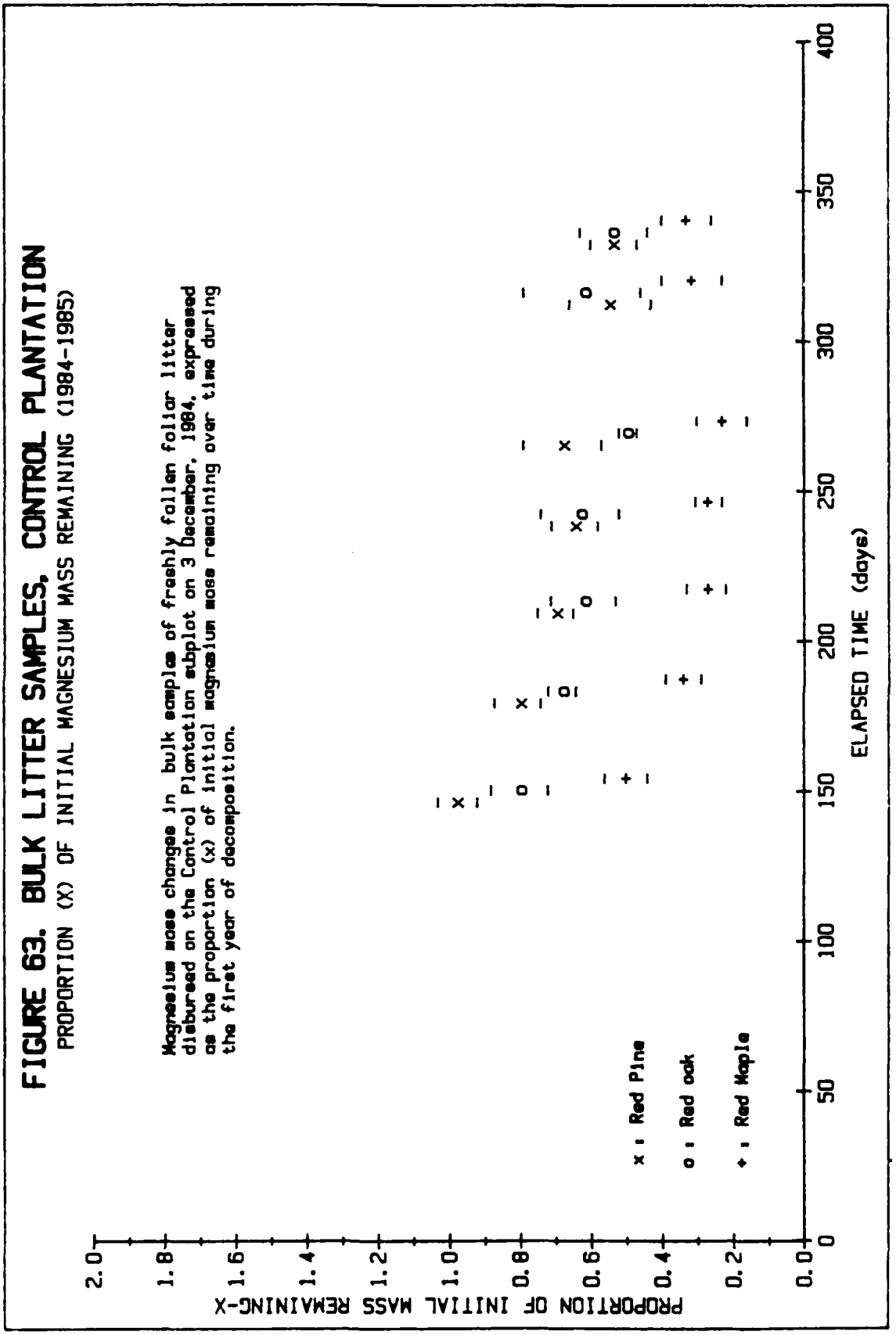


FIGURE 63. BULK LITTER SAMPLES, CONTROL PLANTATION
PROPORTION (X) OF INITIAL MAGNESIUM MASS REMAINING (1984-1985)
Magnesium mass changes in bulk samples of freshly fallen foliar litter disbursed on the Control Plantation subplot on 3 December, 1984, expressed as the proportion (x) of initial magnesium mass remaining over time during the first year of decomposition.
x : Red Pine
o : Red oak
+ : Red Maple
PROPORTION OF INITIAL MASS REMAINING-X
ELAPSED TIME (days)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
0
50
100
150
200
250
300
350
400

FIGURE 64. BULK LITTER SAMPLES, CONTROL POLE-STAND

PROPORTION (X) OF INITIAL MAGNESIUM MASS REMAINING (1984-1985)

Magnesium mass changes in bulk samples of freshly fallen foliar litter disbursed on the Control Pole-stand subplot on 3 December, 1984, expressed as the proportion (x) of initial magnesium mass remaining over time during the first year of decomposition.

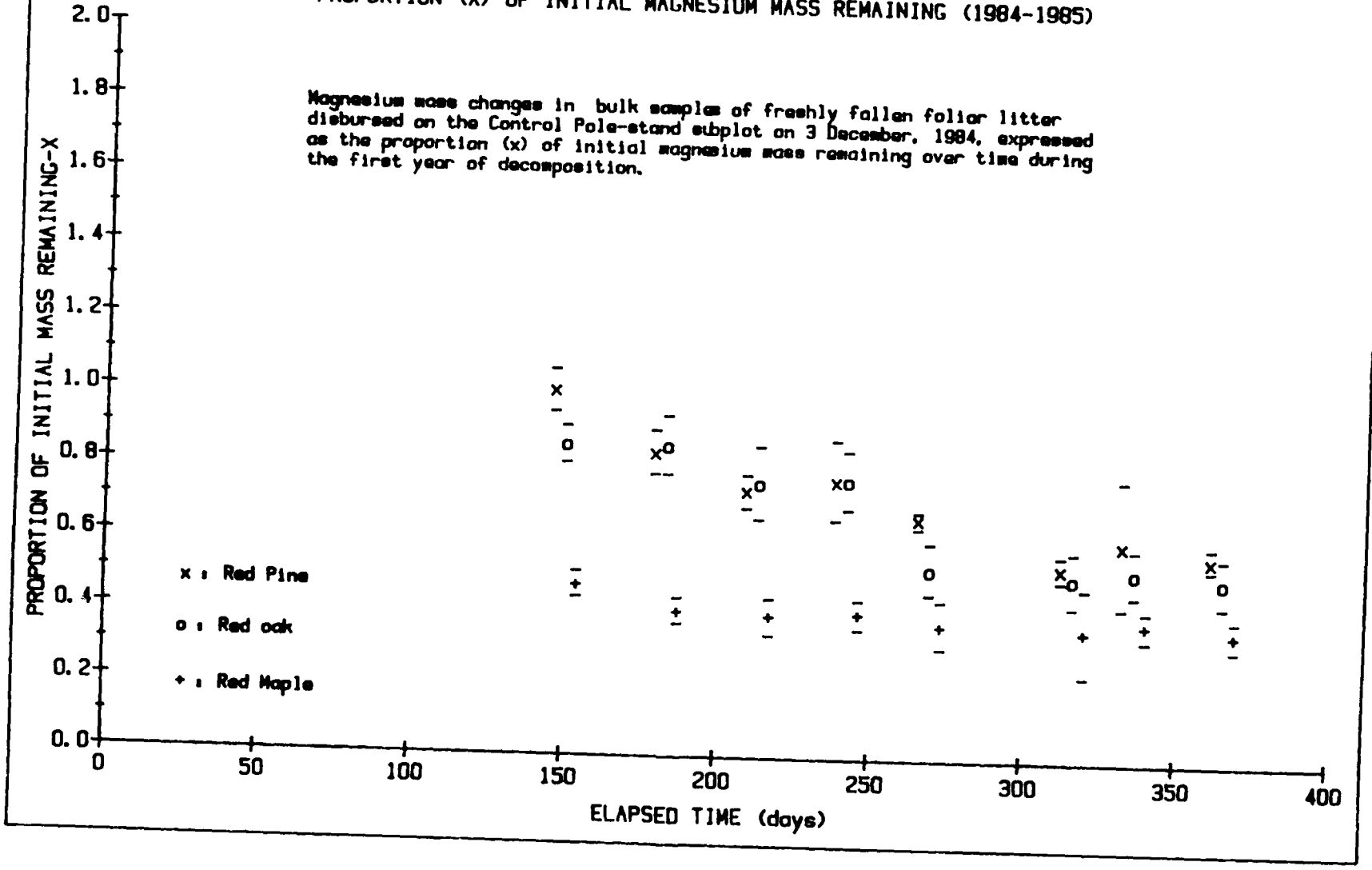


Table 47. Two-way ANOVA table for analysis of differences in nitrogen content of bulk pine samples at the antenna pole-stand subplots, by year and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	4	.009	.451	.771
Year	1	.011	.541	.466
Date	3	.008	.418	.741
Two-way Interactions	3	.039	1.989	.130
Year x Date	3	.039	1.989	.130
Explained	7	.022	1.110	.375
Residual	42	.019		
Total	49	.020		

Table 48. Two-way ANOVA table for analysis of differences in phosphorus content of bulk pine samples at the antenna pole-stand subplots, by year and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	7	.502	59.129	.000
Year	1	2.603	306.608	.000
Date	6	.137	16.086	.000
Two-way Interactions	6	.364	42.853	.000
Year x Date	6	.364	42.853	.000
Explained	13	.438	51.617	0.0
Residual	72	.008		
Total	85	.074		

Table 49. Two-way ANOVA table for analysis of differences in potassium content of bulk pine samples at the antenna pole-stand subplots, by year and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	7	.484	251.622	0.0
Year	1	2.868	1491.284	.000
Date	6	.043	22.481	.000
Two-way Interactions	6	.055	28.612	.000
Year x Date	6	.055	28.612	.000
Explained	13	.286	148.694	0.0
Residual	72	.002		
Total	85	.045		

Table 50. Two-way ANOVA table for analysis of differences in calcium content of bulk pine samples at the antenna pole-stand subplots, by year and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	7	.019	5.560	.000
Year	1	.004	1.175	.282
Date	6	.022	6.433	.000
Two-way Interactions	6	.037	10.967	0.0
Year x Date	6	.037	10.967	0.0
Explained	13	.027	8.110	.000
Residual	72	.003		
Total	85	.007		

Table 51. Two-way ANOVA table for analysis of differences in magnesium content of bulk pine samples at the antenna pole-stand subplots, by year and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	7	.165	51.974	.000
Year	1	.172	54.199	.000
Date	6	.159	49.956	.000
Two-way Interactions	6	.015	4.872	.000
Year x Date	6	.015	4.872	.000
Explained	13	.096	30.234	.000
Residual	72	.003		
Total	85	.017		

1) There was no significant difference between the patterns of nitrogen or calcium flux associated with pine litter decomposition on the antenna pole-stand subplot during 1984 and 1985.

2) Higher levels of phosphorus, potassium and magnesium were retained during 1985 than during 1984.

Recalling that pine litter samples decomposed slightly faster in the 1984-85 study than in the 1983-84 study (Figure 27, Table 13), it is tempting to presume that differences between the patterns of phosphorus, potassium and magnesium retention are tied to the pattern of dry matter mass loss. Reasons for the absence of corresponding differences between the 1984 and 1985 field seasons in nitrogen and calcium retention are unclear.

Differences in the patterns of nutrient flux between subplots and sampling date were also investigated. Two-way ANOVA tables representing nitrogen flux associated with pine, oak and maple litter are presented in Tables 52-54. Corresponding phosphorus, potassium, calcium and magnesium data are presented in Tables 55-57, 58-60, 61-63, and 64-66. The following information is derived from these analyses.

Table 52. Two-way ANOVA table for analysis of differences in nitrogen mass (proportion, X_N, of original mass remaining at sample retrieval) in bulk pine litter samples from the 1984-85 study, by subplot and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	10	.447	20.003	.000
Subplot	4	.555	24.812	.000
Date	6	.377	16.838	.000
Two-way Interactions	24	.137	6.111	.000
Subplot x Date	24	.137	6.111	.000
Explained	34	.228	10.197	.000
Residual	173	.022		
Total	207	.056		

Table 53. Two-way ANOVA table for analysis of differences in nitrogen mass (proportion, X_N, of original mass remaining at sample retrieval) in bulk oak litter samples from the 1984-85 study, by subplot and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	10	.229	6.967	.000
Subplot	4	.160	4.884	.001
Date	6	.274	8.355	.000
Two-way Interactions	24	.085	2.579	.000
Subplot x Date	24	.085	2.579	.000
Explained	34	.127	3.869	.000
Residual	175	.033		
Total	209	.048		

Table 54. Two-way ANOVA table for analysis of differences in nitrogen mass (proportion, X_N, of original mass remaining at sample retrieval) in bulk maple litter samples from the 1984-85 study, by subplot and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	10	.530	23.024	.000
Subplot	4	.758	32.934	.000
Date	6	.372	16.144	.000
Two-way Interactions	24	.044	1.906	.010
Subplot x Date	24	.044	1.906	.010
Explained	34	.187	8.117	.000
Residual	174	.023		
Total	208	.050		

Table 55. Two-way ANOVA table for analysis of differences in phosphorus mass (proportion, Xp, of original mass remaining at sample retrieval) in bulk pine litter samples from the 1984-85 study, by subplot and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	10	.983	32.653	.000
Subplot	4	.667	22.155	.000
Date	6	1.194	39.649	.000
Two-way Interactions	24	.114	3.802	.000
Subplot x Date	24	.114	3.802	.000
Explained	34	.370	12.288	.000
Residual	173	.030		
Total	207	.086		

Table 56. Two-way ANOVA table for analysis of differences in phosphorus mass (proportion, Xp, of original mass remaining at sample retrieval) in bulk oak litter samples from the 1984-85 study, by subplot and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	10	.502	21.879	.000
Subplot	4	.666	29.041	.000
Date	6	.392	17.104	.000
Two-way Interactions	24	.067	2.936	.000
Subplot x Date	24	.067	2.936	.000
Explained	34	.195	8.508	.000
Residual	175	.023		
Total	209	.051		

Table 57. Two-way ANOVA table for analysis of differences in phosphorus mass (proportion, Xp, of original mass remaining at sample retrieval) in bulk maple litter samples from the 1984-85 study, by subplot and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	10	.491	39.094	.000
Subplot	4	.850	67.730	.000
Date	6	.248	19.717	.000
Two-way Interactions	24	.020	1.589	.048
Subplot x Date	24	.020	1.589	.048
Explained	34	.158	12.620	.000
Residual	174	.013		
Total	208	.036		

Table 58. Two-way ANOVA table for analysis of differences in potassium mass (proportion, X_K, of original mass remaining at sample retrieval) in bulk pine litter samples from the 1984-85 study, by subplot and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	10	.136	14.219	.000
Subplot	4	.128	13.403	.000
Date	6	.140	14.677	.000
Two-way Interactions	24	.038	3.973	.000
Subplot x Date	24	.038	3.973	.000
Explained	34	.067	6.986	.000
Residual	173	.010		
Total	207	.019		

Table 59. Two-way ANOVA table for analysis of differences in potassium mass (proportion, X_K, of original mass remaining at sample retrieval) in bulk oak litter samples from the 1984-85 study, by subplot and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	10	.530	22.976	.000
Subplot	4	.524	22.740	.000
Date	6	.533	23.109	.000
Two-way Interactions	24	.091	3.931	.000
Subplot x Date	24	.091	3.931	.000
Explained	34	.224	9.702	.000
Residual	170	.023		
Total	203	.056		

Table 60. Two-way ANOVA table for analysis of differences in potassium mass (proportion, X_K, of original mass remaining at sample retrieval) in bulk maple litter samples from the 1984-85 study, by subplot and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	10	.021	31.550	.000
Subplot	4	.047	69.981	.000
Date	6	.004	6.485	.000
Two-way Interactions	24	.003	4.142	.000
Subplot x Date	24	.003	4.142	.000
Explained	34	.008	12.203	.000
Residual	172	.001		
Total	206	.002		

Table 61. Two-way ANOVA table for analysis of differences in calcium mass (proportion, X_{Ca}, of original mass remaining at sample retrieval) in bulk pine litter samples from the 1984-85 study, by subplot and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	10	.069	14.369	.000
Subplot	4	.105	21.807	.000
Date	6	.046	9.465	.000
Two-way Interactions	24	.010	2.027	.005
Subplot x Date	24	.010	2.027	.005
Explained	34	.027	5.657	.000
Residual	173	.005		
Total	207	.009		

Table 62. Two-way ANOVA table for analysis of differences in calcium mass (proportion, X_{Ca}, of original mass remaining at sample retrieval) in bulk oak litter samples from the 1984-85 study, by subplot and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	10	.093	16.020	.000
Subplot	4	.027	4.718	.000
Date	6	.139	23.992	.001
Two-way Interactions	24	.006	1.053	.403
Subplot x Date	24	.006	1.053	.403
Explained	34	.032	5.588	.000
Residual	170	.006		
Total	203	.010		

Table 63. Two-way ANOVA table for analysis of differences in calcium mass (proportion, X_{Ca}, of original mass remaining at sample retrieval) in bulk maple litter samples from the 1984-85 study, by subplot and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	10	.320	49.661	.000
Subplot	4	.214	33.178	.000
Date	6	.390	60.494	.000
Two-way Interactions	24	.018	2.800	.000
Subplot x Date	24	.018	2.800	.000
Explained	34	.107	16.583	.000
Residual	172	.006		
Total	206	.023		

Table 64. Two-way ANOVA table for analysis of differences in magnesium mass (proportion, X_{Mg}, of original mass remaining at sample retrieval) in bulk pine litter samples from the 1984-85 study, by subplot and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	10	.459	92.296	.000
Subplot	4	.026	5.223	.000
Date	6	.747	150.251	.001
Two-way Interactions	24	.012	2.354	.001
Subplot x Date	24	.012	2.354	.001
Explained	34	.143	28.808	.000
Residual	173	.005		
Total	207	.028		

Table 65. Two-way ANOVA table for analysis of differences in magnesium mass (proportion, X_{Mg}, of original mass remaining at sample retrieval) in bulk oak litter samples from the 1984-85 study, by subplot and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	10	.292	35.045	.000
Subplot	4	.156	18.731	.000
Date	6	.385	46.151	.000
Two-way Interactions	24	.015	1.821	.017
Subplot x Date	24	.015	1.821	.017
Explained	34	.099	11.889	.000
Residual	170	.008		
Total	203	.023		

Table 66. Two-way ANOVA table for analysis of differences in magnesium mass (proportion, X_{Mg}, of original mass remaining at sample retrieval) in bulk maple litter samples from the 1984-85 study, by subplot and sampling date.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	10	.213	71.642	.000
Subplot	4	.239	80.214	.000
Date	6	.199	66.779	.000
Two-way Interactions	24	.012	4.122	.000
Subplot x Date	24	.012	4.122	.000
Explained	34	.071	23.981	.000
Residual	172	.003		
Total	206	.014		

A) Nitrogen

1) Pine

a) There was no distinction to be made between nitrogen flux at plantation vs pole-stand subplots. The least nitrogen was retained at the ground plantation, and the most at the control plantation.

b) Significant gains in nitrogen took place during June and August; a significant loss (in the plantations, see Table 32) occurred in October. Pole-stand nitrogen levels remained above original masses into December.

2) Oak

a) Higher levels of nitrogen were recorded at both pole-stands than at any plantation subplot. Significantly less nitrogen was retained at the ground plantation than at either pole-stand, and at the antenna plantation than at the control pole-stand.

b) A significant loss of nitrogen occurred in August (see Table 33). Nitrogen levels remained close to original values in early November.

3) Maple

a) Higher levels of nitrogen were recorded at both pole-stands than at any plantation subplot. Significantly more nitrogen was retained on both pole-stands and on the control plantation than at either the ground or antenna plantations.

b) Significant gains in nitrogen occurred by the end of August (over the level present in early May) and in October. Nitrogen levels were approximately 30 percent higher than original masses in early November.

B) Phosphorus

1) Pine

a) There was no distinction to be made between phosphorus flux at plantation vs pole-stand subplots. The least phosphorus was retained at the ground plantation; more phosphorus was retained at the control plantation than at either the antenna plantation or the control pole-stand.

b) A significant increase in phosphorus content occurred in September, followed by a significant decline in October (see Table 35). Phosphorus levels in early November were approximately 36 percent higher than original masses.

2) Oak

a) Significantly higher levels of phosphorus were retained at both pole-stands than at any plantation subplot. Significantly less phosphorus was retained at the ground and antenna plantations than at either pole-stand or at the control plantation.

b) A significant increase in phosphorus content occurred in August (see Table 36). Phosphorus levels in early November were slightly less than 90 percent of original masses.

3) Maple

a) Higher levels of phosphorus were recorded at both pole-stands than at any of the plantations. Significantly more phosphorus was retained at the control pole-stand than at any other subplot. Significantly less phosphorus was retained at the ground and antenna plantations than at either pole-stand or at the control plantation.

b) Phosphorus increased significantly in August and October (see Table 37). Phosphorus levels in early November were approximately 85 percent of the original mass.

C) Potassium

1) Pine

a) Higher levels of potassium were recorded at the two pole-stands than at any of the three plantations. Significantly less potassium was retained at the ground and antenna plantations than at either pole-stand or at the control plantation.

b) A significant decline in potassium content occurred in May (see Table 38). Potassium levels in early November were slightly less than 50 percent of original mass.

2) Oak

a) Higher levels of potassium were recorded for both pole-stands than for any of the plantation subplots. Significantly higher levels of potassium were retained at the control pole-stand than at the control plantation subplot. Significantly less potassium was retained at the ground and antenna plantations than at either pole-stand or at the control plantation.

b) A significant gain in potassium occurred in September, followed by a significant loss in October (see Table 39). Potassium levels in early November were approximately 80 percent vs 58 percent of original mass, in the pole-stand and plantation subplots, respectively.

3) Maple

a) Significantly more potassium was retained at the control pole-stand than at any other subplot, and at both pole-stands than at any of the three plantations.

b) Significant decreases in potassium occurred in May and August, followed by a significant increase in September (see Table 40). Potassium values in early November remained approximately 10 percent of original mass.

D) Calcium

1) Pine

a) There was no distinction to be made between calcium flux at plantation vs pole-stand subplots. Significantly less calcium was retained at the control pole-stand than at any other subplot, and at the control plantation than at either the ground plantation or the antenna pole-stand.

b) A significant decline in calcium content occurred in May (see Table 41). Calcium levels in early November were very close to original mass.

2) Oak

a) Higher levels of calcium were recorded at the two pole-stands than at any of the three plantations. Significantly more calcium was retained at the antenna pole-stand than at the antenna plantation.

b) Significant declines in calcium content occurred in August and October (see Table 42). Calcium levels in early November were approximately 83 percent of original mass.

3) Maple

a) There was no difference between calcium flux at plantation vs pole-stand subplots. Significantly more calcium was retained at the antenna pole-stand than at any other subplot, and at both antenna subplots than at either control subplot. Significantly less calcium was retained at the control pole-stand than at either antenna subplot or the ground plantation.

b) Calcium declined significantly during May, August (from levels recorded for early July), and September (see Table 43). By early November, calcium levels had dropped to approximately 60 percent of original mass.

E) Magnesium

1) Pine

a) Higher levels of magnesium were recorded for both pole-stands than for any plantation subplot. Significantly more magnesium was retained at both pole-stands than at either the antenna or ground plantations.

b) Significant declines in magnesium content occurred in May, June, August, and September (see Table 44). By early November, magnesium levels were approximately 56 percent of original mass.

2) Oak

a) More magnesium was retained in both pole-stands than in any of the plantations. Significantly more magnesium was retained at the control pole-stand than at any of the three plantations, and at both pole-stands than at either the antenna or ground plantation. Significantly less magnesium was retained at the antenna plantation than at either pole-stand or the control plantation.

b) Magnesium declined significantly in May and August (see Table 45). By early November, magnesium levels had dropped to approximately 50 percent of original mass.

3) Maple

a) Significantly more magnesium was retained at the antenna pole-stand than at any other subplot, and at both pole-stands than at any plantation subplot. Significantly less magnesium was retained at the antenna plantation than at either pole-stand or the control plantation.

b) Magnesium declined significantly during May and August (see Table 46). By early November, magnesium levels had dropped to only 30 percent of original mass.

The patterns of dry matter mass loss and nutrient flux associated with pine, oak, and maple litter samples support the contention that these three litter species differ markedly in decomposition strategy.

1) The pattern of dry matter mass loss for oak litter has much more in common with that of pine than with that of maple (Figures 1-10).

2) The pattern of nitrogen flux for oak litter in 1985 did not especially resemble that of either pine or maple (Figures 40-44).

3) The pattern of phosphorus flux for oak litter in 1985 appeared to have more in common with that of maple than with that of pine (Figures 45-49).

4) The pattern of potassium flux for oak litter during 1985 resembled that of pine more than that of maple, and yet became unique during August in both pole-stand subplots (Figures 50-54).

5) The pattern of calcium flux for oak litter during 1985 generally resembled that of pine more than that of maple, yet tended to become unique later in the season (Figures 55-59).

6) The pattern of magnesium flux for oak litter during 1985 resembled that of pine more than that of maple (Figures 60-64).

These patterns of similarities and differences between the three litter species are undoubtedly based on clear differences in their physical and chemical compositions. These differences in litter substrate, in turn, select for substantially different decomposer communities, both functionally and taxonomically. As a result, the likelihood of detecting any effects of environmen-

tal perturbations are enhanced by studying decomposition of all three litter species rather than only one or two of them.

One of the striking differences between the behavior of the three litter species was the greater variability which built up over time within the maple samples as opposed to the oak samples and, especially, the pine samples. This variability was more noticeable within the individual fascicle/leaf samples than in the bulk samples, and also in the plantations rather than in the pole-stands. One likely explanation is the fact that litterfall began to shelter pole-stand samples from environmental extremes and weathering fairly early in the season. This sheltering effect increases markedly with the onset of major leaf-fall in September (Figures 7.1 and 7.2, p. 169, from the Annual Report 1986 of the Herbaceous Plant Cover and Tree Studies project). The differences in variability between species fit the hypotheses that pine fascicles decompose more uniformly, and somewhat more slowly, than do oak or maple leaves, and that maple leaves decompose least uniformly and most rapidly of the three species. One reason for the apparently greater uniformity of pine fascicle decomposition is the fact that the influence of fragmentation was eliminated for pine by discarding broken fascicles upon retrival from the field. Fragmentation among the tethered maple leaves was much more severe than among the oak leaves. Compared to maple leaves, fragmentation among the oak leaves was due less to their fragile nature and more to the development of localized areas of extreme decomposition. Within tethered oak leaf envelopes, great variability was noted in the relative rates at which individual leaves and portions of leaves decomposed.

The relationships between mass loss and leaf surface area (one side) and leaf density (mass per unit surface area) were investigated for individual oak and maple leaves, in order to determine whether any of the observed variability in mass loss might be explained by differences in decay rate between shade leaves (generally larger and thinner) and sun leaves (generally smaller and thicker). The variability in decomposition rate observed for individual maple leaves (Table 10 and Figures 6-10),

especially on the plantation subplots, is great enough to prevent detection of modest shifts in decomposition rate due to limited environmental perturbation. Leaf area and/or density might prove to be valuable covariates in analysis of hardwood leaf decomposition, if any relationship to decomposition rate could be demonstrated. In an effort to increase the uniformity of conditions for sample leaf decomposition, and thus to lower sample variances, all possibility for sample maple leaves to overlap and thereby shelter portions of other sample leaves from weathering was eliminated in the 1985-86 study by confining each sample maple leaf to one-quarter of a litter envelope. This also eliminated the problem of broken petioles associated with application of the tethered leaf method to maple and helped to maintain leaf integrity. Tables 67 and 68 present Pearson's product moment correlation coefficients between individual leaf mass loss (as of the early November sampling date) and both leaf surface area and density, for oak and maple, respectively. No useful relationship was detected.

The limitations of single exponential decomposition models for explaining decomposition progress in the field were discussed in the 1985 Annual Report. Their major weakness is the fact that they assume a uniform environment throughout the period of study. As a result, values derived from exponential models for "lag period" and "decomposition rate constants" have little biological meaning. In light of these considerations, we are testing a similar form of decomposition model which 1) takes advantage of the variance homogenizing property of the ln transformation and 2) simplifies the inclusion of controlling weather variables. The form of this model is: $\ln(X) = B_0 - kt + B_1 Y_1 + e$, where X is the proportion of dry matter mass remaining, k is the decomposition constant, t is elapsed time, and Y_1 is an independent variable with a controlling influence on decomposition rate.

Table 69 presents Pearson product moment correlation coefficients characterizing the relationships between transformed dry matter mass loss over time (arc sine square root of X) from bulk and individual fascicle/leaf samples of all three litter species

Table 67. Means and standard deviations, for tethered oak leaves retrieved 6 November, 1986, of transformed mass loss (arc-sin square root of X), leaf area, and leaf density, and Pearson's product moment correlation coefficients (r) for transformed mass loss with leaf area and leaf density.

	Bagged Leaves		Unbagged Leaves[a]	
	Plantations[b]	Pole-stands[c]	Plantation	Pole-stand
Sample Size	90	60	15	15
Mean X^d	.68	.68	.65	.61
$S.D._x$	.11	.09	.13	.07
Mean area[e]	40.51	44.29	44.40	49.14
S.D.area	17.95	19.00	25.35	13.99
R_{area}	.16	.10	-.41	-.12
p^f	.06	.22	.06	.34
Mean Density[g]	.0078	.0074	.0077	.0075
$S.D_{density}$	.0012	.0012	.0009	.0018
$R_{density}$	.05	.18	.38	.65
p	.33	.08	.08	.00

a/ Unbagged tethered leaves were disbursed only at the Control plot, for comparison with bagged tethered and bulk sample decomposition.
b/ Data representing the Antenna, Ground and Control plantation subplots are included.
c/ Data representing the Antenna and Control pole-stand subplots are included.
d/ X = proportion of original leaf mass remaining on 6 November, 1986, after 326 days in the field (30°C basis).
e/ mean of three area determinations (cm^2)
f/ attained level of significance, p
g/ initial mass (30°C basis) divided by initial leaf area

Table 68. Means and standard deviations, for bagged individual maple leaves retrieved 6 November, 1986, of transformed mass loss (arcsin square root of X), leaf area, and leaf density, and Pearson's product moment correlation coefficients (r) for transformed mass loss with leaf area and leaf density.

	Plantations[a]	Pole-stands[b]
Sample Size	17	24
Mean X[c]	.34	.50
$S.D._x$	.14	.16
Mean area[d]	29.90	27.54
$S.D._{area}$	13.54	10.88
R_{area}	-.32	.07
p[e]	.10	.37
Mean Density[f]	.0063	.0062
$S.D_{density}$	.0013	.0015
$R_{density}$	.22	.01
p	.20	.48

a/ Data representing the Antenna, Ground and Control plantation subplots are included.
b/ Data representing the Antenna and Control pole-stand subplots are included.
c/ X = proportion of original leaf mass remaining on 6 November, 1986, after 326 days in the field (30°C basis).
d/ mean of three area determinations (cm^2)
e/ attained level of significance, p
f/ initial mass (30°C basis) divided by initial leaf area

Table 69. Relationships between bulk and tethered sample decomposition (transformed to arcsin square root) and selected environmental parameters of air and soil temperature, soil moisture, and precipitation, expressed as Pearson's product moment correlation coefficients.

Variable	Correlation Coefficient (r)[a]					
	Pole-stands[b]			Plantations[c]		
	Pine	Oak	Maple	Pine	Oak	Maple
	-- Bulk Samples --					
ATRT[d]	-.97	-.91	-.90	-.90	-.85	-.84
ATDDRT[e]	-.97	-.90	-.89	-.89	-.84	-.83
ST5DDRT[f]	-.97	-.92	-.91	-.89	-.85	-.85
PRWRT[g]	-.96	-.97	-.94	-.92	-.90	-.86
PR.01RT[h]	-.98	-.95	-.93	-.92	-.90	-.89
PR.10RT[i]	-.96	-.96	-.93	-.91	-.86	-.82
	-- Tethered Samples --					
ATRT	-.88	-.82	-.69	-.88	-.77	-.78
ATDDRT	-.87	-.81	-.68	-.88	-.77	-.78
ST5DDRT	-.88	-.82	-.69	-.88	-.77	-.79
PRWRT	-.90	-.87	-.73	-.88	-.76	-.72
PR.01RT	-.90	-.85	-.73	-.90	-.77	-.75
PR.10RT	-.90	-.85	-.70	-.87	-.75	-.71

a/ All correlations were highly significant ($p = .000$).
b/ Data from both the Antenna and Control pole-stand subplots were included.
c/ Data from the Antenna, Ground, and Control plantation subplots were included.
d/ running total of accumulated mean daily air temperature (°C, 30cm above ground level
e/ running total of air temperature degree days (4.4 °C basis), based on mean daily temperature
f/ running total of soil temperature degree days (4.4°C basis, 5cm below ground level), based on mean daily temperature
g/ running total of precipitation (inches)
h/ number of days with at least .01 in. precipitation
i/ number of days with at least .1 in. precipitation

and cumulative measures of local weather variables. Weather variables analyzed include running totals of mean daily air temperature, air and soil temperature degree days (4.4°C basis, 30 cm above and 5 cm below ground level, respectively), precipitation, and frequency of precipitation events delivering at least .01 or .10 inches of water. All correlation coefficients were highly significant ($p = .000$). Pine litter decomposition provided the highest correlation coefficients 1) with both temperature- and precipitation-related variables, 2) with both bulk and individual fascicle/leaf samples, and 3) on both pole-stand and plantation subplots. For all three litter species, bulk litter sample decomposition was 1) more highly correlated with all weather variables than were individual fascicle/leaf samples and 2) more highly correlated with all weather variables in the pole-stand than in the plantation subplots. Of the three litter species, only individual maple leaves were more highly correlated with temperature-related weather variables in the plantation subplots than in the pole-stand subplots. Soil temperature degree days was only slightly better correlated with decomposition than air temperature or air temperature degree days. Also, the frequency of precipitation events delivering at least .01 inch of water was slightly better correlated with decomposition in the plantation subplots than was the frequency of .10 inch events. Based on this analysis, we will consider soil temperature degree days, total precipitation, and the frequency of precipitation events (.01 inch water or more) for use as covariates 1) to explain decomposition progress through individual field seasons at each subplot, and 2) to explain differences between years and subplots.

Preliminary evaluation of the importance of current weather to periodic decomposition progress is being conducted by correlation of transformed monthly dry matter mass loss (arc sine square root of X_t - arc sine square root of X_{t-1}) with a number of temperature- and moisture-related variables reflecting weather during a) the specified monthly period of decomposition, b) the previous period, and c) both periods combined. Tables 70 and 71

Table 70. Relationships between monthly progress in decomposition of bulk samples (transformed to arcsin square root) and values for selected temperature-related variables representing the corresponding month, previous month, and both months combined, expressed as Pearson's product moment correlation coefficients.

Variable	Correlation Coefficient (r)					
	Pole-stands[a]			Plantations[b]		
	Pine	Oak	Maple	Pine	Oak	Maple
ATC[c]-Pd	.72	.56	.40	.22	.40	.15
	(.000)[g]	(.000)	(.004)	(.06)	(.001)	(.14)
AT -PB[e]	.39	.57	.42	.45	.38	.11
	(.009)	(.000)	(.005)	(.001)	(.005)	(.24)
AT -BP[f]	.75	.62	.46	.52	.28	-.03
	(.000)	(.000)	(.003)	(.000)	(.03)	(.42)
ATDD[h]-P	.68	.60	.40	.28	.42	.14
	(.000)	(.000)	(.004)	(.02)	(.001)	(.15)
ATDD -PB	.32	.58	.47	.39	.42	.15
	(.03)	(.000)	(.002)	(.004)	(.002)	(.16)
ATDD -BP	.66	.67	.48	.51	.35	.01
	(.000)	(.000)	(.002)	(.000)	(.009)	(.47)
ST5[i]-P	.65	.68	.40	.18	.42	.22
	(.000)	(.000)	(.004)	(.10)	(.001)	(.06)
ST5 -PB	.27	.53	.32	.48	.38	.13
	(.06)	(.000)	(.03)	(.000)	(.005)	(.20)
ST5 -BP	.64	.66	.39	.51	.28	.03
	(.000)	(.000)	(.01)	(.000)	(.03)	(.43)
ST5DD[j]-P	.59	.71	.40	.22	.46	.23
	(.000)	(.000)	(.004)	(.06)	(.000)	(.05)
ST5DD -PB	.21	.54	.38	.42	.42	.16
	(.11)	(.000)	(.01)	(.002)	(.002)	(.14)
ST5DD -BP	.53	.68	.42	.49	.36	.07
	(.000)	(.000)	(.006)	(.000)	(.007)	(.31)

a/ the Antenna and Control pole-stand subplots
b/ the Antenna, Ground, and Control plantation subplots
c/ mean daily air temperature (°C, 30cm above ground level)
d/ the period (roughly 1 month) of decomposition
e/ the period prior to that of decomposition
f/ both periods covered by d/ and e/
g/ the attained level of significance, p, for the correlation
h/ accumulated air temperature degree days (4.4 °C, mean daily)
i/ mean daily soil temperature (°C, 5 cm below ground level)
j/ accumulated soil temperature degree days (4.4° C, mean daily)

Table 71. Relationships between monthly progress in decomposition of bulk samples (transformed to arcsin square root) and values for selected moisture-related variables representing the corresponding month, previous month, and both months combined, expressed as Pearson's product moment correlation coefficients.

Variable	Correlation Coefficient (r)					
	Pole-stands[a]			Plantations[b]		
	Pine	Oak	Maple	Pine	Oak	Maple
SM5[c]-pd[d]	-.42	-.25	-.08	-.14	.03	-.05
	(.004)[g]	(.06)	(.31)	(.16)	(.42)	(.35)
SM5 -PB[e]	-.37	-.62	-.39	-.25	-.19	.04
	(.01)	(.000)	(.009)	(.05)	(.11)	(.39)
SM5 -BP[f]	-.28	-.24	-.05	-.23	-.02	.03
	(.05)	(.08)	(.39)	(.06)	(.45)	(.41)
PRWTOT[h]-P	-.09	.41	.10	.43	.49	.21
	(.30)	(.004)	(.26)	(.001)	(.000)	(.07)
PRWTOT -PB	-.41	.17	-.01	.02	.40	.15
	(.007)	(.17)	(.49)	(.46)	(.004)	(.16)
PRWTOT -BP	-.29	.19	-.02	.28	.45	.13
	(.04)	(.14)	(.45)	(.03)	(.001)	(.19)
PR.01[i]-P	.04	.47	.28	.38	.47	.28
	(.39)	(.001)	(.04)	(.002)	(.000)	(.02)
PR.01 -PB	-.24	.21	.04	.06	.39	.13
	(.08)	(.11)	(.40)	(.35)	(.004)	(.20)
PR.01 -BP	-.15	.33	.14	.29	.48	.19
	(.19)	(.03)	(.21)	(.03)	(.000)	(.10)
PR.10[j]-P	.16	.53	.27	.44	.52	.20
	(.16)	(.000)	(.04)	(.001)	(.000)	(.07)
PR.10 -PB	-.35	.16	-.03	.12	.40	.11
	(.02)	(.18)	(.44)	(.21)	(.003)	(.23)
PR.10 -BP	-.12	.28	.07	.35	.44	.09
	(.24)	(.05)	(.34)	(.01)	(.001)	(.28)

a/ the Antenna and Control pole-stand subplots
b/ the Antenna, Ground, and Control plantation subplots
c/ mean daily soil moisture (5 cm below ground level)
d/ the period (roughly 1 month) of decomposition
e/ the period prior to that of decomposition
f/ both periods covered by d/ and e/
g/ the attained level of significance, p, for the correlation
h/ total precipitation (inches)
i/ number of days with at least 0.01 inches precipitation
j/ number of days with at least 0.10 inches precipitation

present the results of these analyses for temperature- and moisture-related weather variables, respectively. The typical inverse relationship between air temperature and precipitation did not materialize in 1986 as it did in 1985. 1986 was a drier year than 1985. Compared to 1985, 1986 was generally characterized by 1) a slightly cooler, much dryer spring, 2) a slightly cooler, dry mid-summer, 3) a cool, much drier late summer, and 4) a cool, much drier autumn (Figures 1.3 through 1.5, 1.16, and 1.17, Annual Report 1986, Herbaceous Plant Cover and Tree Studies). Much lower correlation coefficients were obtained in the analysis of periodic decomposition progress than with the analysis of cumulative seasonal dry matter mass loss progress, suggesting the existence of considerable inertia (Jansson and Berg 1985), no doubt largely in response to the buildup of decomposer populations and their activities. The following additional observations were made.

A) Temperature-related Variables

1) General
   a) Temperature-related variables were all positively correlated with decomposition progress during 1986.
   b) All three species were better correlated with both air and soil temperature-related variables in the pole-stands than in the plantations.

2) Pole-stand Subplots
   a) Pine and maple were the best and least well correlated species, respectively, with air temperature measures.
   b) Oak and maple were the best and least well correlated species, respectively, with soil temperature measures.
   c) Pine, and to a lesser extent maple, decomposition was better correlated with air temperature than with soil temperature measures, while the reverse was true for oak decomposition.

2) Pole-stand Subplots (cont.)

d) Pine decomposition was better correlated with current weather than with weather of the previous period, although correlation coefficients with air temperature measures for the previous period were significant.

e) Oak decomposition was nearly as well correlated with air and soil temperature measures reflecting the previous period as with the same measures reflecting the current period.

f) Maple decomposition was best correlated with air temperature measures reflecting both periods and least well correlated with the current period values.

g) Maple decomposition was better correlated with soil temperature measures for either the current or both periods combined, and least well correlated with measures reflecting the previous period.

3) Plantation Subplots

a) Pine decomposition was best and least well correlated with the combined periods and the current period, respectively, for both air and soil temperature measures.

b) Oak decomposition was best and least well correlated with the current period and both periods combined, respectively, for both air and soil temperature measures.

c) Maple decomposition was poorly correlated with all temperature-related variables.

B) Moisture-related Variables

1) General

a) Decomposition progress for all three species was better correlated with soil moisture measures in the pole-stands than in the plantation subplots.

1) General (cont.)

b) Soil moisture was negatively correlated with monthly decomposition progress for all three species.

c) Pine decomposition tended to be negatively and poorly correlated with frequency of precipitation events in the pole-stands, but positively and better correlated with the same variables for the current period and both periods combined in the plantation subplots.

d) Pine decomposition was negatively correlated with total precipitation for the previous period and for both periods combined in the pole-stand subplots, but positively correlated for the current period and both periods combined in the plantation subplots.

e) Oak decomposition was positively correlated with total precipitation during only the current period in the pole-stands, but for all three periods in the plantation subplots.

f) Oak decomposition was significantly correlated with frequency of precipitation events for the current period and both periods combined in the pole-stands and for all three periods in the plantation subplots.

g) Maple decomposition was not significantly correlated with total precipitation for any of the three periods in either the pole-stand or plantation subplots.

h) Maple decomposition was significantly, though poorly, correlated with frequency of precipitation events in both the pole-stand and plantation subplots, but only for the current period.

2) Pole-stand Subplots

a) Pine decomposition was best correlated with soil moisture during the current period, but was also significantly correlated for the previous period and for both periods combined.

b) Oak and maple decomposition were significantly correlated with soil moisture only for the previous period.

3) Plantation Subplots

a) Only pine decomposition was significantly correlated (though weakly) with soil moisture, and only for the previous period.

The negative correlation between soil moisture and monthly decomposition progress in 1986 (most pronounced for pine and oak in the pole-stand subplots) was undoubtedly related to higher soil moisture values during the cooler months of the year (Figures 1.12 and 1.13, Annual Report 1986, Herbaceous Plant Cover and Tree Studies). Similar correlation analyses will be conducted for the 1985 field season as background leading to covariate analysis.

Element 9: Red Pine Seedling Rhizoplane Streptomycetes

Introduction

Streptomycetes have been implicated in the calcium and phosphorus nutrition of ectotrophic mycorrhizae, and can influence mycorrhizosphere microbial population composition through production of antibiotics, growth factors, etc. (Graustein et al. 1977, Knutson et al. 1980, Marx 1982, Keast and Tonkin 1983). Streptomycetes have also been found to degrade cellulose and lignin/lignocellulose in both coniferous and deciduous litter systems (Crawford 1978, Sutherland et al. 1979, Antai and Crawford 1981). The sensitivity and value of the red pine mycorrhiza studies being conducted by the Herbaceous Plant Cover and Tree Studies project are greatly enhanced through quantitative study of the associated streptomycete populations.

The emphasis of this element during the 1986 sampling season has been on 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 in 1985, the mycorrhizal condition of red pine seedlings in the antenna, ground, and control plot plantations has been followed on a monthly basis in 1986, from May through October, by staff of the Herbaceous Plant Cover and Tree Studies project. Samples of the 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. As in previous years, a single mycorrhiza morphology type, designated type 3, has been studied. Type 3 mycorrhizae have predominated in all three ELF study plantations to date, probably because they are most often caused by species of Laccaria or Thelephora which occur naturally in the area (Herbaceous Plant Cover and Tree Studies, Annual Report 1986, Element 6. Mycorrhiza Characterization and Root Growth, pages 153-165).

In order to increase the statistical value of the resulting streptomycete data, six washed root samples (for macerate plate

counts), twice as many as in 1985, were analyzed from each of the three ELF study red pine plantations. In addition to comparing data among plots and between dates, the streptomycete level and morphotype data obtained during the 1986 sampling season were also compared to similar data obtained in 1985, the only difference being that six samples per plantation were analyzed for each sampling date in 1986 versus three samples per plantation in 1985. Rough comparisons were also made to the streptomycete levels and morphotypes obtained in 1984 from the same mycorrhizal root type on comparable sampling dates.

Analyses of streptomycetes specifically associated with mycorrhizal root tips via an enrichment technique were not conducted during 1986, in order to analyze twice as many washed root samples. It also did not appear likely that these data would be useful in assessing potential ELF effects.

Methods

Red pine washed mycorrhizal fine root samples were collected and prepared monthly from late May to late October at each of the control, antenna, and ground ELF study plantation subplots, with six washed red pine mycorrhizal fine root samples examined per plantation, i.e., two separate composite samples from each of the three plantation subplot replicates. The same plantation replicates were sampled in 1986 as in 1985 and 1984. These samples were stored at 4°C and processed within 24-48 hours of receipt by the Environmental Microbiology lab in the Department of Biological Sciences. The time interval between root sample collection in the field and delivery of washed root samples for streptomycete analysis averaged seven days.

Using flame-sterilized forceps, 0.1 g (wet weight) of washed roots was placed in 9.9 ml 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 for determination of dry weight.

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). At least 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 reverse colony color) were considered to represent one morphological type or strain (Keast et al. 1984). At least one colony per streptomycete morphotype was isolated in pure culture for further study. In order to evaluate the streptomycetes' contribution to mycorrhiza development and root growth, additional tests are being conducted to evaluate calcium oxalate (Jayasuriya 1955, Knutson et al. 1980), cellulose, and lignocellulose (Sutherland 1985) degradation. Not only the numbers but also the recurrence of distinct streptomycete morphotypes found in the 1986 samples were compared to those observed in similar samples from 1985 and 1984 to determine if some of the same types are present after the red pine seedlings have been in the field two years or more and to determine whether the same types were present at the three ELF study plots.

Data for streptomycete levels and morphotypes based on the SCA plate counts were transformed to $\log_{10}$ (Orchard 1984) and evaluated statistically using two-way analysis of variance (SPSS ANOVA) to compare sampling dates, study plots, and years (1985 and 1986) at the $\alpha = .05$ significance level (Zar 1984). Where the analyses showed significant differences between sites or

sampling dates, Tukey's H.S.D. procedure was used to conduct multiple comparisons between sites and/or sampling dates (Dowdy and Wearden 1983). The ability of our experimental design to detect changes in mean values for either streptomycete levels or morphotype numbers was estimated by using the 95 percent confidence interval for each sample mean to calculate the minimum detectable change (expressed as a percentage of each sample mean).

Description of Progress

Detailed information on the 1986 red pine seedling mycorrhiza populations studied here can be found in the Annual Report of the Herbaceous Plant Cover and Tree Studies project (Element 6, pages 153-165). As noted earlier, one mycorrhiza morphology type (Type 3) predominated at all three plantation subplots during the 1986 sampling season, as was the case in 1985 and 1984.

Data for 1986 streptomycete levels and morphotypes associated with washed type 3 mycorrhizal fine roots are presented in Tables 72 and 73 as the mean, standard error of the sample mean, and minimum detectable difference between sample means based on 95 percent confidence intervals for six samples per plantation subplot. There was no significant difference in either streptomycete levels or morphotype numbers between the control, antenna and ground plantations. The relevant Two-way ANOVA tables for levels and morphotypes are presented in Tables 74 and 75. However, there was a significant seasonal effect on both levels ($p = .000$) and morphotype numbers ($p = .000$) at each of the three plots. Using Tukey's H.S.D. procedure, the following significant ($p \leq .05$) differences were found in streptomycete levels.

1. Control Plot
   a. May through July levels were greater than October levels.
2. Antenna Plot
   a. May through September levels were greater than October levels.

Table 72. Mean levels of streptomycetes ($\times 10^5$) isolated from washed type 3 red pine mycorrizae at each of the three ELF study plantations during 1986, the standard errors of the sample means, and corresponding levels of change detectable (α = .05) 95 percent of the time, expressed as a percentage of the associated mean values.

Sampling Date	Sampling Plot								
	Control			Antenna			Ground		
	Mean[a]	S.E.[b]	%[c]	Mean	S.E.	%	Mean	S.E.	%
29 May 1986	3.9	0.20	13	4.3	0.29	17	3.7	0.12	8
23 June 1986	3.7	0.24	17	3.7	0.16	11	4.3	0.20	12
21 July 1986	3.1	0.29	24	3.1	0.24	20	2.1	0.12	15
18 Aug. 1986	2.1	0.12	15	2.6	0.20	20	2.7	0.20	19
23 Sept. 1986	1.9	0.37	50	2.5	0.16	16	2.6	0.29	29
22 Oct. 1986	1.1	0.12	26	1.1	0.08	19	1.2	0.12	26

a/ mean value for six root samples per plot, each sample representing the composited roots of 2-3 red pine seedlings

b/ standard error of the mean

c/ estimated level of population change which would be detected 95 percent of the time (α = .05), calculated as $t_{0.025,5} * S.E./Mean$, and expressed as a percentage of the sample mean

Table 73. Mean numbers of streptomycete morphotypes isolated from washed type 3 red pine mycorrizae at each of the three ELF study plantations during 1986, the standard errors of the sample means, and corresponding levels of change detectable (α = .05) 95 percent of the time, expressed as a percentage of the associated mean values.

Sampling Date	Sampling Plot								
	Control			Antenna			Ground		
	Mean[a]	S.E.[b]	%[c]	Mean	S.E.	%	Mean	S.E.	%
29 May 1986	6.7	0.82	31	7.2	0.53	19	6.5	0.90	36
23 June 1986	5.3	0.41	20	5.5	0.57	27	5.7	0.49	22
21 July 1986	4.0	0.37	24	4.8	0.33	18	4.5	0.24	14
18 Aug. 1986	3.3	0.20	16	3.5	0.24	18	3.7	0.33	23
23 Sept. 1986	3.7	0.41	28	3.2	0.49	39	3.7	0.33	23
22 Oct. 1986	2.8	0.33	30	2.7	0.33	31	2.5	0.24	25

a/ mean value for six root samples per plot, each sample representing the composited roots of 2-3 red pine seedlings

b/ standard error of the mean

c/ estimated level of population change which would be detected 95 percent of the time (α = .05), calculated as $t_{0.025,5} * S.E./Mean$, and expressed as a percentage of the sample mean

Table 74. Two-way ANOVA table for analysis of differences in 1986 streptomycete levels detected in association with type 3 mycorrhizal red pine roots between study plots and sampling dates.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	7	.528	16.039	.000
Site	2	.020	.649	.525
Date	5	.732	23.595	.000
Two-way Interactions	10	.021	.667	.752
Site x Date	10	.021	.667	.752
Explained	17	.230	7.408	.000
Residual	90	.031		
Total	107	.063		

Table 75. Two-way ANOVA table for analysis of differences in 1986 data on numbers of streptomycete types detected in association with type 3 mycorrhizal red pine roots between study plots and sampling dates.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	7	.283	19.004	.000
Site	2	.012	.822	.442
Date	5	.392	26.401	.000
Two-way Interactions	10	.008	.545	.855
Site x Date	10	.008	.545	.855
Explained	17	.121	8.126	.000
Residual	141	.015		
Total	158	.026		

3. Ground Plot
   a. June levels were greater than July levels, and
   b. May, June, August and September levels were greater than October levels.

The following significant ($p \leq .05$) differences were found in morphotype numbers.

1. Control Plot
   a. May numbers were greater than July numbers, and
   b. May and June numbers were greater than August and October numbers.
2. Antenna Plot
   a. May numbers were greater than July numbers,
   b. May and June numbers were greater than August numbers, and
   c. May through July numbers were greater than September and October numbers.
3. Ground Plot
   a. May and June numbers were greater than August numbers, and
   b. May through July numbers were greater than September and October numbers.

Statistical comparisons between the 1986 and 1985 streptomycete levels showed that there was no significant difference between the antenna and ground plot values for the two years (Tables 76 and 77, respectively). At the control plantation, however, June levels were significantly higher in 1986 than in 1985, apparently due to a poor sample in June of 1985. The increased sample size instituted in 1986 should prevent this kind of difference from developing again in the future. There were also significant differences in morphotype numbers recovered from the antenna ($p = .005$, Table 79), ground ($p = .000$, Table 80), and control ($p = .038$, Table 81) plots between 1986 and 1985. One-way ANOVAs for each plot and sampling date were used to test for differences between years. Because fewer observations and classes are included in the one-way ANOVAs, larger critical F

Table 76. Two-way ANOVA table for analysis of differences between streptomycete levels detected on corresponding dates at the Antenna Plantation subplot in 1985 and 1986 in association with type 3 mycorrhizal red pine fine roots.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	6	.324	9.470	.000
Year	1	.088	2.586	.115
Date	5	.371	10.847	.000
Two-way Interactions	5	.014	.418	.834
Year x Date	5	.068	.418	.834
Explained	11	.240	5.355	.000
Residual	42	.051		
Total	53	.090		

Table 77. Two-way ANOVA table for analysis of differences between streptomycete levels detected on corresponding dates at the Ground Plantation subplot in 1985 and 1986 in association with type 3 mycorrhizal red pine fine roots.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	6	.383	7.494	.000
Year	1	.060	1.169	.286
Date	5	.448	8.759	.000
Two-way Interactions	5	.068	1.333	.269
Year x Date	5	.068	1.333	.269
Explained	11	.240	4.694	.000
Residual	42	.051		
Total	53	.090		

Table 78. Two-way ANOVA table for analysis of differences between streptomycete levels detected on corresponding dates at the Control Plantation subplot in 1985 and 1986 in association with type 3 mycorrhizal red pine fine roots.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	6	.362	8.088	.000
Year	1	.559	12.462	.001
Date	5	.371	7.298	.000
Two-way Interactions	4	.014	2.678	.045
Year x Date	4	.068	2.678	.045
Explained	10	.240	5.924	.000
Residual	40	.051		
Total	50	.090		

Table 79. Two-way ANOVA table for analysis of differences between numbers of streptomycete morphotypes detected on corresponding dates at the Antenna Plantation subplot in 1985 and 1986 in association with type 3 mycorrhizal red pine fine roots.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	6	.144	11.088	.000
Year	1	.117	9.006	.005
Date	5	.150	11.505	.000
Two-way Interactions	5	.032	2.447	.049
Year x Date	5	.032	2.447	.049
Explained	11	.093	7.160	.000
Residual	42	.013		
Total	53	.030		

Table 80. Two-way ANOVA table for analysis of differences between numbers of streptomycete morphotypes detected on corresponding dates at the Ground Plantation subplot in 1985 and 1986 in association with type 3 mycorrhizal red pine fine roots.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	6	.150	13.062	.000
Year	1	.175	15.208	.000
Date	5	.146	12.633	.000
Two-way Interactions	5	.015	1.325	.272
Year x Date	5	.015	1.325	.272
Explained	11	.089	7.727	.000
Residual	42	.012		
Total	53	.028		

Table 81. Two-way ANOVA table for analysis of differences between numbers of streptomycete morphotypes detected on corresponding dates at the Control Plantation subplot in 1985 and 1986 in association with type 3 mycorrhizal red pine fine roots.

Source of Variation	Degrees of Freedom	Mean Square	F	Signif. of F
Main Effects	6	.110	11.516	.000
Year	1	.044	4.623	.038
Date	5	.117	12.243	.000
Two-way Interactions	4	.015	1.623	.187
Year x Date	4	.015	1.623	.187
Explained	10	.072	7.558	.000
Residual	40	.010		
Total	50	.022		

values are required to indicate significant differences. This analysis provides the following insights.

1. Control Plot: While no significant differences were found between years by sampling date, the overall significant difference between years was probably due partly to higher September values in 1986 than in 1985 ($p = .071$).
2. Antenna Plot: August values were significantly higher ($p = .0004$) in 1986 than in 1985.
3. Ground Plot: August ($p = .021$) and September ($p = .007$) values were significantly higher in 1986 than in 1985.

Similar trends were found between the 1986 and 1985 data for streptomycete levels and morphotype numbers. In general, the highest streptomycete levels and morphotype numbers were found in May/June and the lowest values were detected in September/October. As was noted in the 1985 Annual Report, similar trends in levels and morphotype numbers were also observed with the 1984 data, although too few samples, specifically with red pine mycorrhiza type 3 roots, were collected to allow for statistical analysis.

Correlation analyses exploring the relationships between seasonal estimates of streptomycete levels and morphotype numbers and environmental variables are being conducted to determine their potential value as covariates to reduce the variability of our population estimates. As determinants of microbial activity, soil pH, soil and air temperature, soil moisture, and precipitation are logical variables to consider. Should variables measuring litter decomposition and/or associated nutrient flux, or red pine seedling growth, plant moisture stress, and mycorrhiza formation prove unaffected by ELF electromagnetic fields, they would also be evaluated as logical choices for covariate analyses. As indicated in Tables 72 and 73, the precision obtained with 4 samples per plot provides sufficient power, even prior to covariate analysis, to permit detection of a streptomycete [illegible] shift or difference of approximately 25 percent.

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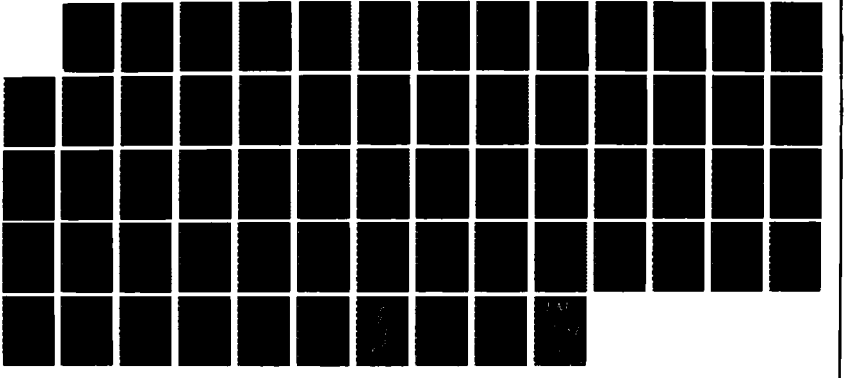

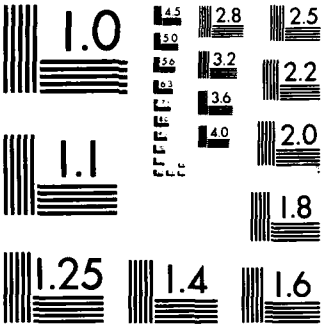

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Streptomycete morphotypes detected on SCA throughout the 1986 sampling season from type 3 washed mycorrhizal fine roots are presented in Table 82. As was found with 1985 samples from the same sites, streptomycete morphotype B was the most commonly detected morphotype at all sites for all sampling dates. Morphotypes C, F, O, and T were also frequently detected from all three plots throughout the sampling season, similar to the results reported in the 1985 Annual Report. In addition, all of the morphotypes characterized from the 1985 red pine type 3 mycorrhizal fine root samples were detected in association with the 1986 washed root samples. These results indicate that similar streptomycete populations of relatively stable composition have become established on red pine seedlings at all three ELF study plantation subplots.

Analysis in 1987 will continue to deal with determination of streptomycete levels and morphotype numbers associated with washed red pine type 3 mycorrhizal fine roots, with no change in the number of samples analyzed per plot or in the streptomycete enumeration/characterization techniques. Increased emphasis will be placed on covariate analysis of the data obtained to date, to determine possible environmental/biological interactions affecting streptomycete population differences between plots, sampling dates, and years.

Table 82. Streptomycete types associated with mycorrhizal type 3 washed roots and fine root tips.

Sampling Date (1986)	Sampling Plot[a]	Streptomycete Type																					
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
29 May	C	X	X[b]	X[b]	X[b]		X[c]									X				X	X			
	A		X[c]	X[b]	X		X[b]				X			X		X[c]				X		X		
	G	X	X[b]	X[b]	X[b]		X[b]			X				X[b]		X[b]	X				X[b]			
23 June	C		X[b]	X	X[b]		X[c]									X			X		X			
	A	X[b]	X[b]	X[b]	X		X[b]	X				X	X[b]		X	X			X[b]	X[b]	X	X		X
	G	X	X[c]	X[b]	X[b]		X[b]				X					X					X			
21 July	C		X[b]	X[b]	X[c]		X[c]							X							X[b]			
	A	X	X[c]	X[c]		X[b]	X[b]	X[b]		X			X			X	X							
	G	X[c]	X[c]	X[b]	X		X[c]		X[b]											X[b]	X	X		
18 August	C		X[b]	X[b]	X		X[c]								X	X								
	A		X[c]				X[b]								X	X			X					
	G	X	X[c]	X	X		X[c]	X		X						X[b]	X		X[b]			X		
23 September	C	X	X[c]	X[b]			X[b]		X			X[b]			X						X			X
	A		X[b]	X[b]			X	X								X[b]	X	X[b]	X[b]	X	X		X	X[b]
	G		X[c]	X[b]	X		X[c]					X				X[c]		X			X		X	X
22 October	C		X[c]	X[5]	X		X[c]			X											X			
	A		X[b]	X[b]			X	X		X[b]						X	X		X	X			X	X
	G		X[c]	X[b]	X	X	X[b]	X								X				X	X			

[a] C - Control Plot; A - Antenna Plot; G - Ground Plot
[b] detected in two or more of replicate samples/site
[c] predominant type in two or more of replicate samples/plot

LITERATURE CITED

Andrews, J. H. and C. M. Kenerley. 1979. The effects of a pesticide program on microbial population from apple leaf litter. Canadian Journal of Microbiology 12: 1331-1344.

Antai, S.P., and D. L. Crawford. 1981. Degradation of softwood, hardwood and grass lignocelluloses by two Streptomyces strains. Applied and Environmental Microbiology 42:378-380.

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

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

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

Dowdy, S., and S. Wearden. 1983. Statistics for Research. John Wiley and Sons, New York. 537 p.

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

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

Jansson, P.-E., and B. Berg. 1985. Temporal variation of litter decomposition in relation to simulated soil climate. Long-term decomposition in a Scots pine forest. V. Canadian Journal of Botany 63: 1008-1016.

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

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

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

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

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

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

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

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

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

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

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

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

Sutherland, J. B., R. A. Blanchette, D. L. Crawford, and A. L. Pometto. 1979. Breakdown of Douglas-fir phloem by a lignocellulose-degrading Streptomyces. Current Microbiology 2:123-126.

Wieder, R. K., and G. E. Lang. 1982. A critique of the analytical methods used in examining decomposition data obtained from litter bags. Ecology 63: 1636-1642.

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

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

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The Effects of Exposing the Slime Mold Physarum polycephalum to Electromagnetic Fields

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GLOSSARY - ACRONYMS

Respiration:	The utilization of oxygen by cells to obtain energy.
QO_2	The rate of oxygen utilization: ul of oxygen consumed/ minute/mg protein.
Antenna ground:	A conducting connection between the transmitting antenna and the earth.
Axenic culture:	Growth of a single organism (slime mold) in the absence of contaminating organisms such as bacteria, fungi, etc
Plasmodium:	A multinucleated mass of protoplasm visible to the eye; the entire structure is delimited by a plasma membrane. In the laboratory it is usually maintained on a solid substrate such as agar or filter paper.
Micro-plasmodia:	Plasmodia mantained in submerged shake flasks.
Shake flask culture:	A method for maintaining micro-plasmodia in a liquid medium. The flask is continuously shaken to provide the culture with oxygen.
Cell cycle:	The number of hours between succesive divisions of the nucleus.
WTF:	Wisconsin Test Facility
ELF:	Extremely low-frequency electromagnetic fields

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ABSTRACT

We have previously shown that continuous laboratory exposure of the slime mold Physarum polycephalum to extremely low frequency electromagnetic fields (EMF) similar to those generated by he Navy's ELF communication system can depress the rate of respiration, and lengthen the mitotic cell cycle(Goodman et al.1976, 79, Greenebaum et al.1982). We now seek to determine whether exposing Physarum to the field environment around the Wisconsin Test Facility (WTF) will induce an altered physiological state.

To answer this question a research program comprising both laboratory and field components have been developed. Unlike the 1985 season when the duty cycle of the antenna was erratic, the 1986 duty cycle was at full power for most of the field season. Since the exact nature of the effective field component was unknown, the field and laboratory experiments were designed to examine the effects of predominantly current density or the electric field. The exposure sites were selected so that each of these components would be the predominant factor. The exposure system in the laboratory mimicked the current density and electric field environment found in the vicinity of the buried ground of the antenna.

The data show that the respiration rates and ATP levels from the WTF control site were similar in both the 1985 and 1986 season. A decrease in both parameters was noted during the 1986 season. The statistical significance of the observed decreases is being examined.

INTRODUCTION

Background: Using the slime mold Physarum polycephalum as an experimental system, we have shown that continuous exposure (> 60 days) to extremely weak electromagnetic fields (EMF) ranging from 45-75 Hz., 10 uT - 0.2 mT., and 0.035 - 1.0 V/m can depress the cell's ATP levels and respiration rate and lengthen the mitotic cell cycle (Goodman et al. 1976,79; Marron et al. 1986). The program described in this report addresses the question of whether exposing Physarum to the fields generated by the Navy's ELF antenna can induce similar perturbations.

To answer this question a research program encompassing both a laboratory and field component was initiated in the summer of 1983. During 1983/84, Physarum was exposed in the laboratory to a 76 Hz sinusoidal field of 0.1 mT, 1.0 V/m for 15 hours/day, 5 days/week. This exposure attempted to mimic the operational cycle of the WTF transmitter at the time. This intermittent exposure regimen lengthened the mitotic cell cycle and increased the cell's respiration rate (Goodman et al.1984). The lengthened mitotic cycle was consistent with our earlier data on weak-field effects on Physarum; however, the increase in respiration was the inverse of our experimental data for continuous (24 hr/day) exposure. Based on these data, we concluded that the exposure regimen or duty cycle, in addition to field intensity and waveform were factors involved in inducing an EMF bioeffect.

During this same period, laboratory cultures were also exposed to a continuously applied 76 Hz modulated (MSK)field of 0.1 mT and 1.0 V/m. A small but significant decrease in the length of the mitotic cell cycle of the exposed cells was observed; no significant differences were observed in the respiration rate.

Field exposure at the Wisconsin Test Facility (WTF) during 1984 produced a statistically significant increase in the mitotic cell cycle of cells exposed at the ground (G) and antenna (A) sites relative to controls. Although these data were statistically significant, certain deviations from earlier laboratory responses of Physarum to EMF were apparent. These deviations prompted us examine the way cultures exposed at the WTF were handled to determine whether our protocols might be affecting the outcome of our studies. In the 1985 season we instituted several protocol changes, particularly in the way plasmodia were transported from the test site to Parkside. We also changed the methods used to re-establish suspension cultures from the agar-based plasmodium being used for field exposure. During the 1985 season, no significant changes were found in ATP levels, respiration rate or the length of the mitotic cell cycle in cultures exposed at the WTF test site. Although significant alterations were not observed we were unable to conclude that exposure to WTF fields had no significant effect because of the erratic nature of the antenna operation during 1985. The latter was primarily the result of installing and testing new transmission equipment. Thus, we entered the 1986 season with at best, contrasting data on the effects of field exposure at the WTF site; the antenna, however, was almost fully operational. During the 1986 season, laboratory fields were decreased to the same order of magnitude as the electric and current density fields at the WTF ground site.

CONTROL AND EXPERIMENTAL SITES

The same three sites used in the 1985 field studied were employed in 1986 (1 control and 2 experimental or exposure sites). The first site is located parallel to the west ground (G); the second (A) is located about 3 miles from the ground site below the overhead cables of the antenna; and the control (C) is located about 20 miles east of both experimental sites. At each site two cultures were exposed to an electric field in the growth medium that was adjusted to equal the electric field in the nearby soil. The third exposure site had cultures in which the electric field in the medium was reduced to create a current density equal to that of the nearby soil.

We generally attempted to make two field measurements at each site on a weekly basis. The data are shown in Appendix A, Tables 1-3. In general, two measurements are found on each date; the first measurement was made before the cultures that had been growing and exposed the previous week were removed. The second measurement was made after the cultures had been transferred and placed back in the ground. Since E-fields were adjusted at the time the cultures are placed back into the ground, the difference in field intensities provides a means of assessing the change or drift through a week of exposure. There were a few problems encountered at the A-2 site because of a poor connection between the ground and the collector resulting in a lower E-field at this site. Because of this problem, cultures exposed at the A-1 site were predominantly used for the E-field studies.

PROTOCOLS FOR FIELD EXPOSURE AND MAINTENANCE OF PHYSARUM:

Field Exposure System: Cultures of Physarum were placed in the field on May 24, 1986 (Day-1) and maintained there until October 18, 1986 (Day-147). Cultures were grown in autoclavable polyethylene chambers (7" x 4" x 2 1/4") with a tight fitting top; two stainless steel electrodes were placed 6" apart and about 1/4" from the bottom of the chamber. Each chamber was filled with 150 ml of growth medium. A 9 cm circle of sterile filter paper was placed in each chamber to facilitate respiration experiments at the W.T.F.site (see discussion of S-3A experiments). The growth chambers were placed inside an outer protective chamber (10" x 10" x 20"); a tight fitting lid provided a reasonably waterproof environment for the cultures. A 1/2" U-shaped vent was attached to the lid of the outer chamber to facilitate gas exchange. On several occasions, the vent pipes were separated from the outer chamber, presumably by animals. When the the latter occurred, the plasmodia were generally contaminated and backup cultures were used. The protective chamber containing the growth chamber was placed in a hole about 20" x 20" x 20"; 8" square copper collector plates were buried 1 meter from the hole along a line with the predominant electric field. Electric fields were brought to the growth boxes by buried wire leads that ran from the collector plates to a plug on the outer wall of the protective chamber. To protect the exposure system, each hole was covered with a plywood board. Each site contained three exposure systems; two were used for E-field effects and the third for examining the effects of current density. Temperature was monitored by placing battery operated Dickson monitors inside the protective chambers. The monitors were calibrated in the lab prior to their use in the field. These recorders

generally performed satisfactorily except when the vent pipes were broken and water got into the chamber. A monthly temperature summary for the season is shown in Appendix B. Initially, the temperature at the control site tracked 2-3°F higher than either experimental site, a phenomenon also observed in 1985. The temperature differential continued through June, becoming less evident during July and August and September. The recorders were recalibrated in the lab at the end of the field season; the control recorder tracked about 2°F lower than the A or G site recorders. Since all three recorders were calibrated at the beginning of the field season, apparently either through handling or transport the control recorder was altered. It is unclear when this change occurred, however, the data suggests that something may have happened in July, when the temperature differential seen earlier, was no longer apparent.

Culture Maintenance: Physarum was maintained in the field on an agar substrate using the growth medium of Daniel and Baldwin (1964) diluted to half strength with water, sterile rolled oats (1 % w/v) and 3 % agar. To facilitate QO_2 determinations at the WTF site, sterile 9 cm filter papers were placed on the solidified agar. In theory the plasmodium would be expected to grow and cover the filter paper. At the time of subculture, the filter paper containing the mold would be readily removed from the agar and subjected to oxygen analysis using the S-A3 O_2 analyzer located in IITRI laboratory at Clam Lake. Although this technique worked at Parkside, sufficient growth was never obtained in the field experiments to allow on-site measurements to be made at the WTF.

All media preparation and sterilizations were performed at U.W.-Parkside; growth containers were placed in sterile plastic bags and transported to the exposure site. Growth chambers were held at the WTF for a week in a plexiglass chamber fitted with a bank of timer-controlled uv lights. These precautions allowed us to identify any growth boxes that became contaminated during transport and decreased the chance of introducing contamination from an exogenous source. From May through the end of August, agar cultures of Physarum were transferred on a weekly basis.

The following protocols were followed to transfer cultures in the field: (1) The outer chambers were disconnected from the collector plates (after making field measurements) and brought to the mobile lab. The outside of the container was thoroughly washed to remove mud and debris before being brought into the lab. (2) The growth chambers were removed from the containers and their outer surfaces thoroughly cleaned using a disposable wipe saturated with Zorbacide. (3) The growth chambers were placed in a laminar flow hood and a 2.5 cm^2 piece of plasmodium was removed from the outer edge of the culture and transferred to a new growth chamber. (4) Plasmodia were scraped from the agar surface and placed in a 50% solution of sterile growth medium; upon returning to the University laboratory they were immediately placed on a shaker. Generally the suspension cultures were on a shaker within 9 hours after of subculture.

Suspension plasmodia were re-transferred to full strength medium within the next 24 hours and maintained as suspension cultures in 125ml Erlenmeyer flasks until growth was adequate to perform analyses (usually within 48 to 72 hours).

Thus, the time between removal from the test site and the performance of an experiment ranged from 2 to 3 days, depending on the rapidity with which plasmodia adapted to liquid culture. Submerged cultures from field-exposed and control sites were grown on the same shaker in the laboratory without additional exposure to electromagnetic fields. Although backup cultures had to be used on several occasions, Physarum were continuously exposed to their appropriate environments for the entire 147 day season.

During the latter part of the season (>day119), the exposed cultures were returned to the laboratory in the agar growth boxes rather than in liquid medium. Upon return, they were then placed in 50 % growth medium and immediately shaken. This modification seemed to facilitate conversion to shake cultures, and we intend to continue using it during the 1987 season.

Laboratory Exposure of Physarum: Microplasmodia were maintained as submerged shake flask cultures in rectangular boxes (Goodman et al.;1975). Microplasmodia were continuously exposed (24 hrs/day, 7 days/wk) to 76 Hz MSK modulated (mod) fields of 17.5 uT and 1.0 V/m; the function generator was supplied by IITRI.

Macroplasmodia maintained on agar-filled boxes identical to those used in the field, were subjected to 76 Hz_{mod} 17.5 uT magnetic fields and either 10 mV/m [matched current densities (J)] or 800 mV/m electric fields [matched E-fields]. To the extent possible, laboratory exposure conditions attempted to mimic field conditions at the Ground site.

We did not attempt to mirror the temperature fluctuations at the WTF field sites however, because of limited incubator and exposure equipment. The possible residual effect(s) of depressed temperature (less than the 25.8°C normally used in the laboratory) was examined by growing agar cultures at 68°F (20°C). Respiration and ATP determinations were performed using suspension cultures (maintained at the normal lab temperature) derived from these agar cultures. To test for either weak-field (or temperature) effects, the macroplasmodia growing an agar were returned to suspension cultures maintained at 78.4°F (25.8°C) using the procedures described above. Submerged, shake flask cultures were used in all tests.

EXPERIMENTAL OVERVIEW

RESPIRATION: The rate of oxygen consumption is expressed as the QO_2 (ul of oxygen consumed /min / mg protein). A measurement is made by placing a 1.0ml aliquot of suspension culture and 2.0 ml of aerated growth medium into the water jacketed reaction vessel (YSI model 53) maintained at 25.8°C. The system is closed by placing a calibrated oxygen probe into the reaction vessel, and it is allowed to equilibrate for 5 min. Oxygen consumption is measured over the next 2-3 minute period. The microplasmodia are removed from the vessel, and their protein content determined to facilitate normalization of the data. Three separate measurements are made on each suspension culture; the data in Tables 1-4,and 9-14 represent the averages of the three measurements for a given day and exposure regimen.

ATP: To extract ATP from microplasmodia, duplicate 1.0 ml samples were

removed from the shake flasks and placed in tared polycarbonate tubes containing 2.5ml Tris-borate buffer (pH 9.2) that had been brought to 98 °C in a boiling water bath. The tubes were capped with a marble and the ATP was extracted for 15 min. Following extraction, the tubes were removed, wiped to remove exterior moisture and weighed. The weight was used to ascertain the final volume of the extract. The extracts were centrifuged at 84,000g. The supernatants were used for ATP analysis; the protein content of the pellet was determined to facilitate normalization of the data (Marron et al.;1986).

ATP was measured using a Packard Picolite luminometer. The data in Tables 5-8 and 15-20 are expressed as nM ATP /mg protein. The data represent the average of the duplicate samples measured on a given day.

MITOSIS: Because we felt that the QO_2 and ATP assays were more sensitive to subtle EMF-alterations, the measurements on mitosis were sharply curtailed during the 1986 season. To perform a mitosis experiment, suspension cultures in the log phase of growth are harvested by centrifugation (400g for 10 sec.). The packed volumes of the pellet were noted, and the supernatants decanted. The pellets were rapidly washed with sterile distilled water using a Vortex mixer and recentrifuged. The supernatants were decanted and the pellets resuspended in 2 vol of distilled water; 0.2ml aliquots were pipetted to 9 cm Petri plates containing 8.2 cm filter papers supported by stainless-steel mesh grids. After the suspension had coalesced (30 min), 17.5 ml of growth medium was added to each plate; the time was noted and referred to as "zero". The plates were placed in the control incubator and the onset of metaphase of the second postfusion mitosis is determined with alcohol fixed smears examined under phase optics. The timing of metaphase was independently determined by two individuals in a blind manner. The data are presented as the number of hours required by each culture to reach metaphase of the second mitotic division. Because mitosis in Physarum occurs in a synchronous manner, a mitotic index is not required.

DATA ANALYSIS

The data acquired during 1986 was analyzed using the STATPAL statistical package (edited by Bruce Chalmer and distributed by Marcel Dekker). The field data was coded using QO_2, ATP, site, and days of field exposure as variables. The duplicate or triplicate values for QO_2 or ATP for a given analysis were averaged and the single value was entered for the day. The experimental variables in the data summaries show the mean value for the parameter being examined and the number of days Physarum was exposed to the field being studied. In examining the data, one finds that in many cases, the exposure days are the same (i.e. several different entries for ATP but the same number of exposure days). In these cases, the plasmodial suspension has been subcultured and re-analyzed on successive days, that is, 2,3,4...days after removal from a particular field exposure.

Initially, ANOVA's were run using either ATP or QO_2 as the dependent variable and site (or exposure regimen) as the grouping variable. As we began to examine these data it became clear that time factors (laboratory experiments have shown that there is a latent period before bio-effects become manifest), as well as how one handles multiple data similar treatment regimens (eg. week

1, 2, etc) added several layers of complexity to the analyses. Depending on how one handled these questions significant differences could be found. To prevent the possibility of claiming a significant bio-effect because of improper statistical procedures, we have decided to subject our data to additional and more comprehensive analyses.

EMF-EFFECTS: LABORATORY EXPOSURE

QO_2: The mean QO_2 (ul O_2 consumed/min/mg protein ± standard deviation) for cells maintained on agar during the exposure period and then transferred to suspension cultured for analyses showed the following values for control and experimental cultures: The data are found in Tables 1-4.

1. 109 days of exposure to 76 Hz_{mod} 0.175 G, 10 mV/m (matched J)

$$[\ C = .58 \pm .07 \text{ vs } E_J = .54 \pm .09\ ]$$

2. 98 days of exposure to 76 Hz_{mod} 0.175 G, 800mV/m (matched-E)

$$[\ C = .58 \pm .07 \text{ vs } E_E = .56 \pm .12\ ]$$

These differences are not statistically significant at p =.05.

3. A comparison of cells maintained on agar at 20°C (C_T) for 98 days compared to controls maintained at 25.8°C (C) showed:

$$[\ C = .58 \pm .07 \text{ vs } C_T = .59 \pm .1\ ]$$

These differences are not statistically significant of p =.05.

ATP: The mean ATP content (nM/mg protein ± standard deviation) for cultures maintained and exposed to weak-fields on agar, and then transferred to suspension culture for analysis gave the following results: The data are found in Tables 5-8).

1. Exposure to 76 Hz_{mod} 0.175 G, 10 mV/m (matched-J) from days 1-91:

$$[\ C = 22.7 \pm 7.1 \text{ vs } E_J = 21.6 \pm 3.9\ ]$$

2. Exposure to 76 Hz_{mod} 0.175 G, 800 mV/m (matched-E) from days 1-95:

$$[\ C = 22.7 \pm 7.1 \text{ vs } E_E = 22.1 \pm 6.2\ ]$$

These differences are not statistically significant at p =.05.

3. Comparing the mean ATP content of plasmodia exposed to low temperature (C_T) for 95 days showed:

$$[\ C = 22.7 \pm 7.1 \text{ vs } C_T = 24.4 \pm 6.4\ ]$$

These data are not significant at p = .05

MITOSIS: The time required to reach metaphase of the second post fusion mitosis was determined using non-exposed and EMF-exposed (76 Hz_{mod} .175 G, 1.0 V/m) suspension cultures continuously exposed for 146 days. The mean time in hours (± standard deviation) required to reach the second mitotic division is shown below; the data are shown in Table 9

[C = 17.69 ± 1.1 vs E = 18.41 ± .88]

The difference is significant at p = .05.

EMF-EFFECTS: FIELD STUDIES

The field levels at the C,G, and A sites were routinely measured before removing cultures (pre-transfer) and readjusted following transfer (Appendix A, Tables1-3). This procedure allowed us to determine the extent to which the field intensities changed week to week. In general the antenna was close to maximum power during most of the season. From time to time problems were encountered because of poor connections to the collector plates or disconnected wires to the protective containers.

Effects of Field Exposure on QO_2: The suspension cultures generally were used within 48 to 72 hours after return from the W.T.F. exposure site. In general a longer period (72 hr) was required to obtain vigorous growth at the beginning and end of the field season. The suspension cultures were routinely sub-cultured and multiple experiments were performed from a given week's exposure. The W.T.F respiration data are summarized in Tables 10-15. The same suspension cultures used for respiration measurements were also used for the ATP protocols.

A summary for the entire 147 day exposure period for the control (C_E) and matched electric field sites [A_E & G_E] are given below as the mean ± standard deviation.

[C_E = .62 ± .99 vs A_E = .54 ± .62]
[C_E = .62 ± .99 vs G_E = .54 ± .77]

The summary data for the matched current density sites (J) were:

[C_J = .58 ± .95 vs A_J = .55 ± .89]
[C_J = .58 ± .95 vs G_J = .51 ± .68]

An analysis of variance suggests that there are no intrasite differences between the E and J control sites, E and J An enna sites or E and J Ground sites.

A comparison of the QO_2 data from 1986 with those acquired during 1985 show that the control sites have about the same QO_2 (C_E = 0.62, C_J =.58 1985) but that the respiration rates at the A and G sites are lower [A_E & G_E = .54, A_J & G_J = .59 in 1985].

ATP: The ATP concentration for the 147 day exposure period is expressed as the mean value ± the standard deviation. The ATP data are summarized in Tables 16-21. Culture handling techniques and the statistical approach is the same as described above for respiration. The following is the summary data for the matched electric field sites: (C_E = control, A_E = antenna, G_E = ground)

$$[\ C_E = 20.72 \pm 6.8 \text{ vs } A_E = 19.73 \pm 5.2\ ]$$
$$[\ C_E = 20.72 \pm 6.8 \text{ vs } G_E = 19.37 \pm 9.1\ ]$$

The data for the matched-J sites are:

$$[\ C_J = 22.17 \pm 8.7 \text{ vs } A_J = 19.99 \pm 5.7\ ]$$
$$[\ C_J = 22.17 \pm 8.7 \text{ vs } G_J = 18.9 \pm 5.9\ ]$$

SUMMARY

FIELD EXPOSURE EXPERIMENTS:

GROUND SITE: Exposure of Physarum to weak fields generated at the ground site may be depressing the cell's respiration rate. At this time it is unclear whether similar differences exist in the cell's ATP content. The complicating element is whether there is a time requirement (minimum number of exposure days) before the ATP difference to becomes statistically significant.

ANTENNA SITE: Significant differences in ATP levels are not immediately apparent if data for the entire exposure period was examined.

ANOVA's were also performed to test for possible intrasite differences; that is, are the matched-E and matched-J positions at the ground site different. The data indicate that the E and J sites at each location are not dissimilar.

LABORATORY EXPERIMENTS:

Plasmodia grown on agar and exposed to conditions similar to those encountered at the ground site (76 Hz_{mod} 0.175 G and either 10 mV/m [matched-J] or 800 mV/m [matched-E] show no significant differences if the entire exposure period was analyzed. Cells growing at a lower than normal temperature (20°C) had ATP levels that did not differ significantly from control cultures growing at 25.8°C.

Significant differences were not obtained in the respiration rate (QO_2) of plasmodia exposed to either matched current density, or matched electric-fields through 91 days of exposure. One problem encountered at about the third month of (95-100) of laboratory culture was that plasmodia growing on agar became less vigorous and began to senesce. The latter phenomenon has been previously observed with long term exposure on agar (Clark and Hakim, 1980). One difference between field-exposed cultures growing on agar compared to laboratory cultures is their frequency of subculture. In the field, cultures were transferred once a week or about 17 times during the field season. In contrast, because of more vigorous growth in the laboratory it was necessary to transfer the cultures twice a week.

Experiments on the mitotic cell cycle were only performed with suspension cultures exposed to 76 Hz_{mod} 0.175 G, 1.0 V/m for 146 days. These data (Table 21) show that the mitotic cell cycle of EMF-exposed plasmodia was slowed relative to non-exposed controls.

A conclusion as to whether weak field exposure at the WTF alters the ATP levels and respiration rate in Physarum requires a more in-depth statistical analyses than could be performed for this report. These analyses are currently in progress.

Table 1

SUMMARY OF OXYGEN CONSUMPTION QO_2 (ul O_2 consumed/mg protein/min) at U.W. - Parkside

A summary of the QO_2 levels in non-exposed control cultures maintained on agar at U.W.-Parkside. Analysis of oxygen consumption was performed on suspension cultures. The data are grouped according to the plasmodial QO_2 and the number of days the culture was grown on agar. Cases in which the days are repeated indicate that the suspension culture was subcultured and the analysis repeated. Summary statistics give the mean, standard deviation and standard error of the mean.

QO_2	.544	QO_2	.536
Days	9	Days	84
QO_2	.568	QO_2	.487
Days	13	Days	91
QO_2	.513	QO_2	.687
Days	20	Days	98
QO_2	.573	QO_2	.550
Days	35	Days	98
QO_2	.642	QO_2	.581
Days	38	Days	98
QO_2	.648	QO_2	.627
Days	38	Days	102
QO_2	.624	QO_2	.593
Days	38	Days	102
QO_2	.617	QO_2	.496
Days	42	Days	109
QO_2	.434	QO_2	.587
Days	84	Days	112

Mean: 0.577 **Std Dev.: .07** **Std. Error: .02**

TABLE 2

SUMMARY of OXYGEN CONSUMPTION QO_2
(ul O_2 consumed/mg protein/min)
at U. W. - Parkside

A summary of the QO_2 levels in cultures grown on agar and exposed to 75 $Hz_{(mod)}$ 0.175 G, 10 mV/m at U.W.-Parkside. In these experiments, the current density has been matched to the soil at the WTF ground site. The data are grouped according to the plasmodial QO_2 and the number of days the culture was exposed. Cases in which the "days exposed" is repeated means that the samples have been subcultured and analyzed more than once in the laboratory. If multiple analyses were performed, they were always done on successive days. Summary statistics give the mean, standard deviation and standard error of the mean.

QO_2	.557	QO_2	.464
Days exp	3	Days	71
QO_2	.493	QO_2	.660
Days exp	13	Days	78
QO_2	.520	QO_2	.639
Days exp	20	Days	88
QO_2	.593	QO_2	.526
Days exp	38	Days	88
QO_2	.704	QO_2	.476
Days exp	38	Days	88
QO_2	.632	QO_2	.374
Days exp	38	Days	91
QO_2	.573	QO_2	.447
Days exp	45	Days	95
QO_2	.498	QO_2	.497
Days exp	60	Days	109
QO_2	.498		
Days exp	67		

Mean: 0.541 Std Dev.: .09 Std. Error .02

TABLE 3

SUMMARY of OXYGEN CONSUMPTION QO_2
(ul O_2 consumed/mg protein/min)
at U. W. - Parkside

A summary of the QO_2 levels in cultures grown on agar and exposed to 75 $Hz_{(mod)}$ 0.175 G, 800 mV/m at U.W.-Parkside. In these experiments, the electric field has been matched to the soil at the WTF ground site. The data are grouped according to the plasmodial QO_2 and the number of days the culture was exposed. Cases in which the "days exposed" is repeated means that the samples have been subcultured and analyzed more than once in the laboratory. If multiple analyses were performed, they were always done on successive days. Summary statistics give the mean, standard deviation and standard error of the mean.

QO_2	.595	QO_2	.498
Days exp	16	Days exp	84
QO_2	.492	QO_2	.698
Days exp	20	Days exp	84
QO_2	.540	QO_2	.457
Days exp	38	Days exp	84
QO_2	.650	QO_2	.518
Days exp	38	Days exp	91
QO_2	.831	QO_2	.399
Days exp	38	Days exp	94
QO_2	.600	QO_2	.647
Days exp	41	Days exp	95
QO_2	.495	QO_2	.386
Days exp	48	Days exp	98
QO_2	.486		
Days	70		

Mean: 0.558 Std. Dev. .12 Std Error. .03

TABLE 4

SUMMARY of OXYGEN CONSUMPTION QO_2
(ul O_2 consumed/mg protein/min)
at U. W. - Parkside

A summary of the respiration rate levels in non-exposed control cultures maintained at 20°C on agar at U.W.-Parkside. Analysis of QO_2 was performed on suspension cultures. The data are grouped according to the plasmodial QO_2 and the number of days the culture was grown on agar. Cases in which the days are repeated indicate that the suspension culture was subcultured and the analysis repeated. Summary statistics give the mean, standard deviation and standard error of the mean.

QO_2	.552	QO_2	.446
Days exp	9	Days exp	88
QO_2	.476	QO_2	.754
Days exp	10	Days exp	88
QO_2	.561	QO_2	.590
Days exp	13	Days exp	88
QO_2	.753	QO_2	.495
Days exp	13	Days exp	91
QO_2	.632	QO_2	.619
Days exp	35	Days exp	91
QO_2	.614	QO_2	.636
Days exp	42	Days exp	95
QO_2	.560	QO_2	.458
Days exp	81	Days exp	98
QO_2	.450	QO_2	.692
Days exp	87	Days exp	102

Mean: 0.585 **Std. Dev.: .10** **Std. Error: .03**

TABLE 5

SUMMARY of ATP CONCENTRATION
(nM ATP / mg protein)
at U. W. - Parkside

A summary of the ATP levels in non-exposed control cultures maintained on agar at U.W.-Parkside. Analysis of ATP was performed on suspension cultures. The data are grouped according to the plasmodial ATP concentration and the number of days the culture was grown on agar. Cases in which the days are repeated indicate that the suspension culture was subcultured and the analysis repeated. Summary statistics give the mean, standard deviation and standard error of the mean.

ATP	21.57	ATP	19.55
Days	1	Days	49
ATP	11.09	ATP	28.21
Days	14	Days	91
ATP	13.93	ATP	34.69
Days	21	Days	91
ATP	18.7	ATP	30.09
Days	25	Days	98
ATP	15.01	ATP	28.02
Days	28	Days	98
ATP	16.39	ATP	36.48
Days	35	Days	98
ATP	21.42	ATP	31.65
Days	39	Days	102
ATP	20.53	ATP	27.36
Days	39	Days	102
ATP	15.89	ATP	20.59
Days	39	Days	109
ATP	18.03	ATP	24.94
Days	39	Days	109

Mean: 22.71 **Std. Dev.: 7.15** **Std. Error: 1.60**

TABLE 6

SUMMARY of ATP CONCENTRATION
(nM ATP / mg protein)
at U. W. - Parkside

A summary of the ATP levels in cultures grown on agar and exposed to $75Hz_{(mod)}$ 0.175 G, 10 mV/m at U.W.-Parkside. In these experiments, the current density has been matched to the soil at the WTF ground site. The data are grouped according to the plasmodial ATP content and the number of days the culture was exposed. Cases in which the "days exposed" is repeated means that the samples have been subcultured and analyzed more than once in the laboratory. If multiple analyses were performed, they were always done on successive days. Summary statistics give the mean, standard deviation and standard error of the mean.

ATP	20.62
Days exp	2
ATP	25.62
Days exp	9
ATP	22.05
Days exp	14
ATP	24.56
Days exp	21
ATP	17.62
Days exp	28
ATP	15.78
Days exp	29
ATP	13.5
Days exp	35
ATP	22.66
Days exp	39
ATP	18.35
Days exp	51
ATP	21.81
Days exp	51
ATP	17.64
Days exp	51
ATP	27.23
Days	81
ATP	26.03
Days	88
ATP	24.2
Days	88
ATP	23.98
Days	88
ATP	21.56
Days	91
ATP	24.36
Days	95

Mean: 21.62 **Std. Dev.: 3.87** **Std. Error: 0.94**

TABLE 7

SUMMARY of ATP CONCENTRATION
(nM ATP / mg protein)
at U. W. - Parkside

A summary of the ATP levels in cultures grown on agar and exposed to 75 $Hz_{(mod)}$ 0.175 G, 800 mV/m at U.W.-Parkside. In these experiments, the electric field has been matched to the soil at the WTF ground site. The data are grouped according to the plasmodial ATP content and the number of days the culture was exposed. Cases in which the "days exposed" is repeated means that the samples have been subcultured and analyzed more than once in the laboratory. If multiple analyses were performed, they were always done on successive days. Summary statistics give the mean, standard deviation and standard error of the mean.

ATP	13.49	ATP	35.02
Days exp	10	Days	81
ATP	27.39	ATP	24.35
Days exp	37	Days	88
ATP	13.52	ATP	21.98
Days exp	42	Days	84
ATP	19.56	ATP	22.03
Days exp	57	Days	84
ATP	27.5	ATP	27.03
Days exp	78	Days	91
ATP	29.91	ATP	23.18
Days exp	78	Days	95
ATP	21.54	ATP	16.06
Days exp	78	Days	95
ATP	15.96	ATP	15.8
Days exp	78	Days	95

Mean: 22.15 **Std. Dev.: 6.24** **Std. Error: 1.56**

TABLE 8

SUMMARY of ATP CONCENTRATION
(nM ATP / mg protein)
at U. W. - Parkside

A summary of the ATP levels in non-exposed control cultures maintained at 20 °C on agar at U.W.-Parkside. Analysis of ATP was performed on suspension cultures. The data are grouped according to the plasmodial ATP concentration and the number of days the culture grown on agar. Cases in which the days are repeated indicate that the suspension culture was subcultured and the analysis repeated. Summary statistics give the mean, standard deviation and standard error of the mean.

ATP	24.04	ATP	23.1
Days exp.	1	Days exp.	57
ATP	23.41	ATP	34.82
Days exp	11	Days	84
ATP	21.61	ATP	25.07
Days exp	11	Days	88
ATP	25.84	ATP	25.87
Days exp	11	Days	88
ATP	18.28	ATP	37.32
Days exp	11	Days	88
ATP	36.86	ATP	27.35
Days exp.	14	Days	91
ATP	14.76	ATP	21.72
Days exp.	21	Days	91
ATP	22.05	ATP	23.85
Days exp	23	Days	95
ATP	29.16	ATP	19.94
Days exp.	36	Days	95
ATP	17.64		
Days exp.	43		

Mean: 24.37 **Std. Dev.: 6.40** **Std. Error: 1.43**

TABLE 9

Effects on the Mitotic Cell Cycle of *Physarum polycephalum* Induced With Continuous Laboratory Exposure to 76 $Hz_{(mod)}$ 0.175 G., 1.0 V/m

This table compares the onset of the second mitotic division (following addition of medium) in Control and EMF-exposed (Experimental) plasmodia. Each data set shows the average time required for each culture to reach metaphase of the second, post-fusion mitosis. The exposure period is shown under "days".

DAYS	CONTROL (HRS)	EXPERIMENTAL (HRS)
56	17.22	18.17
	16.33	18.25
	16.08	18.58
	16.17	18.25
	16.08	18.25
71	16.18	18.53
	16.72	17.88
	17.25	18.87
	15.95	17.83
	15.5	18.87
72	17.37	20.05
	17.58	20.08
	17.92	20.33
	19.17	19.83
73	18.45	19.5
	20.25	20.25
	17.92	19.82
	18.03	20.75
	18.58	
82		17.2
	17.95	17.23
	17.83	17.78
	17.83	18.07
		17.62
96	17.93	17.93
	17.42	17.15
	17.07	17.87
	17.87	17.75
	17.87	17.48
104	16.97	16.95
	16.12	16.55
	16.2	16.88
	17.1	16.87
	16.63	17.6
124	18.2	18.18
	18.12	18.35
	17.5	18.2
	18.33	18.6
	17.92	17.95

DAYS	CONTROL (HRS)	EXPERIMENTAL (HRS)
125	18.12	17.95
	17.8	17.37
	18.12	17.63
	18.12	17.62
131	16.95	18.45
	17.28	19.55
	17.42	18.95
	17.7	19.55
	17.95	18.58
132	17.95	18.42
	17.7	19.35
	17.58	18.05
	17.5	19.43
	17.67	18.37
139	16.25	17.1
	16.28	17.47
	16.25	17.3
	16.63	17.48
	17.0	17.45
140	17.37	18.7
	17.33	18.75
	16.3	18.67
	17.43	19.72
	17.04	
145	19.08	18.28
	18.48	18.03
	18.43	17.77
	18.33	18.17
	18.42	18.45
146	19.4	18.3
		18.17
	20.95	18.57
	21.08	18.58
	20.44	18.17
(mean ± std. dev.)	17.68 ± 1.1	18.41 ± .88

SS	DF	MS	F	Prob	Significance
3.87	1	3.87	3.99	0.05	+
27.16	28	0.97			

TABLE 10

SUMMARY of OXYGEN CONSUMPTION QO_2
(ul O_2 consumed/mg protein/min)
at the WTF CONTROL SITE

A summary of the oxygen consumption rates of control cultures in which the electric field has been matched to that of the soil. The data are grouped according to the QO_2 and the number of days the culture was exposed at the WTF site. Cases in which the "days exposed" is repeated means that the samples have been analyzed more than once in the laboratory. If multiple analyses were performed, they were always done on successive days. Summary statistics give the mean, standard deviation and standard error of the mean.

QO_2	.663	QO_2	.584	QO_2	.707
Days exp	10	Days exp	80	Days exp	108
QO_2	.406	QO_2	.570	QO_2	.638
Days exp	24	Days exp	80	Days exp	108
QO_2	.576	QO_2	.691	QO_2	.631
Days exp	31	Days exp	87	Days exp	119
QO_2	.539	QO_2	.616	QO_2	.675
Days exp	38	Days exp	87	Days exp	119
QO_2	.527	QO_2	.585	QO_2	.813
Days exp	45	Days exp	94	Days exp	133
QO_2	.410	QO_2	.746	QO_2	.577
Days exp	66	Days exp	94	Days exp	133
QO_2	.601	QO_2	.679	QO_2	.639
Days exp	66	Days exp	94	Days exp	133
QO_2	.505	QO_2	.723	QO_2	.569
Days exp	73	Days exp	101	Days exp	147
QO_2	.475	QO_2	.623	QO_2	.767
Days exp	73	Days exp	101	Days exp	147
QO_2	.695	QO_2	.672	QO_2	.717
Days exp	73	Days exp	108	Days exp	147
				QO_2	.472
				Days exp	147

Mean: .616 Std. Dev.: .99 Std. Error: .17

TABLE 11

SUMMARY of OXYGEN CONSUMPTION QO_2
(ul O_2 consumed/mg protein/min)
at the WTF CONTROL SITE

A summary of the oxygen consumption rates of control cultures in which the current density has been matched to that of the soil. The data are grouped according to the QO_2 and the number of days the culture was exposed at the WTF site. Cases in which the "days exposed" is repeated means that the samples have been analyzed more than once in the laboratory. If multiple analyses were performed, they were always done on successive days. Summary statistics give the mean, standard deviation and standard error of the mean.

QO_2	.554	QO_2	.624	QO_2	.429
Days exp	10	Days exp	80	Days exp	108
QO_2	.401	QO_2	.642	QO_2	.587
Days exp	24	Days exp	87	Days exp	108
QO_2	.523	QO_2	.545	QO_2	.492
Days exp	38	Days exp	87	Days exp	119
QO_2	.573	QO_2	.502	QO_2	.641
Days exp	45	Days exp	94	Days exp	119
QO_2	.398	QO_2	.671	QO_2	.632
Days exp	59	Days exp	94	Days exp	119
QO_2	.576	QO_2	.674	QO_2	.580
Days exp	66	Days exp	94	Days exp	133
QO_2	.420	QO_2	.715	QO_2	.748
Days exp	66	Days exp	94	Days exp	133
QO_2	.595	QO_2	.662	QO_2	.528
Days exp	66	Days exp	94	Days exp	133
QO_2	.536	QO_2	.660	QO_2	.546
Days exp	73	Days exp	101	Days exp	147
QO_2	.492	QO_2	.676	QO_2	.750
Days exp	73	Days exp	101	Days exp	147
QO_2	.742	QO_2	.591	QO_2	.601
Days exp	73	Days exp	101	Days exp	147
QO_2	.513	QO_2	.637		
Days exp	80	Days exp	108		

Mean .584 **Std. Dev.:** .95 **Std. Error:** .16

TABLE 12

SUMMARY of OXYGEN CONSUMPTION QO_2
(ul O_2 consumed/mg protein/min)
at the WTF ANTENNA SITE

A summary of the oxygen consumption rates of cultures exposed to weak fields under the WTF antenna. In these experiments the electric field has been matched to that of the soil at the exposure site. The data are grouped according to the QO_2 and the number of days the culture was exposed at the WTF site. Cases in which the "days exposed" is repeated means that the samples have been analyzed more than once in the laboratory. If multiple analyses were performed, they were always done on successive days. Summary statistics give the mean, standard deviation and standard error of the mean.

QO_2	.423	QO_2	.597
Days exp	24	Days exp	108
QO_2	.583	QO_2	.533
Days exp	31	Days exp	108
QO_2	.541	QO_2	.611
Days exp	66	Days exp	108
QO_2	.590	QO_2	.562
Days exp	66	Days exp	119
QO_2	.482	QO_2	.609
Days exp	80	Days exp	119
QO_2	.562	QO_2	.520
Days exp	80	Days exp	119
QO_2	.445	QO_2	.548
Days exp	87	Days exp	147
QO_2	.616	QO_2	.551
Days exp	87	Days exp	147
QO_2	.404	QO_2	.522
Days exp	94	Days exp	147
QO_2	.583	QO_2	.581
Days exp	101	Days exp	147

Mean: .543 **Std. Dev.:** .62 **Std. Error:** .14

TABLE 13

SUMMARY of OXYGEN CONSUMPTION QO_2
(ul O_2 consumed/mg protein/min)
at the WTF GROUND SITE

A summary of the oxygen consumption rates of cultures exposed to weak fields at the WTF ground site. In these experiments, current density has been matched to that of the soil. The data are grouped according to the QO_2 and the number of days the culture was exposed at the WTF site. Cases in which the "days exposed" is repeated means that the samples have been analyzed more than once in the laboratory. If multiple analyses were performed, they were always done on successive days. Summary statistics give the mean, standard deviation and standard error of the mean.

QO_2	.520	QO_2	.493	QO_2	.489
Days exp	10	Days exp	80	Days exp	108
QO_2	.420	QO_2	.457	QO_2	.478
Days exp	24	Days exp	80	Days exp	108
QO_2	.536	QO_2	.515	QO_2	.510
Days exp	45	Days exp	87	Days exp	108
QO_2	.400	QO_2	.528	QO_2	.619
Days exp	59	Days exp	94	Days exp	133
QO_2	.476	QO_2	.566	QO_2	.568
Days exp	66	Days exp	94	Days exp	133
QO_2	.433	QO_2	.385	QO_2	.473
Days exp	66	Days exp	94	Days exp	133
QO_2	.541	QO_2	.487	QO_2	.537
Days exp	66	Days exp	94	Days exp	147
QO_2	.520	QO_2	.575	QO_2	.461
Days exp	73	Days exp	101	Days exp	147
QO_2	.395	QO_2	.631	QO_2	.562
Days exp	73	Days exp	101	Days exp	147
QO_2	.662	QO_2	.527		
Days exp	73	Days exp	101		

Mean: .509 **Std. Dev.:** .68 **Std. Error** .13

TABLE 14

SUMMARY of OXYGEN CONSUMPTION QO_2
(ul O_2 consumed/mg protein/min)
at the WTF GROUND SITE

A summary of the oxygen consumption rates of cultures exposed to weak fields at the WTF ground site. In these experiments, electric field has been matched to that of the soil. The data are grouped according to the QO_2 and the number of days the culture was exposed at the WTF site. Cases in which the "days exposed" is repeated means that the samples have been analyzed more than once in the laboratory. If multiple analyses were performed, they were always done on successive days. Summary statistics give the mean, standard deviation and standard error of the mean.

QO_2	.534	QO_2	.634	QO_2	.567
Days exp	10	Days exp	80	Days exp	133
QO_2	.387	QO_2	.554	QO_2	.598
Days exp	24	Days exp	87	Days exp	133
QO_2	.552	QO_2	.448	QO_2	.467
Days exp	31	Days exp	87	Days exp	147
QO_2	.647	QO_2	.477	QO_2	.540
Days exp	45	Days exp	94	Days exp	147
QO_2	.401	QO_2	.639	QO_2	.425
Days exp	66	Days exp	94	Days exp	147
QO_2	.547	QO_2	.592	QO_2	.554
Days exp	66	Days exp	108	Days exp	147
QO_2	.573	QO_2	.620		
Days exp	73	Days exp	108		
QO_2	.411	QO_2	.585		
Days exp	73	Days exp	119		
QO_2	.576	QO_2	.615		
Days exp	73	Days exp	119		
QO_2	.461	QO_2	.527		
Days exp	80	Days exp	119		

Mean: .536 **Std. Dev.:** .78 **Std. Error:** .15

TABLE 15

SUMMARY of OXYGEN CONSUMPTION QO_2
(ul O_2 consumed/mg protein/min)
at the WTF GROUND SITE

A summary of the oxygen consumption rates of cultures exposed to weak fields at the WTF ground site. In these experiments, current density has been matched to that of the soil. The data are grouped according to the QO_2 and the number of days the culture was exposed at the WTF site. Cases in which the "days exposed" is repeated means that the samples have been analyzed more than once in the laboratory. If multiple analyses were performed, they were always done on successive days. Summary statistics give the mean, standard deviation and standard error of the mean.

QO_2	.520	QO_2	.493	QO_2	.489
Days exp	10	Days exp	80	Days exp	108
QO_2	.420	QO_2	.457	QO_2	.478
Days exp	24	Days exp	80	Days exp	108
QO_2	.536	QO_2	.515	QO_2	.510
Days exp	45	Days exp	87	Days exp	108
QO_2	.400	QO_2	.528	QO_2	.619
Days exp	59	Days exp	94	Days exp	133
QO_2	.476	QO_2	.566	QO_2	.568
Days exp	66	Days exp	94	Days exp	133
QO_2	.433	QO_2	.385	QO_2	.473
Days exp	66	Days exp	94	Days exp	133
QO_2	.541	QO_2	.487	QO_2	.537
Days exp	66	Days exp	94	Days exp	147
QO_2	.520	QO_2	.575	QO_2	.461
Days exp	73	Days exp	101	Days exp	147
QO_2	.395	QO_2	.631	QO_2	.562
Days exp	73	Days exp	101	Days exp	147
QO_2	.662	QO_2	.527		
Days exp	73	Days exp	101		

Mean: .509 **Std. Dev.:** .68 **Std. Error** .13

TABLE 16

SUMMARY of ATP CONCENTRATION
(nM ATP / mg protein)
at the WTF CONTROL SITE

A summary of the ATP levels in cultures at the WTF control site. In these experiments, the electric field has been matched to that of the soil. The data are grouped according to the plasmodial ATP concentration and the number of days the culture was exposed at the WTF site. Cases in which the "days exposed" is repeated means that the samples have been analyzed more than once in the laboratory. If multiple analyses were performed, they were always done on successive days. Summary statistics give the mean, standard deviation and standard error of the mean.

TABLE 16

ATP	39.16	ATP	29.91	ATP	21.57
Days exp	12	Days exp	66	Days exp	101
ATP	18.96	ATP	28.36	ATP	22.81
Days exp	24	Days exp	73	Days exp	101
ATP	12.09	ATP	18.24	ATP	23.97
Days exp	24	Days exp	73	Days exp	101
ATP	8.93	ATP	21.38	ATP	16.06
Days exp	24	Days exp	73	Days exp	101
ATP	14.11	ATP	36.34	ATP	10.98
Days exp	31	Days exp	80	Days exp	119
ATP	12.33	ATP	38.98	ATP	15.65
Days exp	31	Days exp	80	Days exp	119
ATP	25.82	ATP	24.22	ATP	17.55
Days exp	38	Days exp	87	Days exp	119
ATP	24.87	ATP	23.1	ATP	24.66
Days exp	45	Days exp	87	Days exp	133
ATP	18.49	ATP	17.68	ATP	17.46
Days exp	45	Days exp	87	Days exp	133
ATP	18.32	ATP	17.77	ATP	16.42
Days exp	59	Days exp	94	Days exp	133
ATP	21.03	ATP	22.2	ATP	16.72
Days exp	59	Days exp	94	Days exp	147
ATP	12.18	ATP	24.03	ATP	19.5
Days exp	66	Days exp	94	Days exp	147
ATP	17.59	ATP	17.91	ATP	18.8
Days exp	66	Days exp	94	Days exp	147

Mean: 20.67 **Std. Dev.:** 6.93 **Std. Error:** 1.10

TABLE 17

SUMMARY of ATP CONCENTRATION (nM ATP / mg protein) at the WTF CONTROL SITE

A summary of the ATP levels in cultures at the WTF control site. In these experiments, the current density has been matched to that of the soil. The data are grouped according to the plasmodial ATP concentration and the number of days the culture was exposed at the WTF site. Cases in which the "days exposed" is repeated means that the samples have been analyzed more than once in the laboratory. If multiple analyses were performed, they were always done on successive days. Summary statistics give the mean, standard deviation and standard error of the mean.

TABLE 17

ATP	26.41	ATP	20.74	ATP	23.15
Days exp	12	Days exp	66	Days exp	101
ATP	17.63	ATP	29.01	ATP	14.79
Days exp	24	Days exp	66	Days exp	101
ATP	13.28	ATP	28.61	ATP	18.44
Days exp	24	Days exp	73	Days exp	101
ATP	14.85	ATP	21.96	ATP	15.66
Days exp	31	Days exp	73	Days exp	119
ATP	13.4	ATP	28.42	ATP	21.44
Days exp	31	Days exp	73	Days exp	119
ATP	24.1	ATP	28.74	ATP	17.9
Days exp	38	Days exp	80	Days exp	119
ATP	25.32	ATP	31.36	ATP	25.94
Days exp	45	Days exp	80	Days exp	133
ATP	42.55	ATP	33.51	ATP	17.07
Days exp	45	Days exp	87	Days exp	133
ATP	55.81	ATP	25.93	ATP	16.36
Days exp	45	Days exp	87	Days exp	133
ATP	14.21	ATP	20.42	ATP	17.78
Days exp	45	Days exp	87	Days exp	133
ATP	16.6	ATP	25.37	ATP	18.33
Days exp	59	Days exp	94	Days exp	147
ATP	11.58	ATP	22.61	ATP	17.8
Days exp	59	Days exp	94	Days exp	147
ATP	11.02	ATP	22.14	ATP	17.9
Days exp	59	Days exp	94	Days exp	147
ATP	13.71	ATP	22.71		
Days exp	66	Days exp	94		
ATP	10.77	ATP	36.95		
Days exp	66	Days exp	101		

Mean: 22.15 **Std. Dev.:** 8.68 **Std. Error:** 1.34

TABLE 18

SUMMARY of ATP Content
(nM ATP / mg protein/min)
at the WTF ANTENNA SITE

A summary of the ATP content of cultures exposed to weak fields under the WTF antenna. In these experiments the electric field has been matched to that of the soil at the exposure site. The data are grouped according to the ATP content and the number of days the culture was exposed at the WTF site. Cases in which the "days exposed" is repeated means that the samples have been analyzed more than once in the laboratory. If multiple analyses were performed, they were always done on successive days. Summary statistics give the mean, standard deviation and standard error of the mean.

TABLE 18

ATP	12.2	ATP	20.34
Days exp	12	Days exp	87
ATP	23.65	ATP	16.01
Days exp	24	Days exp	87
ATP	13.66	ATP	24.93
Days exp	24	Days exp	101
ATP	18.78	ATP	24.63
Days exp	31	Days exp	101
ATP	15.08	ATP	21.74
Days exp	31	Days exp	101
ATP	18.51	ATP	20.6
Days exp	38	Days exp	101
ATP	33.17	ATP	18.5
Days exp	45	Days exp	119
ATP	14.14	ATP	18.59
Days exp	66	Days exp	119
ATP	25.25	ATP	17.01
Days exp	66	Days exp	119
ATP	27.77	ATP	15.81
Days exp	66	Days exp	147
ATP	23.51	ATP	13.46
Days exp	80	Days exp	147
ATP	21.62	ATP	12.57
Days exp	80	Days exp	147
ATP	16.85		
Days exp	87		

Mean: 19.54 **Std. Dev.:** 5.21 **Std. Error:** 1.04

TABLE 19

SUMMARY of ATP CONCENTRATION
(nM ATP / mg protein)
the WTF ANTENNA SITE

A summary of the ATP levels in cultures exposed to weak fields under the WTF antenna In these experiments, current density has been matched to that of the soil. The data are grouped according to the plasmodial ATP content and the number of days the culture was exposed at the WTF site. Cases in which the "days exposed" is repeated means that the samples have been analyzed more than once in the laboratory. If multiple analyses were performed, they were always done on successive days. Summary statistics give the mean, standard deviation and standard error of the mean.

TABLE.19

ATP	14.2	ATP	22.66
Days exp	24	Days exp	87
ATP	17.41	ATP	16.51
Days exp	24	Days exp	87
ATP	18.04	ATP	16.91
Days exp	31	Days exp	87
ATP	13.19	ATP	25.45
Days exp	31	Days exp	94
ATP	20.06	ATP	16.74
Days exp	38	Days exp	94
ATP	40.22	ATP	21.93
Days exp	45	Days exp	94
ATP	28.27	ATP	16.6
Days exp	66	Days exp	94
ATP	12.6	ATP	28.12
Days exp	66	Days exp	101
ATP	15.87	ATP	24.86
Days exp	66	Days exp	101
ATP	18.78	ATP	20.87
Days exp	66	Days exp	101
ATP	20.66	ATP	19.12
Days exp	73	Days exp	101
ATP	19.19	ATP	11.92
Days exp	73	Days exp	119
ATP	20.4	ATP	13.96
Days exp	73	Days exp	119
ATP	15.99	ATP	24.85
Days exp	80	Days exp	147
ATP	18.06	ATP	21.63
Days exp	80	Days exp	147

Mean: 19.84 **Std. Dev.:** 5.77 **Std. Error:** 1.05

TABLE 20

SUMMARY of ATP CONCENTRATION
(nM ATP / mg protein)
at the WTF GROUND SITE

A summary of the ATP levels in cultures exposed to weak fields at the WTF ground site. In these experiments, the electric field has been matched to that of the soil. The data are grouped according to the plasmodial ATP content and the number of days the culture was exposed at the WTF site. Cases in which the "days exposed" is repeated means that the samples have been analyzed more than once in the laboratory. If multiple analyses were performed, they were always done on successive days. Summary statistics give the mean, standard deviation and standard error of the mean.

TABLE 20

ATP	26.97	ATP	28.18
Days exp	12	Days exp	80
ATP	21.71	ATP	23.85
Days exp	24	Days exp	87
ATP	11.57	ATP	14.33
Days exp	24	Days exp	87
ATP	18.13	ATP	17.05
Days exp	31	Days exp	87
ATP	14.66	ATP	24.89
Days exp	31	Days exp	101
ATP	20.06	ATP	12.56
Days exp	45	Days exp	101
ATP	58.3	ATP	20.81
Days exp	45	Days exp	119
ATP	22.85	ATP	15.41
Days exp	45	Days exp	119
ATP	11.66	ATP	11.73
Days exp	66	Days exp	133
ATP	12.52	ATP	10.77
Days exp	66	Days exp	133
ATP	20.23	ATP	13.15
Days exp	66	Days exp	133
ATP	23.6	ATP	13.33
Days exp	73	Days exp	147
ATP	21.47	ATP	12.87
Days exp	73	Days exp	147
ATP	19.05	ATP	16.09
Days exp	73	Days exp	147
ATP	23.9		
Days exp	80		

Mean: 19.37 **Std. Dev.:** 9.08 **Std. Error:** 1.69

TABLE 21

SUMMARY of ATP CONCENTRATION
(nM ATP / mg protein)
at the WTF GROUND SITE

A summary of the ATP levels in cultures exposed to weak fields at the WTF ground site. In these experiments, current density has been matched to that of the soil. The data are grouped according to the ATP concentration and the number of days the culture was exposed at the WTF site. Cases in which the "days exposed" is repeated means that the samples have been analyzed more than once in the laboratory. If multiple analyses were performed, they were always done on successive days. Summary statistics give the mean, standard deviation and standard error of the mean.

TABLE 21

ATP	23.83	ATP	17.36	ATP	12.83
Days exp	12	Days exp	66	Days exp	94
ATP	19.64	ATP	12.05	ATP	19.66
Days exp	24	Days exp	66	Days exp	94
ATP	13.06	ATP	16.26	ATP	21.93
Days exp	24	Days exp	66	Days exp	94
ATP	18.19	ATP	22.91	ATP	23.4
Days exp	31	Days exp	66	Days exp	94
ATP	18.71	ATP	25.76	ATP	27.77
Days exp	31	Days exp	73	Days exp	101
ATP	18.08	ATP	15.03	ATP	23.69
Days exp	38	Days exp	73	Days exp	101
ATP	21.73	ATP	20.76	ATP	15.91
Days exp	45	Days exp	73	Days exp	101
ATP	43.25	ATP	22.26	ATP	15.75
Days exp	45	Days exp	80	Days exp	101
ATP	12.29	ATP	17.67	ATP	16.59
Days exp	45	Days exp	80	Days exp	133
ATP	19.55	ATP	21.21	ATP	14.75
Days exp	59	Days exp	87	Days exp	133
ATP	11.92	ATP	15.53	ATP	18.65
Days exp	59	Days exp	87	Days exp	133
ATP	9.94	ATP	19.8	ATP	14.42
Days exp	59	Days exp	87	Days exp	147
				ATP	12.45
				Days exp	147

Mean: 18.77 **Std. Dev.:** 5.95 **Std. Error:** 0.98

APPENDIX A

Weekly data on field intensities at the Control (C), Antenna (A) and Ground (G) Sites. Data are grouped to indicate the fields before a culture was transferred (exposed in the field for 1 week) and the field intensities after transfer to new growth medium. The calculated current densities, and matched electric fields at each site are also shown.

APPENDIX A

Table 1 (C Site)
Direct Field Measurements at W.T.F.

		V_{OC}(mV)			V_{CI}(mV)			V_R(500K) (mV)		
		Chambers			Chambers			Chambers		
Date	E field ($mV \cdot m^{-1}$)	1[a]	2[a]	3[b]	1	2	3	1	2	3
6 5 86	1.05	3.0	2.76	1.45	.16	.16	—	—	—	1.35
6 17 86					.16	.06	—	—	—	1.25
6 17 86	1.10	2.7	3.0	1.4	.04	.02	—	—	—	1.35
6 24 86					.36	.14	—	—	—	1.35
7 1 86					.03	—	—	—	—	1.2
7 8 86					1.7	.16	—	—	—	1.4
7 8 86	1.23	3.1	2.74	1.4	.19	.16	—	—	—	1.36
7 15 86					.46	1.25	—	—	—	1.35
7 15 86	1.11	3.1	2.7	1.4	.17	.17	—	—	—	1.35
7 22 86					.38	.35	—	—	—	1.34
7 22 86	1.07	2.9	2.9	1.35	.165	.16	—	—	—	1.36
7 29 86					.24	.23	—	—	—	1.37
7 29 86	.10	3.01	2.6	1.36	.17	1.1	—	3.01	—	1.36
8 5 86					.22	1.1	—	—	—	1.3
8 5 86	.10	3.0		1.7	—	—	—	—	—	—
8 12 86	1.20	3.0	2.6	1.49	.19	.19	—	—	—	1.6-1.23
8 19 86	1.03	3.1	2.7	1.4	.16	.16	—	—	—	1.27
8 26 86				—	—	.20	1.20	1.25	—	—
10 3 86	1.17	3.0	2.7	1.36	.17	.17	—	—	—	1.34

V_{OC} = open circuit voltage
V_{CI} = voltage across test cell
V_R = resistance across 100 ohm resistor
a = matched electric field exposure sites
b = matched current density exposure sites

APPENDIX A

Table 1 (C Site) (continued)
Calculated Field Exposures at W.T.F.

Date	Current Density ($mA \cdot m^{-2}$) Chamber 1[a]	Chamber 2[a]	Chamber 3[b]	Electric Field ($mV \cdot m^{-1}$) Chamber 1	Chamber 2	Chamber 3
6 5 86	.18	.18	•	•	•	—
6 17 86	.18	.67	•	•	•	.08
6 17 86	.4	.22	•	•	•	.09
6 24 86	.40	.18	•	•	•	.015
7 1 86	.333	--	•	•	•	.08
7 1 86	.19	.18	•	•	•	.09
7 8 86	.18	.17	•	•	•	.06
7 8 86	.21	.17	•	•	•	.09
7 15 86	.51	.13	•	•	•	.09
7 15 86	.19	.18	•	•	•	.09
7 22 86	.42	.38	•	•	•	.09
7 22 86	.14	.11	.0046			.07
7 29 86	.26	.25	•	•	•	.09
7 29 86	.9	.12	•	•	•	.09
8 5 86	.24	.12	•	•	•	.08
8 5 86	.11	—	•	•	•	—
8 12 86	.21	.20	•	•	•	.01
8 19 86	.22	.22	•	•	•	.084
8 19 86	.18	.18	•	•	•	.082
8 26 86	—	.13	—	•	•	—
8 26 86	.19	.19	—	•	•	.08
10 3 86	.19	.18	•	•	•	.08

•Not determined
a = matched electric field exposure sites
b = matched current density exposure sites

APPENDIX A

Table 2 (A Site)
Direct Field Measurements at W.T.F.

		V_{OC}(mV)			V_{CI}(mV)			V_R(500K) (mV)		
		Chambers			Chambers			Chambers		
Date	E field ($mV \cdot m^{-1}$)	1[a]	2[a]	3[b]	1	2	3	1	2	3
5/25/86	180	460	490	186	28	29	.41	3.8	3.6	183
6/5/86					235	13	.25	3.5	12.5	184
6/5/86	209	450	490	186	30	12	.16	4.5	1.6	184
6/17/86					27	9	.22	7.6	4.	186
6/17/86	226	450	490	190	35	96	.30	5.3	1.0	186
6/24/86					63	30	.32	8.6	4.	189
6/24/86	185	450	500	192	29	27	.44	4.3	3.6	186
7/1/86					30.3	12.9	.38	4.3	1.76	180
7/1/86	206	440	480	186	32	10	.23	5.3	1.5	182
7/8/86					34	21	.22	5.2	.8	83
7/8/86	210	460	510	188	30	23	.22	5.3	3.8	186
7/15/86					41	65	.3	6.	9.8	194
7/15/86	175	460	510	196	30	27	.36	4.6	4.8	193
7/22/86					30	30	.3	4.	4.	195
7/22/86	220	450	490	186	34	34	.24	5.	5.	185
7/29/86					39	13	.30	6.	1.4	190
7/29/86	210	460	490	193	32	32	.22	5.	2.5	190
8/5/86					30	20	.27	5.	3.	188
8/5/86	200	460	500	190	30	26	.24	5.	3.9	189
8/12/86					17	13	.28	3.6	—	190
8/12/86	210	470	500	192	33	33	.25	4.8	5.	187
8/19/86					33	33	.25	4.2	3.8	186
8/19/86	199	460	500	190	30	30	.29	4.8	4.8	187
8/26/86					37	31	.32	4.9	4.3	189
8/26/86	210	460	510	194	30	30	.46	3.5	3.3	186
10/3/86					17	34	.30	3.	5.	189

V_{OC} = open circuit voltage

V_{CI} = voltage across test cell

V_R = resistance across 100 ohm resistor

a = matched electric field exposure sites

b = matched current density exposure sites

APPENDIX A

Table 2 (A Site) (continued)
Calculated Field Exposures at W.T.F.

Date	Current Density ($mA \cdot m^{-2}$) Chamber 1[a]	Chamber 2[a]	Chamber 3[b]	Electric Field ($mV \cdot m^{-1}$) Chamber 1	Chamber 2	Chamber 3
5/25/86	31.1	32.2	.45	245	232	1.18
6/5/86	26.1	14.4	.28	225	80.6	1.18
6/5/86	33.3	13.3	.18	290	103	1.18
6/17/86	30	10	.24	490	260	1.2
6/17/86	38.8	10.7	.33	342	---	1.2
6/24/86	70.6	33.3	.36	555	258	1.21
6/24/86	32.2	30	.49	277	232	1.2
7/1/86	33.7	14.3	.42	277	195	1.16
7/1/86	35.5	...1	.256	342	167	1.17
7/8/86	37.8	23	.24	335	88.9	5.35
7/8/86	.33	25	.24	342	42.2	1.20
7/15/86	45.6	72.2	.33	388	645	1.25
7/15/86	33.3	30.0	.41	296	310	6.45
7/22/86	33.3	33.3	.33	258	258	1.25
7/22/86	37.8	37.7	.11	323	323	1.19
7/29/86	13.2	14.4	.33	390	90	1.2
7/29/86	35.6	35.6	.241	323	61	1.22
8/5/86	33.3	22.2	.30	323	194	1.21
8/5/86	33.3	28.8	.26	323	232	1.21
8/12/86	11.1	11.1	.31	232	—	1.22
8/12/86	37	36.7	.28	309.7	323	1.21
8/19/86	30	36.6	.27	271	64.5	1.20
8/19/86	33.3	33.3	.32	309	309	1.21
8/26/86	14.4	11.4	.12	95.5	116.1	6.06
8/26/86	33.3	33.3	.51	225	212	1.2
10/3/86	18.9	64.5	.19	194	323	1.22

a = matched electric field exposure sites
b = matched current density exposure sites

APPENDIX A

Table 3 (G Site)
Direct Field Measurements at W.T.F.

Date	E field ($mV \cdot m^{-1}$)	V_{OC}(mV) Chambers 1[a]	2[a]	3[b]	V_{Cl}(mV) Chambers 1	2	3	V_R(500K) (mV) Chambers 1	2	3
5/25/86	640	1940	1690	790	128	99	1.12	12	18	760
6/5/86					97	89	1.2	13.6	12	780
6/5/86	710	1950	1760	830	110	106	.86	19.5	15	780
6/17/86					120	103	.95	9	13	740
6/17/86	680	2020	1770	790	105	96	.96	16	16	740
6/24/86					120	125	.93	18	17	740
6/24/86	570	1900	1800	280	110	105	.85	19	18	740
7/1/86					160	129	1.24	23	19	920
7/1/86	740	2500	2300	980	115	115	1.06	20	19	910
7/8/86					106	103	1.03	8.0	16	840
7/8/86	780	2200	1940	890	115	100	1.05	4	17	840
7/15/86					150	135	1.05	13	16	840
7/15/86	640	2150	1960	860	100	102	1.02	19	18	840
7/22/86					150	140	1.21	23	22	1000
7/22/86	820	2600	2300	1040	127	127	1.13	20	20	1000
7/29/86					140	130	1.28	25	20	1020
7/29/86	850	2600	2400	1050	130	130	1.1	2	21	1020
8/5/86					130	110	1.2	19	17	1010
8/5/86	870	2700	2400	1050	130	120	1.05	25	12	1000
8/12/86					140	140	1.13	24	19	960
8/12/86	820	2500	2400	1000	127	127	.95	16	18	730
8/19/86					130	130	.138	15	18	940
8/19/86	840	2600	2400	990	130	130	.11	12	18	900
8/26/86					100	100	.91	14	15	700
8/26/86	620	1900	1800	730	96	96	.96	14	15	700
10/3/86					55	70	.92	10	6	700
10/3/86	130	1800	1680	710	100	100	.98	17	16	700

V_{OC} = open circuit voltage

V_{Cl} = voltage across test cell

V_R = resistance across 100 ohm resistor

a = matched electric field exposure sites

b = matched current density exposure sites

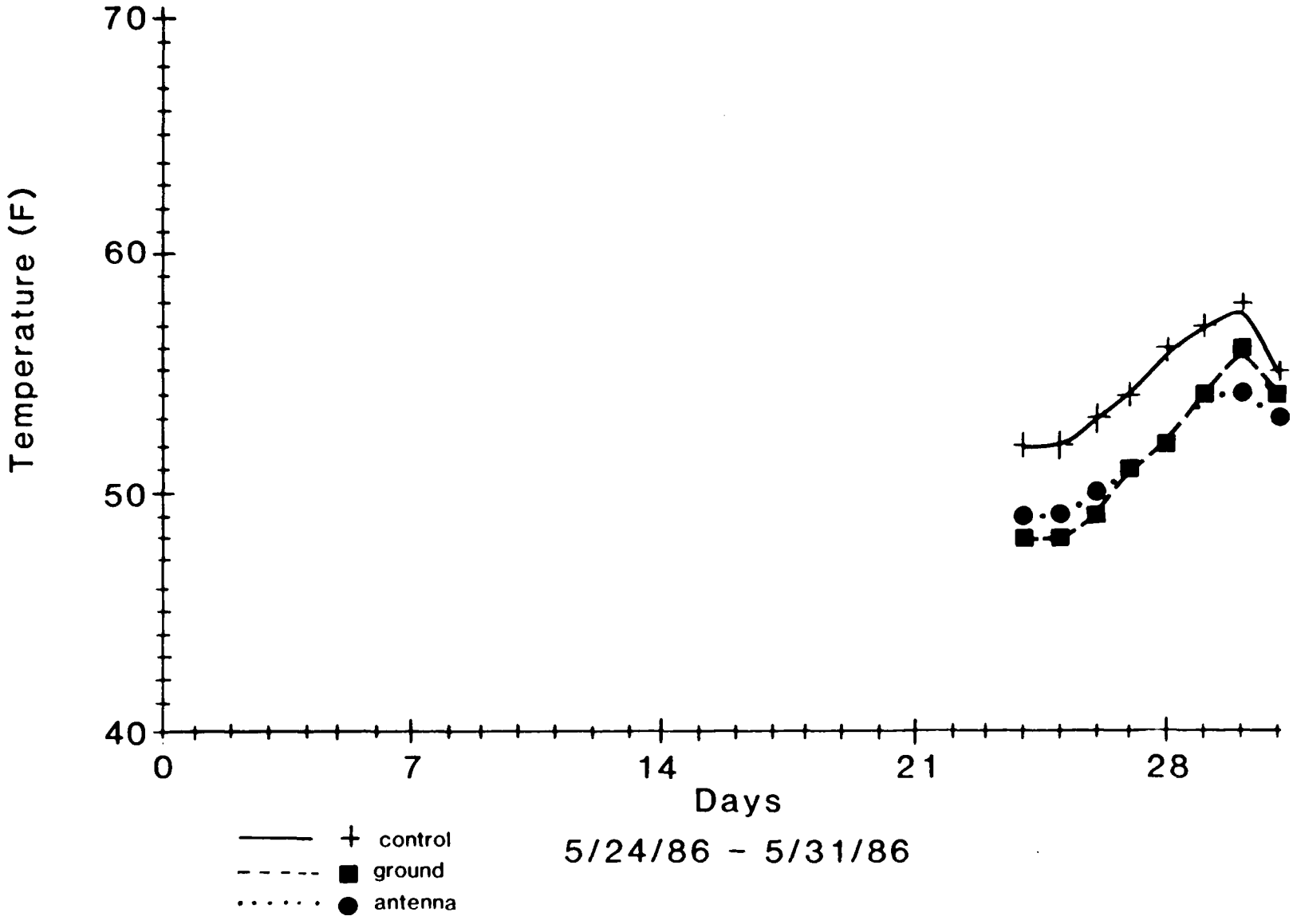
Table 3 (G Site) (continued)
Calculated Field Exposures at W.T.F.

Date	Current Density ($mA \cdot m^{-2}$) Chamber 1[a]	Chamber 2[a]	Chamber 3[b]	Electric Field ($mV \cdot m^{-1}$) Chamber 1	Chamber 2	Chamber 3
5/25/86	142	110	1.24	770	760	4.9
6/5/86	107	98.9	1.3	810	768	5.0
6/5/86	122	117	.95	1258	955	5.03
6/17/86	133	114	1.05	581	838	4.78
6/17/86	116	106	1.06	1030	887	4.7
6/24/86	133	138	1.03	1160	1097	4.77
6/24/86	122	116	.94	1226	1200	4.77
7/1/86	178	113	1.3	1484	1211	5.93
7/1/86	128	127	1.1	1290	1211	5.87
7/8/86	118	114	1.14	516	—	5.42
7/8/86	128	111	1.1	258	—	5.42
7/15/86	166	150	1.16	840	645	5.41
7/15/86	111	113	1.13	1226	1161	5.40
7/22/86	167	155	1.3	1510	1387	6.45
7/22/86	141	111	1.2	1290	1290	6.45
7/29/86	155	144	1.42	1613	1290	6.58
7/29/86	114	114	1.22	1290	1355	6.58
8/5/86	144	122	1.33	1226	1097	6.52
8/5/86	144	133	1.1	1613	774.2	6.45
8/12/86	160	165	1.25	1548	1226	6.19
8/12/86	140	141	1.05	1032	1161	4.71
8/19/86	144	114	1.53	955	1161	6.06
8/19/86	144	144	1.23	774	1161	6.0
8/26/86	111	111	.58	903	961	4.52
8/26/86	61.9	61.9	.669	929	968	4.52
10/3/86	35.5	45.1	.59	613	387	4.52
10/3/86	64.5	64.5	1.08	1065	1032	4.52

*Not measured
a = matched electric field exposure sites
b = matched current density exposure sites

APPENDIX B

A daily temperature summary at the Control, Antenna and Ground Sites.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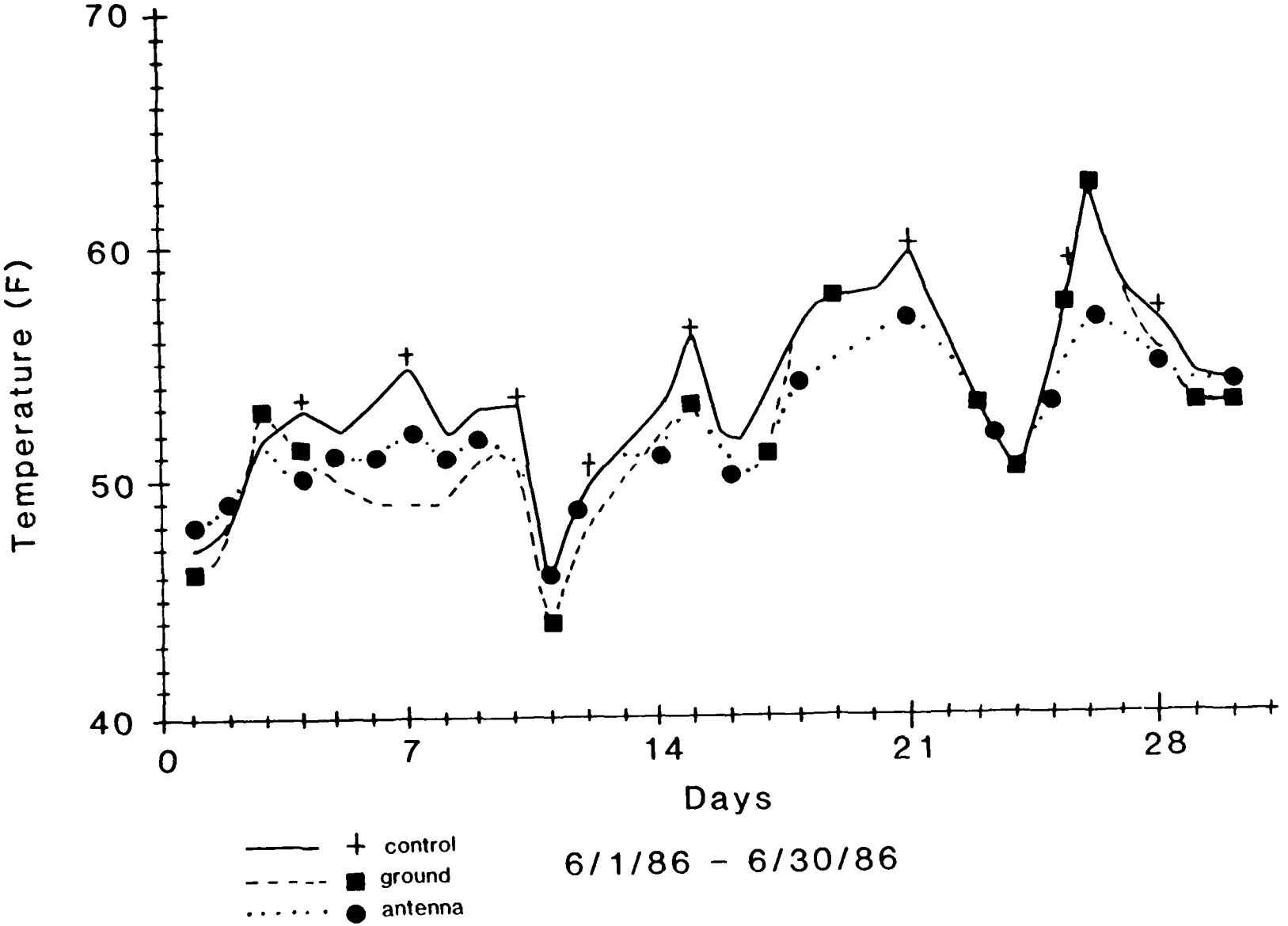
50
40
Temperature (F)
0
7
14
21
28
Days
control
ground
antenna
5/24/86 - 5/31/86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60
50
40
Temperature (F)
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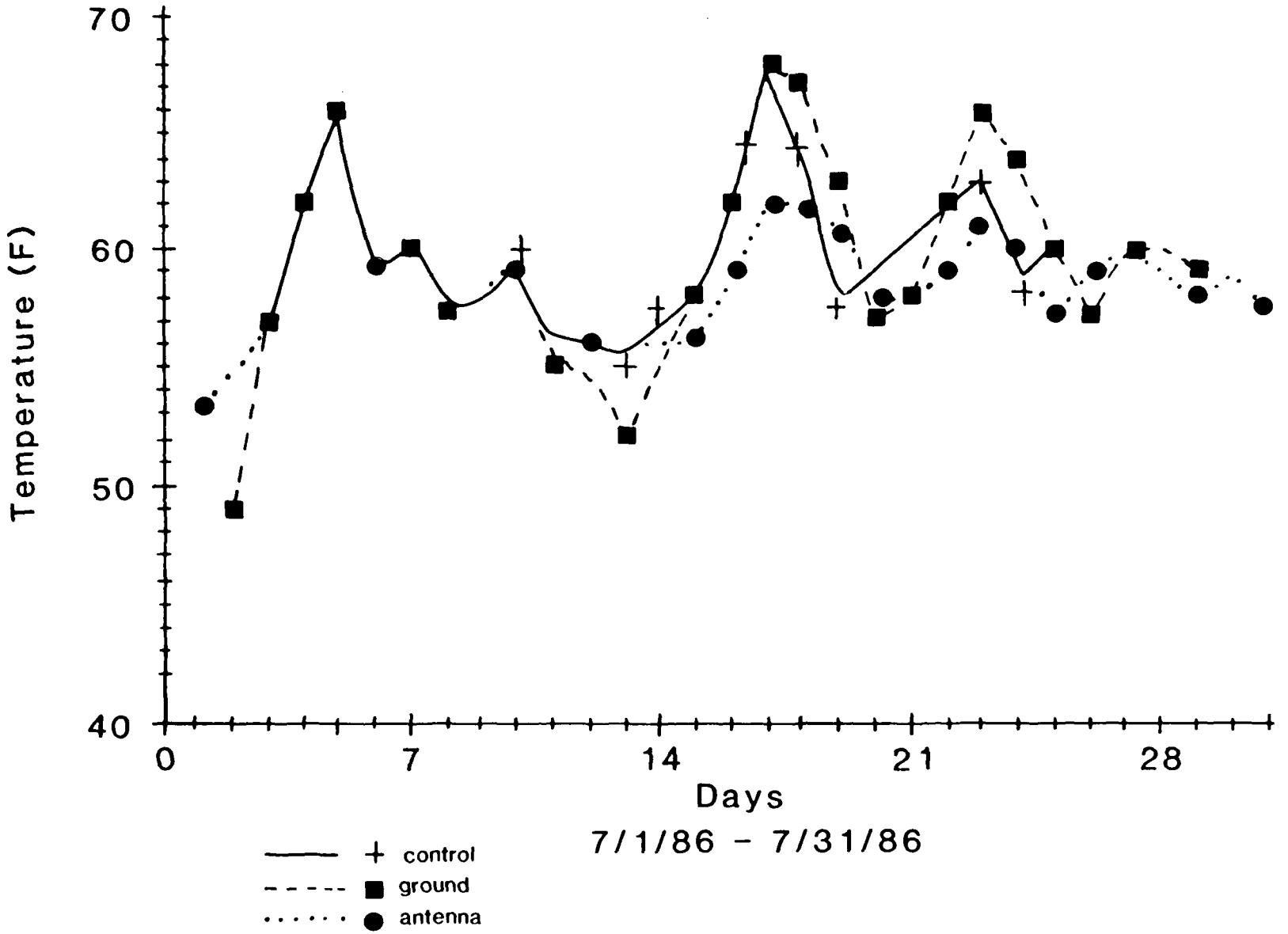
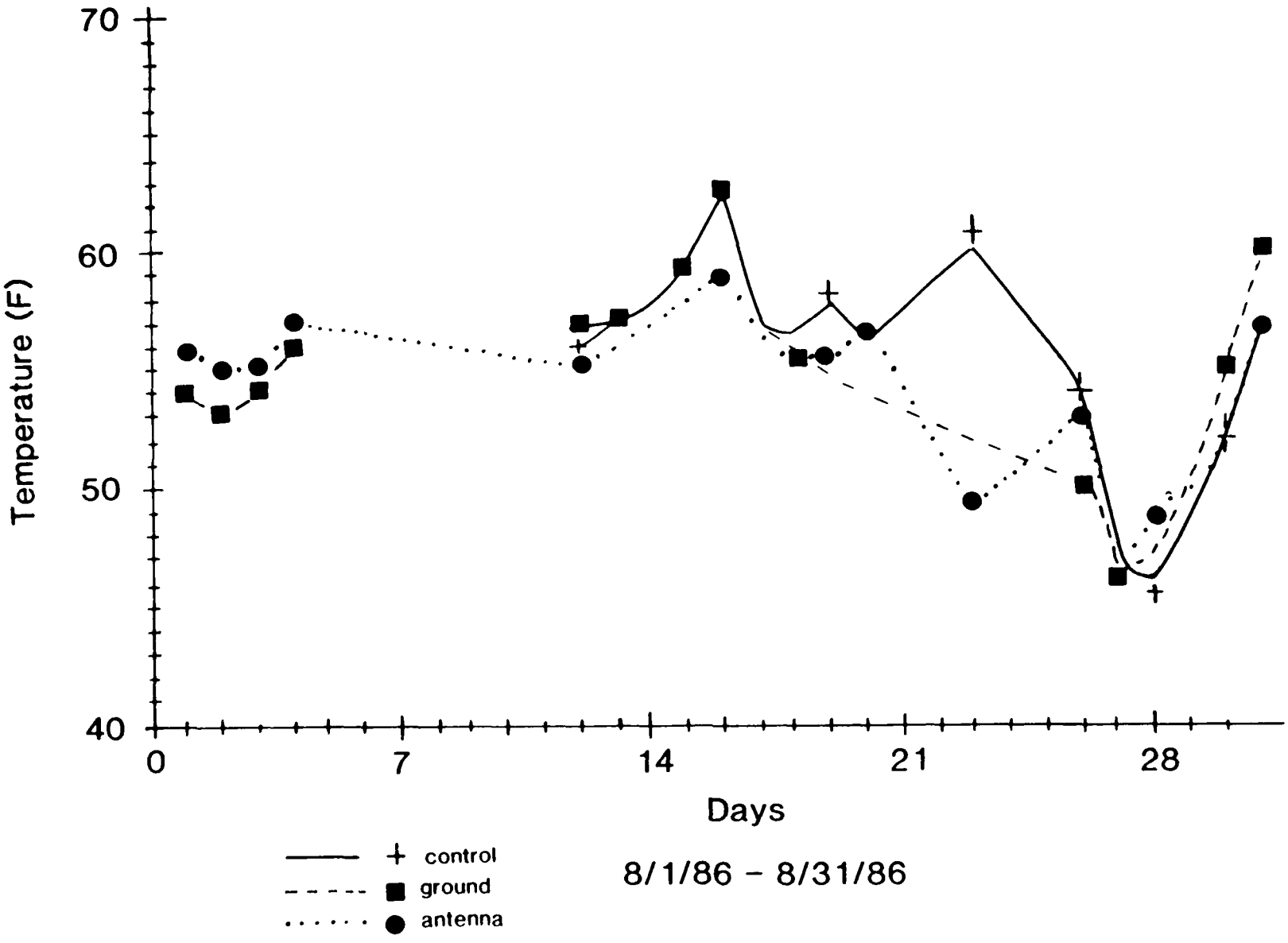
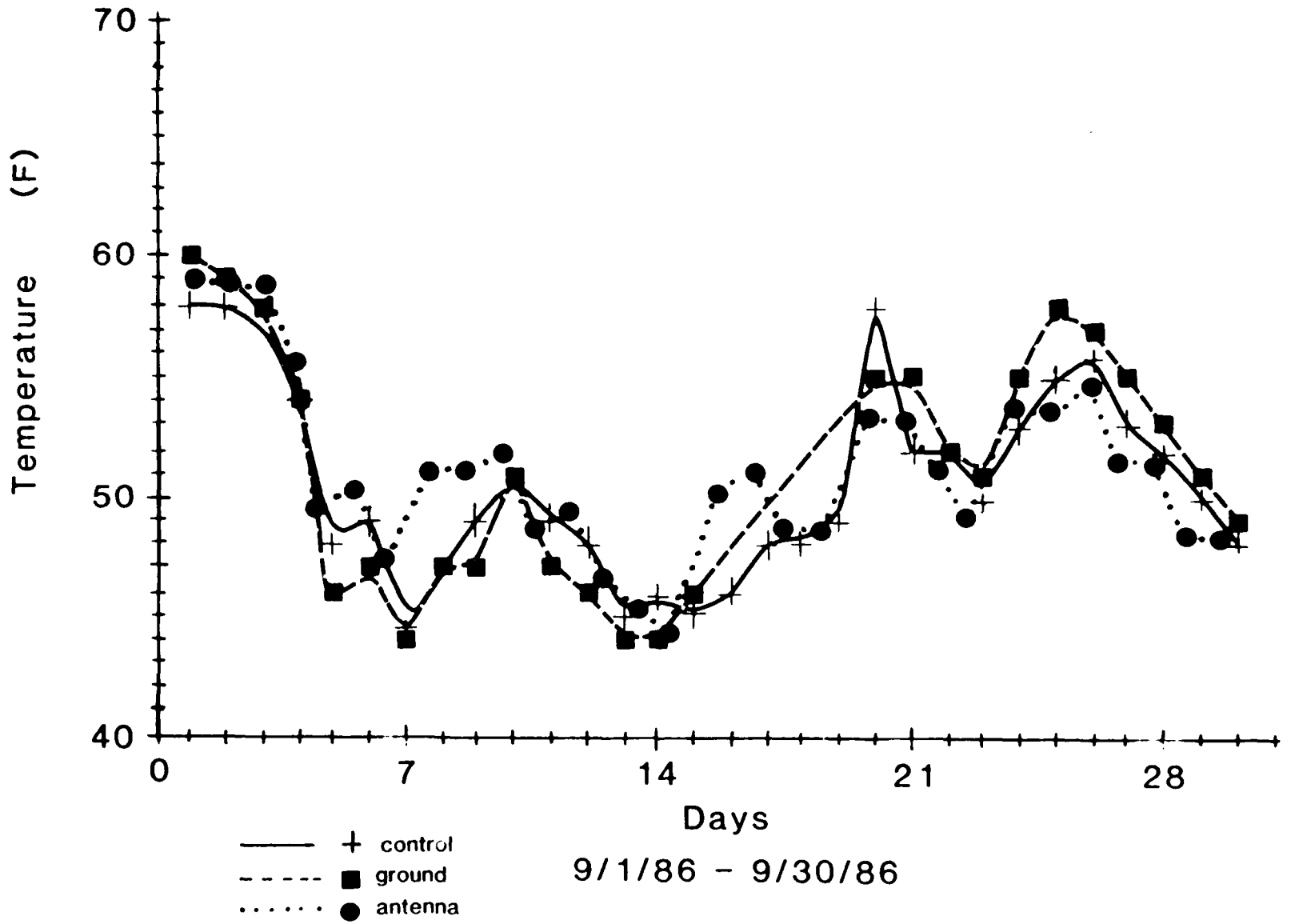
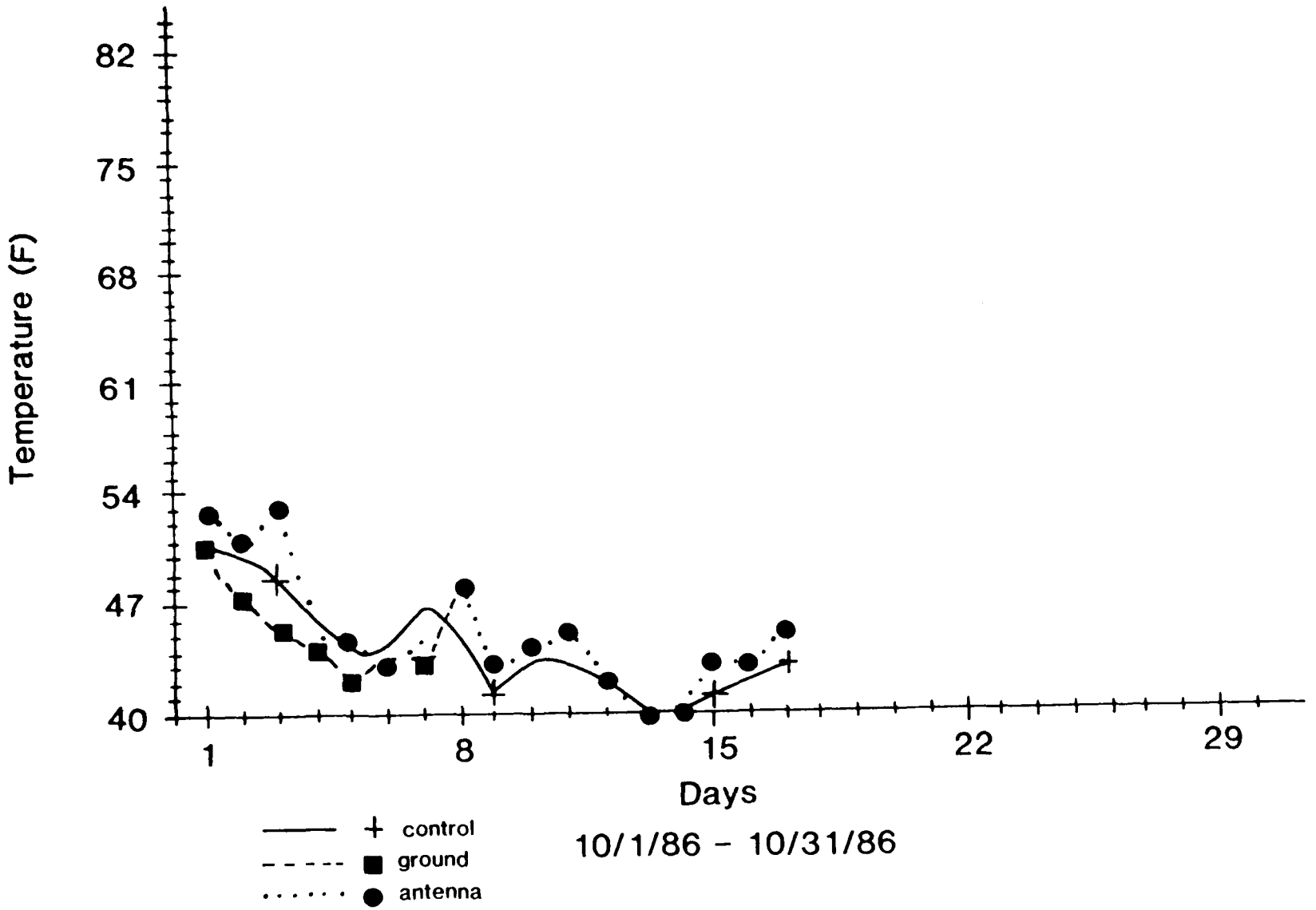
7
14
21
28
Days
control
ground
antenna
6/1/86 - 6/30/86


70
60
50
40
Temperature (F)
0
7
14
21
28
Days
7/1/86 - 7/31/86
control
ground
antenna


70
60
50
40
Temperature (F)
0
7
14
21
28
Days
control
ground
antenna
8/1/86 - 8/31/86


70
60
50
40
Temperature (F)
0
7
14
21
28
Days
control
ground
antenna
9/1/86 - 9/30/86


82
75
68
61
54
47
40
Temperature (F)
1
8
15
22
29
Days
control
ground
antenna
10/1/86 - 10/31/86

REFERENCES

Daniel, J.W., Baldwin, H.H. (1964) Methods of culture for plasmodial myxomycetes. Methods in Cell Physiol. 1:9-41.

Goodman, E.M., Greenebaum, B., and Marron, M. T. (1976) Effects of extremely low frequency electromagnetic fields on Physarum polycephalum. Radiat. Res. 66:531-540.

Goodman, E.M., Greenebaum, B., and Marron, M.T. (1979) Effects of extremely low frequency electromagnetic fields on Physarum polycephalum: Variation with intensity, waveform, and individual or combined electric and magnetic fields. Radiat. Res. 78: 485-501.

Greenebaum, B., Goodman, E.M., and M. T. Marron. (1982) Magnetic Field Effects on Mitotic Cycle Length in Physarum. Eur. J. Cell Biol. 27: 156-160.

Marron, M. T., Goodman, E. M., Greenebaum, B., and Tipnis, P. (1986) Effects of sinusoidal electric and magnetic fields on ATP levels in the slime mold Physarum polycephalum. Bioelectromagnetics. 7:307-314.

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