Factors in Plant Survival for Revegetation in the Antelope Valley for Particulate Matter Control

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Table of Contents

DISCLAIMER ..... **II**

ACKNOWLEDGMENTS ..... **III**

TABLE OF CONTENTS ..... **IV**

LIST OF FIGURES ..... **VI**

ABSTRACT ..... **VIII**

INTRODUCTION **1**

MATERIALS AND METHODS **4**

PLANT MATERIALS AND SITE PREPARATION 4
Plant material *4*
Site Preparation *4*
MICROENVIRONMENTAL MONITORING 5
Soil Temperature *5*
Within-Canopy Air Temperature *6*
Within-Canopy Relative Humidity *6*
Dew Persistence on Leaves *6*
Ambient microenvironmental measurements *6*
Data Logging *7*
PLANT PHYSIOLOGICAL MEASUREMENTS 7
Photosynthesis Response Curves *7*
Leaf Water Potential *9*

RESULTS AND DISCUSSION **10**

AMBIENT ENVIRONMENTAL CONDITIONS 10
Rainfall *10*
Photosynthetically Active Radiation *11*
Air Temperature *11*
Wind Speed *12*
EFFECT OF SITE MODIFICATIONS ON MICROENVIRONMENTAL PARAMETERS 13
Herbivory Protection *13*
Mulches *14*
May versus September *20*
Deep Pipe versus Surface Irrigation *20*
Berm versus No Berm *21*
EWP versus 50th St. East *22*
Water potential *23*

CONCLUSIONS **25**

RECOMMENDATIONS **26**

REFERENCES **27**

PUBLICATIONS PRODUCED **30**

APPENDIX A **33**

APPENDIX B 37

APPENDIX C 55

APPENDIX D 62

APPENDIX E 75

APPENDIX F 81

APPENDIX G 87

APPENDIX G 88

APPENDIX H 96

List of Figures

FIGURE 1. MONTHLY RAINFALL TOTALS AT THE 50TH ST. EAST SITE.....10

FIGURE 2. PHOTOSYNTHETICALLY ACTIVE RADIATION MEASURED AT THE 50TH ST. EAST SITE. 11

FIGURE 3. REPRESENTATIVE SEASONAL AVERAGE AIR TEMPERATURE MEASURED AT THE 50TH ST. EAST SITE..12

FIGURE 4. MAXIMUM WIND GUSTS AT THE 50TH EAST SITE IN THE YEAR 2000.....13

FIGURE 5. AVERAGE WITHIN CANOPY TEMPERATURE AND RELATIVE HUMIDITY FOR PLANTS GROWN WITH TREEPEE SHELTERS AND WITHOUT IN NOVEMBER, 1999 AT THE 50TH ST. EAST SITE.....15

FIGURE 6. AVERAGE WITHIN CANOPY TEMPERATURE AND RELATIVE HUMIDITY FOR PLANTS GROWN WITH TREEPEE SHELTERS AND WITHOUT IN JULY, 1999 AT THE 50TH ST. EAST SITE.....16

FIGURE 7. SOIL TEMPERATURES AT 0.02 M UNDER PLANTS GROWN WITH AND WITHOUT TREEPEES AT THE 50TH ST. EAST SITE IN DECEMBER 1999.....17

FIGURE 8. SOIL TEMPERATURES AT 0.02 M UNDER PLANTS GROWN WITH AND WITHOUT TREEPEES AT THE 50TH ST. EAST SITE IN JULY 1999.....17

FIGURE 9. REPRESENTATIVE CUMULATIVE DEW PERSISTENCE ON PLANTS WITH AND WITHOUT PROTECTIVE SHELTERS AT THE 50TH ST EAST SITE IN JULY 2000. 18

FIGURE 10. REPRESENTATIVE CUMULATIVE DEW PERSISTENCE ON PLANTS WITH AND WITHOUT PROTECTIVE SHELTERS AT THE 50TH ST EAST SITE IN JANUARY 2000. 18

FIGURE 11. EFFECT OF COMPOST MULCH AT THE 50TH ST. EAST SITE IN JULY 1999.....19

FIGURE 12. EFFECT OF COMPOST MULCH AT THE 50TH ST. EAST SITE IN DECEMBER 1999. 19

FIGURE 13. CARBON ASSIMILATION RESPONSE CURVES FOR *ATRIPLEX* SPECIES IN SPRING AND FALL OF 2000 AT THE 50TH ST. EAST SITE 20

FIGURE 14. CARBON ASSIMILATION RESPONSE CURVES FOR *ATRIPLEX* SPECIES IN THE DEEP PIPE AND SURFACE IRRIGATION TREATMENTS IN FALL OF 2000 AT THE 50TH ST. EAST SITE. 21

FIGURE 15. COMPARISON OF PHOTOSYNTHETIC RATES BETWEEN ATRIPLEX SPECIES GROWN IN WINDBREAK (BERM) PLOTS AND NON-WINDBREAK (NO BERM) PLOTS 22

FIGURE 16. COMPARISON OF PHOTOSYNTHETIC RESPONSE TO VARYING CO_2 LEVELS FOR TWO *ATRIPLEX* SPECIES GROWN FROM TRANSPLANTS AT THE 50TH ST. EAST SITE AND PLANTS FROM DIRECT SEEDING IN THE EWP AREA 23

Abstract

To develop reliable revegetation protocols for arid regions subject to fugitive dust, environmental conditions and the microenvironmental impacts of, and plant physiological responses to, site modification techniques were measured. Temperature, humidity, photosynthetically active radiation, and wind speed measured at two meters above ground level were typical for this location over the evaluation period. Rainfall was observed only between February and April. Clear skies led to high levels of incident radiation, but this was reduced by half in winter. The temperature regime was similar in summer and early fall, and in winter and early spring. Wind speeds were considerably greater in summer than in winter, but maximum wind gusts in the year 2000 were near 15 m s^{-1} in all months except May, 2000.

Effects on microenvironment were investigated for herbivory protection (with and without plastic shelters) and surface applied soil amendments (with and without a compost mulch). Within-canopy temperatures, relative humidity, leaf surface wetness, and soil temperatures were all affected by growth within protection. Plants grown inside protective shelters had higher within-canopy air and soil temperatures, particularly during the day and during the summer, with much smaller effects at night and during the cool season. Shelters similarly increased relative humidity and dew formation and persistence inside the shelters during active growth periods, ie. the winter, and both day and night. Compost mulch in a thin layer applied to the surface did little to alleviate soil heating during summer, but resulted in warmer soil temperatures in cooler months, both day and night.

Plant physiological responses to modifications were assayed in these treatments and in two irrigation treatments (surface and deep pipe injection) and two windbreaks (with and without berms of soil). Modifications were compared using diagnostic gas exchange responses to intercellular carbon dioxide concentration, manipulated only during the measurements and not throughout the growth period. Photosynthetically active radiation, humidity and temperature were held constant during measurements. Photosynthetic rates were greater in May than in September, and overall in *Atriplex canescens* than in A. polycarpa. Significant treatment differences in maximal photosynthetic rate were observed in the Fall. No differences were observed in carboxylation efficiencies, CO_2 compensation points, and stomatal limitations. Plants grown on open sites exhibited greater maximal photosynthesis than those grown with wind protecting soil berms. Similarly plants watered by surface irrigation surpassed those watered with deep pipe injection. This may have reflected different root placement, and the occurrence of rainfall prior to measurements. The transplanted shrubs at this site exhibited much greater photosynthetic rates than those previously established by direct seeding in the Emergency Watershed Protection program. This probably reflects irrigation and younger plant age, as well as residual soil nitrogen. Further physiological measurements are required to fully characterize the behavior of these species in revegetation programs.

These physiological investigations suggest that *A. canescens* is the best species for revegetating abandoned and eroding lands in this environment.

Executive Summary

Interdisciplinary research and demonstration projects involving revegetation techniques for control of fugitive dust emissions have been underway with local Antelope Valley agencies, organized as the DustBusters TaskForce, since 1991. During the drought of the late 1980's and early 1990's, seasonally high winds created dust storms which contributed to repeated violations of the federal and state ambient air quality standards for particulate matter in the downwind urban areas of Lancaster and Palmdale. Numerous incidences of reduced visibility and traffic accidents occurred, buildings and property were inundated with blowing sand, and field and tree crops were damaged. The current period of nearly normal rainfall has ameliorated the problem. However, historical records indicate that a return to drought conditions is inevitable. Without considerable development of fugitive dust mitigation techniques, a return to particulate matter exceedances is also inevitable.

Research projects conducted to address these problems have identified feasible and affordable land use practices that suppress fugitive dust. Results at this time are preliminary. A project goal is to develop recommendations that will be robust, and apply in this and other low rainfall areas of the arid west. In previous research efforts we have demonstrated the long term dust mitigation benefits of revegetation with perennial species. We have previously documented the difficulties and uncertainties of successfully reestablishing shrub vegetation in this harsh environment--both cold winters and hot and dry summers. The current project, reported here, documents effects of site modification techniques on plant microenvironment, and examines plant physiological response to the imposed site modifications. Some minimal site modification is likely to be required to enhance the probability of successful establishment of the native shrubs under study. This enhanced probability of success will be essential prior to recommendations to land managers to implement the revegetation protocols under development.

To improve understanding of the revegetation results we have monitored the environmental parameters at the experimental site. Wind speed, photosynthetically active radiation, air temperature, and relative humidity were also measured at 2.0 m above ground level near plant height over the course of the research project. A continuous record over two annual cycles was thus obtained. Rainfall was observed only in February to April. Very high rates of photosynthetically active radiation were observed in summer, with reduction by about half in

winter. Air temperatures were similar in summer-fall and in winter-spring, but differed substantially between the two periods. Summer maximum temperatures exceeded 35C while winter temperatures reached 0C. This is clearly a distinctively harsh environment for plant establishment and growth. Native species, and even local biotypes are likely to be required for successful revegetation.

Wind, associated in this area with fugitive dust and exceedances of particulate matter violations, was considerably higher in summer than winter months. Mean wind velocities were relatively low, though gust activity was pronounced. While gust generated excursions of particulate matter concentration have been documented in our previous studies, particularly in the spring, at the current 50th Street East site gusts of relatively low magnitude were observed at all times of the year.

Site modification techniques, evaluated for plant growth and survival by a collaborator in the DustBuster TaskForce project, included two types of irrigation (surface and perforated deep-pipe), three types of surface applied soil amendments (wood chips, compost, control), and modification of local topography through the construction of windbreak plots—berms of soil 1 m high x 15 m in length. Five native plant species were grown from locally collected seed and transplanted in replicated plots representing all combinations of site modifications. All transplants were covered with conical or cylindrical shaped plastic herbivory protective devices. After an initial establishment period of about six months, protective devices were removed from some plants to allow investigation of microenvironmental differences between plants with protective shelters and those without. Site modifications can have significant impact on microenvironmental parameters affecting plant establishment and subsequent growth. Resulting temperature changes in canopy air space and soil root zone, and concomitant alterations in humidity and dew point affect not only physiological status of the plants, but may have impacts on biotic (disease) impediments to growth. Microenvironmental measurements were conducted on selected treatment combinations of special interest, and plant physiological measurements on these and additional combinations of interest.

Vegetation based micro-environmental measurements focused on *Atriplex* species (representing three of the five transplanted species, and shown in previous research to be the most successful in revegetation efforts) in non-windbreak (shrub) plots. Within-canopy

measurements of air temperature, relative humidity, and leaf wetness (dew formation and persistence), and below canopy soil temperature at 0.2 m and 0.33 m were conducted on plants growing with and without plastic shelters, with and without a surface cover of compost mulch, and with surface irrigation and perforated deep pipe irrigation.

Herbivory of transplanted vegetation is severe in arid environments. Our previous results demonstrated that herbivory protection is required for successful shrub establishment. In the current study, a companion site at 90th Street East was destroyed by rabbits, and required replanting. The shelters used for herbivory protection change plant growth by altering environmental parameters. Substantial differences in microenvironment existed between plants grown with protective herbivory shelters and those grown without were observed.

Within canopy air temperature was considerably higher in mid-summer inside the measured shelters compared with canopy temperatures in plants without shelters. Even larger midday differences were observed in winter. There was little effect at night in either season.

Humidity and dew persistence were substantially greater during the active plant growth periods inside the shelters than outside. There was considerably less impact on these parameters in summer, when plant physiological activity and transpirational water vapor loss much less.

Soil temperatures at 0.02 m depth were generally higher under plants covered by protective shelters. Soil temperatures at this depth closely tracked the diurnal cycle of air temperature, regardless of plot treatment, rising in the morning hours but lagging the increasing air temperature. Temperatures remained higher during the nighttime hours.

The spreading of compost mulch over the soil surface had little effect during the summer, reducing midday soil temperature only slightly. Soil temperature differences between mulched and control plots were evident mostly during the non-summer months when the mulched soils exhibited higher temperatures during the midday period, and to a reduced extent at night.

Physiological assessments of the transplanted shrubs were conducted in May and September of 2000 by measuring photosynthetic response to CO_2 concentration (manipulated from 400 to 0 micromoles per mole CO_2 in the air surrounding the leaf during measurement). Response curves of carbon assimilation versus CO_2 concentration within the leaf, constructed from these results, were used to estimate differences between species and treatments for the derived parameters, maximum photosynthetic rate, carboxylation efficiency, CO_2 compensation

point, and limitations to photosynthesis imposed by stomatal closure. Exposed leaf water potentials were measured near the midday period on plants being assessed for physiological performance.

Maximum photosynthetic rate was greater in May than in September over all species and treatments, but carboxylation efficiency, CO_2 compensation point, and stomatal limitation were not different between the Spring and Fall periods. Assessment of physiological parameters in the Fall season involved a larger sample size than in the Spring, and contributed to detection of treatment differences between some site modifications.

Maximum photosynthetic rate for *Atriplex* species was greater under surface irrigation (14.5 μmol m^{-2} s^{-1}) than under deep pipe irrigation (9.5 μmol m^{-2} s^{-1}). An unusual rainfall occurred just prior to the September 28, 2000 evaluation. Previously surface irrigated plants may have benefited from previously established near-surface root systems to utilize this rainfall and enhance late season photosynthetic rate relative to the deeper rooted deep pipe treatment.

The data suggested that the CO_2 compensation point may be lower for surface irrigated plants than for those watered by deep pipe, and within the surface irrigated plants *A. canescens* may be significantly lower than *A. polycarpa* for this parameter. *Atriplex* species did not differ under the deep pipe watering scheme. Methodological uncertainties require that the compensation point data be reevaluated during further field sampling before conclusions can be drawn.

Maximum photosynthetic rate for *Atriplex* species was greater on non-windbreak plots (14.1 μmol m^{-2} s^{-1}) than on windbreak plots (10.3 μmol m^{-2} s^{-1}).

As part of our ongoing evaluation of the directly seeded Emergency Watershed Protection program of 1991-2, we compared the shrubs at 50th Street West with shrubs established in the EWP. At both locations A. canescens outperformed A. polycarpa. The younger transplanted individuals at 50th Street East vastly outperformed the older shrubs in the EWP area.

Further evaluation of the transplanted shrubs at 50th Street East, and at the companion site at 90th Street East, will be required to fully characterize the success of establishment. Over the next three growing seasons, it will become possible to identify the successful site modifications, to further document the most successful species, and to identify any physiological screening parameters that may accelerate such identifications in the future. A comprehensive manual of

protocols for revegetation and other techniques to mitigate fugitive dust and particulate matter exceedances in the Antelope Valley is to be prepared by the DustBusters TaskForce in 2004.

Introduction

Although abandoned land in humid, temperate zones is usually colonized rapidly by annual and perennial herbs (Horn, 1974), arid regions that have been subjected to land degradation pose unique problems, and often require intervention since revegetation by natural recruitment tends to be slow and uncertain in these environments (Call and Roundy, 1991; Jackson et al., 1991).

Since 1991, the Dustbuster's TaskForce has undertaken research projects in the Antelope Valley of the western Mojave Desert to determine cost efficient methods that land managers may use to re-establish self sustaining ecosystems on degraded land to mitigate and control fugitive dust emissions. As with natural recruitment, desert revegetation through direct seeding fails in most years (Bainbridge et al., 1993; Jackson et al., 1991; Cox et al., 1982; Bleak et al., 1965), although direct seeding coupled with fortuitously timed rainfall resulted in highly successful plant establishment in a large area of the Antelope Valley in the early 1990's (Grantz et al., 1998a). Establishment of large, homogeneous shrub populations may not be necessary however, since limited cover (e. g., 20 to 30%, Carpenter et al., 1986) is typical of these arid regions, and is sufficient to reduce fugitive dust emissions by up to 75% (Bilbro and Fryrear, 1995). The use of transplants as a means of desert revegetation has received increased attention in the last decade, and techniques for successful establishment have been evaluated (Bainbridge et al., 1995; Bainbridge et al., 1993; Bainbridge and Virginia, 1990; Romney et al., 1987) Transplantation of native shrubs does not guarantee survival however (Grantz et al., 1998b), and the focus of current research effort in the Antelope Valley has been to further delineate the environmental and plant physiological factors that impact establishment, survival, and growth of transplanted native species.

Water availability is generally considered the single most limiting resource for plant growth (Boyer, 1985). The highly variable rainfall patterns that exist in arid and semi-arid areas are viewed as a dominant factor influencing the seemingly stochastic nature of natural plant establishment (Allen, 1991; Carpenter et al., 1986; Silcock, 1986; Webb et al., 1983; Cox et al., 1982; Bleak et al., 1965). Thus supplemental irrigation protocols are often required, and should

be minimally applied to promote survival while minimizing growth of, for example, exotic annual grasses. Methods of applying supplemental water include simple basin watering, deep pipes, buried clay pots, porous capsules, wicks, and drip systems (Bainbridge and Virginia, 1990).

Permanent changes in the edaphic environment can be imposed by agriculture or other anthropogenic disturbance. Extensive tillage, use of mineral fertilizers and organic pesticides, and soil compaction may reduce populations of important symbionts such as vesicular-arbuscular mycorrhizal (VAM) fungi (Bainbridge, 1993; Bainbridge and Virginia, 1990) which form mutualistic associations with about 90% of species from arid and semiarid lands (Trappe, 1981). Spatial variability in shrub-dominated arid and semiarid sites is characterized by enhanced soil nutrients and organic matter under existing plant canopies, relative to areas between plants (Allen, 1991). In interventions where transplanting of native species is undertaken, the use of recalcitrant organic mulches such as straw or bark has been shown to promote soil symbionts and enhance establishment of transplanted native plants (Zink, 1994).

Herbivory is a third critical factor in plant establishment in arid and semiarid environments (Bainbridge and Virginia, 1990; Romney et al., 1987; McAuliffe, 1986), with grazing by blacktail jack rabbits (*Lepus californicus*) often a limiting factor in the Mojave Desert and Great Basin environments (Romney et al., 1987). A variety of plant protection techniques have been used, including plastic tree shelters, metal screens, rock mulches, plant collars, animal repellents, straw stubble, and mulches of standing senescent biomass. Applicability of each is determined by cost and individual site requirements (Bainbridge et al., 1995).

As part of a larger effort to develop well-defined mitigation techniques for dust emissions, the current project was initiated to examine the effect of certain site modifications on the microenvironment and physiological status of transplanted native seedlings. Project cooperators at the Soil Ecology and Restoration Group at San Diego State University were responsible for establishing and maintaining the plants, as well as for making growth measurements over time. Details of their efforts to date are available (Calhoun et al., 2000).

In January, 1999, about 1400 seedings of five native desert shrub species were transplanted in two locations in the Antelope Valley. They were grown in plots receiving either surface irrigation or deep pipe irrigation, and either compost mulch, wood chip mulch or no

mulch. Plants were grown in either "windbreak" or "shrub" (non-windbreak) plots. Windbreak plots were earthen berms 1 m tall and 15 m wide. All plants were initially protected with plastic TreePee or Tubex herbivory shelters. After six months, shelters covering plants in representative treatments were removed to allow comparison of within-canopy microenvironmental measurements between sheltered and unsheltered plants. These measurements included air temperature, relative humidity, and leaf wetness (dew formation) within the canopy of *Atriplex* species grown with and without herbivory shelters and receiving either surface or deep pipe irrigation. Measuring effects of the compost mulch treatment was planned, but for practical purposes this mulch layer was thin to non-existent during the majority of the 2 year evaluation period, presumably blown away by seasonally high winds.

Materials and Methods

A number of site modifications were implemented at an experimental site near Lancaster, CA to examine their effect on within- and beneath-canopy microenvironmental parameters of five transplanted native desert shrubs, and to examine plant physiological response to the imposed modifications.

Plant Materials and Site Preparation

Site preparation and cultural and agronomic activities associated with establishment of the plant materials used in this research were undertaken by project collaborators at the Soil Ecology and Restoration Group (SERG) at San Diego State University. A synopsis is provided here, but details may be obtained from their 1999 Annual Report (Calhoun et al., 2000).

Plant material

Five native plant species were chosen for evaluation. Three saltbushes, fourwing saltbush (*Atriplex canescens*), allscale saltbush (*A. polycarpa*), and quailbush (*A. lentiformis*) are well adapted to the study area and occur commonly throughout the western Mojave Desert. Photographs of these species may be found in Appendix A. Honey mesquite (*Prosopis glandulosa* var *torreyana*), a deep-rooted, leguminous species, considered endemic but now uncommon in the study area has proven successful for stabilizing disturbed areas both by direct seeding and by transplanting (Hickman, 1993, Bainbridge et al., 1993). In transplant trials at a nearby location in 1995-1997 this plant was highly susceptible to herbivory following removal of protection (Grantz et al., 1998b), but warranted further study. The fifth plant, creosotebush (*Larrea tridentata*), is widespread in the western Mojave Desert. Seeds of these species were collected locally and grown in greenhouses at the SERG facility, and were moved to a lath house in Riverside, CA two months before transplanting to allow them to acclimate to desert conditions. Seedlings were transplanted at two sites in January 1999.

Site Preparation

Two sites were selected for the plant evaluations, but only one of these was used by our group for microenvironmental monitoring and plant physiological investigations. This site was

located near 50th St East, between Avenues N and P, east of the city of Lancaster (N 34° 37.425′ W 118° 02.450′) on an abandoned agricultural field with high residual nitrogen. In November and December of 1998, plots were back bladed and ripped to 12" depth, and windbreak plots were constructed. Deep pipe irrigation was installed in January, 1999, followed by installation of plants and amendment treatments.

Microenvironmental Monitoring

Soil Temperature

Soil temperatures were monitored at 12 locations at the 50th St. East site with YSI Series 401 thermistors (YSI Inc., Yellow Springs, OH) with approximately logarithmic, negative temperature coefficients. These thermistors were epoxy encapsulated for weather-proofing and fitted with electrical leads. To make the resistance-temperature characteristics more linear, the rate of resistance change must decrease as the temperature decreases, and this was accomplished by adding a single shunt resistor in series to form a half bridge circuit, which, when connected across a constant voltage source, yields a nearly linear output voltage versus temperature curve. The datalogger program then applies an empirical mathematical expression (Hart-Steinhart equation) for the resistance-temperature relationship of a negative temperature coefficient resistor. Six *Atriplex* (*A. canescens* or *A. lentiformis*) plants were chosen and two thermistors were placed in the soil beneath each plant, one at 0.02 m depth and the other at 0.33 m depth. To protect the electrical leads from damage by rodents (previous research had been interrupted by rodents chewing cables) the portion of the cable within 0.5 m of ground level was enclosed in electrical metallic tubing about 1.2 cm (0.5 in) in diameter and anchored in a vertical position. Four of the six plants were in a plot receiving deep pipe irrigation and no mulch treatment. The herbivory protection (TreePees) on two of these four plants was removed to allow comparison with plants having protective shelters. Two of the six plants were in a plot having compost mulch and surface irrigation. These plants had herbivory protection. Thermistors were interrogated every 10 seconds and recorded as 30 minute averages.

Within-Canopy Air Temperature

Within-canopy air temperature was monitored on the same six plants outlined above. Temperature was measured with 76 micron (0.003 in) diameter Type T thermocouples which were placed in the middle of the plant canopy, 5 cm from the main stem. Thermocouples were interrogated every 10 seconds and recorded as 30 minute averages.

Within-Canopy Relative Humidity

Within-canopy relative humidity on these six plants was measured with Vaisala HMP14U relative humidity sensors (Campbell Scientific, Logan, UT). Sensors were laboratory calibrated utilizing a precision YSI thermistor and a LI-610 dew point generator (LiCor Inc, Lincoln, NE) in a sealed box, and linear regressions were developed relating voltage output to humidity. Sensors were placed in the plant canopy near the thermocouples, interrogated every 10 seconds and recorded as 30 minute averages.

Dew Persistence on Leaves

Dew persistence on leaves in the canopy was measured with Model 237 Leaf Wetness sensors (Campbell Scientific, Logan, UT) made from a circuit board with interlacing copper fingers and covered with latex paint to allow water droplets to spread. The presence of moisture (dew) causes the impedance of the sensor to decrease. Sensors were placed inside the canopy of the six experimental plants, with the painted side facing downward at an angle of 45°. Sensors were interrogated every 10 minutes, and data recorded as either wet or not wet based on the impedance reading of the sensor.

Ambient microenvironmental measurements

In addition to the canopy based measurements, local environmental conditions were monitored at the 50th St East site. Wind speed was measure at 2.0 m AGL with a model 03101-5 R. M. Young Wind Sentry anemometer (Campbell Scientific, Logan, UT). Photosynthetically active radiation was measured at 2.0 m AGL with a Licor model 190SB quantum sensor (Licor,Inc., Lincoln, NE). Between the initial deployment of sensors in July, 1999 and September of 2000, ambient temperature was measured with a fine wire Type T thermocouple suspended in

the air at 2.0 m AGL. In September of 2000, this thermocouple was removed, and a Campbell Scientific 207 sensor was deployed at 2.0 m. This sensor measures both air temperature and relative humidity. A Model TE525 Tipping Bucket Rain Gauge (Texas Electronics, Dallas, TX) was deployed at the site for the duration of the experiment.

Data Logging

All microenvironmental sensors were controlled with a Campbell Scientific datalogger (Model 21X; Campbell Scientific, Logan, UT). Except for the leaf wetness sensors, which were interrogated every 10 minutes, sensors were read every 10 seconds and results recorded as 30 minute averages which were stored in solid state data storage modules (SM192; Campbell Scientific, Logan, UT). Rainfall was totalized on a half hour basis in millimeters.

Plant Physiological Measurements

Plant physiological measurements were undertaken at the 50th St. East location in May and September of 2000 using the Licor 6400 portable photosynthesis system (Licor, Inc., Lincoln, NE). Identical measurements were made on *A. canescens* and *A. polycarpa* plants, during the same time periods, in the Emergency Watershed Protection (EWP) area that was part of previous efforts in the early 1990's to revegetate 2500 acres of severely eroding land through direct seeding efforts. This made possible preliminary observations between plants established from direct seeding and natural rainfall and plants transplanted with supplemental irrigation.

In addition to the Licor 6400 measurements, plant leaf water potential was determined at various times of the day and used to describe plant water status.

Photosynthesis Response Curves

These measurements were aimed at describing the rate of carbon assimilation at varying levels of intercellular CO_2 concentration (A/ci response curves) of the different species under the imposed site modifications. Response curves of this type (assimilation against CO_2 concentration at the mesophyll cell surface) have many applications. They offer a method of separating stomatal from mesophyll limitations, and they can be used in separating in vivo carboxylation from electron transport limitations within the mesophyll. They are used here to provide estimates

of maximum photosynthetic rate, carboxylation efficiency, CO_2 compensation point, and the relative limitation imposed by the stomata.

Obtaining the data for each response curve consists of several steps. The instrument consists of a multitude of integrated sensors and environmental controls which were checked for proper functioning several times during the course of a day. The instrument is capable of maintaining leaf chamber conditions at constant levels while varying one parameter. Thus, chamber temperature, humidity, and light level (controlled by a special set of blue and red photodiodes) were kept constant while CO_2 levels were varied from near ambient to zero micromols. In practice the nominal levels were decreased from 400 to 0 micromols CO_2 in steps of 100, followed by an increase back to 400, and in some cases continued increases up to 600 or 700 micromols. Data logging would take place after equilibrium at each CO_2 concentration was obtained. The nominal time for completion of one curve, including setup, varied from 20 to 30 minutes. Over the course of the experiment, 41 such curves were obtained.

One extremely important aspect of these types of measurements is the measurement of the amount of leaf area in the chamber. In the case of many agronomic crops, this is usually not a big issue because the leaf will completely cover the known area of the leaf chamber. For these desert plants however, special techniques were used to obtain the leaf area measurement. Leaves of the *Atriplex* species, for example, are small and highly variable. Generally multiple leaves had to be included in each measurement. When the photosynthesis measurement process was complete, the chamber was opened carefully, and the leaves marked with a permanent ink to delineate the portions exposed in the chamber. The stem section supporting the leaves was excised, placed in a plastic bag, sealed and stored in a cooler. In the laboratory, the leaves were be placed on a sheet of paper with a ruler marked in millimeters, and covered with plastic. This was photocopied, yielding a silhouette which could be scanned and imported into a computer. Following this photocopy process, the multiple leaves per sample were physically separated from one another, and the photocopy process was repeated for the "destructive" leaf sample. This allowed calculation of photosynthesis both on a projected and a destructive leaf area basis. After digitizing the leaf images, a commercially available imaging program (SigmaScan; SPSS Inc., Chicago, IL) was calibrated with the photocopied ruler and used to obtain total exposed leaf area.

For every curve obtained, all calculated variables had to be recomputed using the appropriate leaf area.

Leaf Water Potential

In the May 2000 campaign, leaf water potentials were obtained near midday with a Sholander type pressure vessel on plants at the 50th east location, in the EWP, and on native plants existing near these areas. Leaf water potential was also obtained coincidentally with each photosynthesis response curve. In the September 2000 campaign, leaf water potentials were measured near midday at the 50th St. East site.

Results and Discussion

The effect of the site modifications on microenvironmental parameters is presented and discussed along with the general environmental conditions during the course of the evaluation period. Representative seasonal examples of these effects are included in the text, and a full representation of the monthly summarized data is presented in Appendix B.

Ambient Environmental Conditions

Rainfall

Total rainfall for the year 2000 measured at the 50th St. East site was 12.1 cm, considerably less than the 20 year average of about 20 cm per year. Nearly all of this precipitation occurred between January and April of that year (Fig.1). In addition to the naturally occurring rainfall, transplants at this location had received monthly watering until July of 2000 by SERG personnel. Unseasonal precipitation did occur in September 2000, just prior to physiological evaluations of the plants.

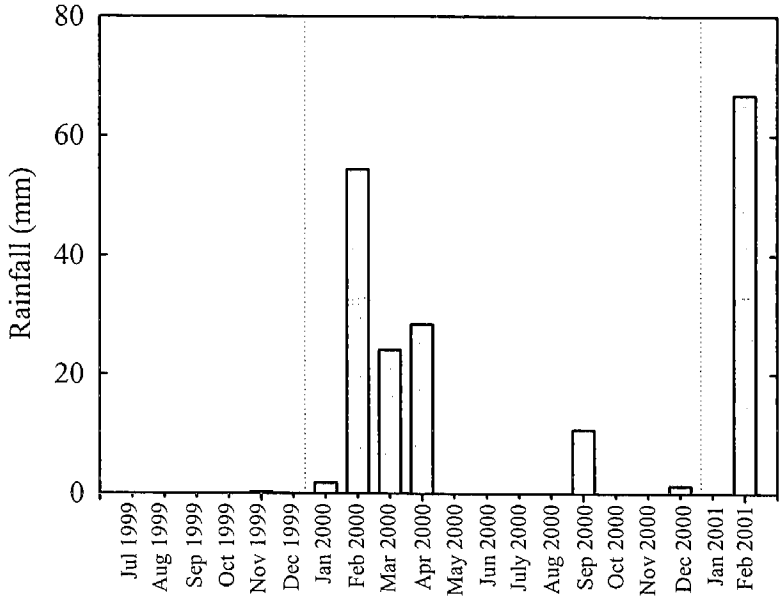

Figure 1. Monthly rainfall totals at the 50th St. East site.

Photosynthetically Active Radiation

Generally clear skies prevail in this high desert area, so in the absence of passing fronts or storms, a smooth bell shaped curve results when plotting photosynthetically active radiation against time of day. Solar radiation levels vary with time of year (Fig. 2).

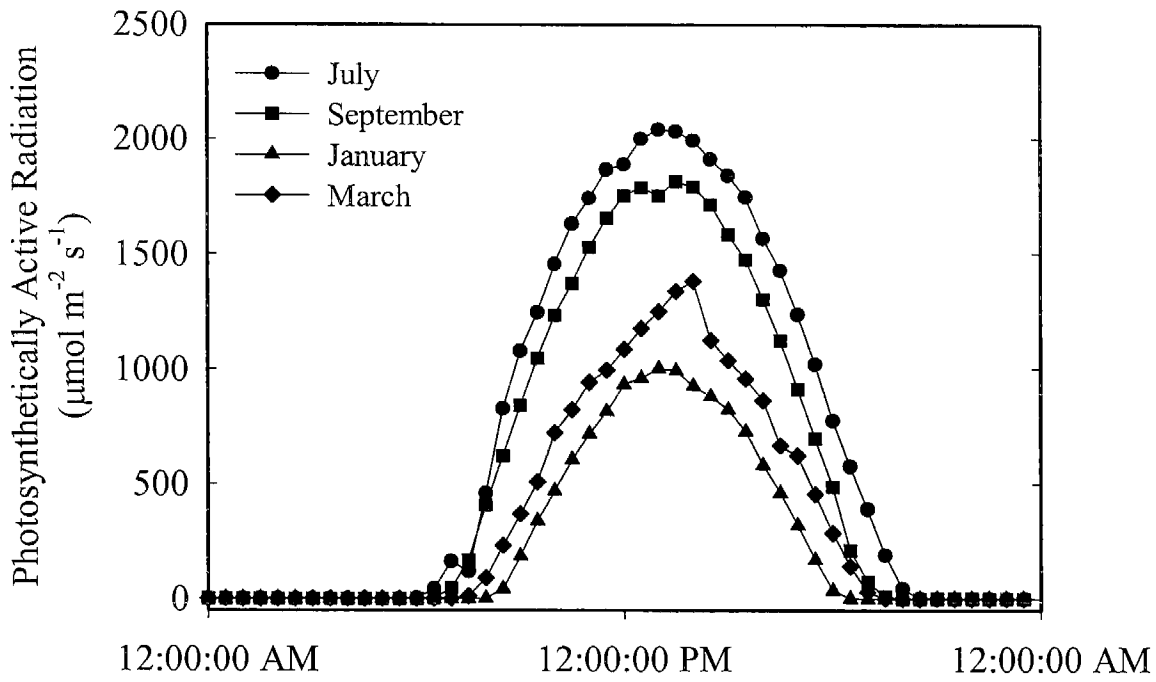

Figure 2. Photosynthetically active radiation measured at the 50th St. East site.

Air Temperature

Representative monthly (seasonal) average air temperatures measured at 2.0 m are shown in Figure 3. Maximum daily temperatures were frequently near 38° to 40° C at the 50th East St. site, while winter minimums were as low as -10° C.

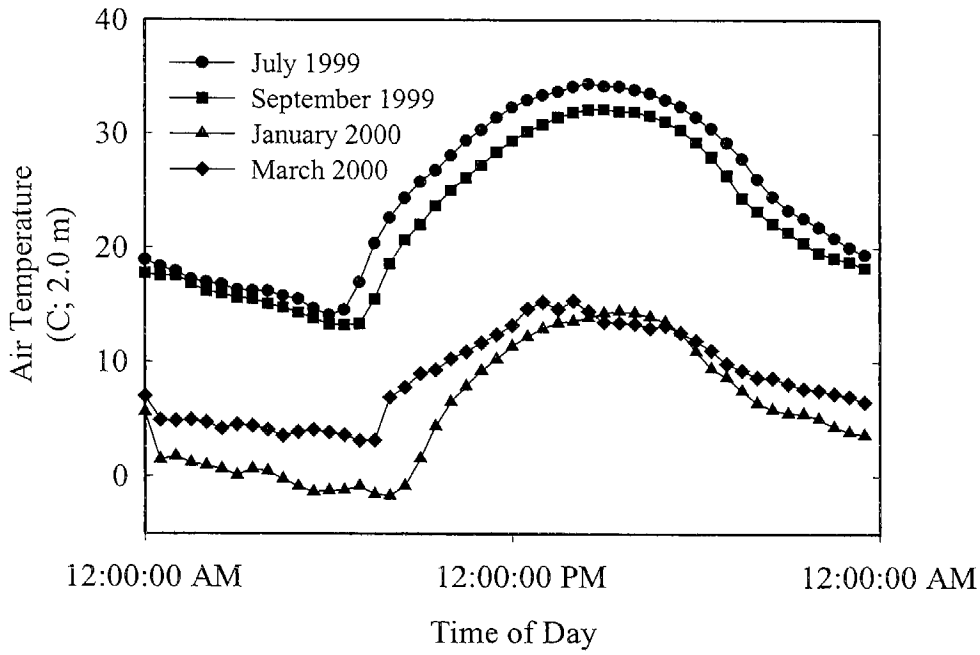

Figure 3. Representative seasonal average air temperature measured at the 50th St. East site.

Wind Speed

Wind speeds are highly variable and season dependent in the Antelope Valley. Maximum wind gusts by month for the year 2000 are in agreement with historical data for this area (Fig. 4).

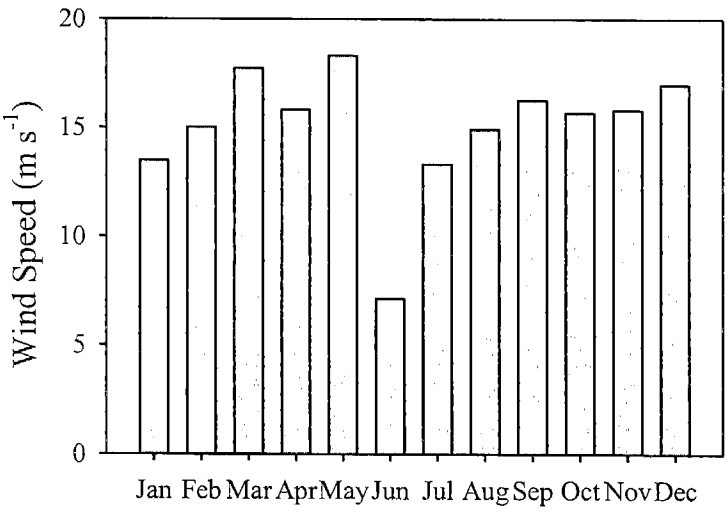

Figure 4. Maximum wind gusts at the 50th East Site in the year 2000.

Effect of Site Modifications on Microenvironmental Parameters

Herbivory Protection

The need for herbivory protection of transplanted seedlings has been demonstrated in this area of the Mojave Desert (Grantz et al., 1998b), but there has been little documentation of the potential for these shelters to alter the microenvironment of the enclosed plants. TreePees are conically-shape and opaque plant protective covers, open to the atmosphere at the top only, which were used in this study. Tubex shelters, similar to TreePees but cylindrical in shape, were also used to protect transplants, but these were not evaluated for microenvironmental effects.

Canopy Air Temperature and Relative Humidity

Within canopy air temperature and relative humidity were affected substantially by the use of plastic herbivory shelters. Differences were more pronounced in the non-summer months (Fig. 5) than in mid-summer (Fig. 6), as solar radiation was sufficiently high, but air temperatures cool, to cause large differentials through a greenhouse effect exerted by the shelters. Within canopy temperatures were consistently higher during daytime hours, with little effect at night.

Within canopy relative humidity was also generally higher inside the shelters than outside, with larger differentials in the non-summer months than in summer months (Figs. 5, 6). This is associated with greater physiological activity, and associated transpiration in the cooler months. The shelters retarded dispersion of the transpired water vapor, thereby incrasing the humidity.

Soil Temperatures

Soil temperatures were affected by the presence of the herbivory shelters, and varied in pattern with season of the year. Soil temperatures at 0.02 m depth were generally greater underneath plants with shelters during midday periods during the non- summer months (Fig. 7). In summer months differences were less distinct. In mid-afternoon the shelter reduced soil temperature, by shading the soil surface (Fig. 8).

Dew Persistence

The development of dew on plants inside TreePee shelters was more frequent and persisted for longer periods of time than on plants without shelters (Figs. 9, 10). There was considerably more dew inside and outside the shelters in the winter, and more dew in winter than summer. This also reflects greater physiological activity and transpiration in the cool season.

Mulches

The compost mulch was evaluated against the control (no mulch) for microenvironmental effects.

Soil Temperature

Soil temperatures were most affected during non-summer months (Figs. 11, 12).

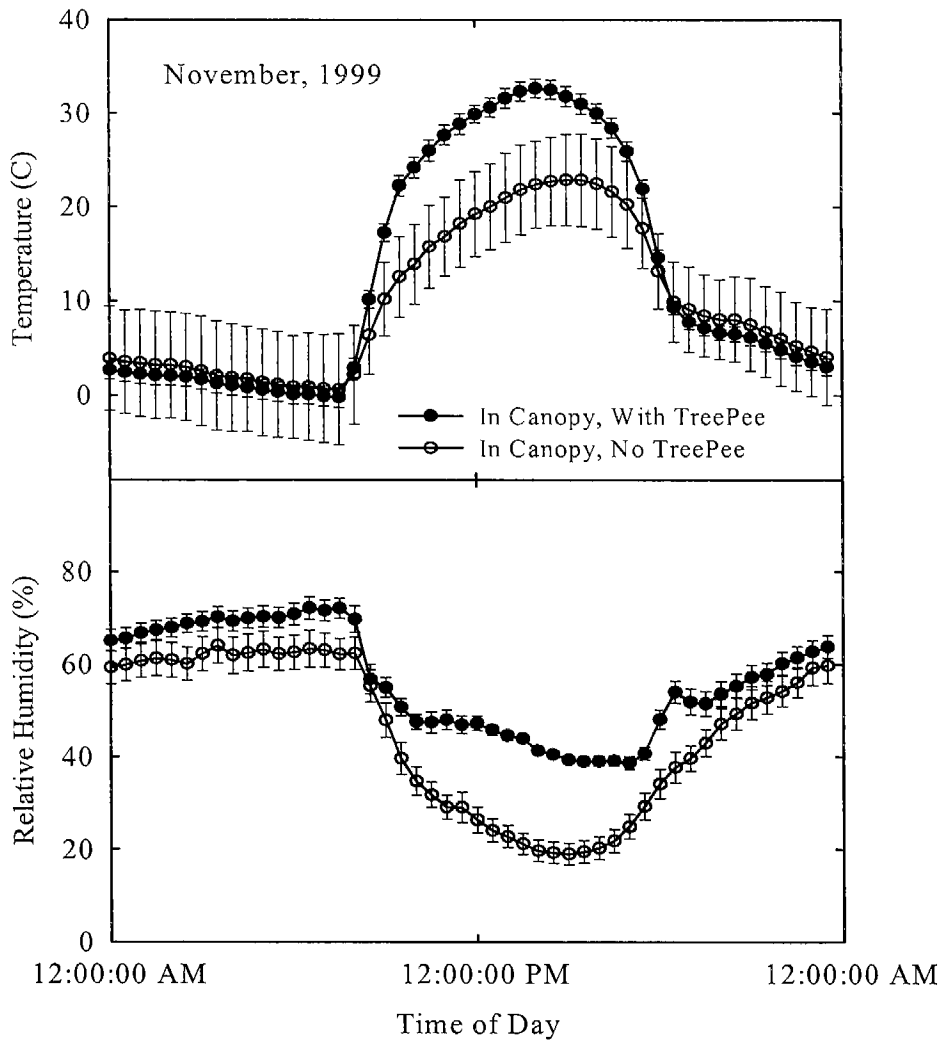

Figure 5. Average within canopy temperature and relative humidity for plants grown with TreePee shelters and without in November, 1999 at the 50th St. East site.

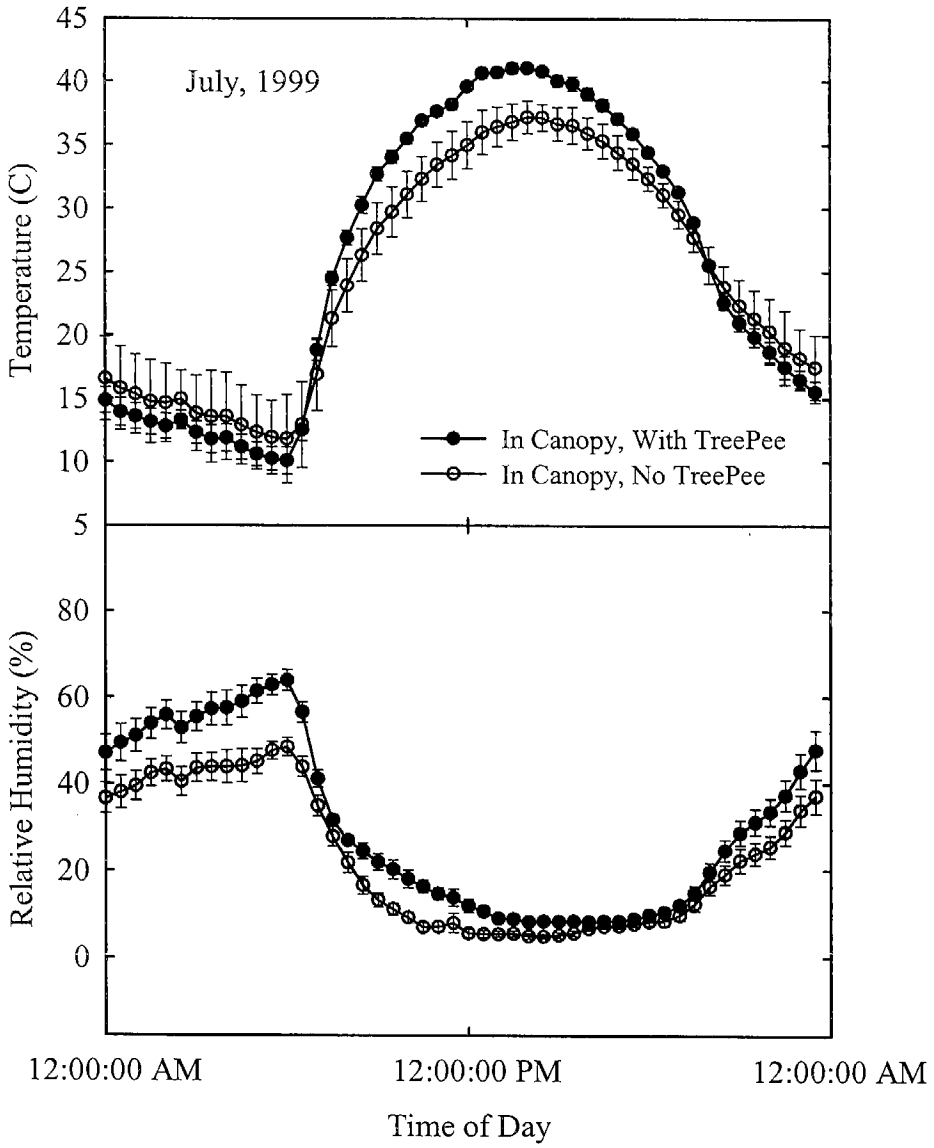

Figure 6. Average within canopy temperature and relative humidity for plants grown with TreePee shelters and without in July, 1999 at the 50th St. East site.

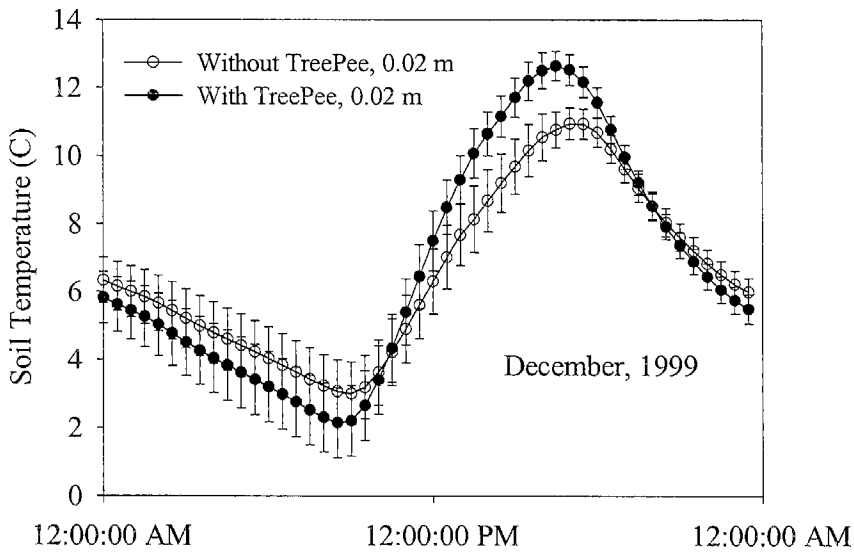

Figure 7. Soil temperatures at 0.02 m under plants grown with and without TreePees at the 50th St. East Site in December 1999.

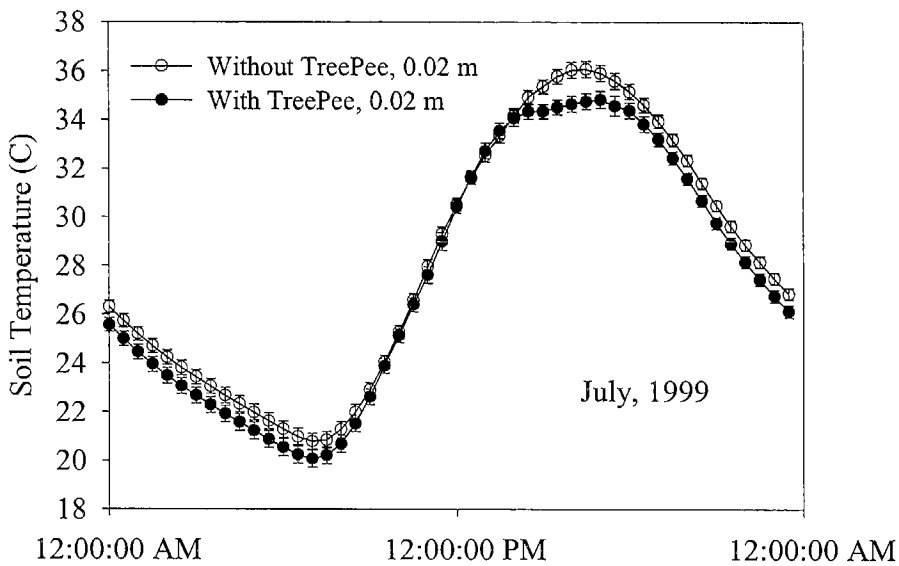

Figure 8. Soil temperatures at 0.02 m under plants grown with and without TreePees at the 50th St. East Site in July 1999.

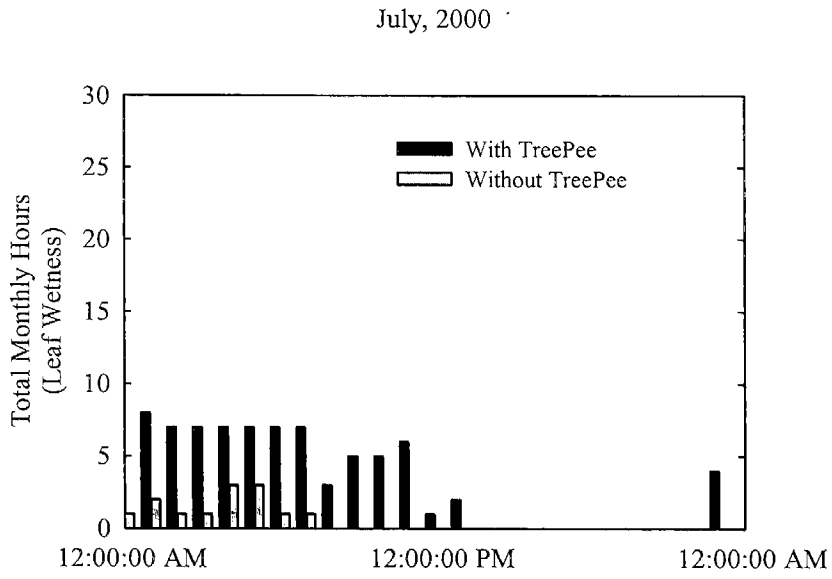

Figure 9. Representative cumulative dew persistence on plants with and without protective shelters at the 50th St East site in July 2000.

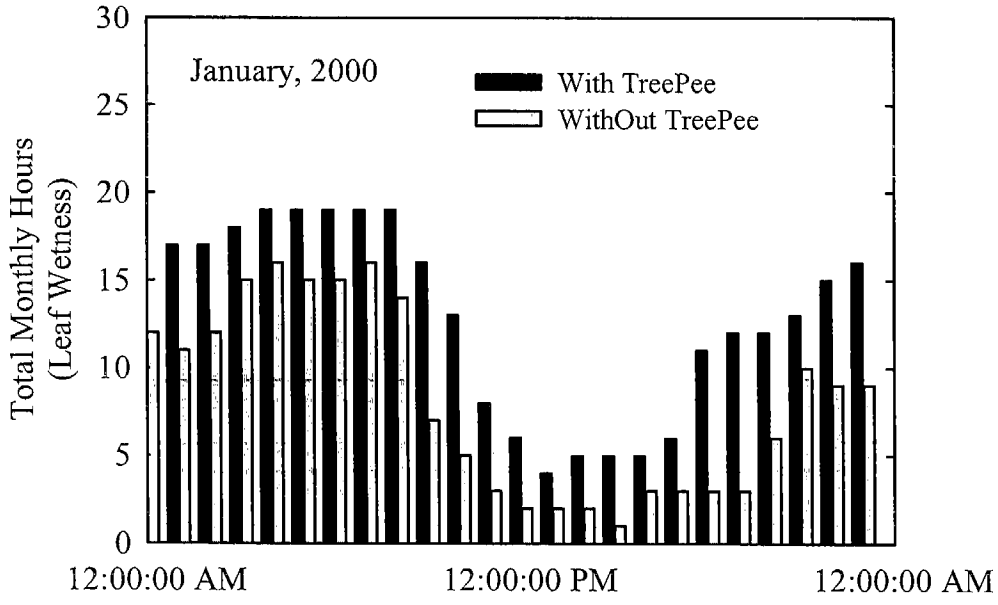

Figure 10. Representative cumulative dew persistence on plants with and without protective shelters at the 50th St East site in January 2000.

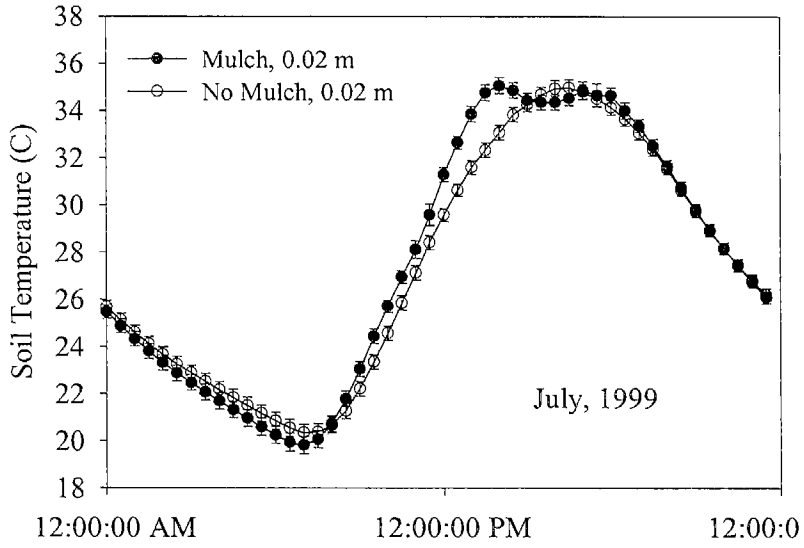

Figure 11. Effect of compost mulch at the 50th St. East site in July 1999.

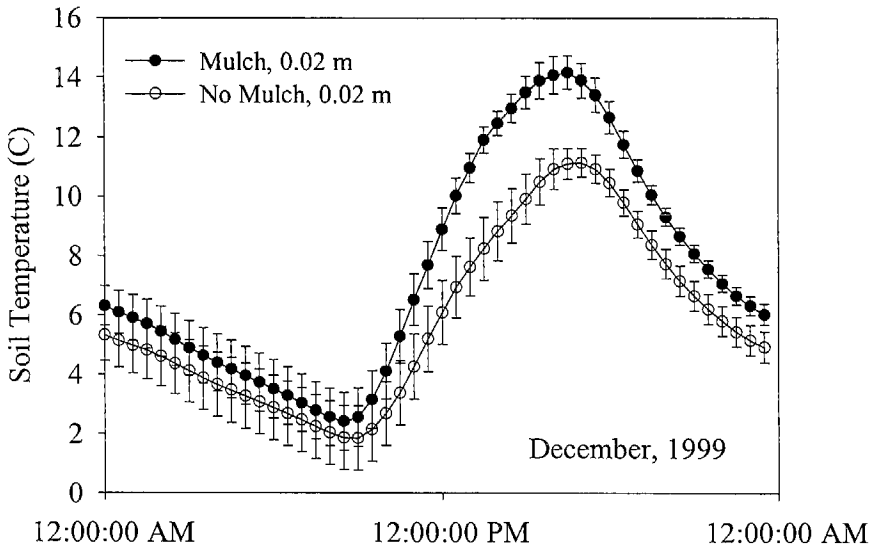

Figure 12. Effect of compost mulch at the 50th St. East site in December 1999.

Effect of Site Modifications on Plant Physiology

May versus September

For *Atriplex* species, maximum photosynthetic rate was different between Spring and Fall ($p = 0.03$; Fig. 13). Rates were about a third higher in Spring than Fall (15 versus 10 micromols/m^2/s). However, carboxylation efficiency, CO_2 compensation point, and stomatal limitation were not significantly different between these times. This indicates that the vigor of these plants, driven seasonally by radiation and water availability, is best indicated by maximum photosynthetic rate. This provides an instantaneous measurement of vigor, independently of the long term growth measurements otherwise required. The other parameters, that did not change seasonally, in contrast, may be useful to identify poor sites, plant disease, or other negative impact on plant establishment that is site specific.

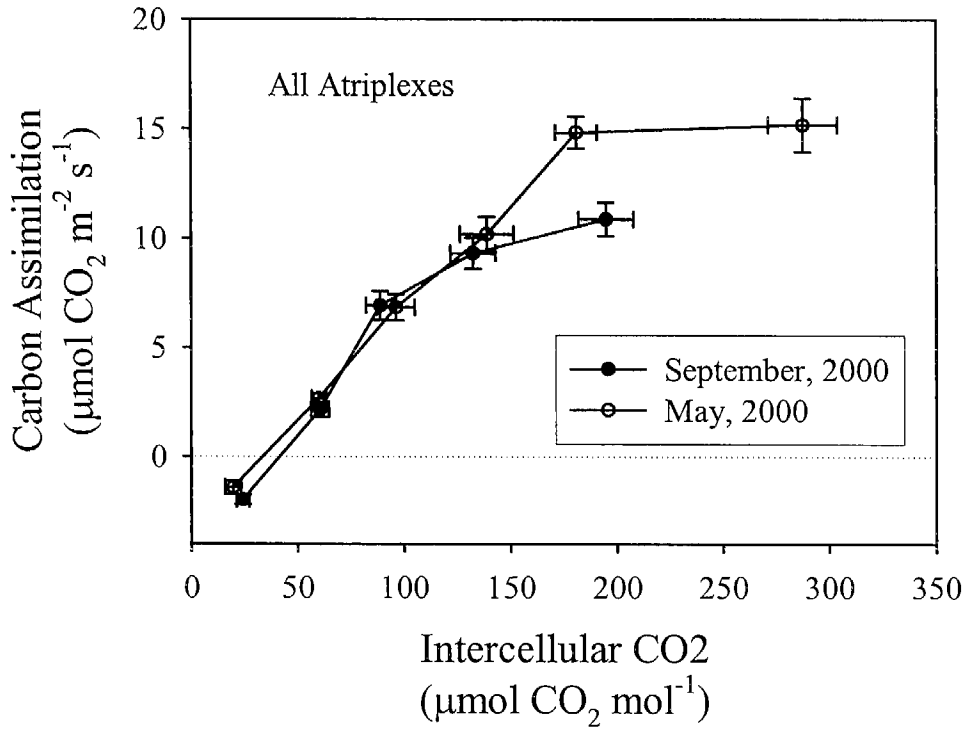

Figure 13. Carbon assimilation response curves for *Atriplex* species in Spring and Fall of 2000 at the 50th St. East site.

Deep Pipe versus Surface Irrigation

Maximum photosynthetic rate was significantly different between deep pipe and surface irrigation treatments at the 50th St. East site in September of 2000 (Fig. 14). This reflects a

greater availability of water in the vicinity of the roots in the surface irrigated plots. However, this is likely a short term response to recent precipitation, and the greater root density in the upper levels of the soil profile in surface irrigated plants. However, in this case, the carboxylation efficiency was also higher in the surface irrigated plants. This may indicate the general state of water stress in the Fall, since similar measurements following only brief water deprivation should reflect the greater overall efficiency of irrigation through the deep pipe system.

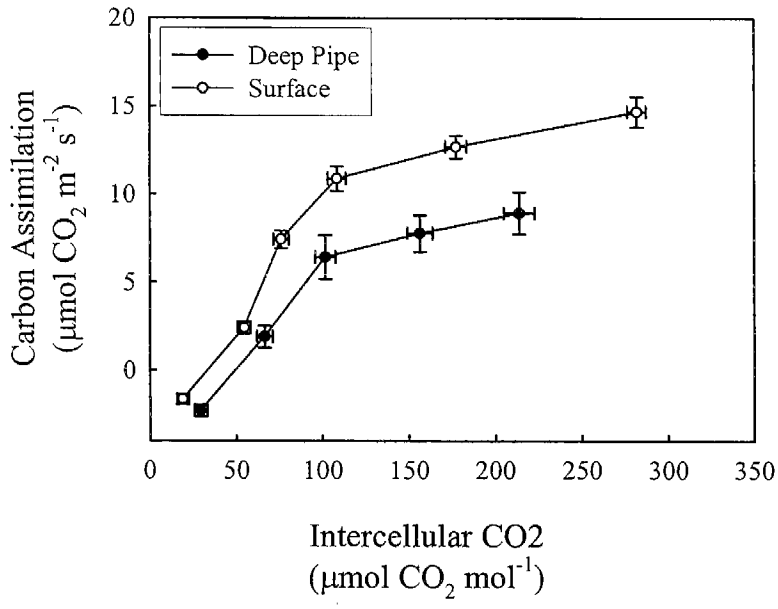

Figure 14. Carbon assimilation response curves for *Atriplex* species in the deep pipe and surface irrigation treatments in Fall of 2000 at the 50th St. East site.

Berm versus No Berm

Maximum photosynthetic rate was significantly greater for plants grown on plots without berms (shrub plots) than those grown with berms (windbreak plots; Fig. 15). This observation may also reflect the recent precipitation at the time of these measurements. In general the berm should reduce evaporation to some extent, and concentrate the irrigation and occasional precipitation in the vicinity of the plant root system.

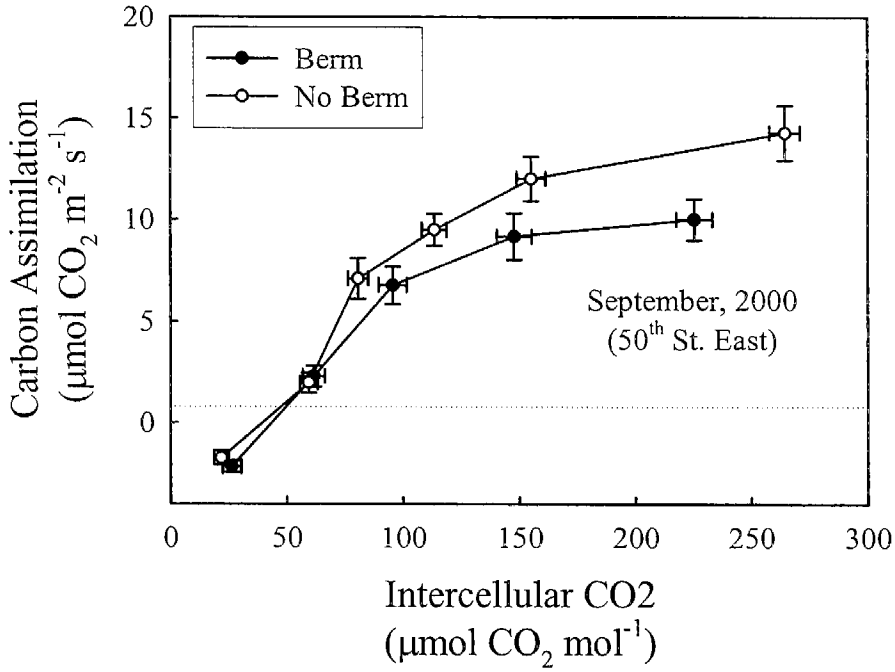

Figure 15. Comparison of photosynthetic rates between Atriplex species grown in windbreak (Berm) plots and non-windbreak (No Berm) plots.

EWP versus 50th St. East

Atriplex species grown at 50th St. West were higher in maximum photosynthetic rate than plants grown from seed in the EWP (Fig. 16). Plants in the EWP had been established from seed in 1992, and were under rainfed conditions which led to greater water stress and limitation of photosynthetic activity compared to the transplants receiving supplemental irrigation at 50th St, East.

Additionally, the site at 50th Street East has been found to contain a rather large residual content of nitrogen. This may derive from previous land use as agricultural cropland, or may reflect some land application of biosolids. Many of the photosynthetic parameters that can be determined using the gas exchange techniques described here, depend on photosynthetic enzymes whose synthesis and content are highly dependent on nitrogen nutrition. Therefore, while the 50th Street East site was extremely useful for comparisons of species and irrigation techniques, it may not fully reflect responses to be expected in less nitrogen rich areas of the Mojave Desert.

The EWP plants have previously been found to behave similarly to adjacent areas of naturally established native vegetation. Therefore, in these comparisons, the EWP plants may better reflect the performance of long term, well established Atriplex spp. shrubs in this environment.

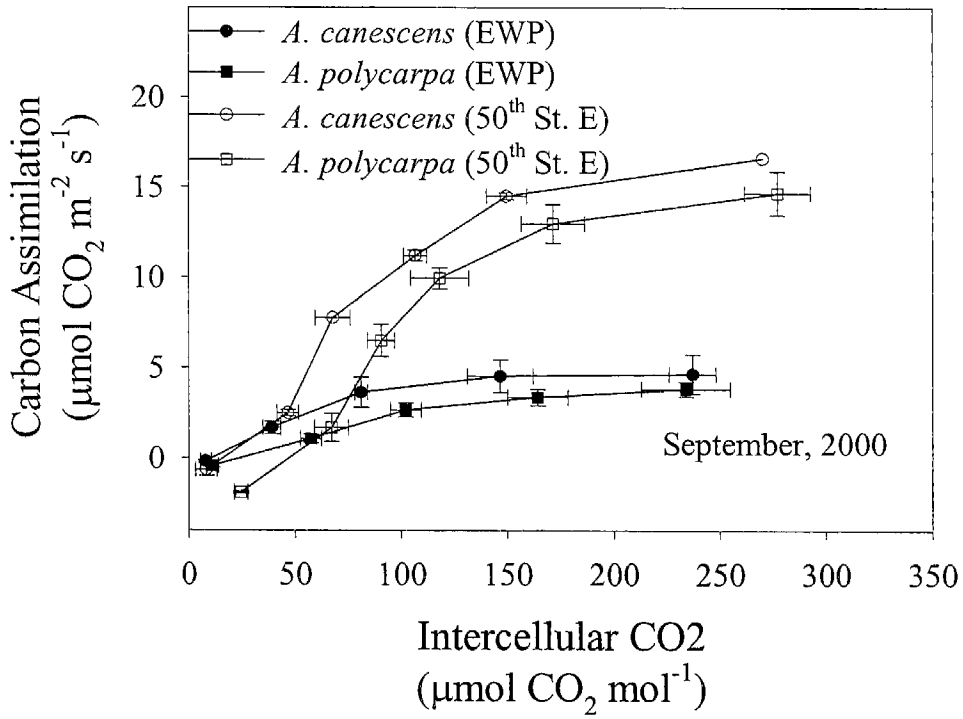

Figure 16. Comparison of photosynthetic response to varying CO_2 levels for two *Atriplex* species grown from transplants at the 50th St. East site and plants from direct seeding in the EWP area.

Water potential

When considered over all species and treatments, midday water potential was not different between the 50th St. East site and the EWP site, but it was significantly higher (less negative) for the surface irrigated plants at the 50th St. East site (-10.8 ± 2.3 bars) than for plants under deep pipe irrigation at the same site (-27.2 ± 3.0 bars) or for the direct seeded species growing in the rainfed EWP site (-27.4 ± 2.0 bars). Among *Atriplex* species, *A. lentiformis* (-11.0 ± 4.0 bars) had higher midday water potential than did either *A. canescens* (-27.1 ± 2.4 bars) or *A. polycarpa* (-29.9 ± 2.1 bars).

Within the deep pipe irrigation treatment during the September evaluation period, *A. polycarpa* had more negative potentials (-37.1 ± 1.2 bars) than did *A. canescens* (-31.8 ± 1.7 bars), suggesting a difference in rooting patterns may affect plant water during this time period. Additionally, these two species grown on the shrub (non-windbreak) plots had more negative potentials (-36.7 ± 1.3 bars) than those grown on windbreak plots (-32.2 ± 1.8 bars).

Conclusions

Revegetation with native species offers the most enduring means of stabilizing disturbed arid lands, but has historically proven difficult to achieve in these harsh environments. Site modifications, including herbivory protection with plastic shelters, deep pipe and surface irrigation, addition of recalcitrant mulches, and the construction of earthen berms as windbreaks, were evaluated for microenvironmental effects and plant physiological response of transplanted native shrubs. Within-canopy microenvironmental effects, including air and soil temperature, relative humidity, and dew persistence were evaluated continuously and measurements of ambient temperature, humidity, photosynthetically active radiation, rainfall, and wind speed were made concurrently. Plant physiological measurements were made in the Spring and Fall seasons by evaluating response to varying levels of CO_2 while holding other environmental variables constant.

Ambient environmental conditions were typical for this environment over the course of the evaluation period, but several factors were modified substantially in and near the plant canopies by the imposed site modifications. Within-canopy air temperatures and beneath-canopy soil temperatures were generally higher inside the plastic herbivory shelters than outside, as were humidity and dew formation during active growth periods. Compost applied as a mulch increased soil temperatures in the non-summer months, but had little effect during summer.

Photosynthetic rates were greater in May than in September, and overall in Atriplex canescens than in A. polycarpa. Significant treatment differences in maximal photosynthetic rate were observed in the Fall. No differences were observed in carboxylation efficiencies, CO_2 compensation points, and stomatal limitations. Plants grown on open sites exhibited greater maximal photosynthesis than those grown with wind protecting soil berms. Similarly plants watered by surface irrigation surpassed those watered with deep pipe injection. The transplanted shrubs at this site exhibited much greater photosynthetic rates than those previously established by direct seeding in the Emergency Watershed Protection program. This probably reflects irrigation and younger plant age

Further evaluation of the transplanted shrubs at 50th Street East, and at the companion site at 90th Street East, will be required to fully characterize the success of establishment. Over the next three growing seasons, it will become possible to identify the successful site modifications, to further document the most successful species, and to identify any physiological screening parameters that may accelerate such identifications in the future.

Recommendations

Future research will enhance the reliability of current revegetation techniques, and continued evaluation of the microenvironmental and physiological impacts of site modification techniques is warranted.

Atriplex species were shown to be the most generally adapted plant species tested under the imposed site modifications, with Fourwing saltbush (*A. canescens*) exhibiting somewhat greater photosynthetic rates than other species. Further research should continue to focus on this genus of plants for revegetation of disturbed areas in the Antelope Valley, with *A. canescens* serving as a useful benchmark species against which others may be compared.

Microenvironmental conditions in the soil surface layers are poorly characterized, but appear to control biological responses such as germination and root growth. Soil physical and chemical characteristics should be further evaluated and correlated with biological responses.

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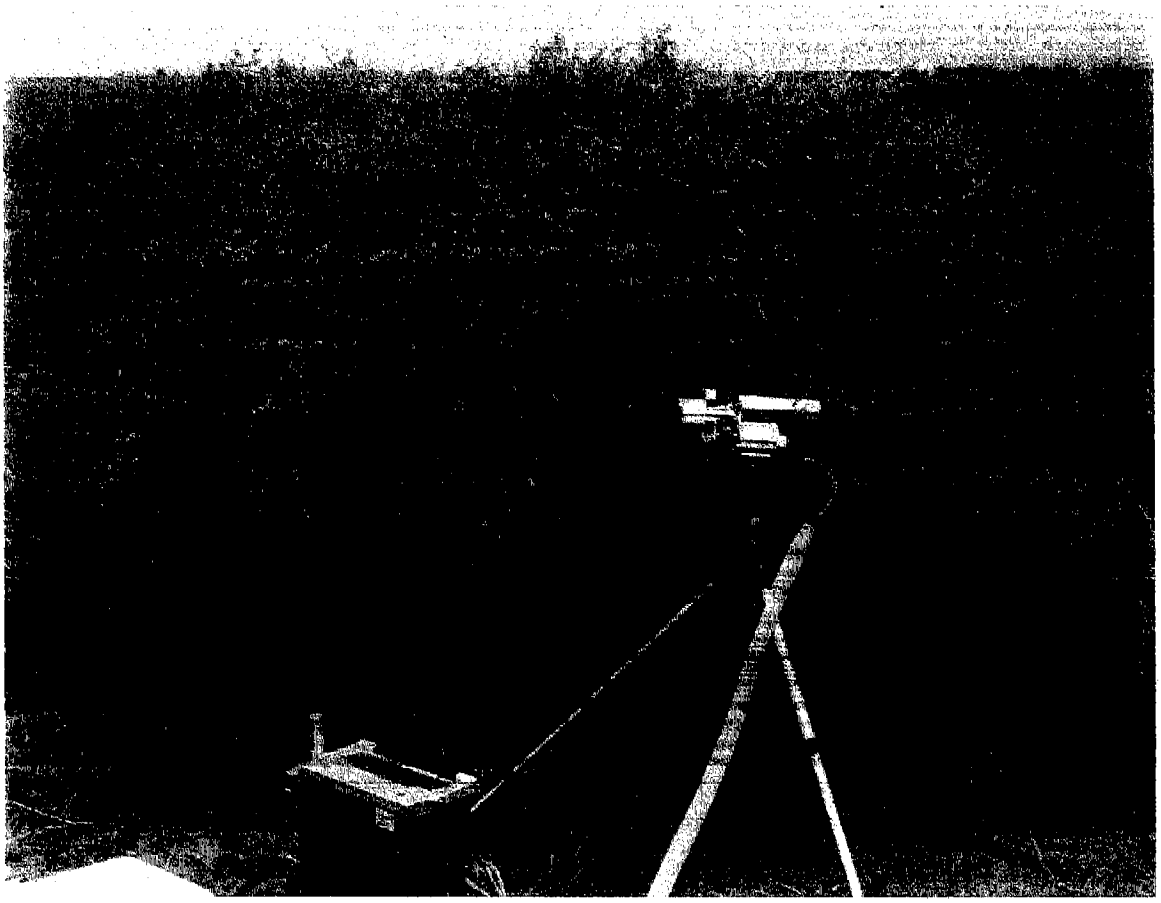
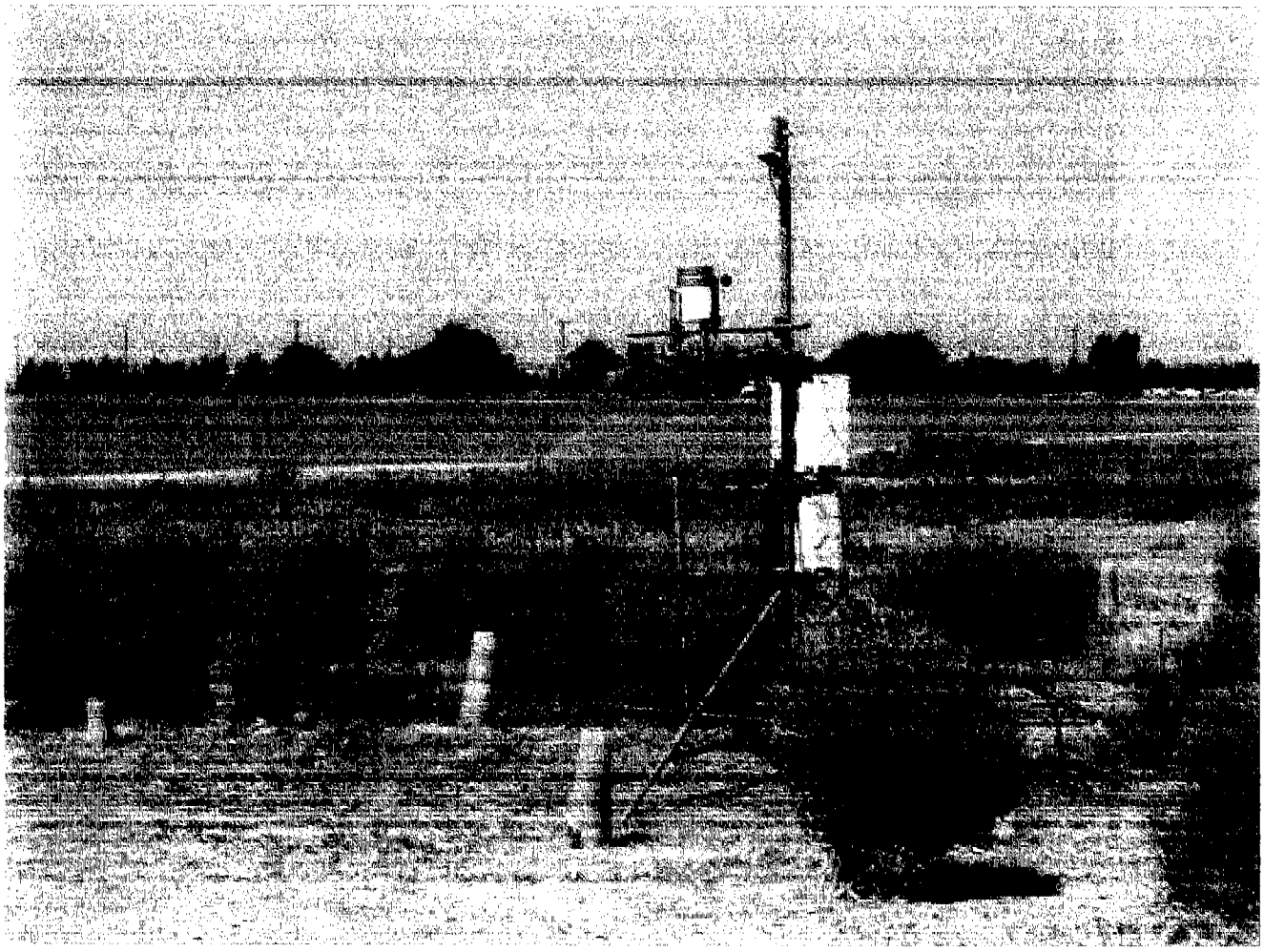
Appendix A



A dense and well established community of Atriplex Canescens in the area that was directly seeded in 1992 during the Emergency Watershed Protection Program (EWP).

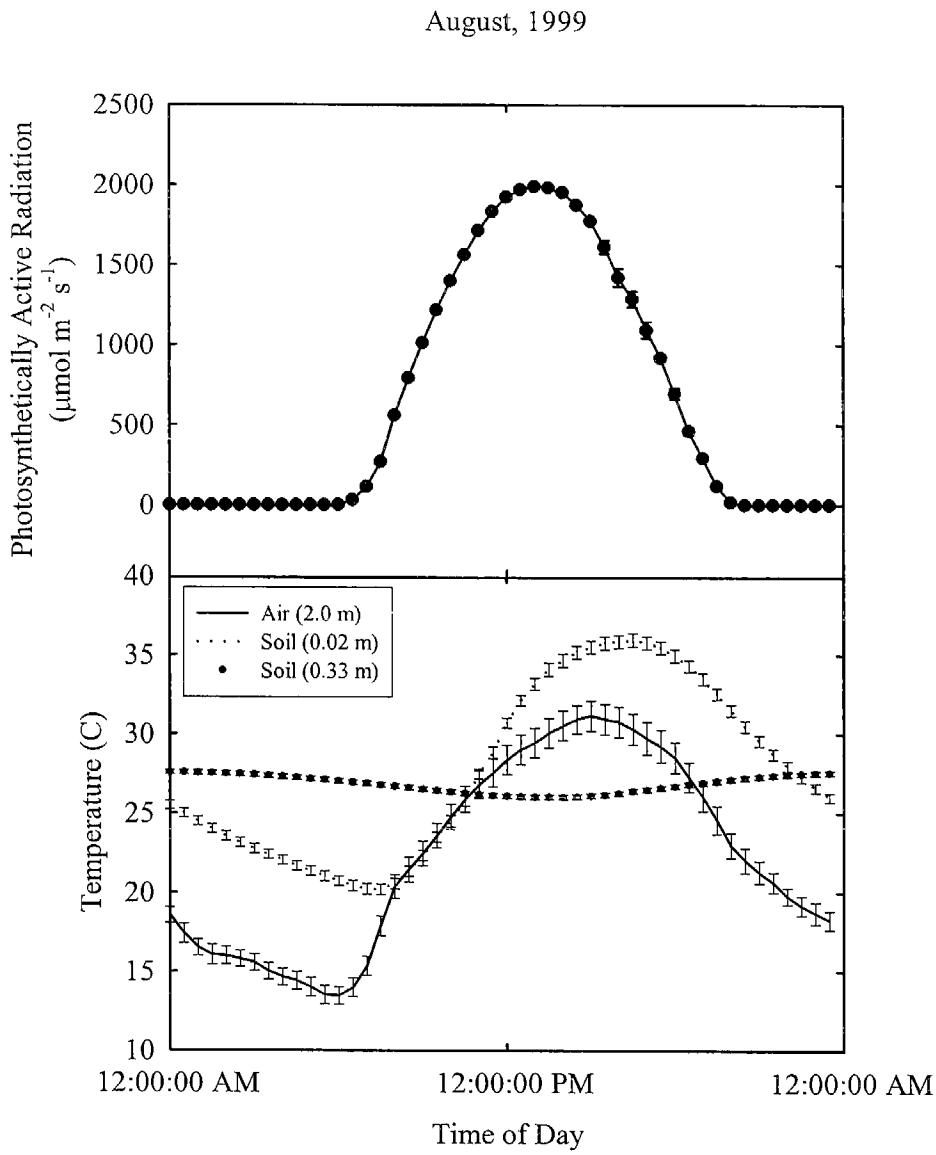
A typical community of Atriplex polycarpa in a naturally established area of vegetation. Ground cover is typically about 25%



Experimental site at 50th Street East, in the Mojave Desert, showing mixed species of transplanted saltbush (Atriplex spp.). Also shown are the micrometeorological monitoring station and the TreePee cones to provide herbivory protection.

Individual shrub of Atriplex polycarpa, transplanted at the 50th Street East experimental site in the Mojave Desert.

Appendix B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Photosynthetically Active Radiation
(μmol m-2 s-1)
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2000
1500
1000
500
0
40
35
30
25
20
15
10
Temperature (C)
Air (2.0 m)
Soil (0.02 m)
Soil (0.33 m)
12:00:00 AM
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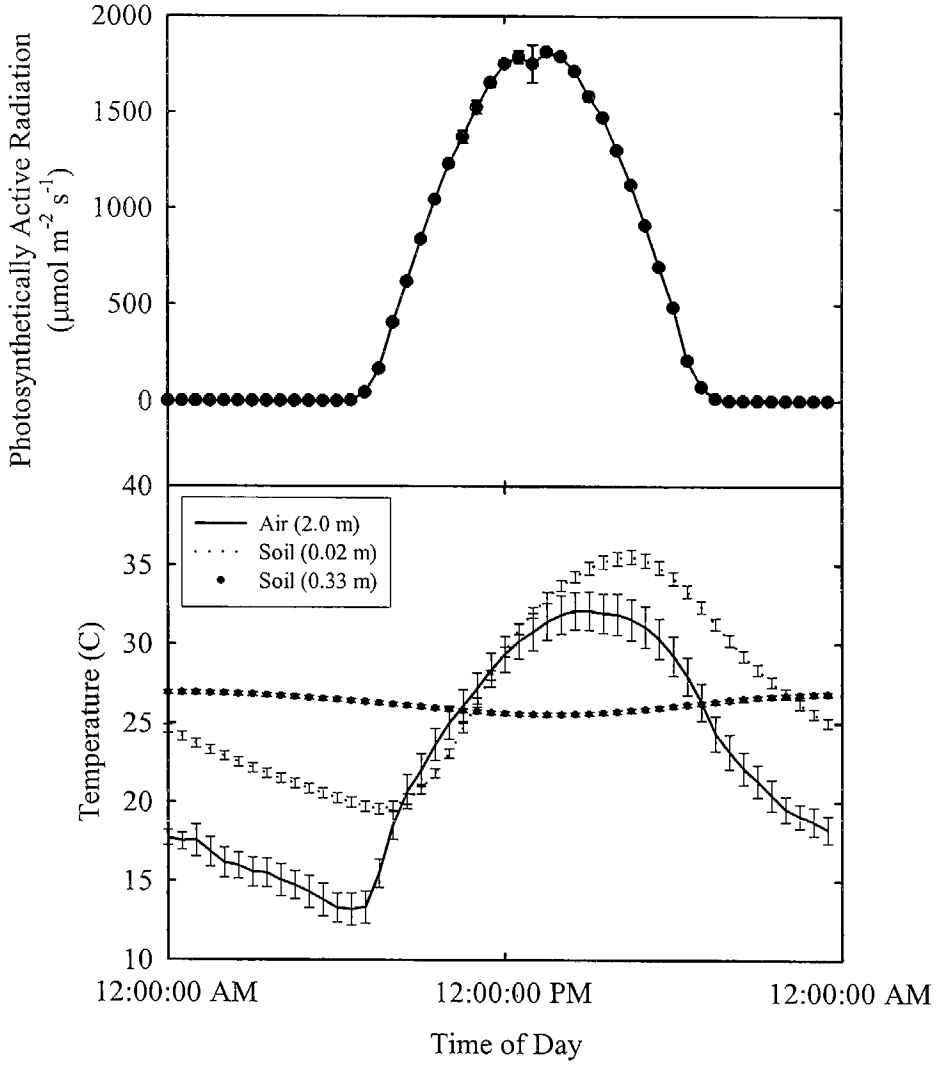
12:00:00 AM
Time of Day

September, 1999



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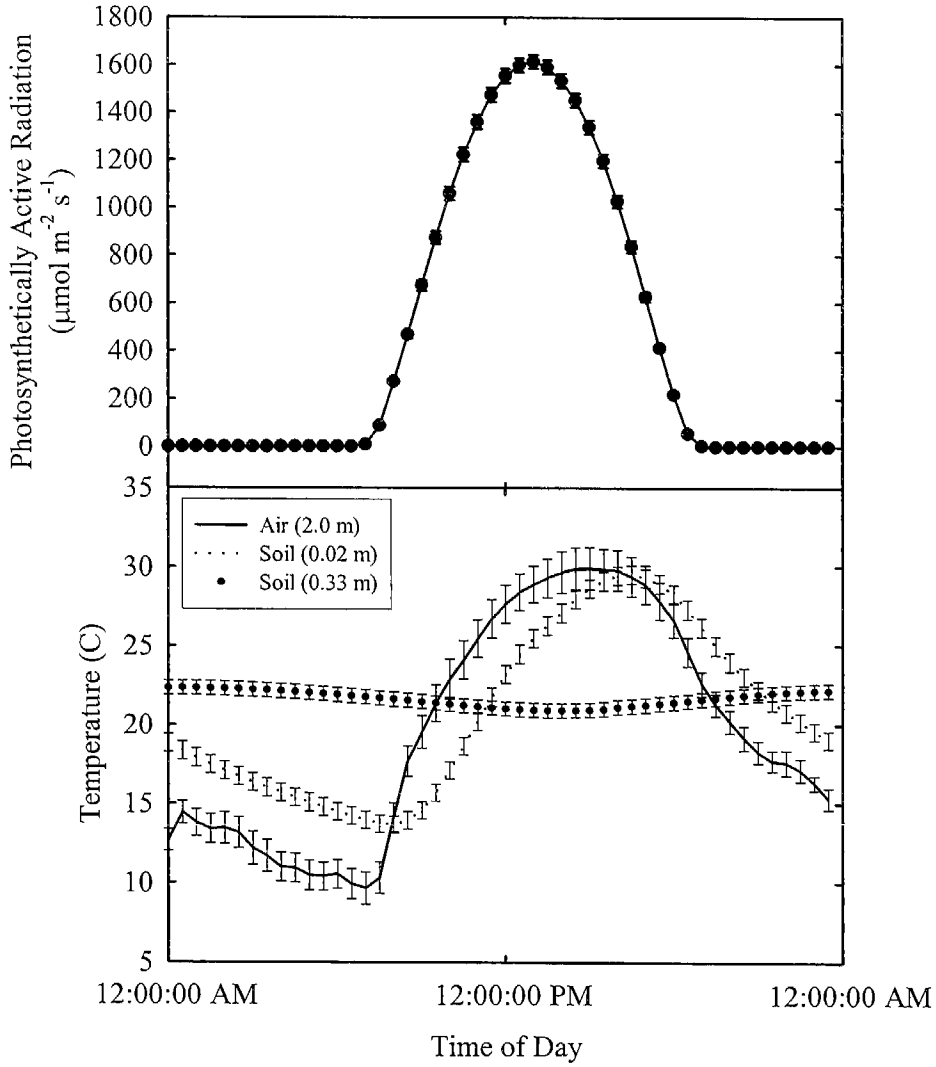

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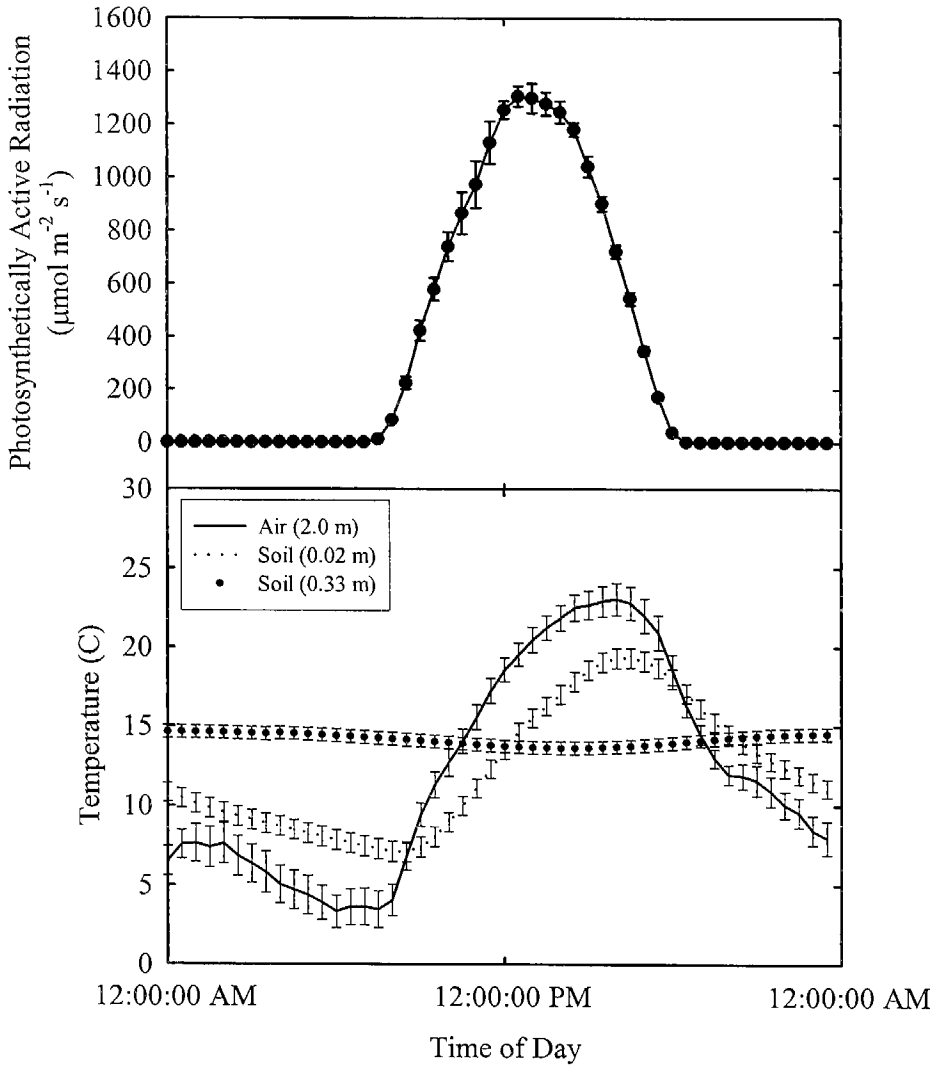
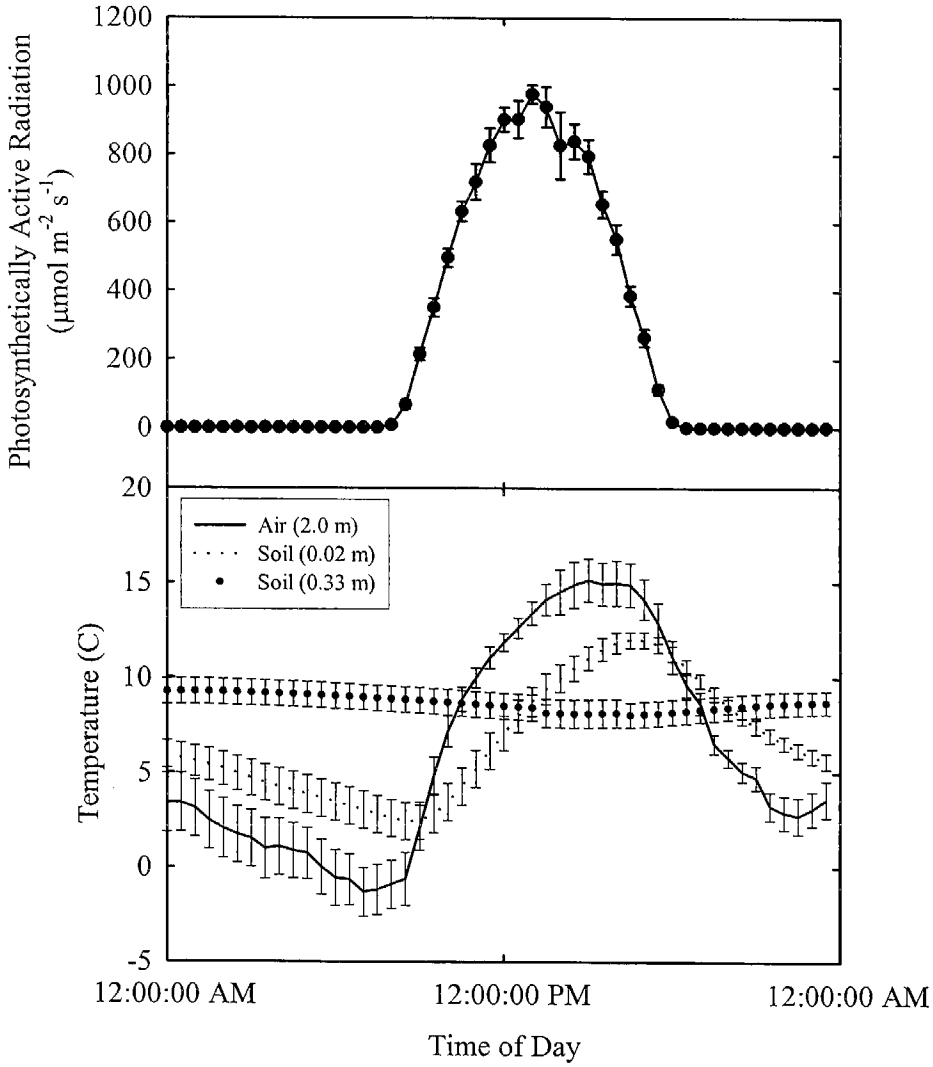
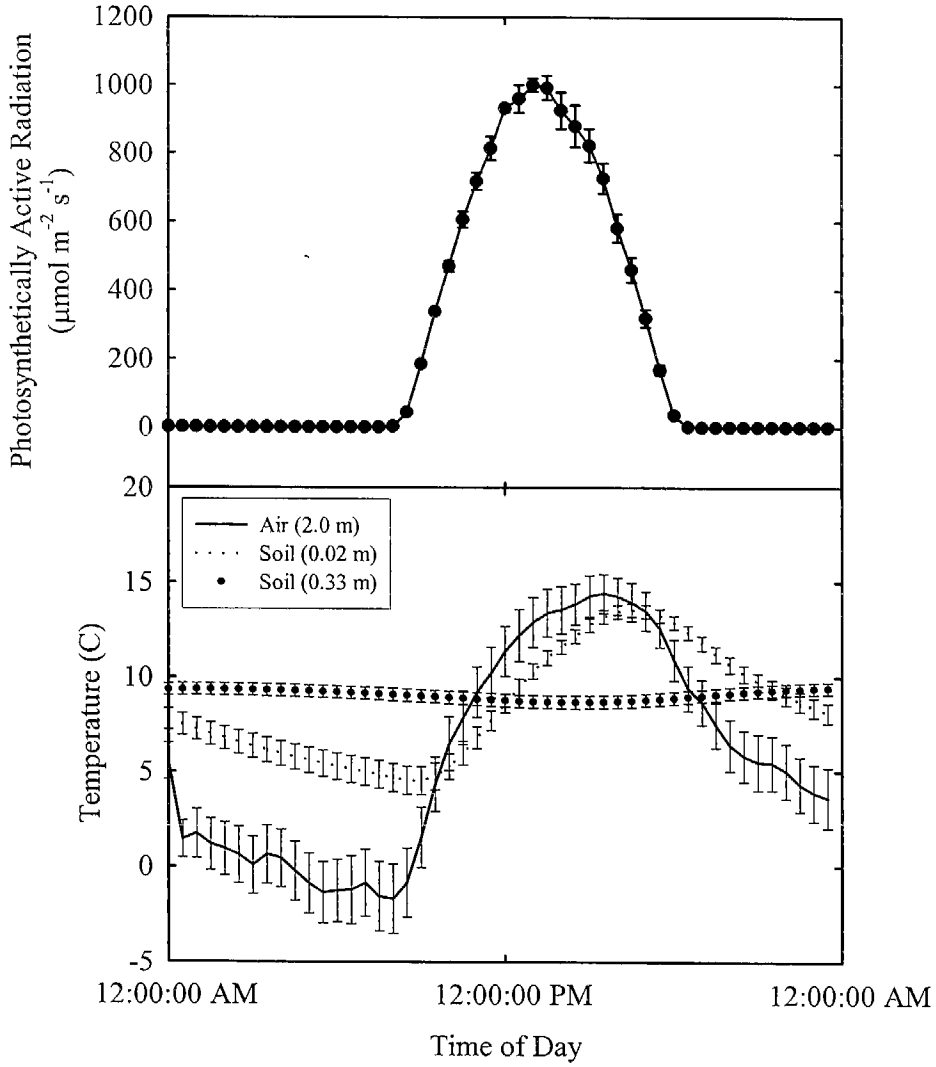


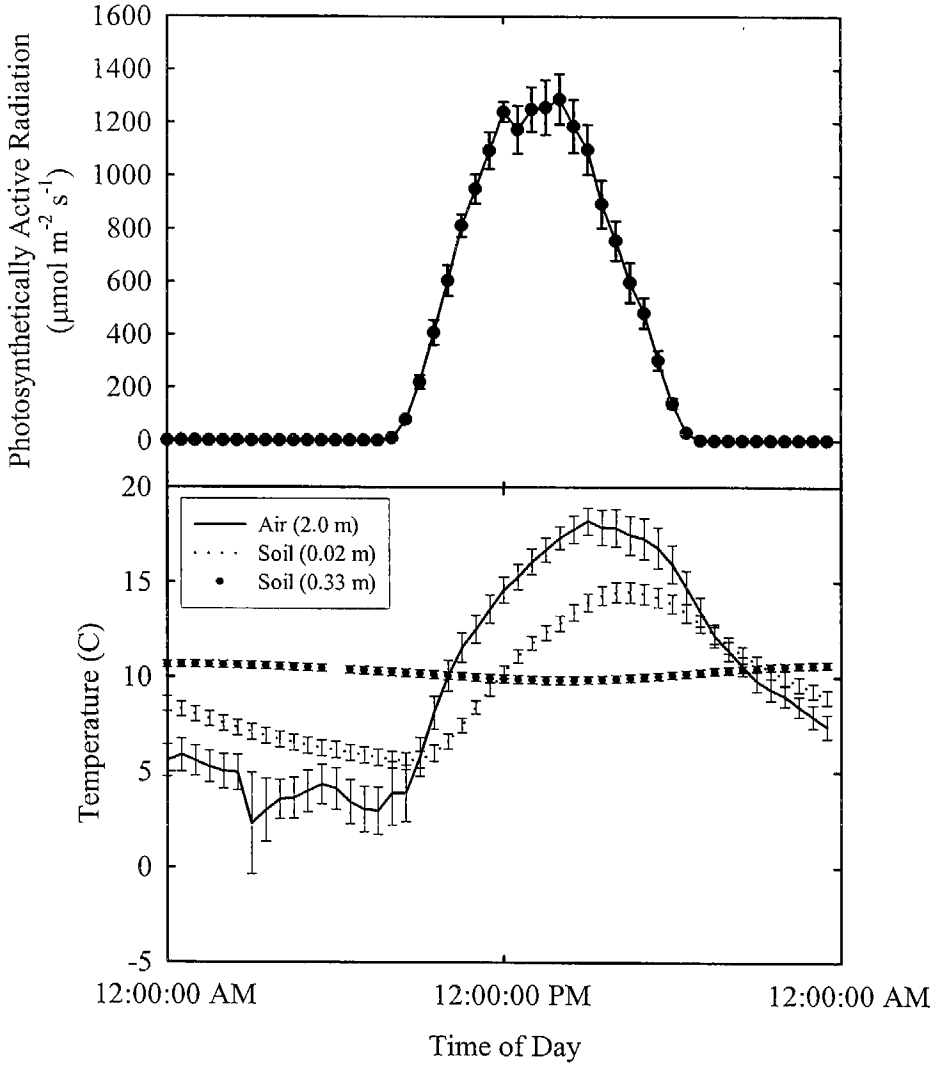
December, 1999



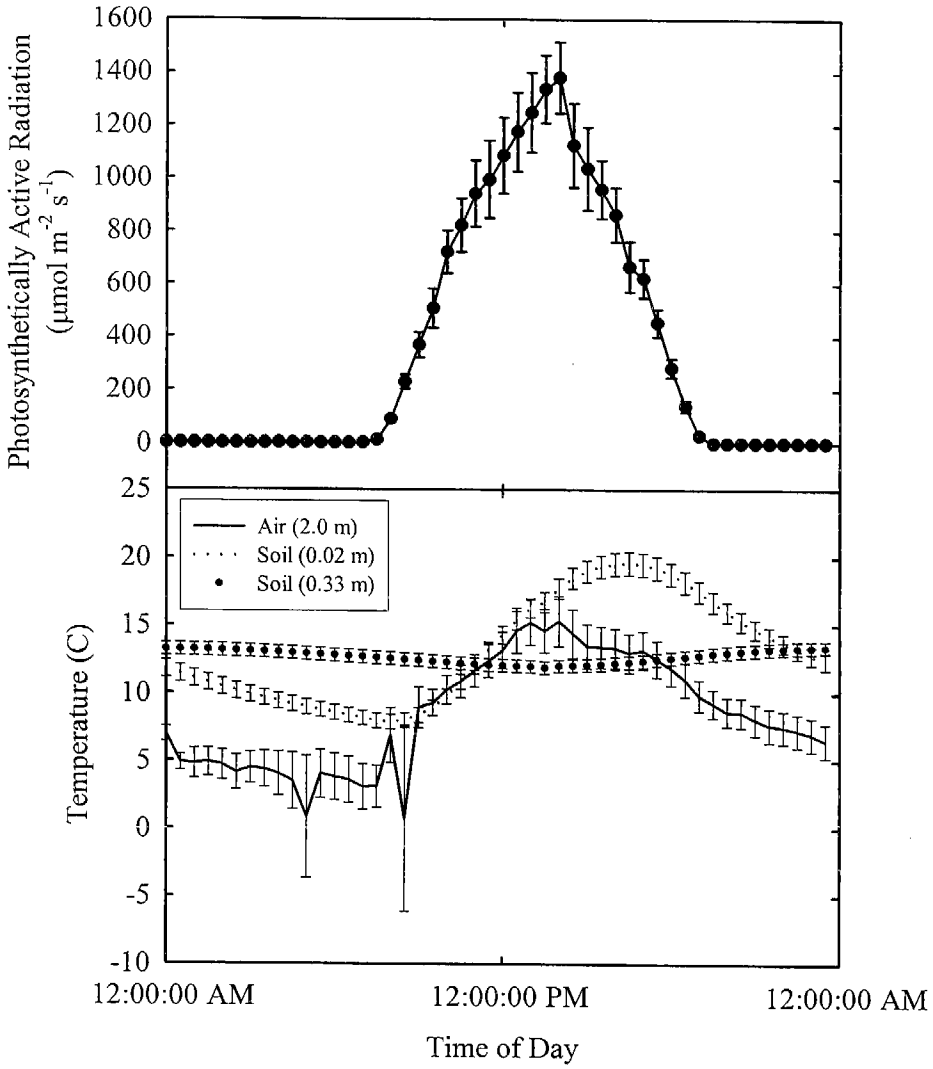
January, 2000



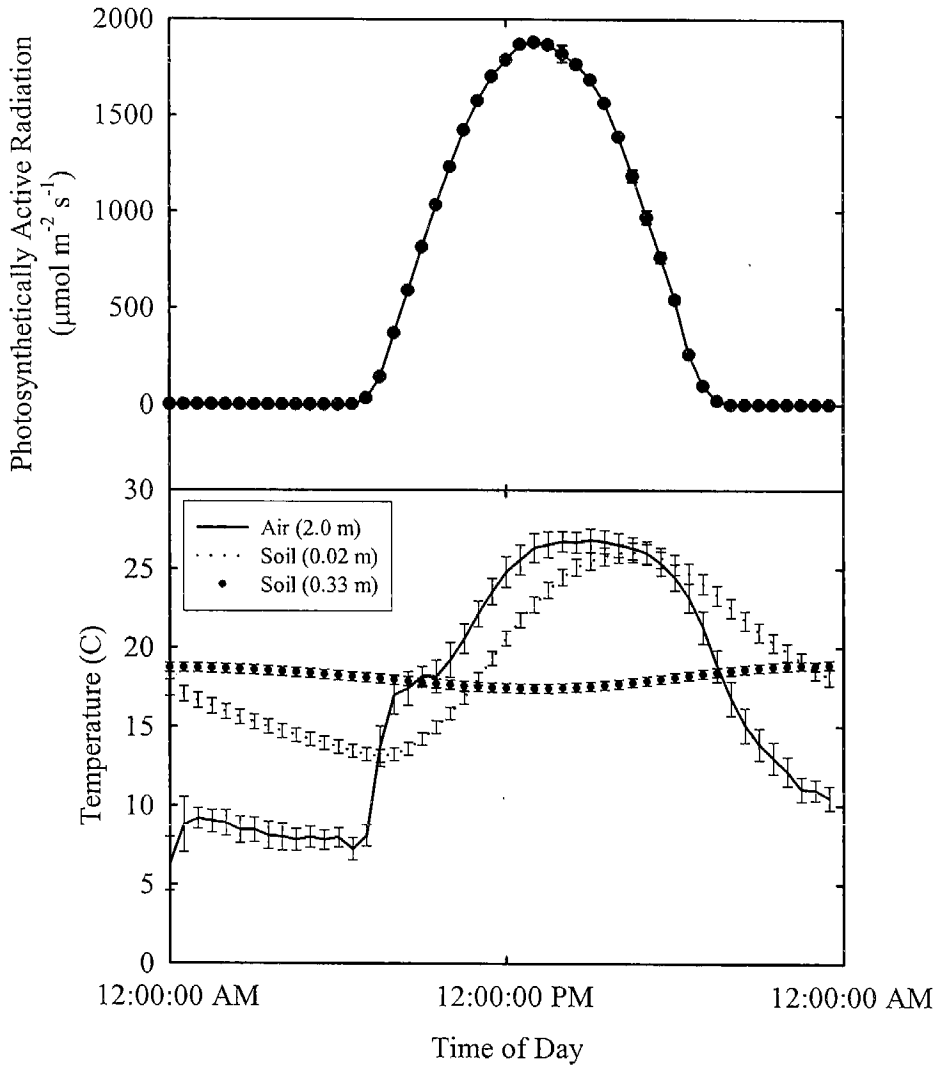
February, 2000



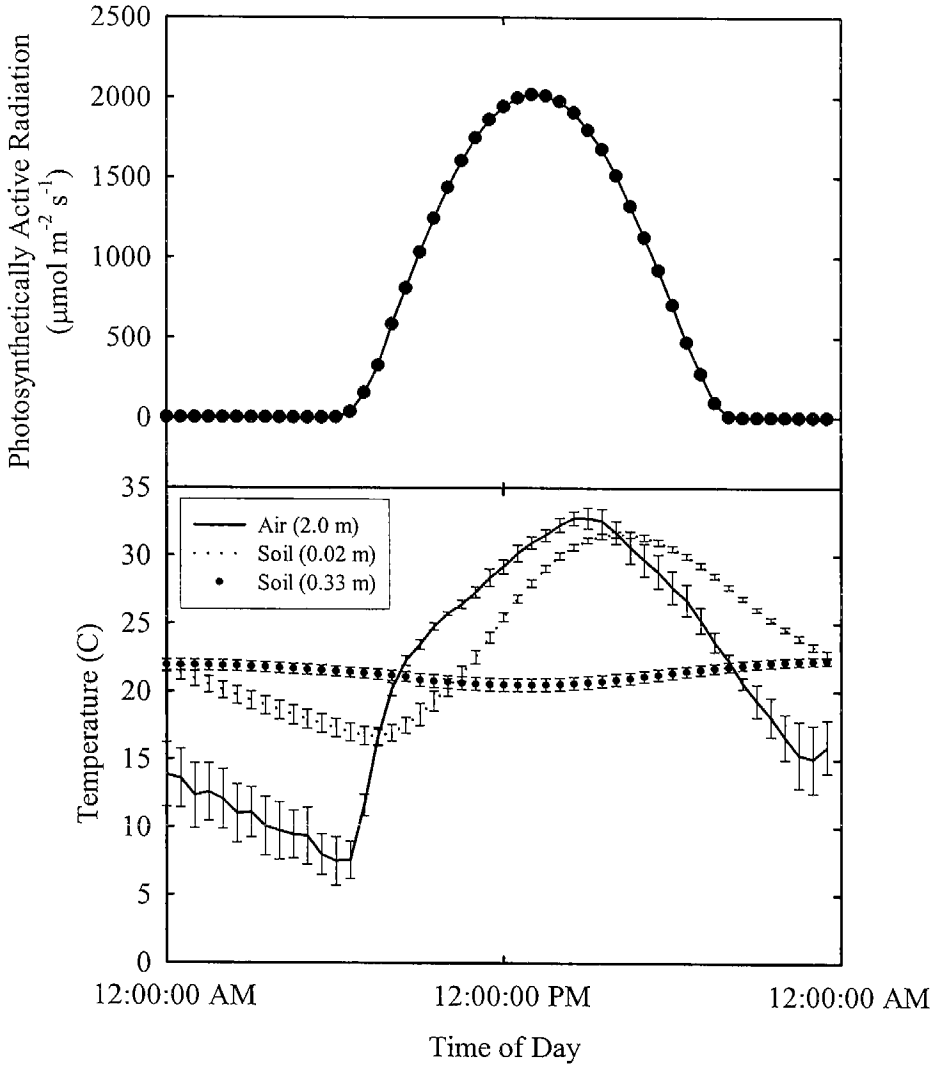
March, 2000


Photosynthetically Active Radiation
(μmol m-2 s-1)
1600
1400
1200
1000
800
600
400
200
0
25
20
15
10
5
0
-5
-10
Temperature (C)
Air (2.0 m)
Soil (0.02 m)
Soil (0.33 m)
12:00:00 AM
12:00:00 PM
12:00:00 AM
Time of Day

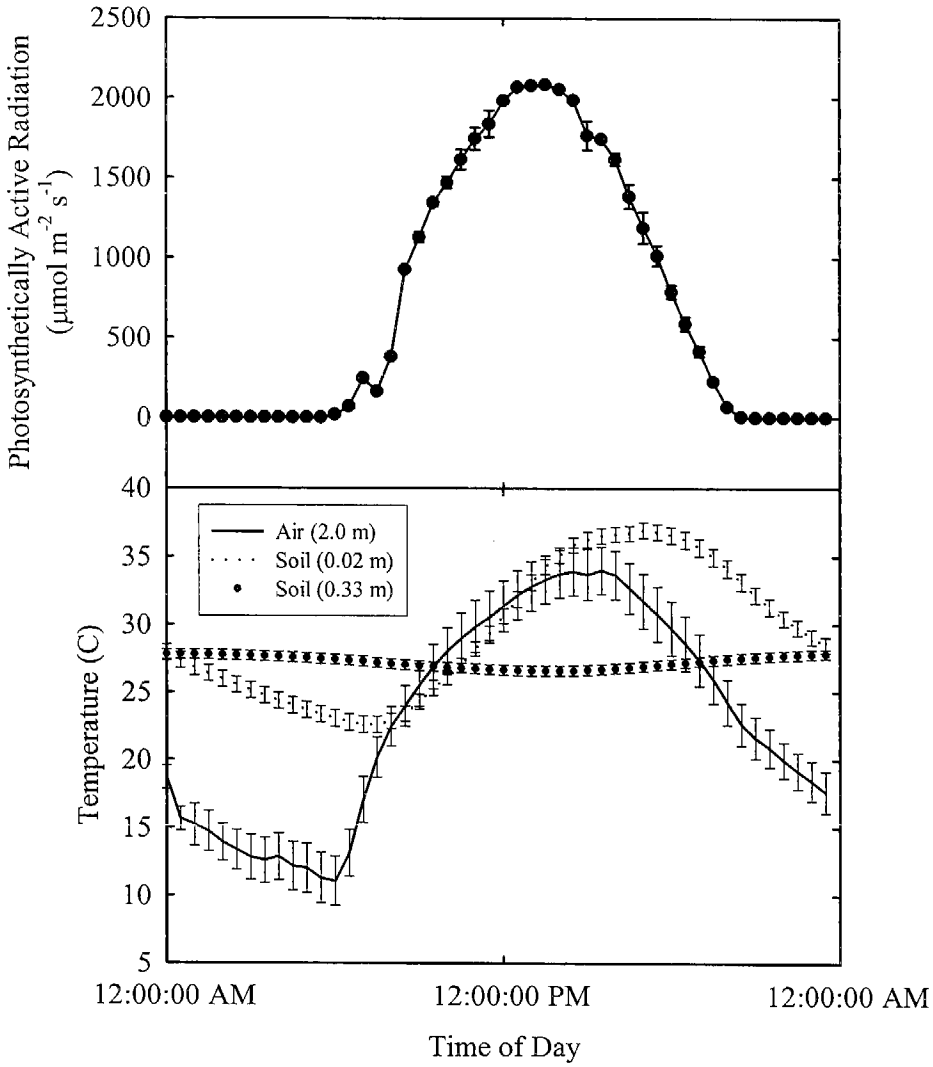
April, 2000


Photosynthetically Active Radiation
(μmol m-2 s-1)
2000
1500
1000
500
0
30
25
20
15
10
5
0
Temperature (C)
Air (2.0 m)
Soil (0.02 m)
Soil (0.33 m)
12:00:00 AM
12:00:00 PM
12:00:00 AM
Time of Day

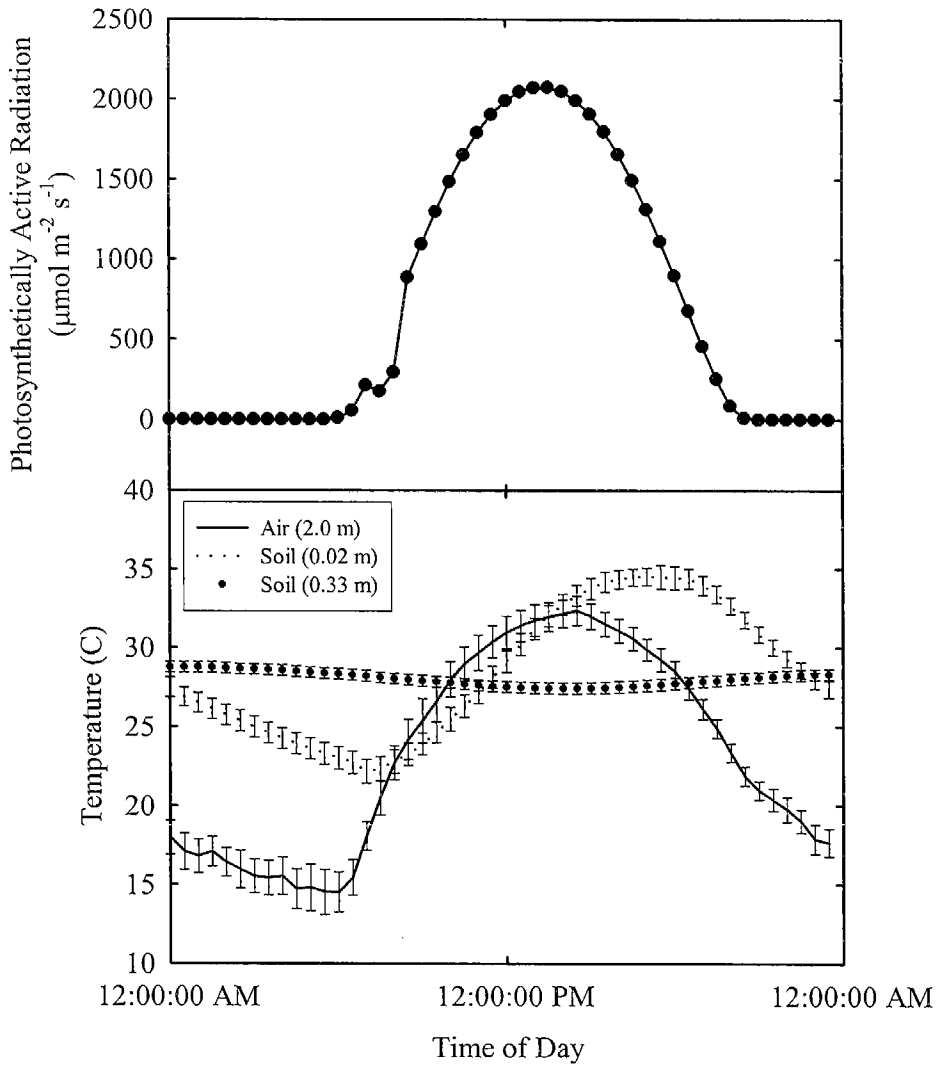
May, 2000


Photosynthetically Active Radiation
(μmol m-2 s-1)
2500
2000
1500
1000
500
0
35
30
25
20
15
10
5
0
Temperature (C)
Air (2.0 m)
Soil (0.02 m)
Soil (0.33 m)
12:00:00 AM
12:00:00 PM
12:00:00 AM
Time of Day

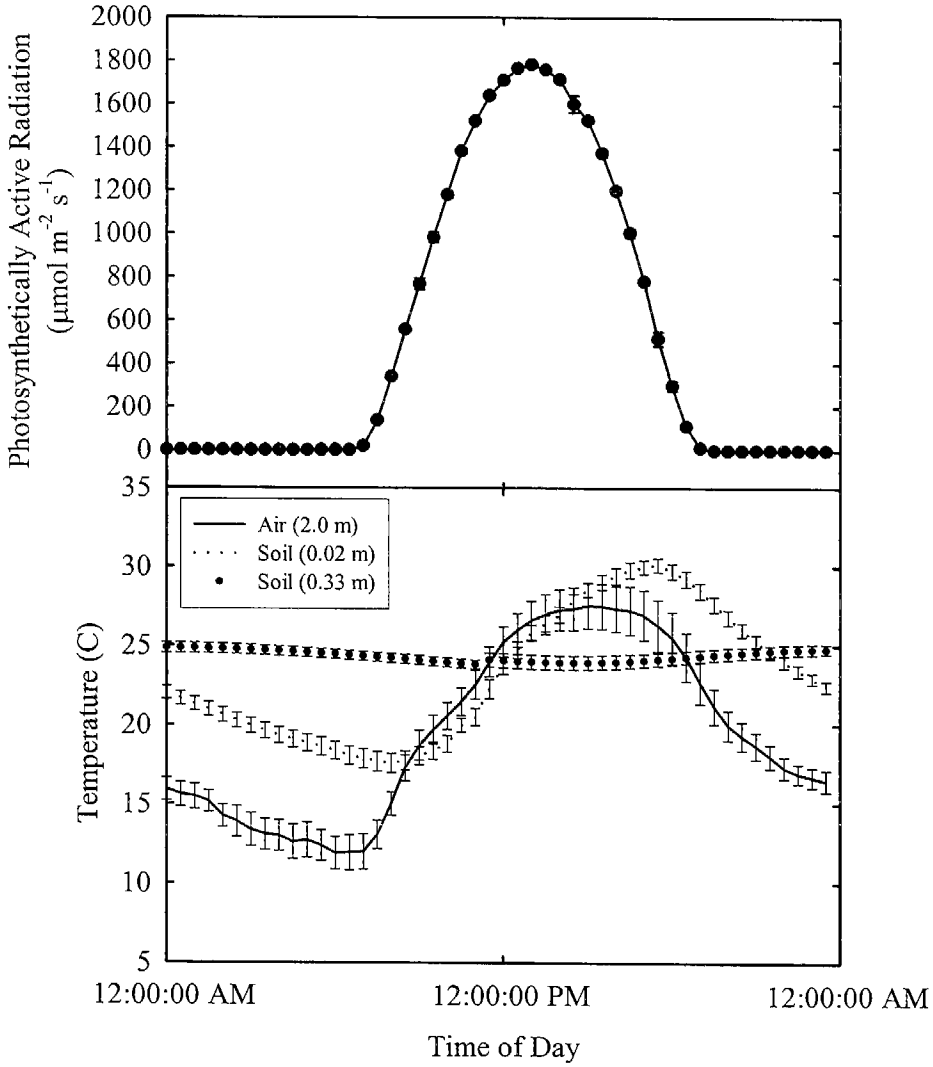
June, 2000


Photosynthetically Active Radiation
(μmol m-2 s-1)
2500
2000
1500
1000
500
0
40
35
30
25
20
15
10
5
Temperature (C)
Air (2.0 m)
Soil (0.02 m)
Soil (0.33 m)
12:00:00 AM
12:00:00 PM
12:00:00 AM
Time of Day

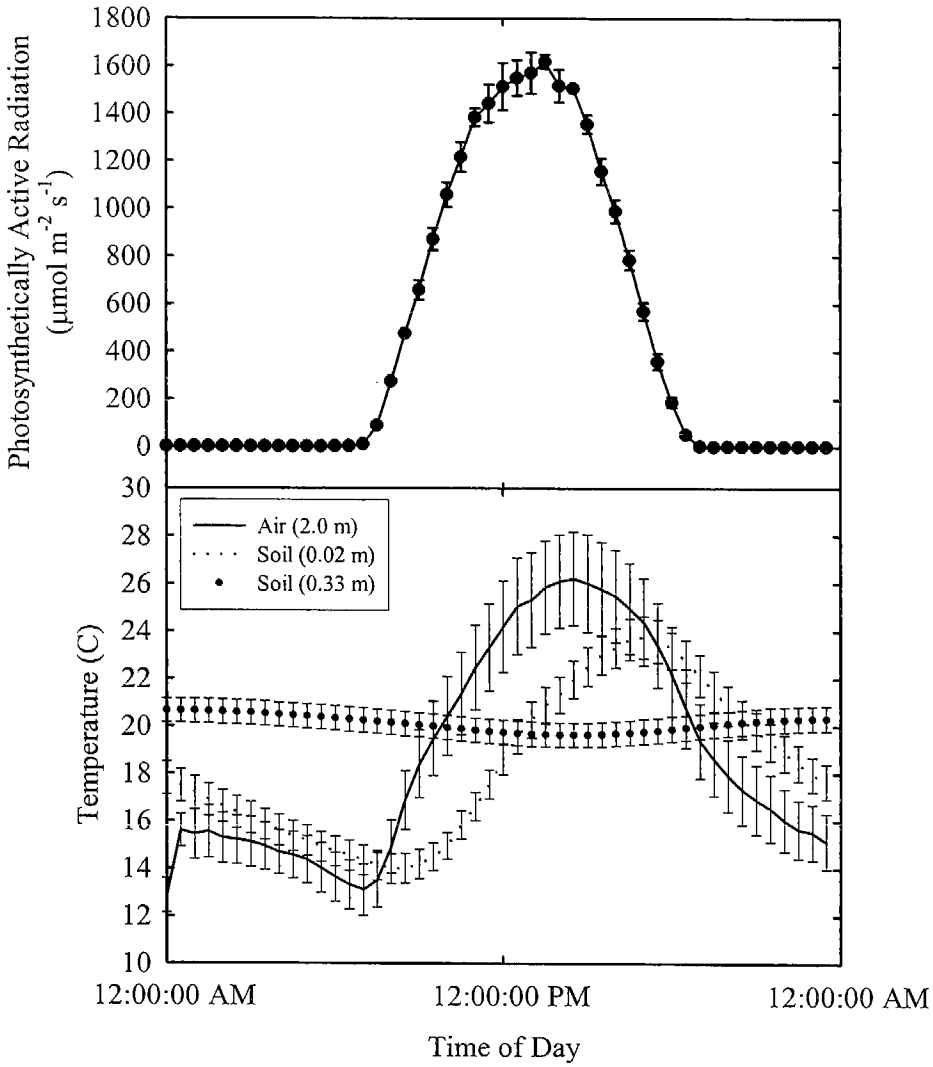
July, 2000


Photosynthetically Active Radiation
(μmol m-2 s-1)
2500
2000
1500
1000
500
0
40
35
30
25
20
15
10
Temperature (C)
Air (2.0 m)
Soil (0.02 m)
Soil (0.33 m)
12:00:00 AM
12:00:00 PM
12:00:00 AM
Time of Day

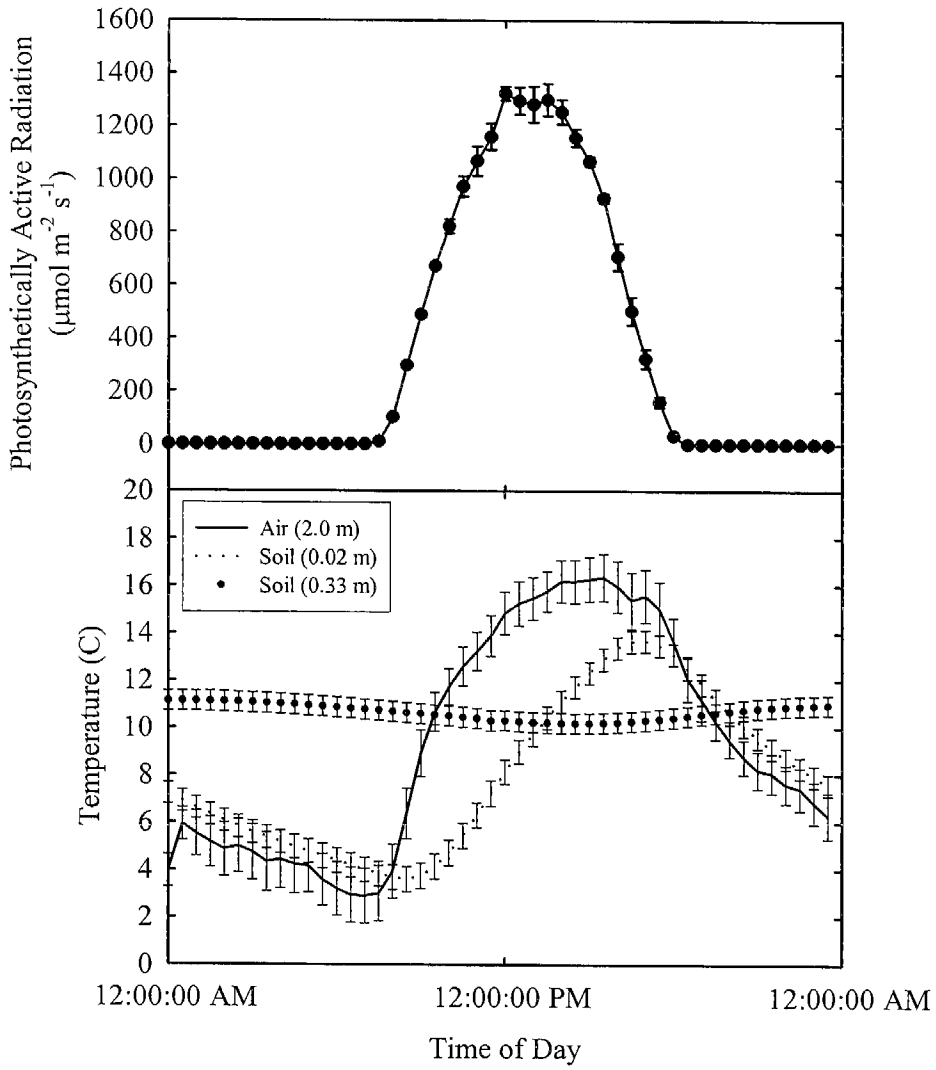
September, 2000



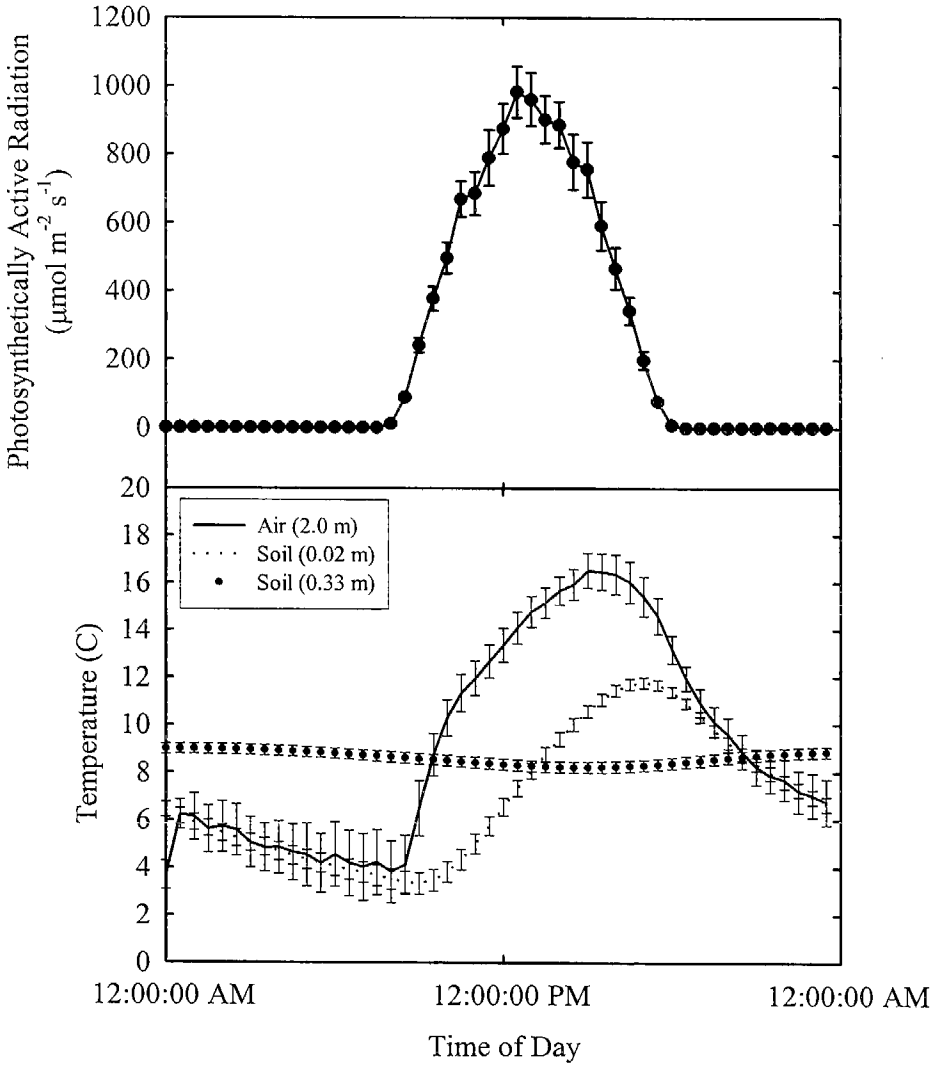
October, 2000



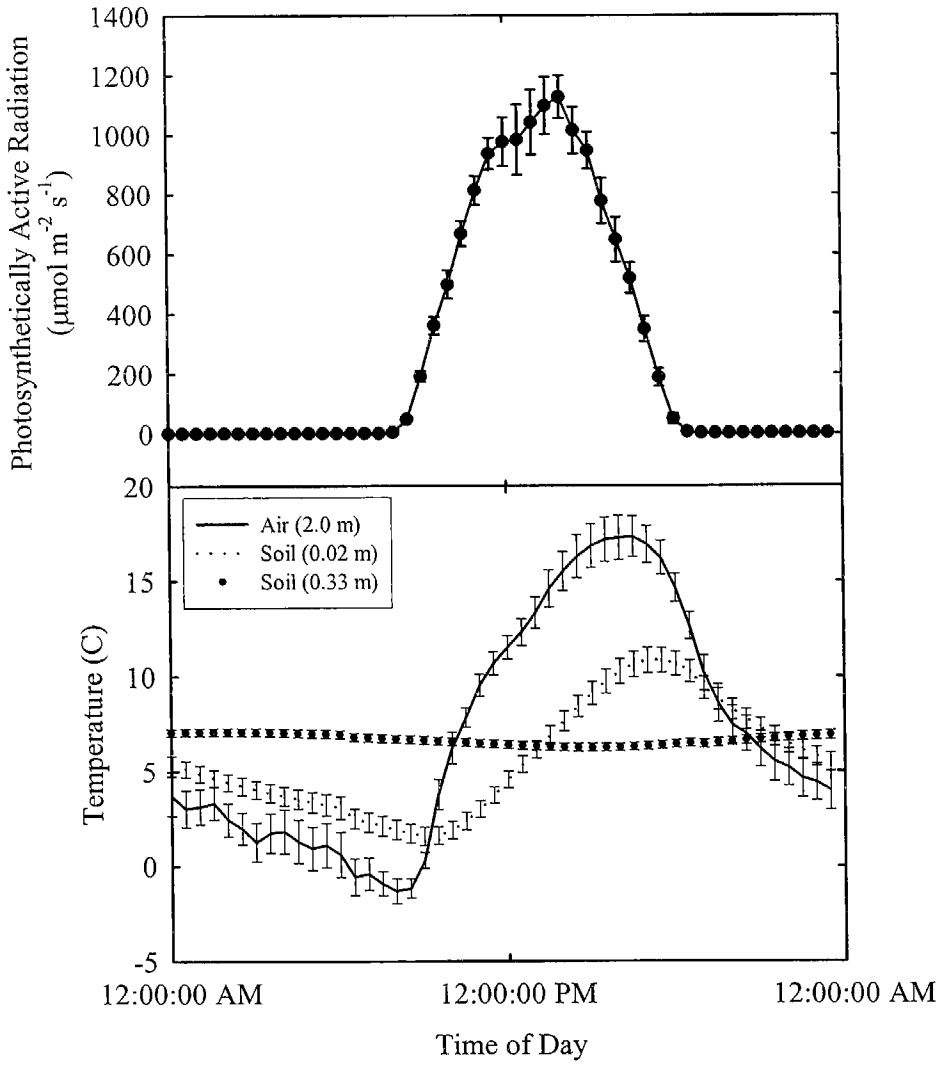
November, 2000



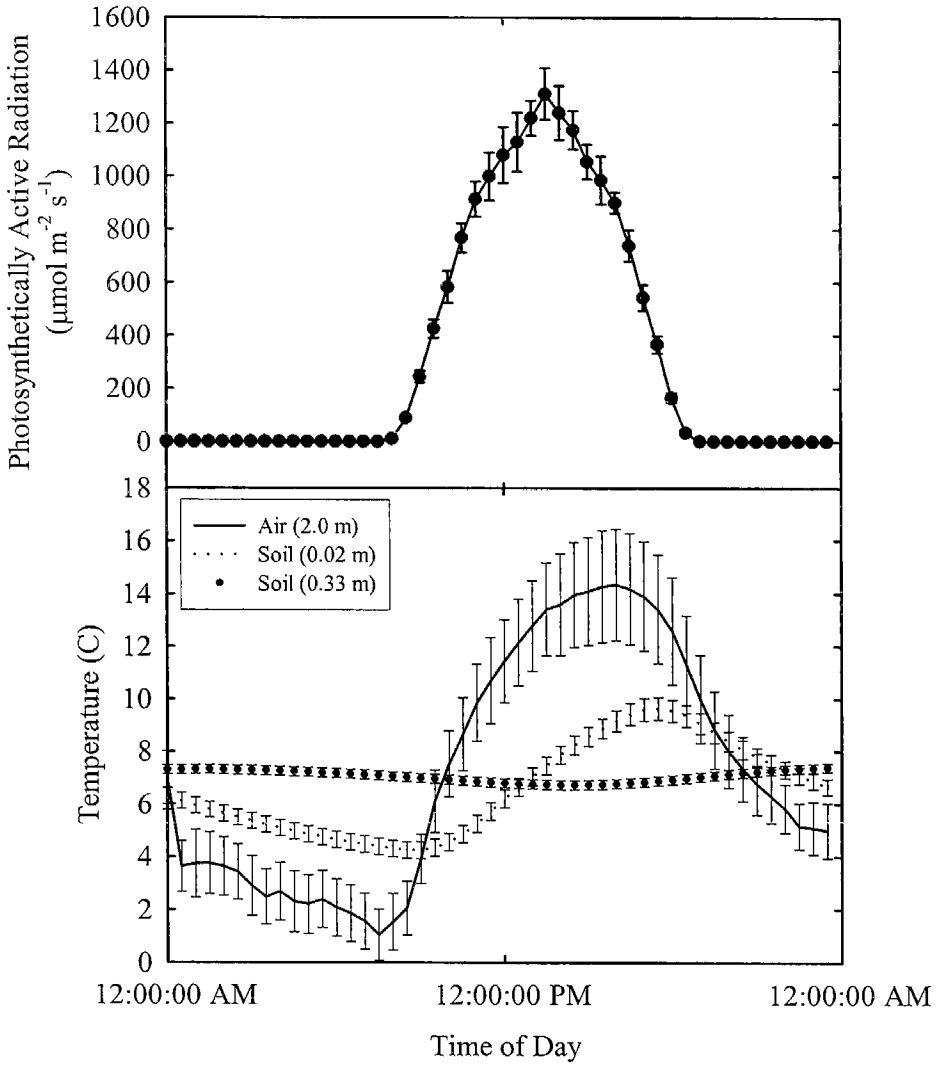
December, 2000



January, 2001

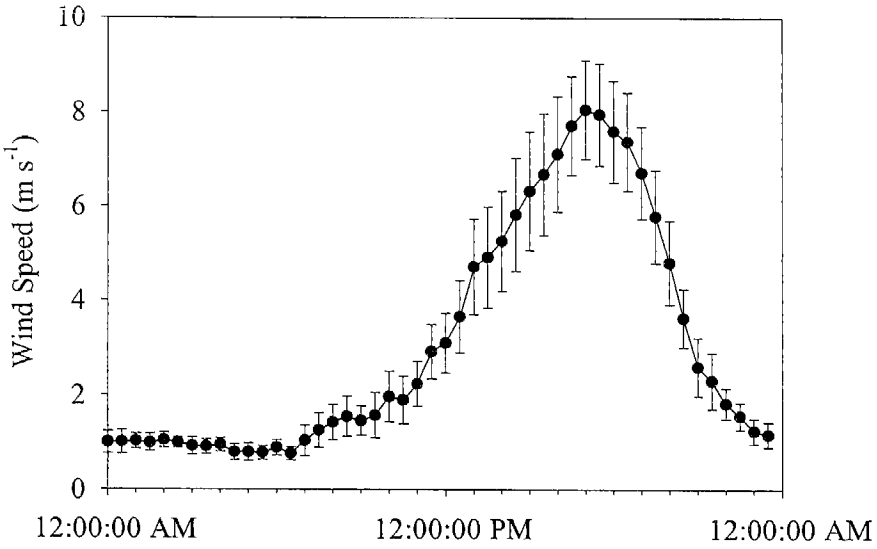


February, 2001

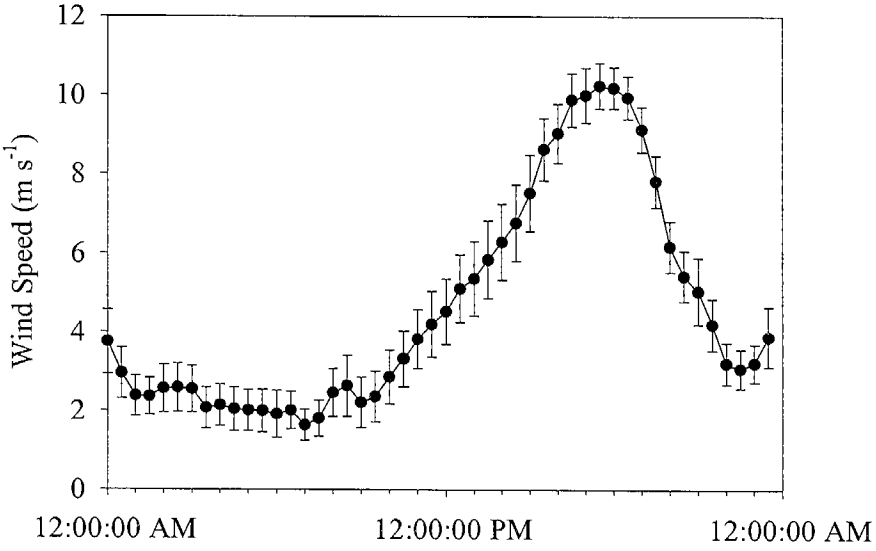


Appendix C

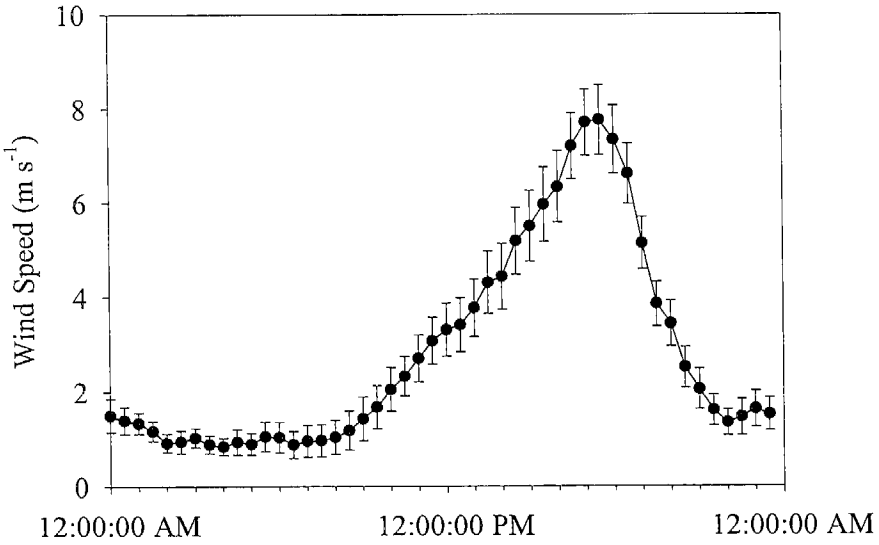
July, 1999



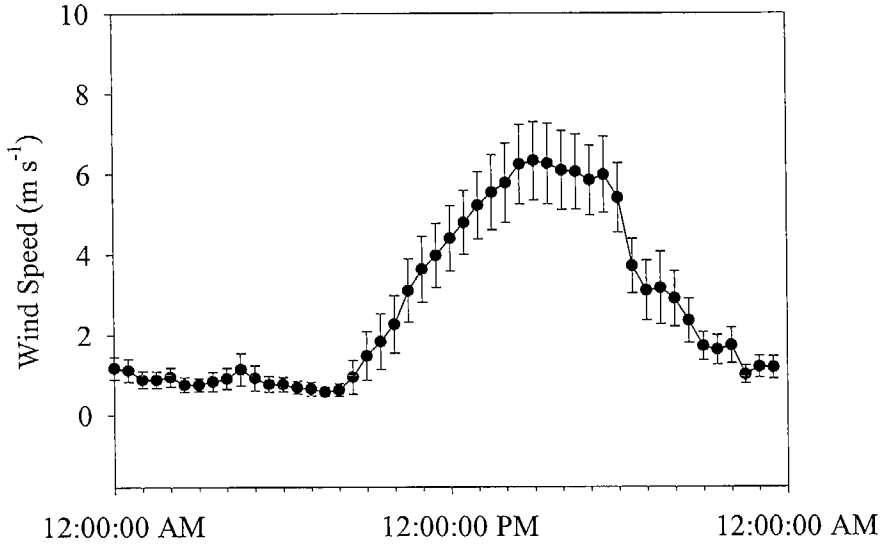
August, 1999



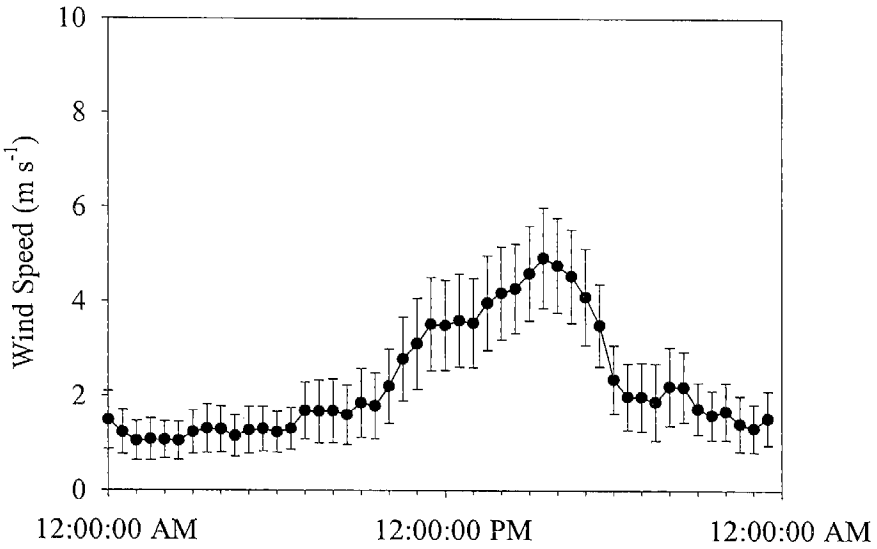
September, 1999



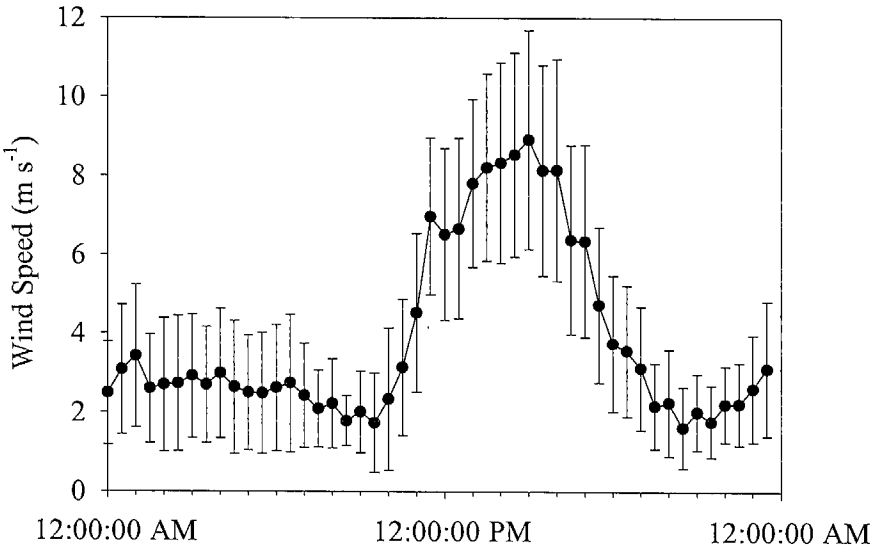
October, 1999



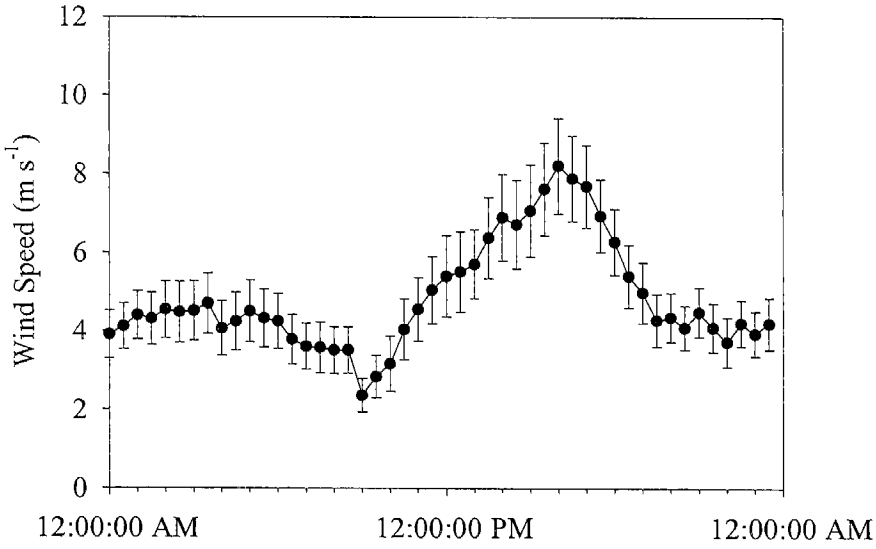
November, 1999



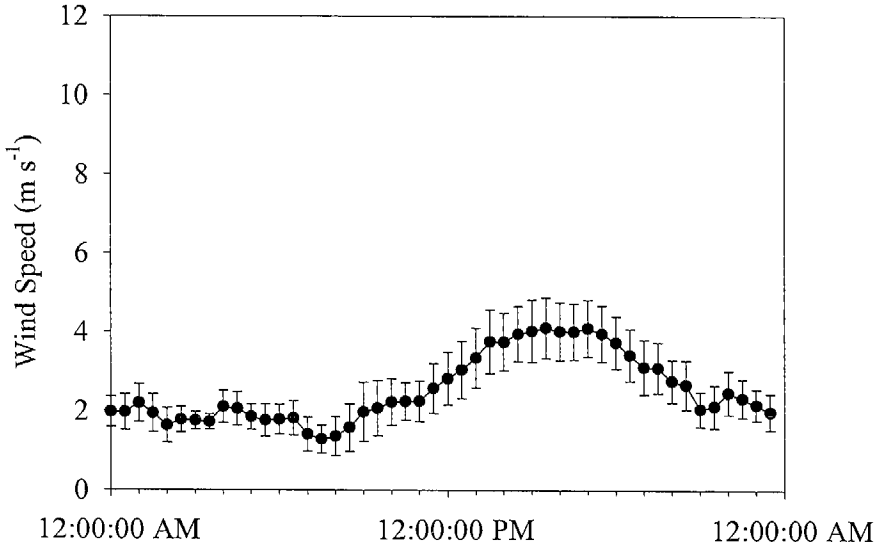
December, 1999



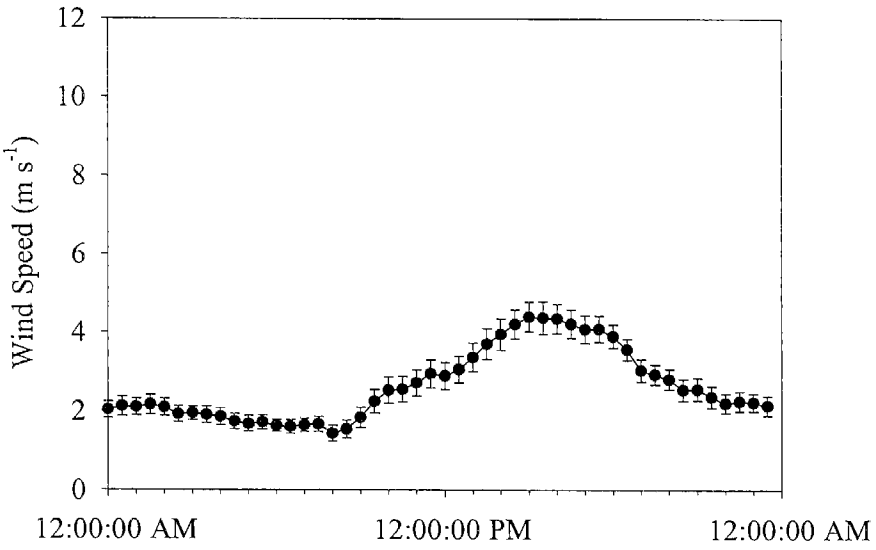
January, 2000



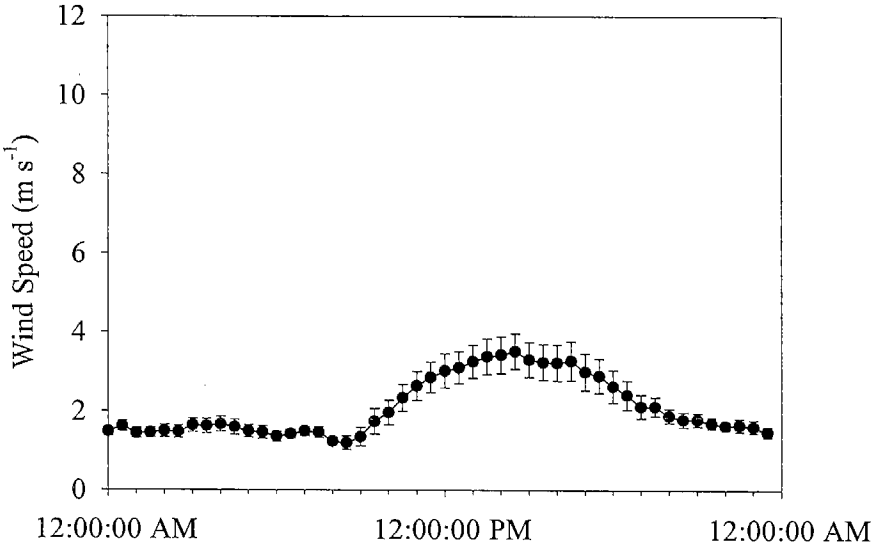
September, 2000



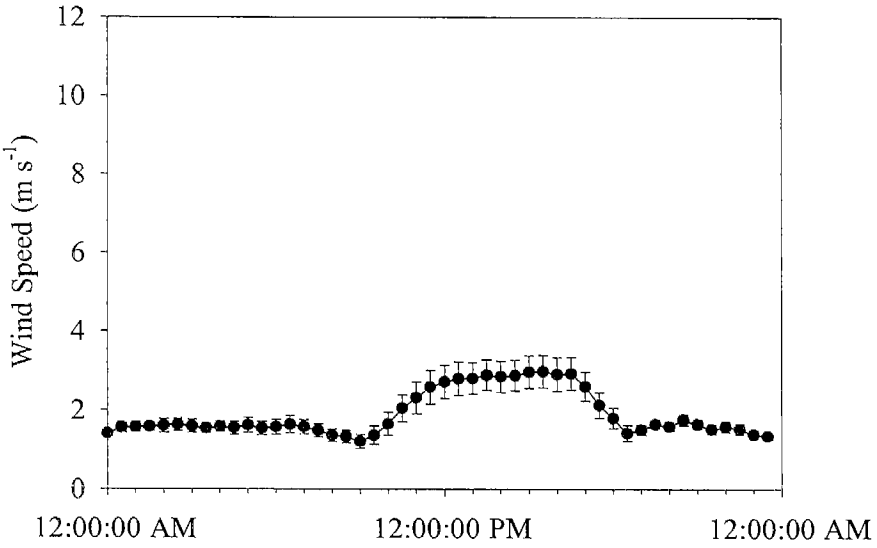
October, 2000



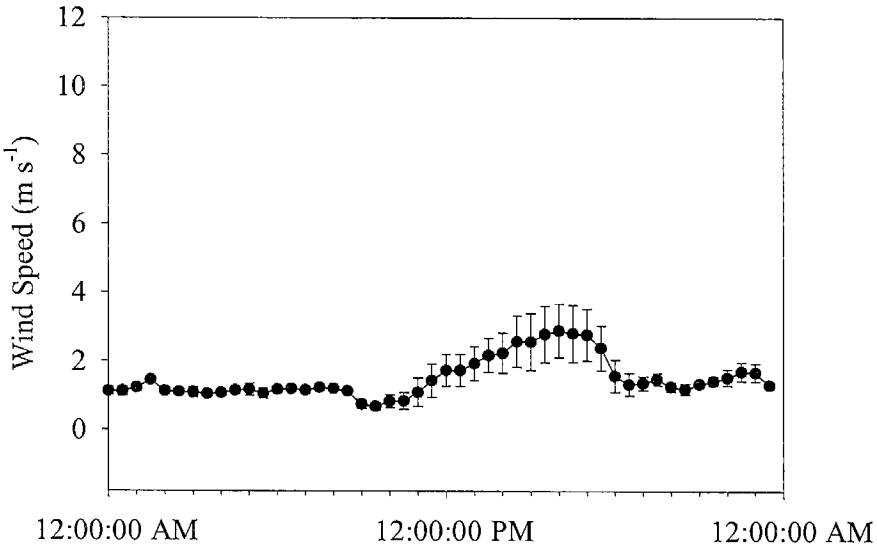
November, 2000



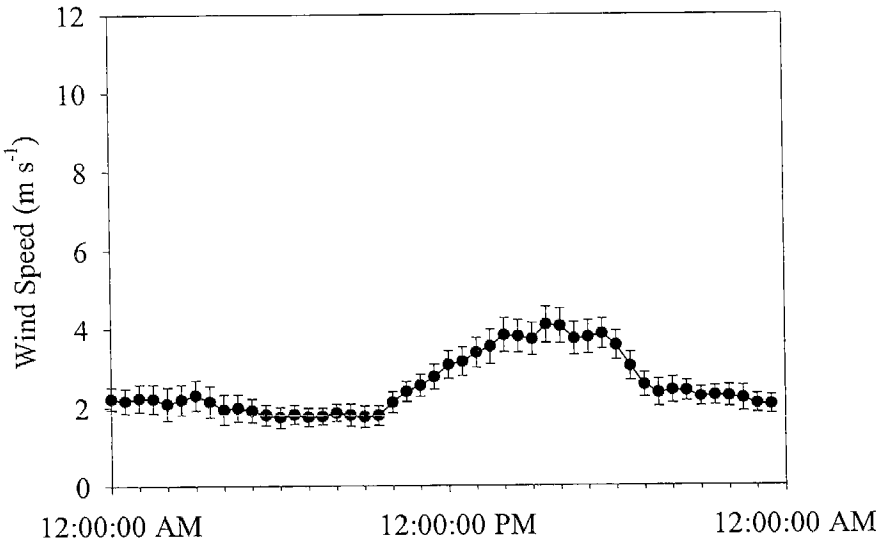
December, 2000



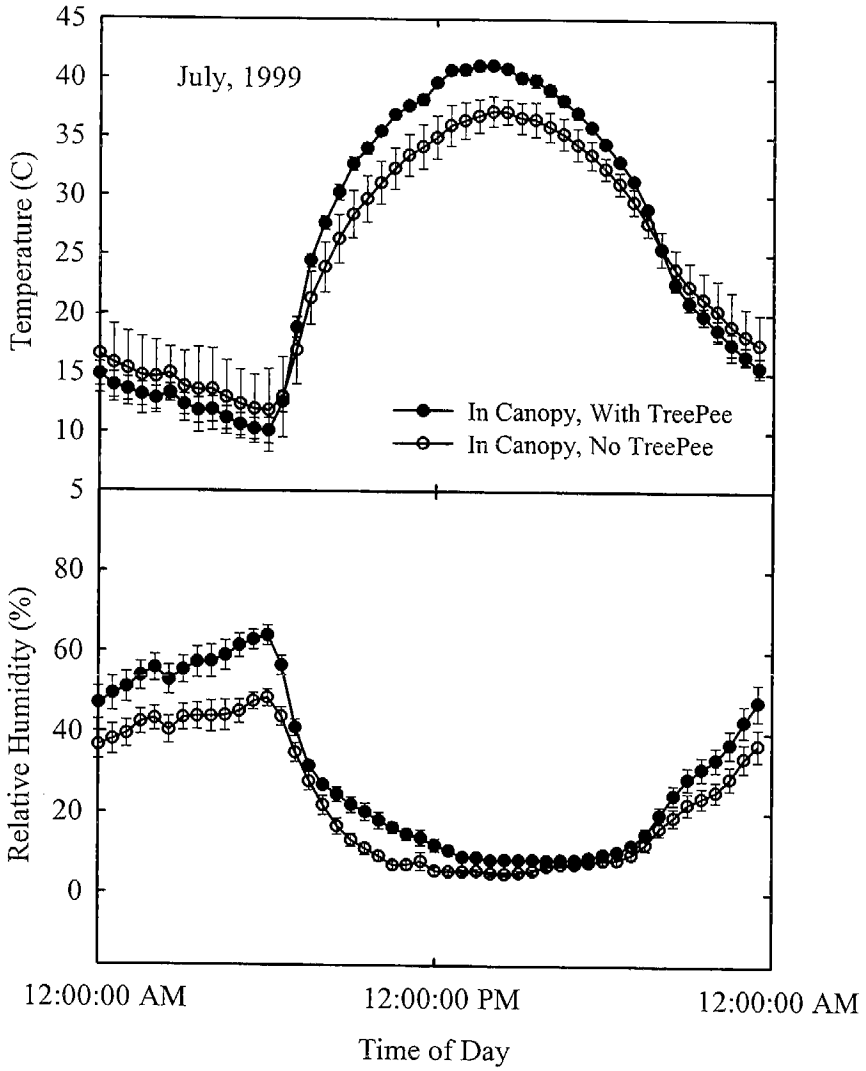
January, 2001



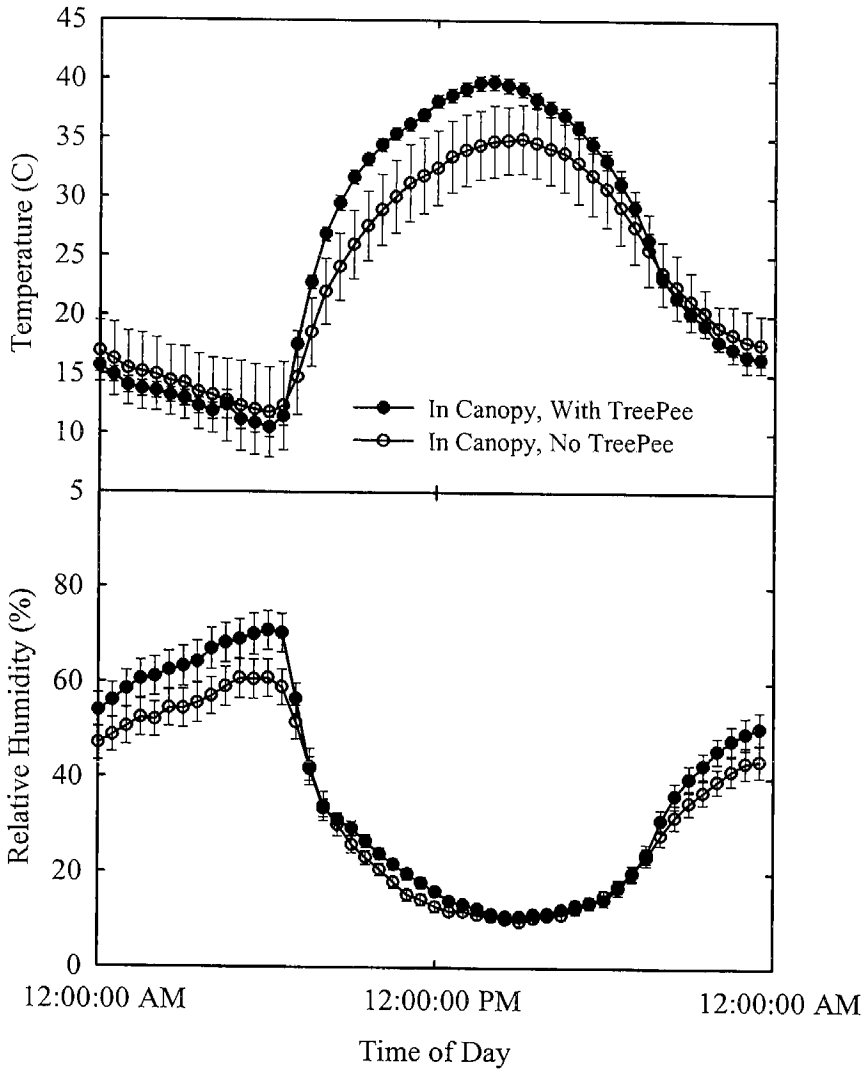
February, 2001



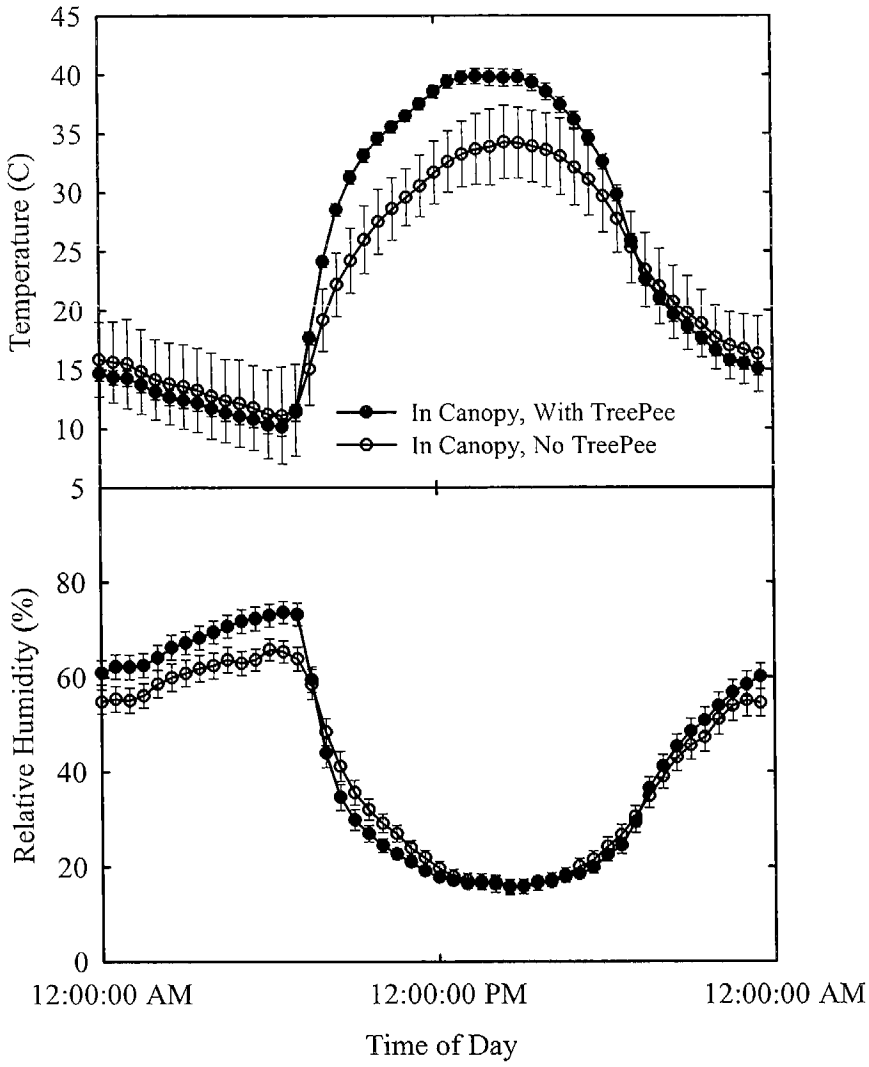
Appendix D


July, 1999
Temperature (C)
45
40
35
30
25
20
15
10
5
In Canopy, With TreePee
In Canopy, No TreePee
Relative Humidity (%)
80
60
40
20
0
12:00:00 AM
12:00:00 PM
12:00:00 AM
Time of Day

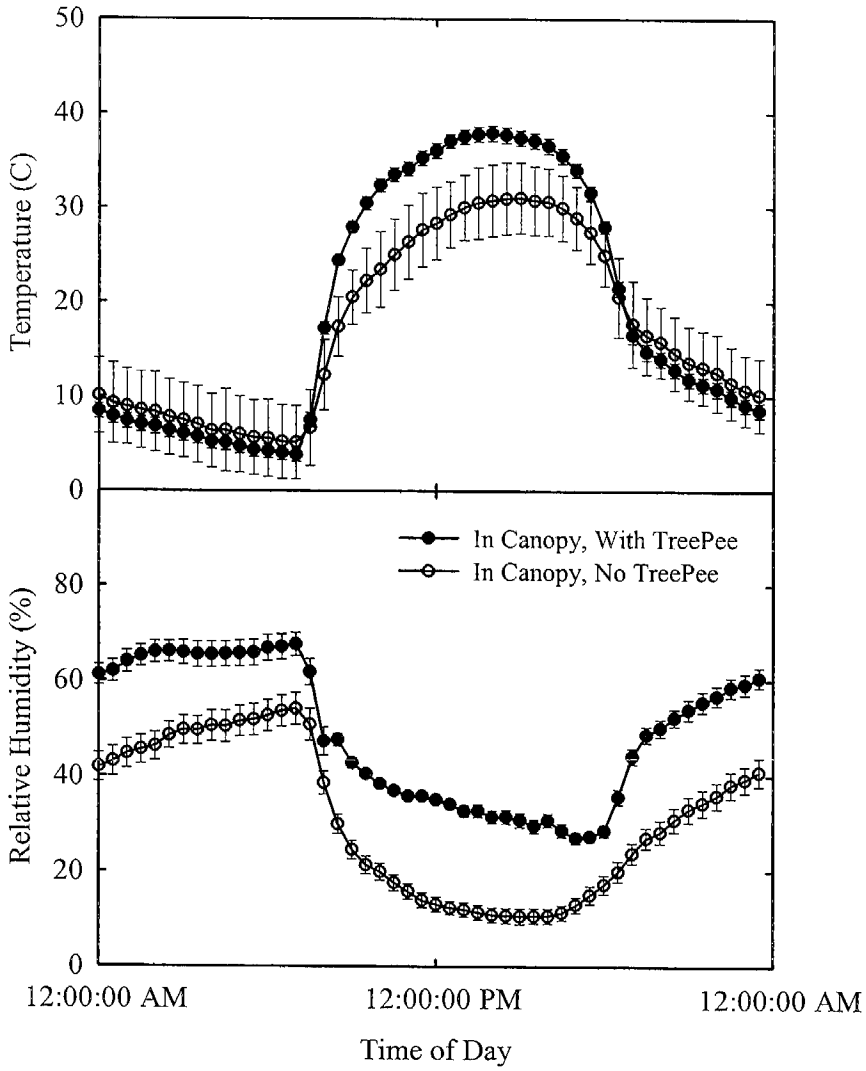
August, 1999

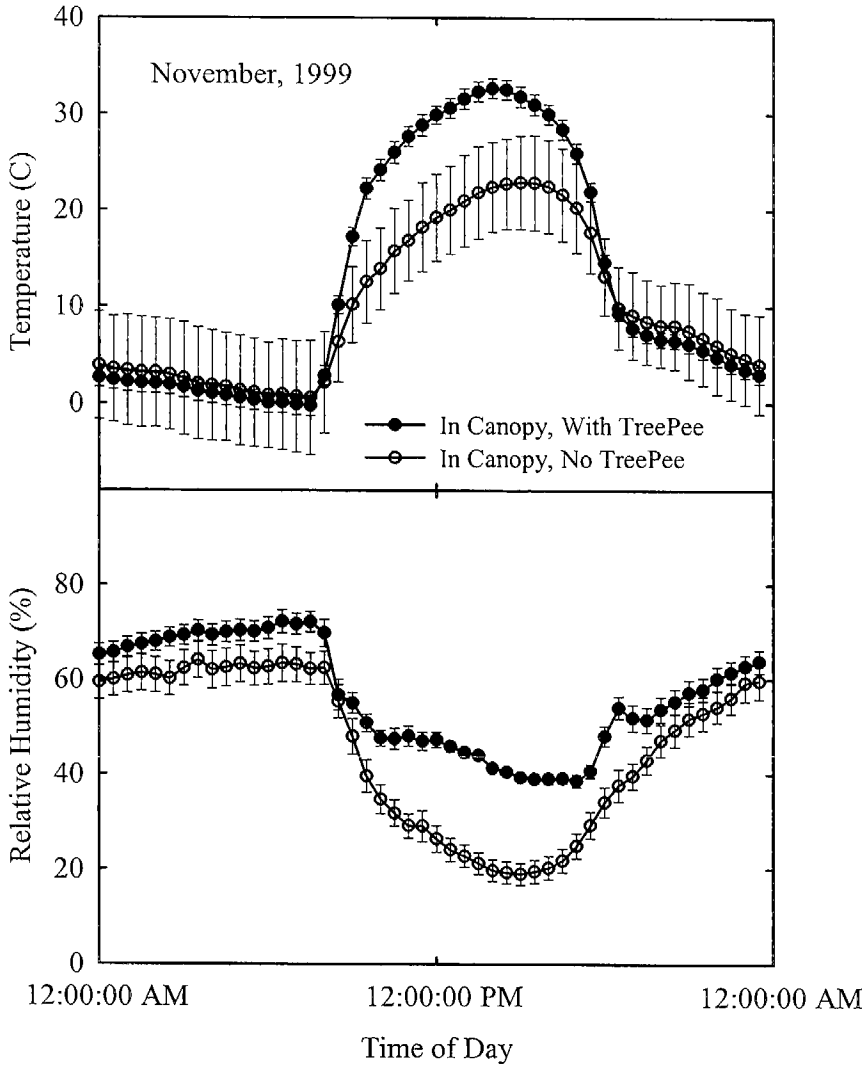

Temperature (C)
45
40
35
30
25
20
15
10
5
In Canopy, With TreePee
In Canopy, No TreePee
Relative Humidity (%)
80
60
40
20
0
12:00:00 AM
12:00:00 PM
12:00:00 AM
Time of Day

September, 1999

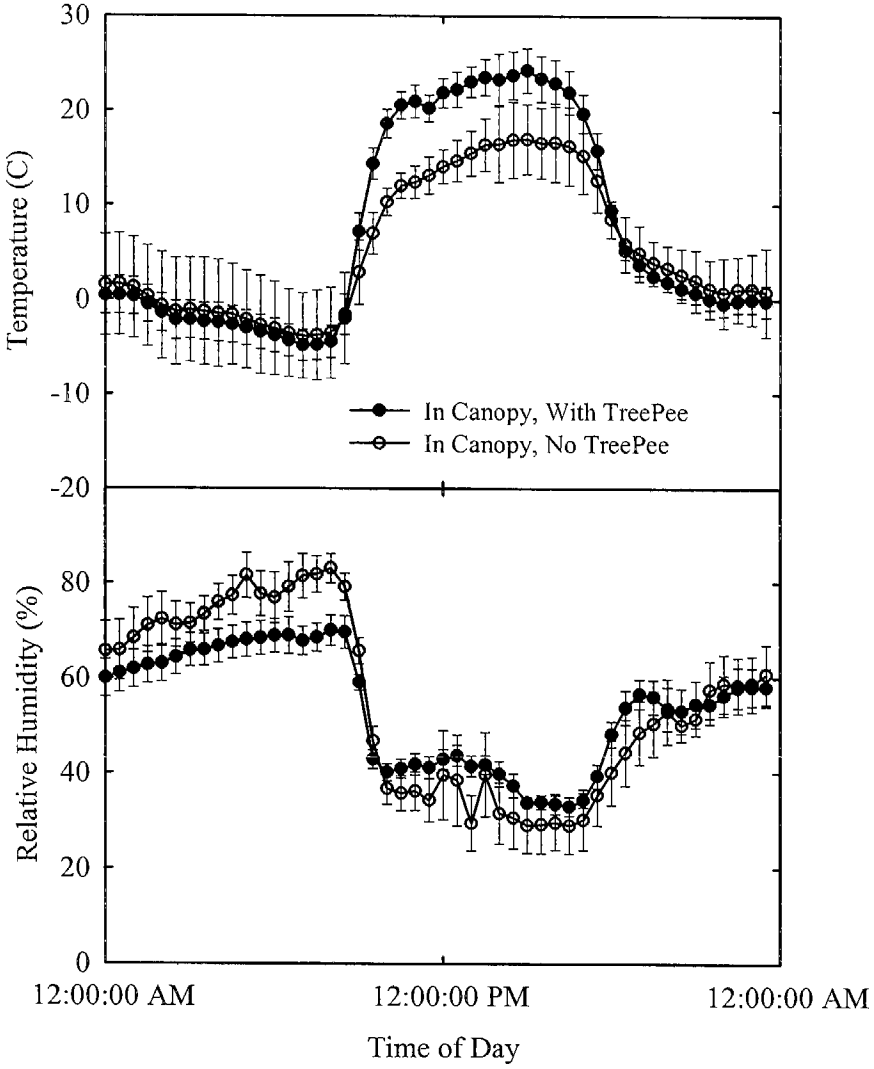


October, 1999

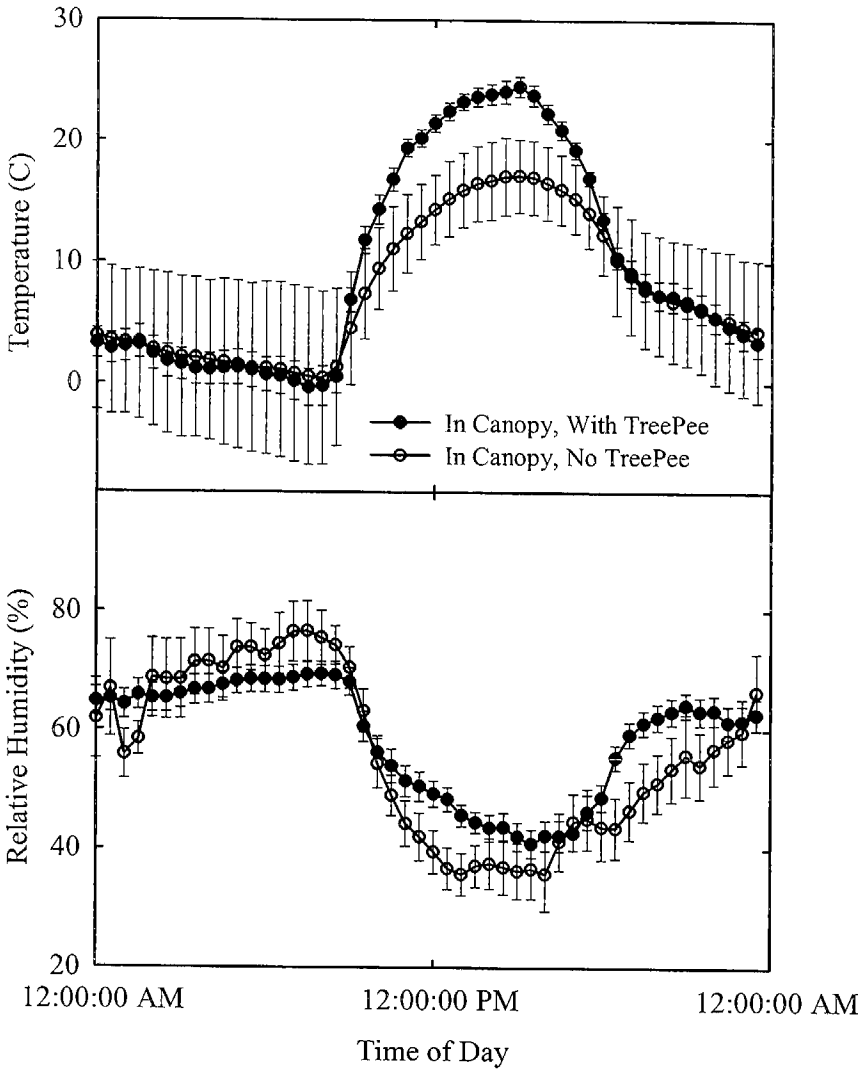



November, 1999
Temperature (C)
40
30
20
10
0
In Canopy, With TreePee
In Canopy, No TreePee
Relative Humidity (%)
80
60
40
20
0
12:00:00 AM
12:00:00 PM
12:00:00 AM
Time of Day

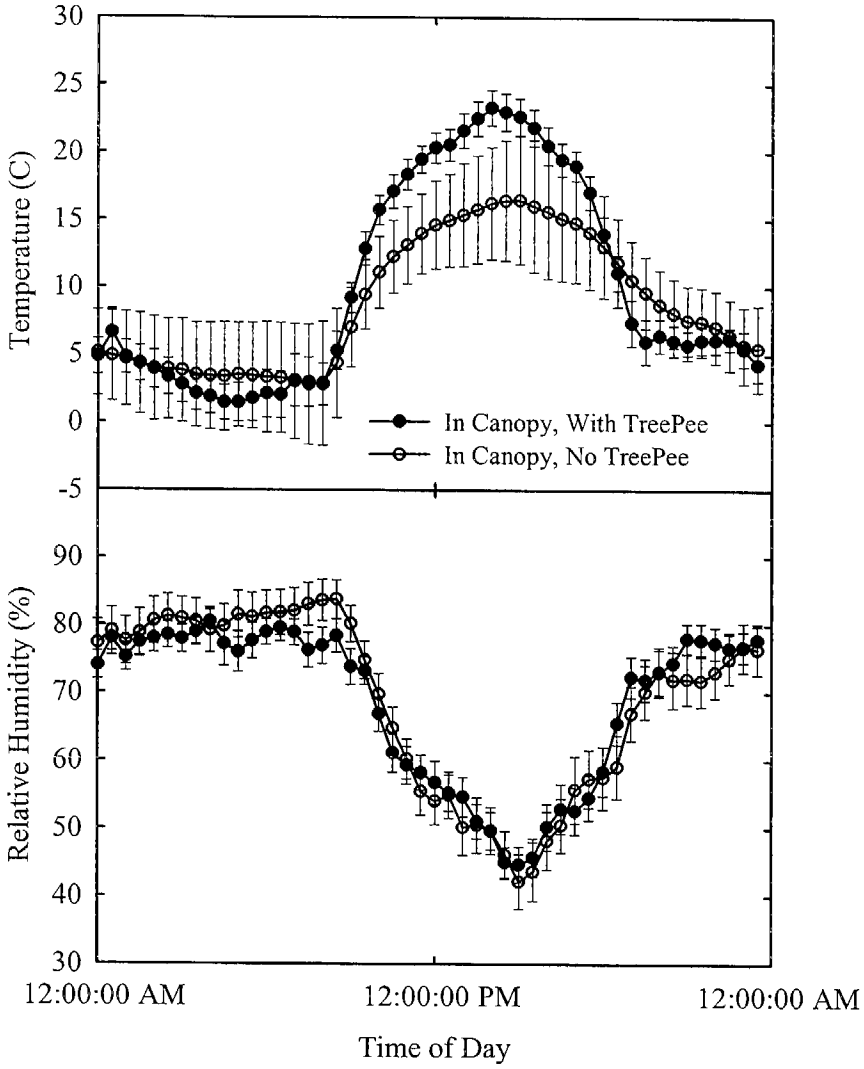
December, 1999



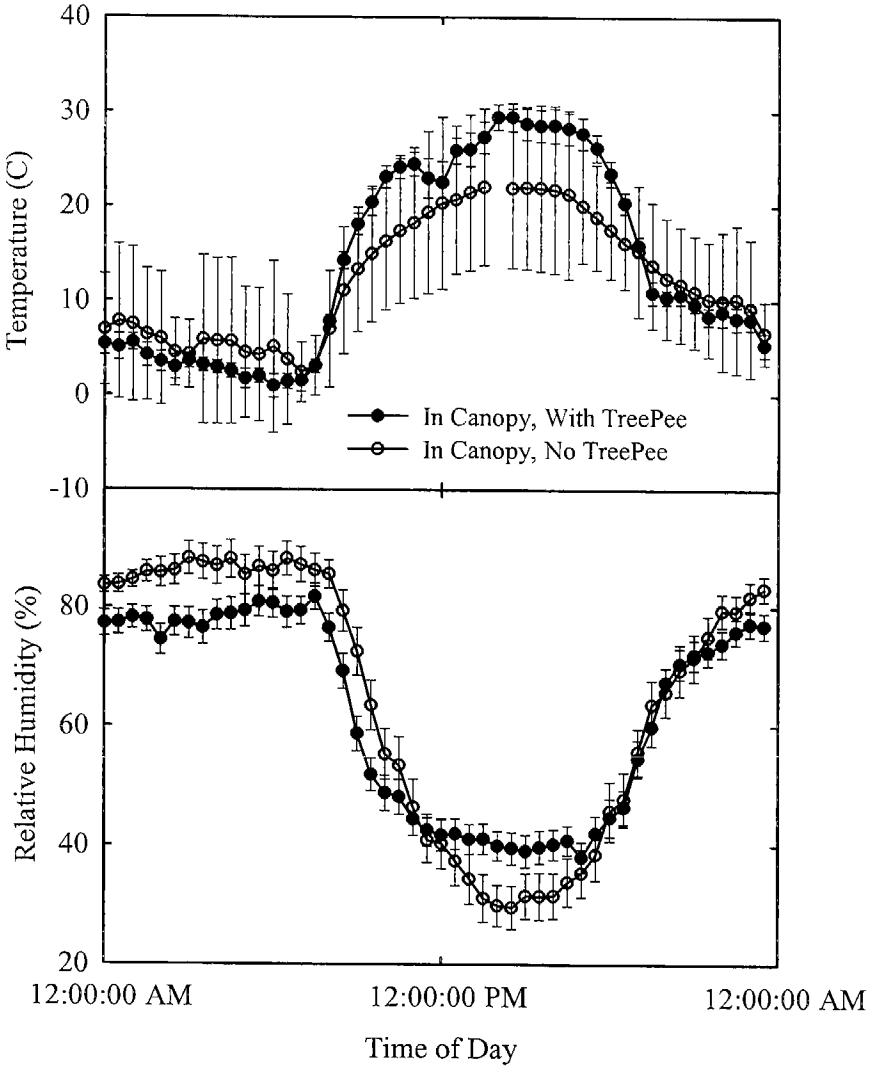
January, 2000



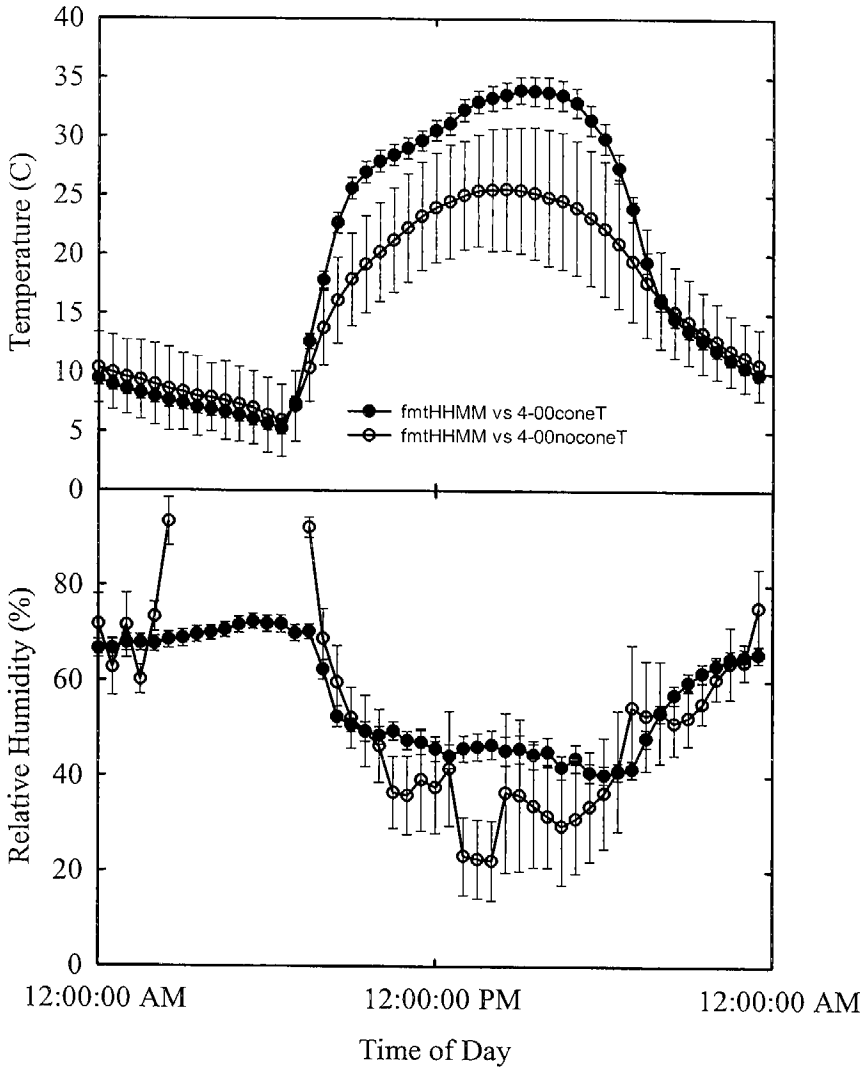
February, 2000



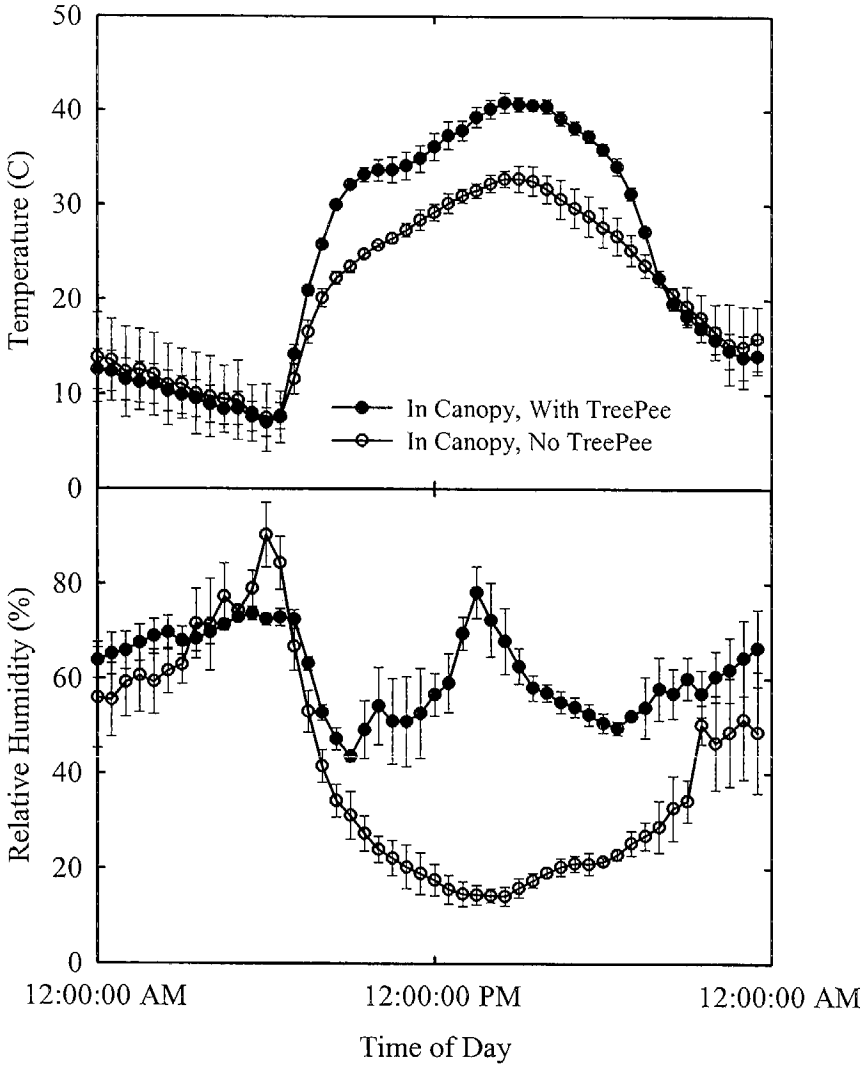
March, 2000


40
30
20
10
0
-10
Temperature (C)
In Canopy, With TreePee
In Canopy, No TreePee
80
60
40
20
Relative Humidity (%)
12:00:00 AM
12:00:00 PM
12:00:00 AM
Time of Day

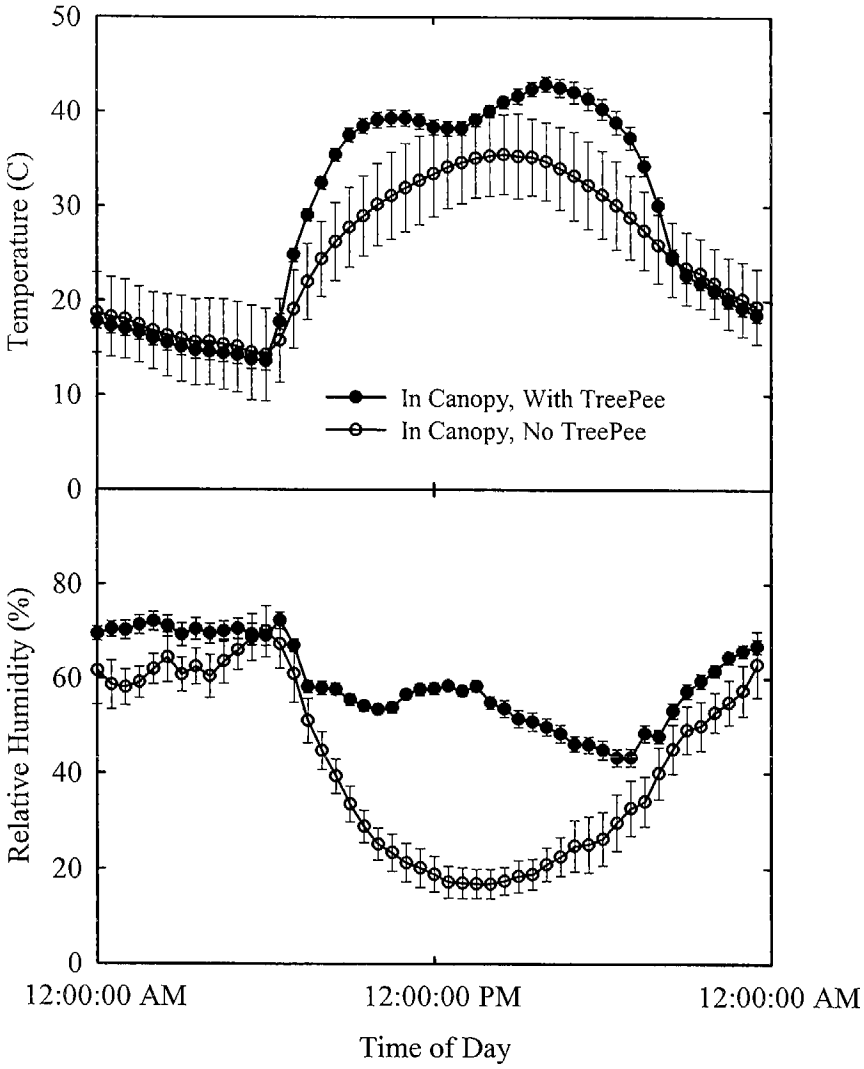
April, 2000


Temperature (C)
40
35
30
25
20
15
10
5
0
fmtHHMM vs 4-00coneT
fmtHHMM vs 4-00noconeT
Relative Humidity (%)
80
60
40
20
0
12:00:00 AM
12:00:00 PM
12:00:00 AM
Time of Day

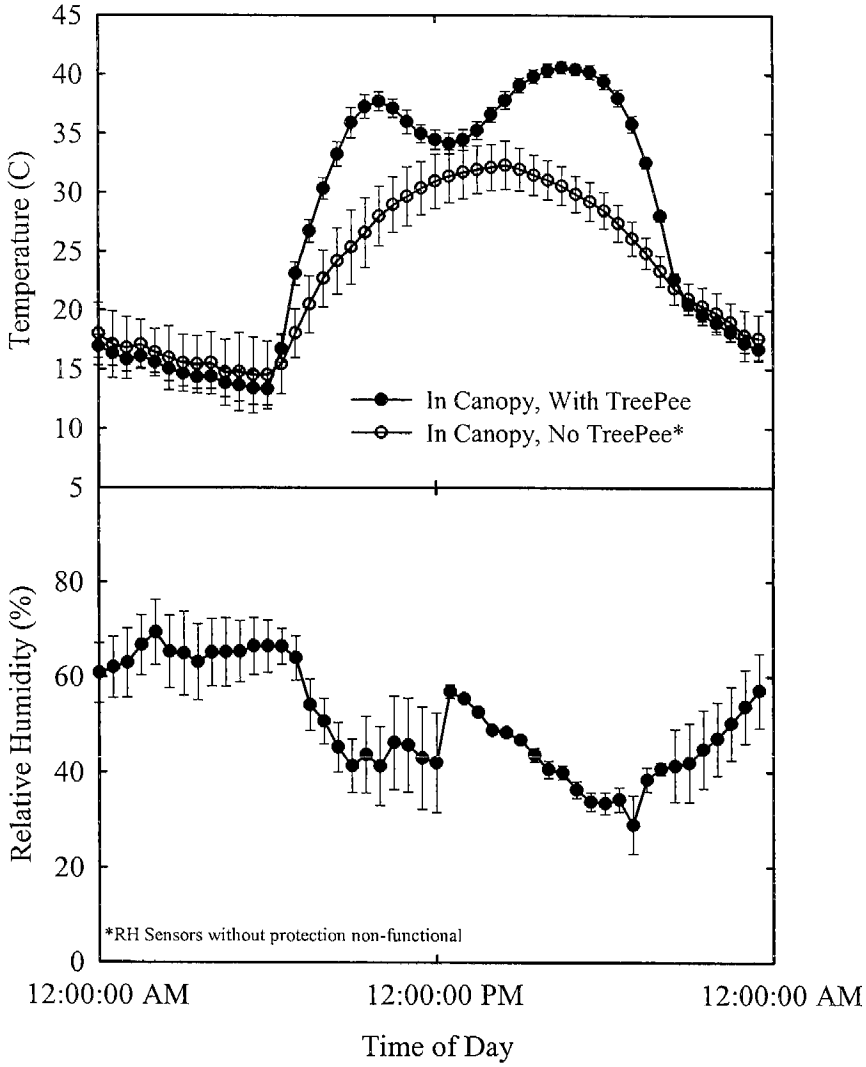
May, 2000


Temperature (C)
50
40
30
20
10
0
In Canopy, With TreePee
In Canopy, No TreePee
Relative Humidity (%)
80
60
40
20
0
12:00:00 AM
12:00:00 PM
12:00:00 AM
Time of Day

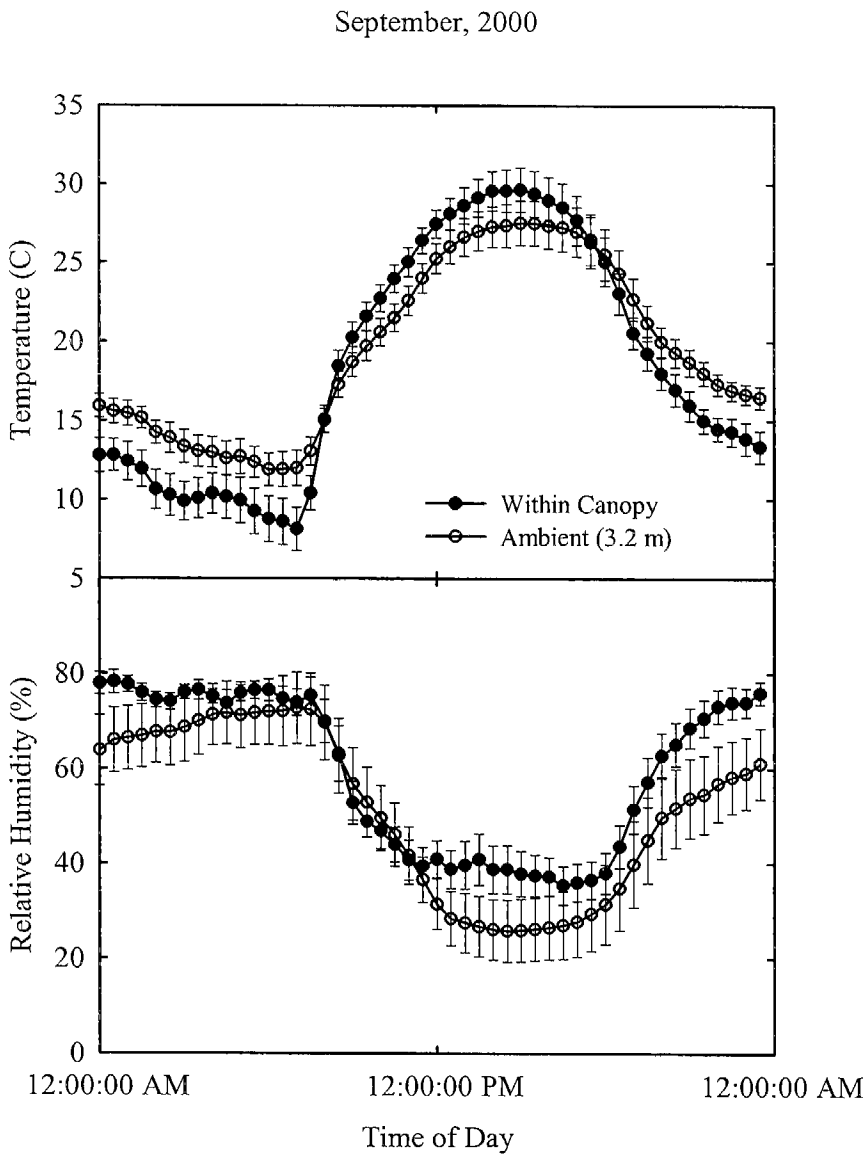
June, 2000


50
40
30
20
10
0
Temperature (C)
In Canopy, With TreePee
In Canopy, No TreePee
80
60
40
20
0
Relative Humidity (%)
12:00:00 AM
12:00:00 PM
12:00:00 AM
Time of Day

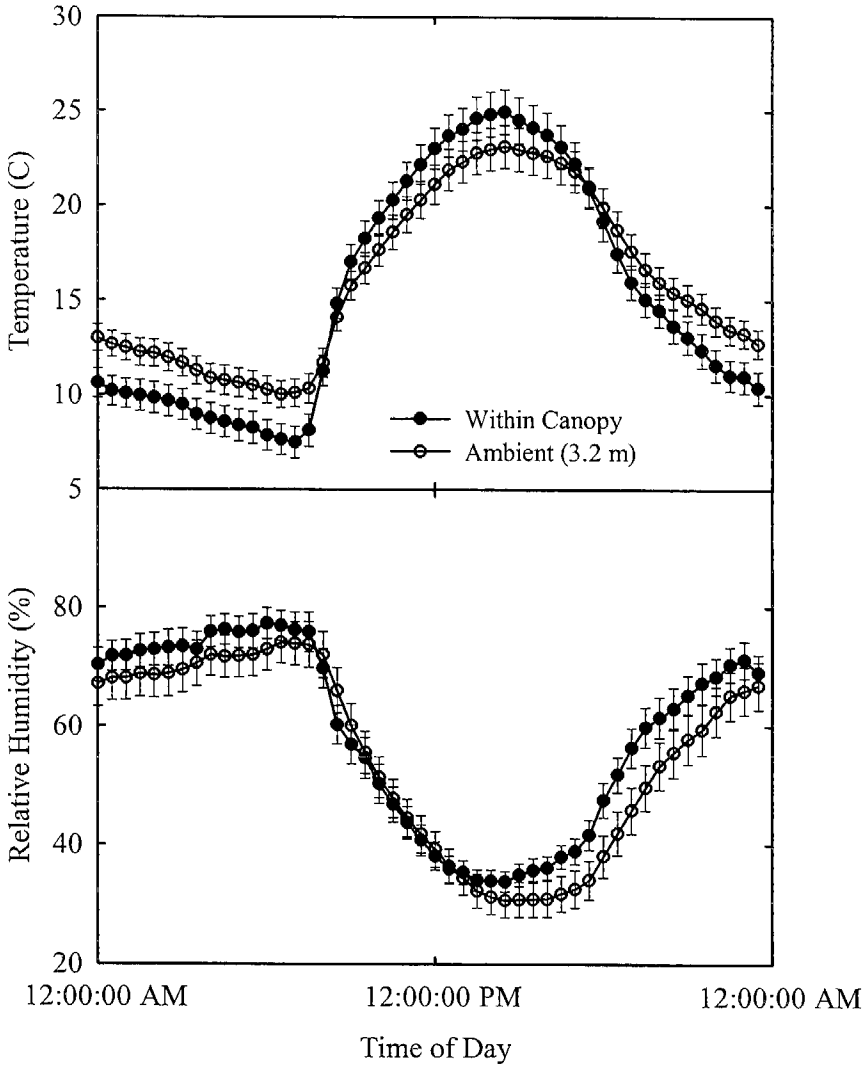
July, 2000


Temperature (C)
45
40
35
30
25
20
15
10
5
In Canopy, With TreePee
In Canopy, No TreePee*
Relative Humidity (%)
80
60
40
20
0
*RH Sensors without protection non-functional
12:00:00 AM
12:00:00 PM
12:00:00 AM
Time of Day

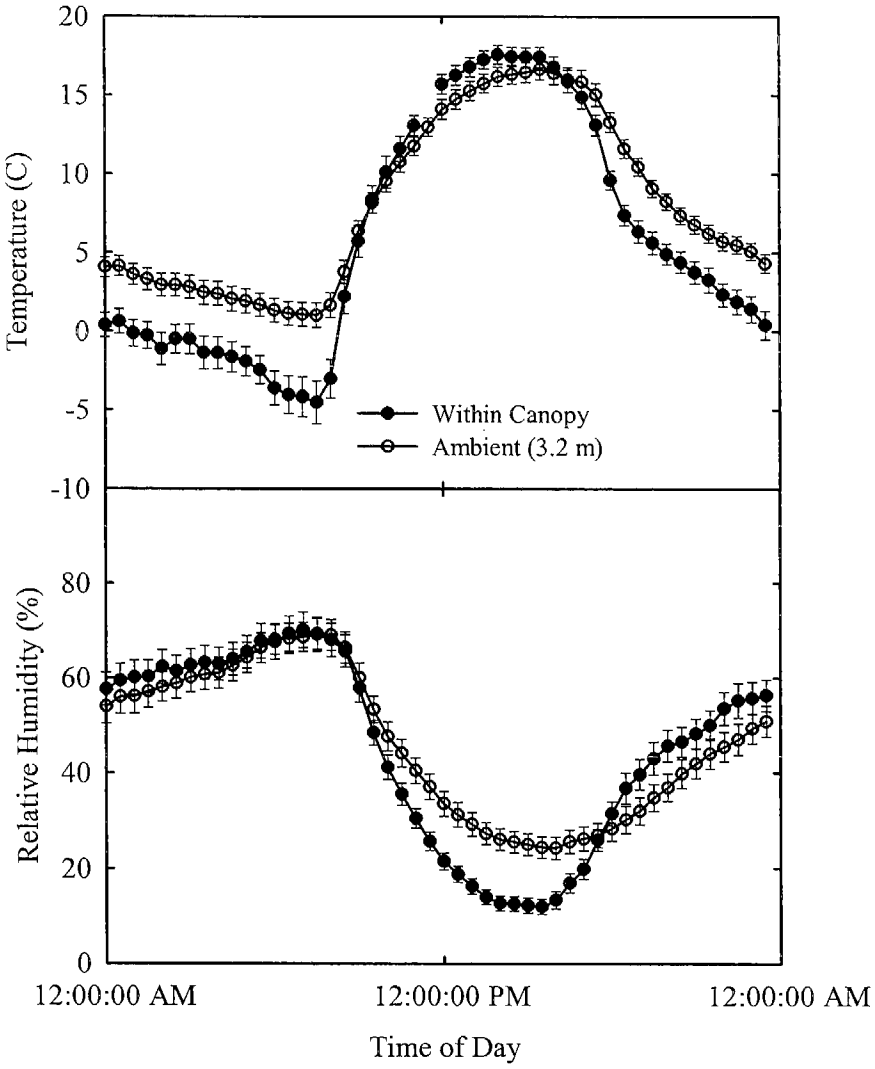
Appendix E


September, 2000
Temperature (C)
35
30
25
20
15
10
5
Within Canopy
Ambient (3.2 m)
Relative Humidity (%)
80
60
40
20
0
12:00:00 AM
12:00:00 PM
12:00:00 AM
Time of Day

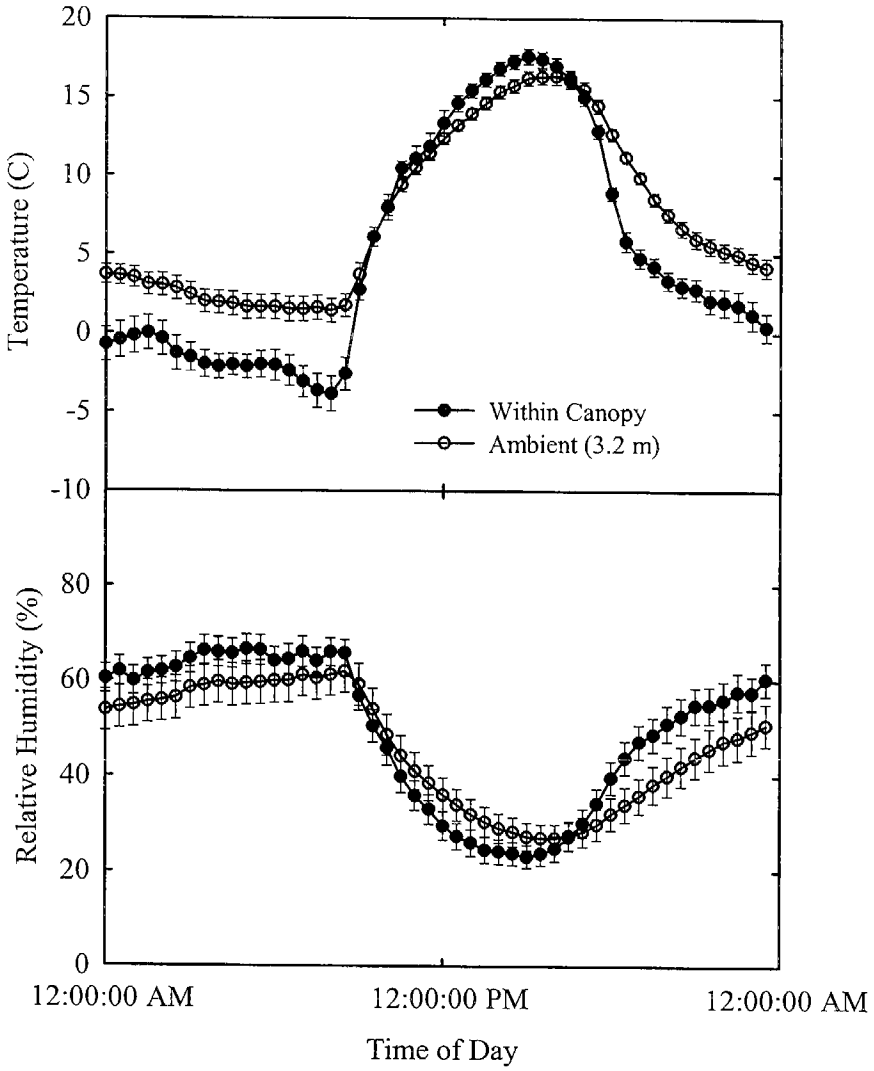
October, 2000



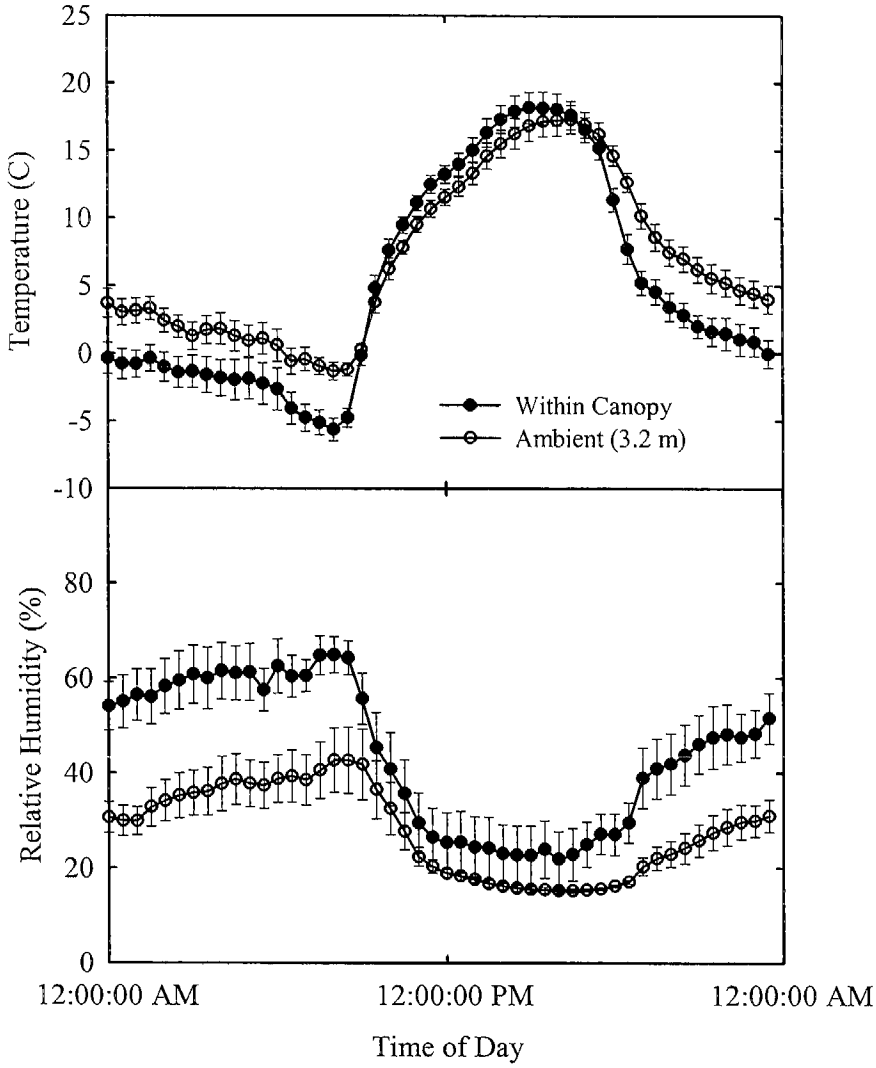
November, 2000



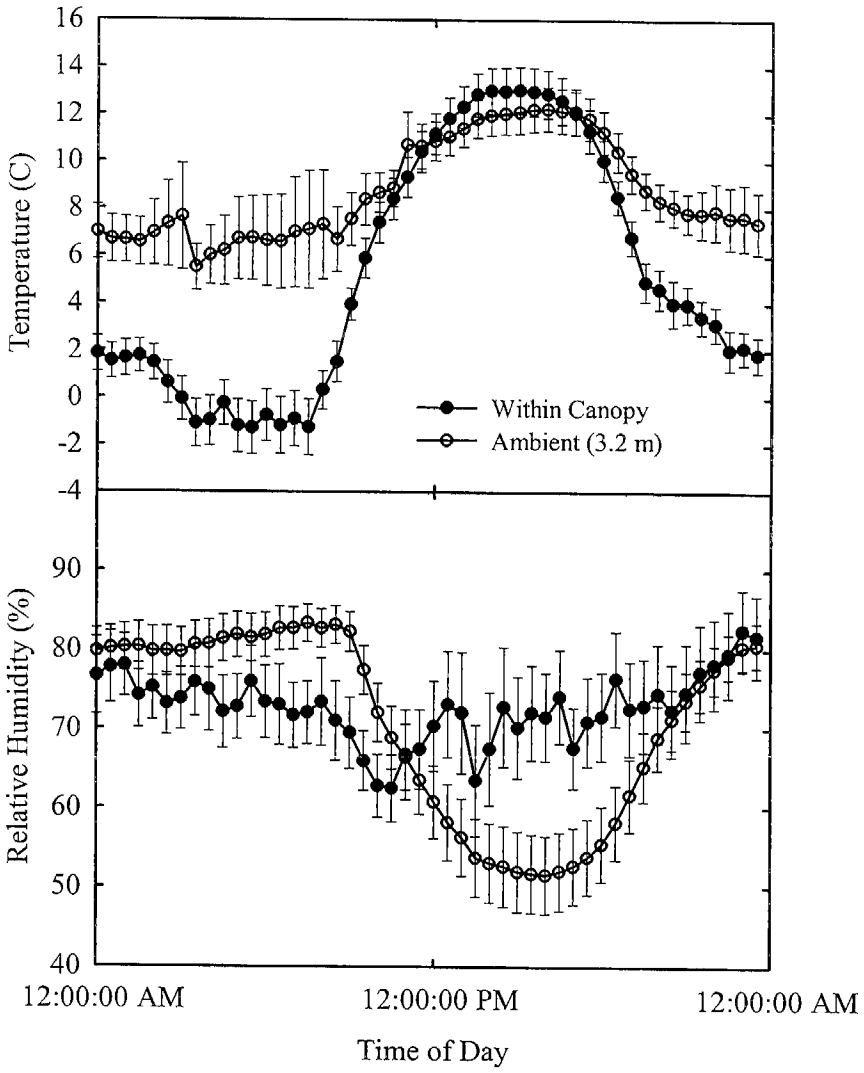
December, 2000



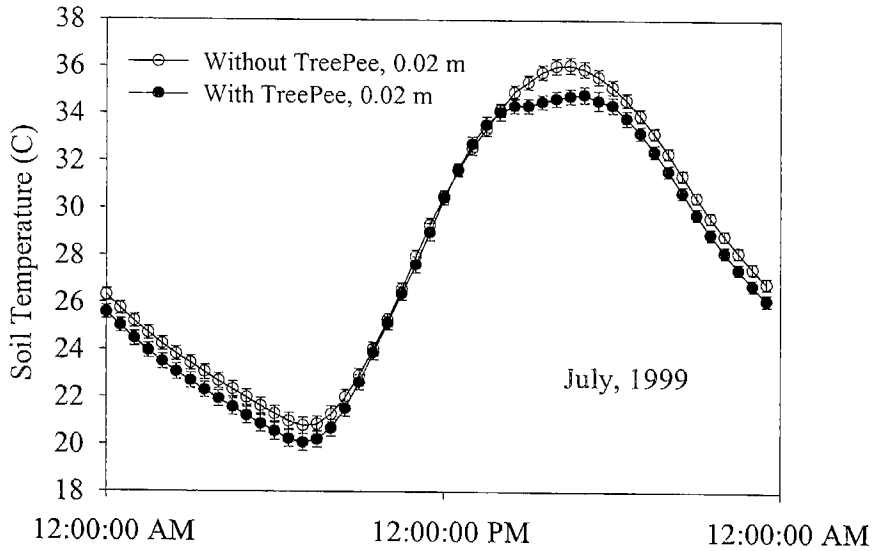
January, 2001



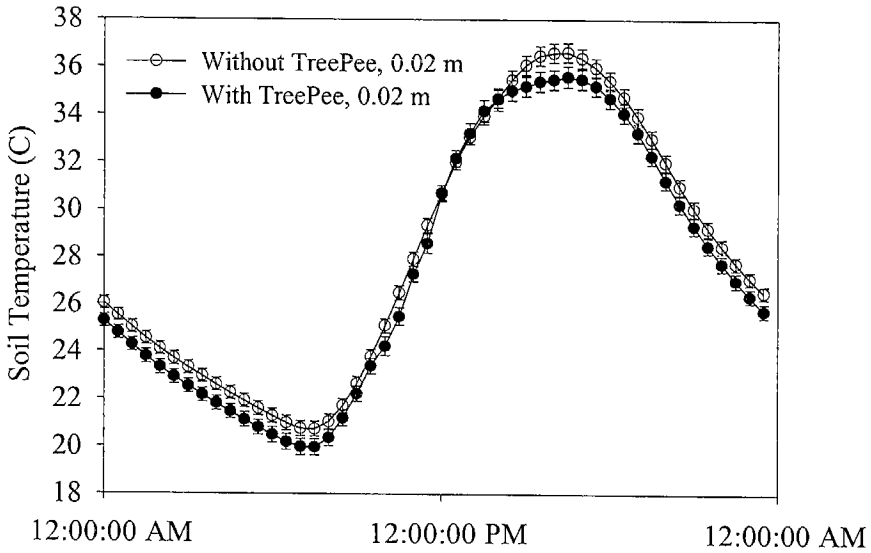
February, 2001



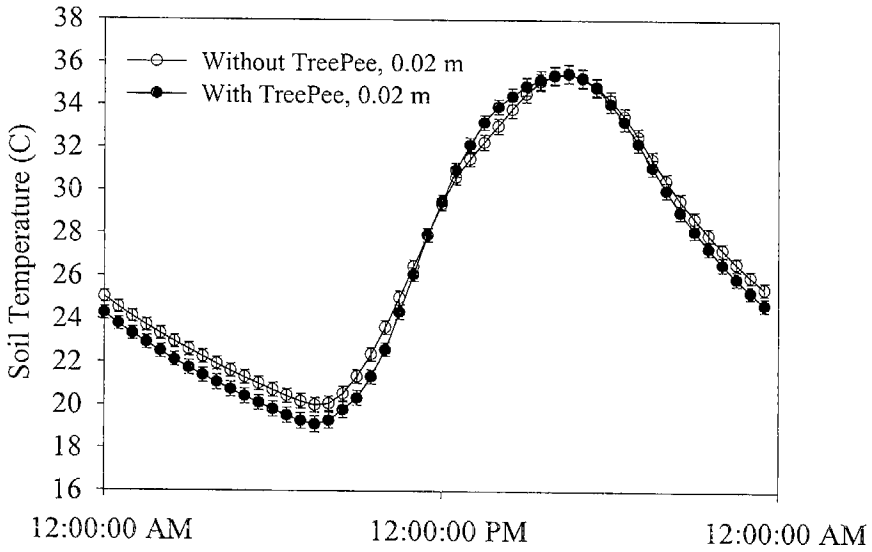
Appendix F



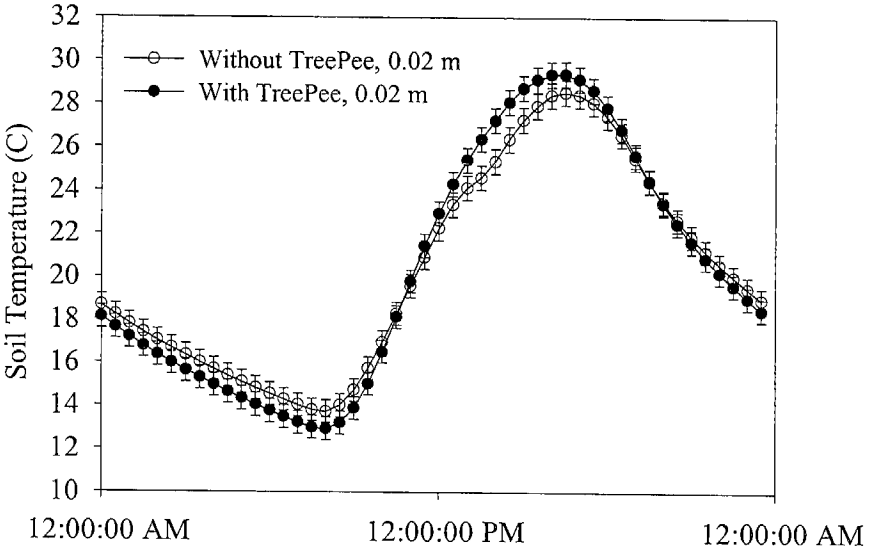
August, 1999

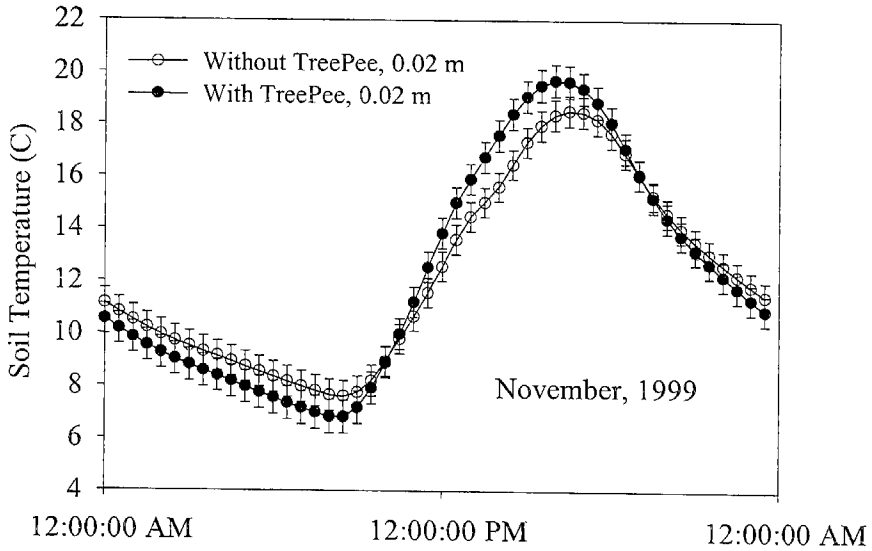


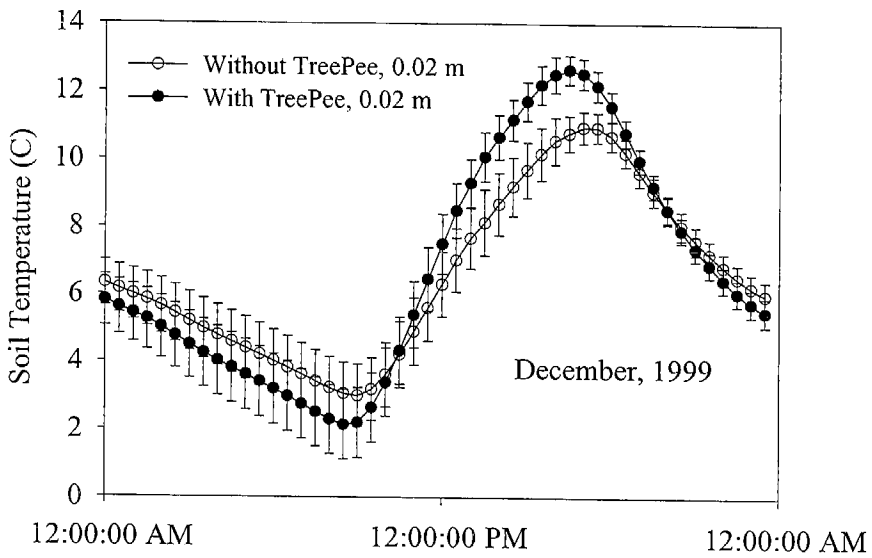
September, 1999



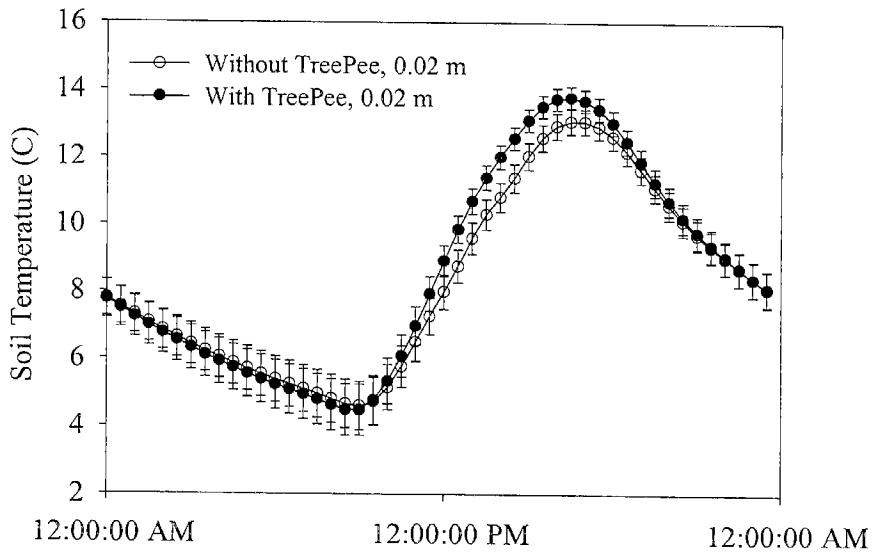
October, 1999



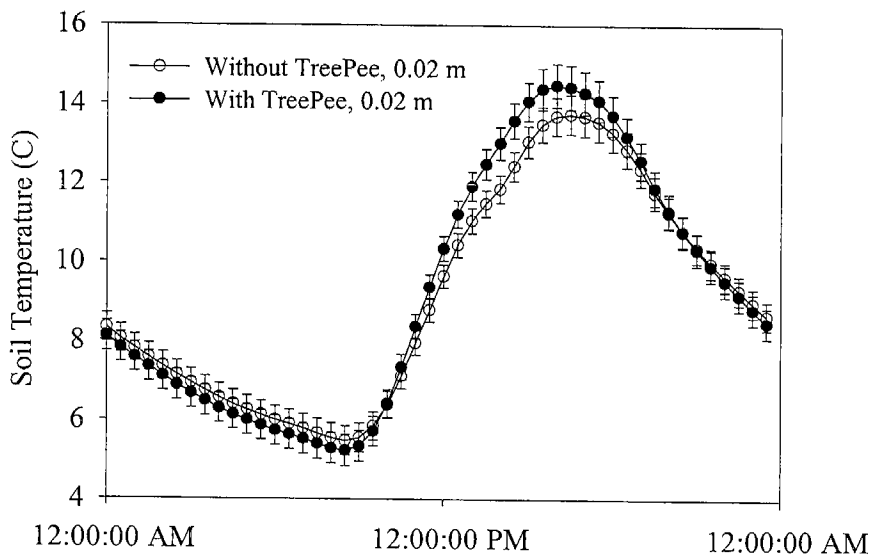

Without TreePee, 0.02 m
With TreePee, 0.02 m
Soil Temperature (C)
22
20
18
16
14
12
10
8
6
4
November, 1999
12:00:00 AM
12:00:00 PM
12:00:00 AM


Without TreePee, 0.02 m
With TreePee, 0.02 m
Soil Temperature (C)
14
12
10
8
6
4
2
0
December, 1999
12:00:00 AM
12:00:00 PM
12:00:00 AM

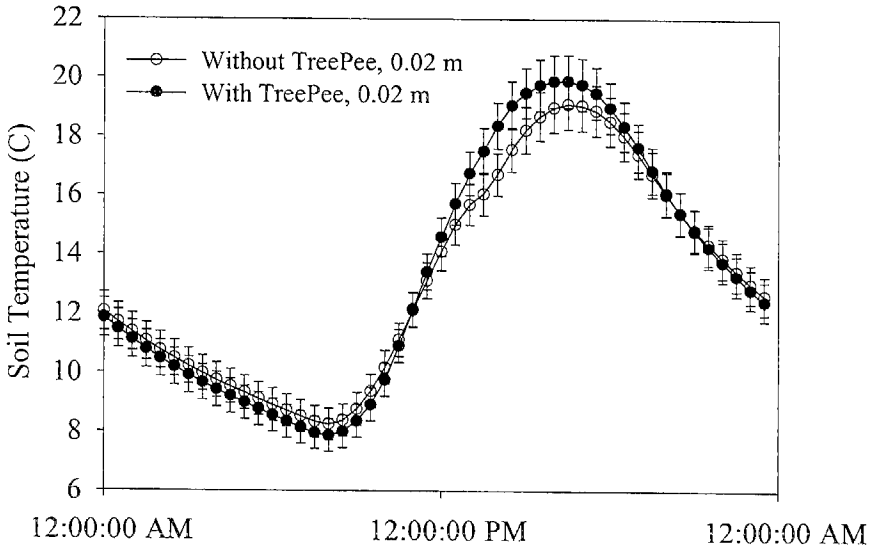
January, 2000



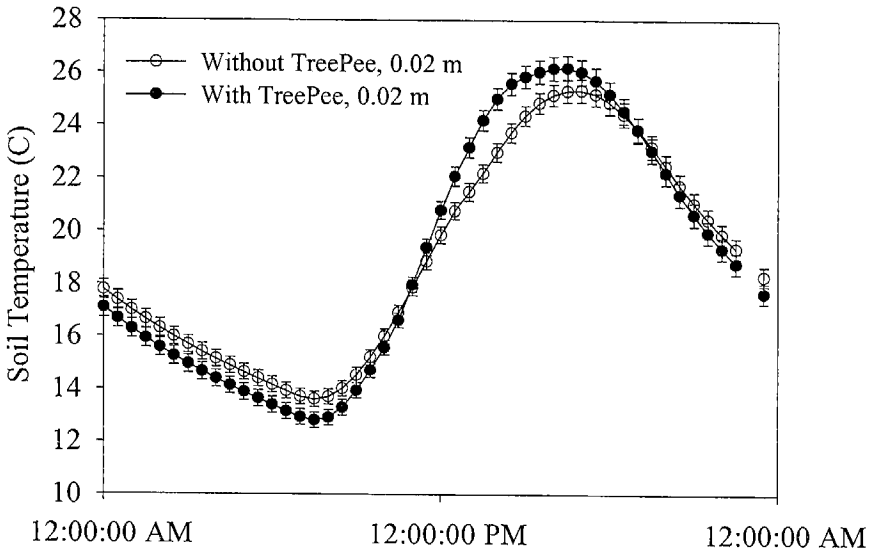
February, 2000



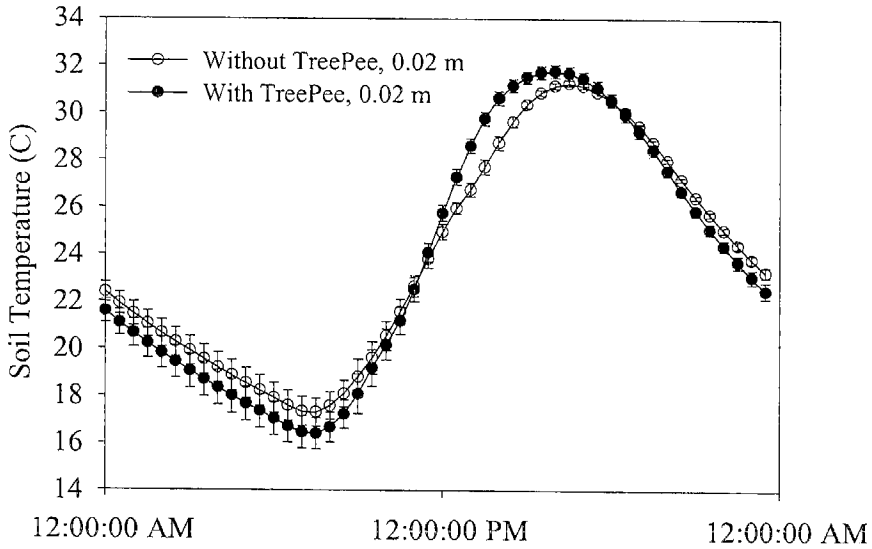
March, 2000



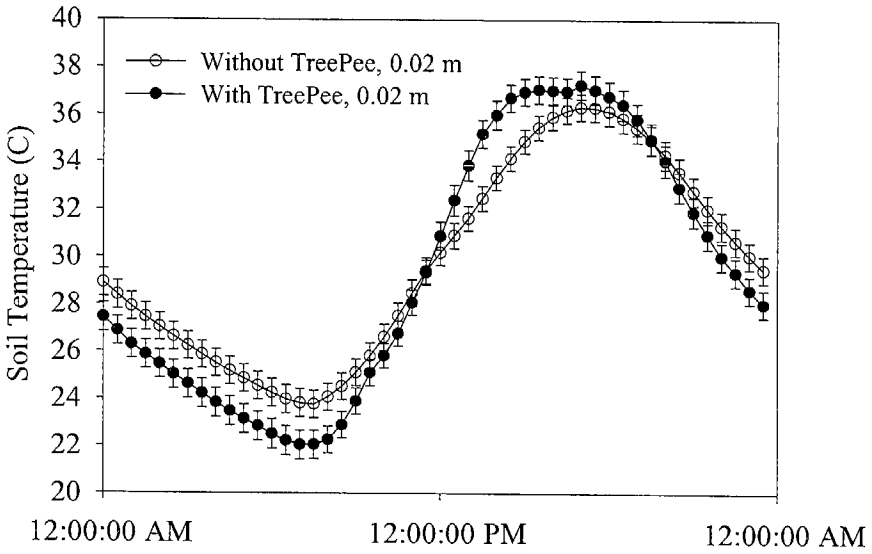
April, 2000



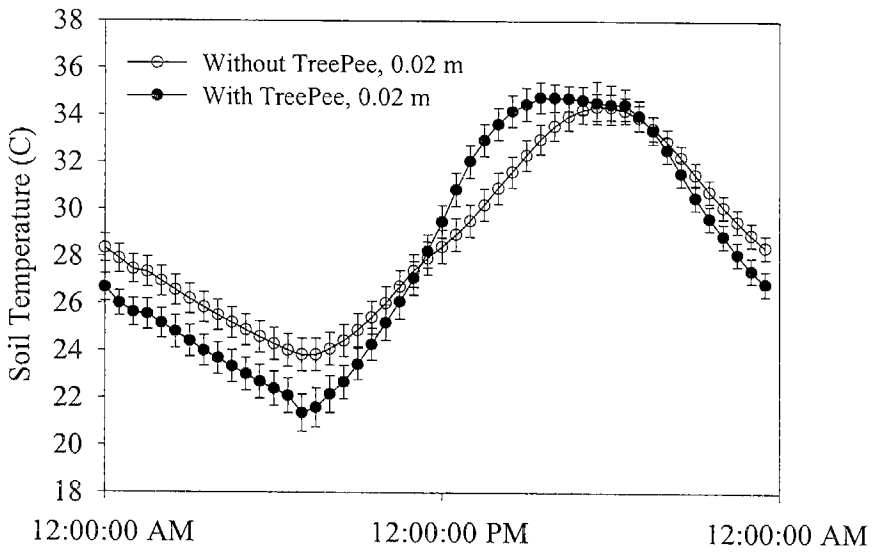
May, 2000



June, 2000

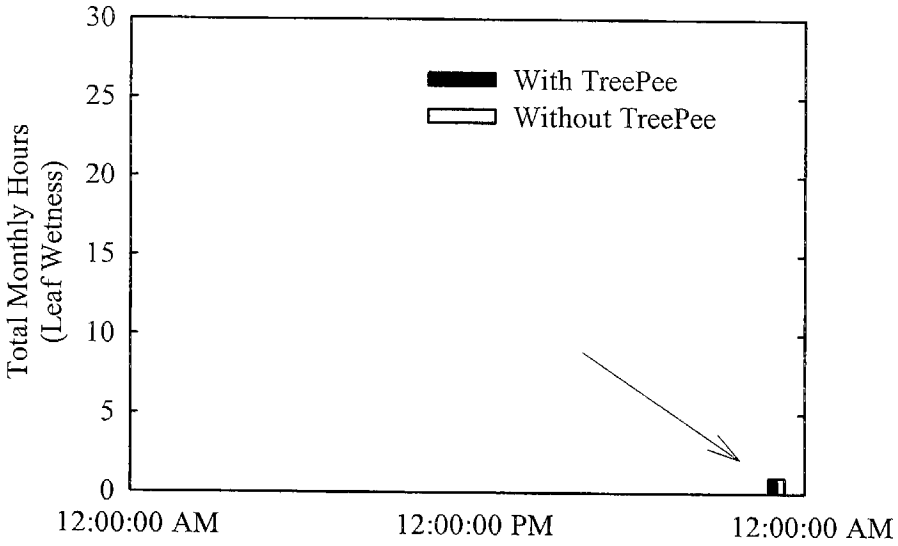


July, 2000

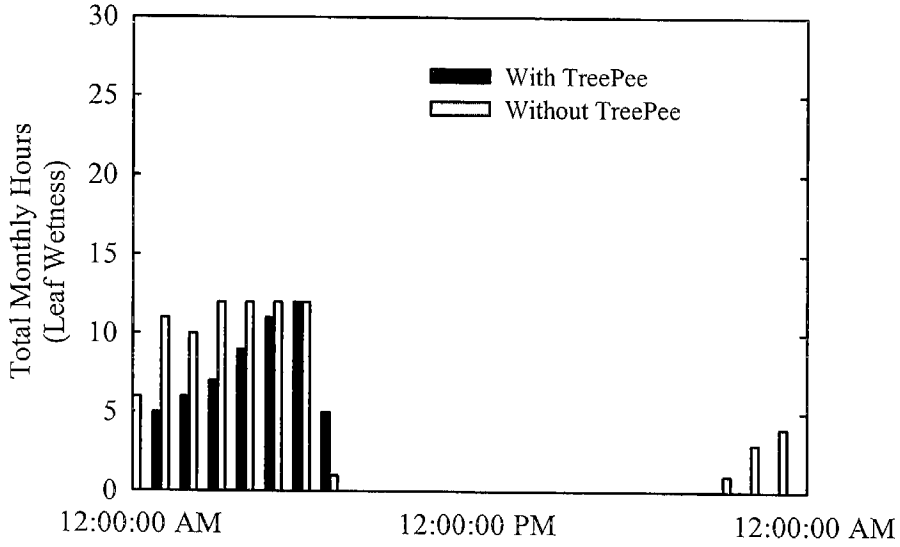

Without TreePee, 0.02 m
With TreePee, 0.02 m
Soil Temperature (C)
38
36
34
32
30
28
26
24
22
20
18
12:00:00 AM
12:00:00 PM
12:00:00 AM

Appendix G

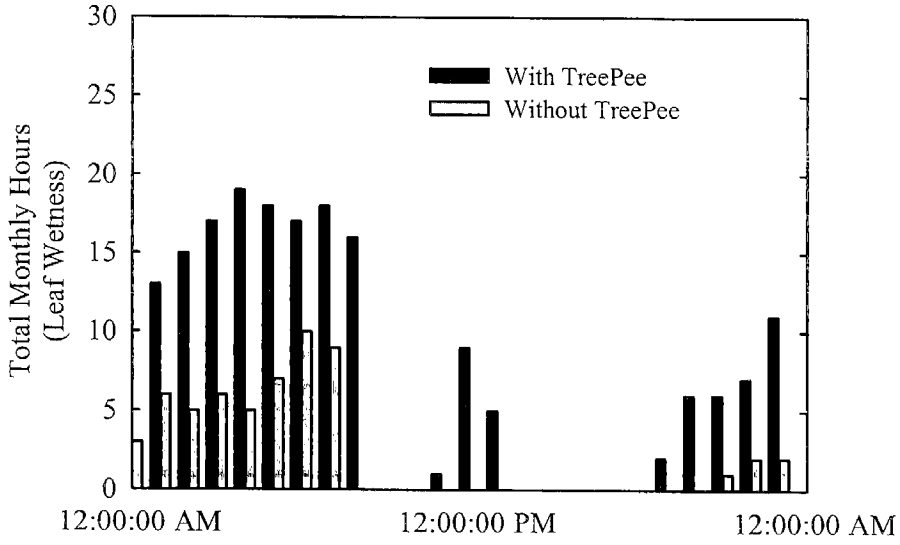
July, 1999



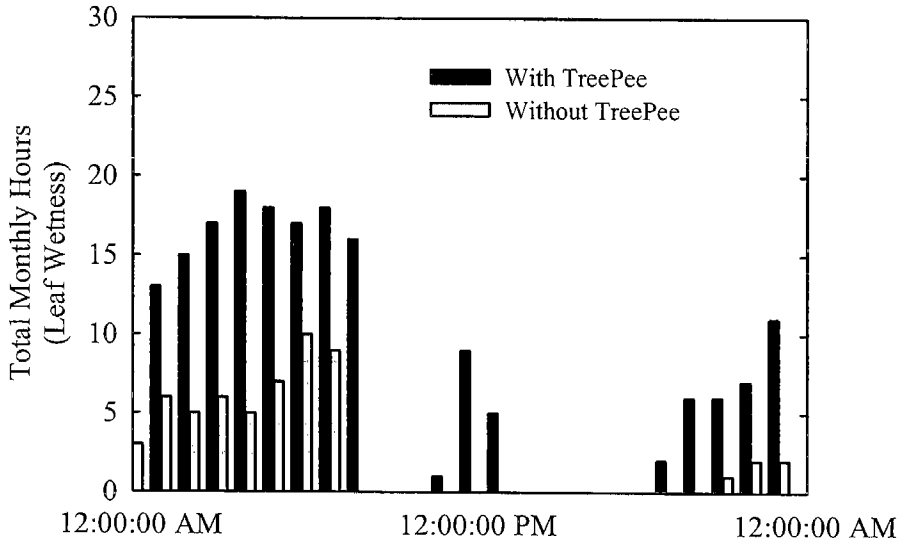
August, 1999



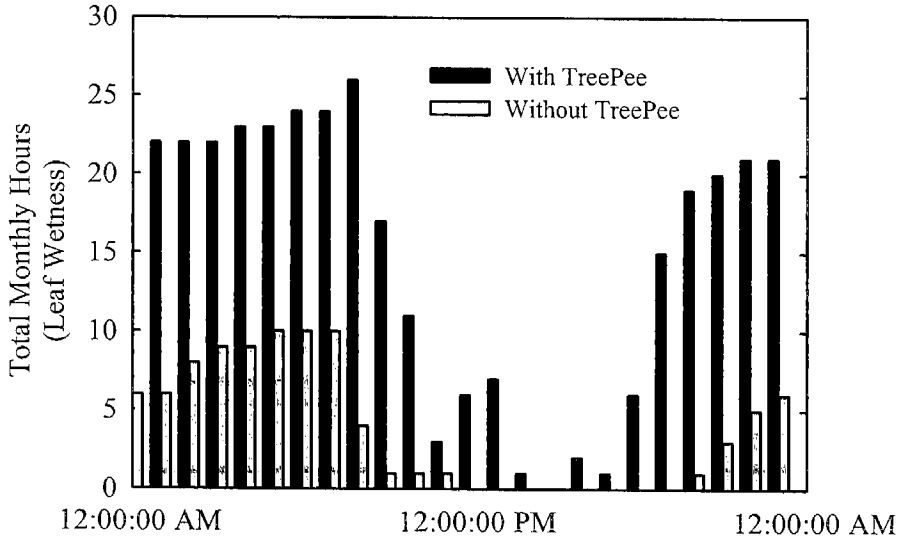
September, 1999



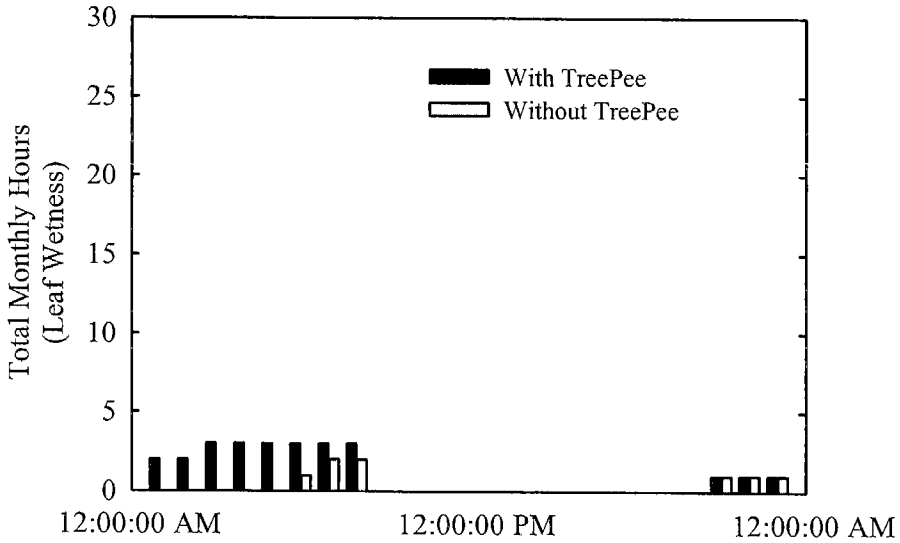
October, 1999



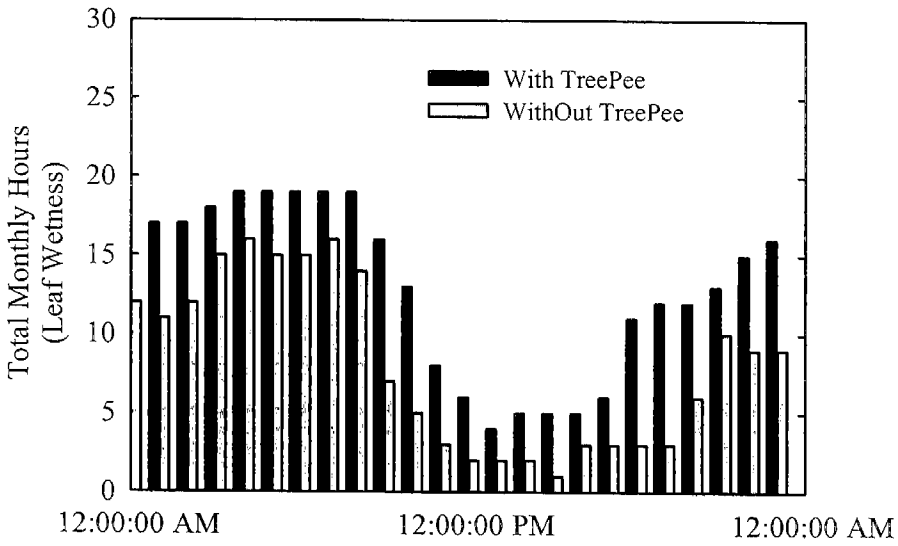
November, 1999



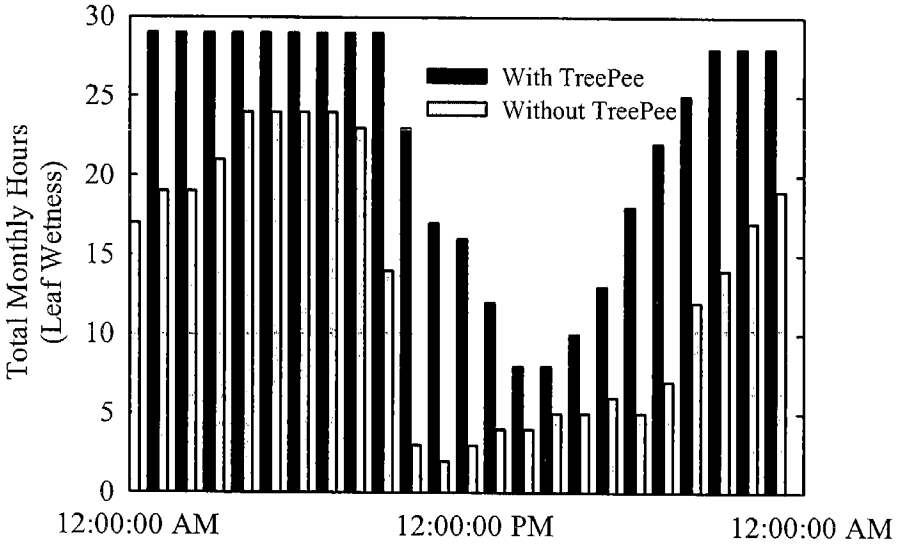
December, 1999



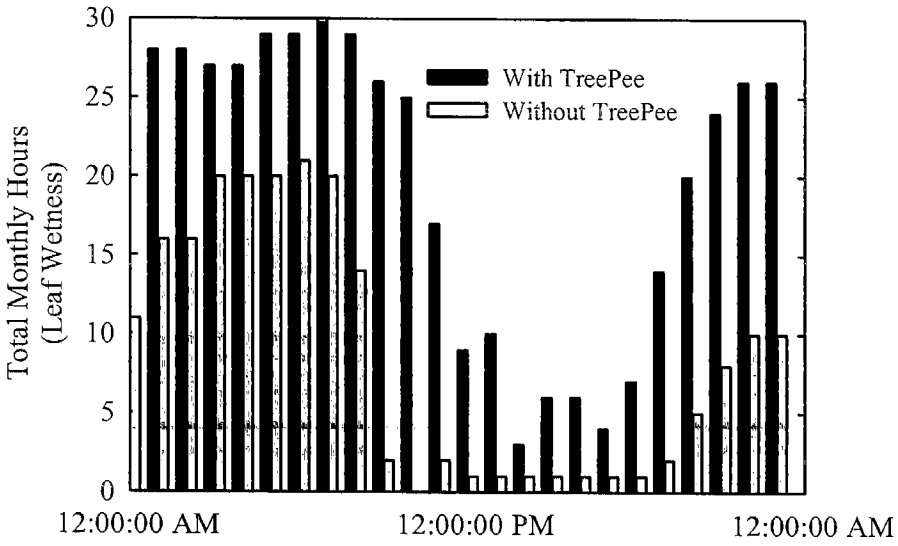
January, 2000



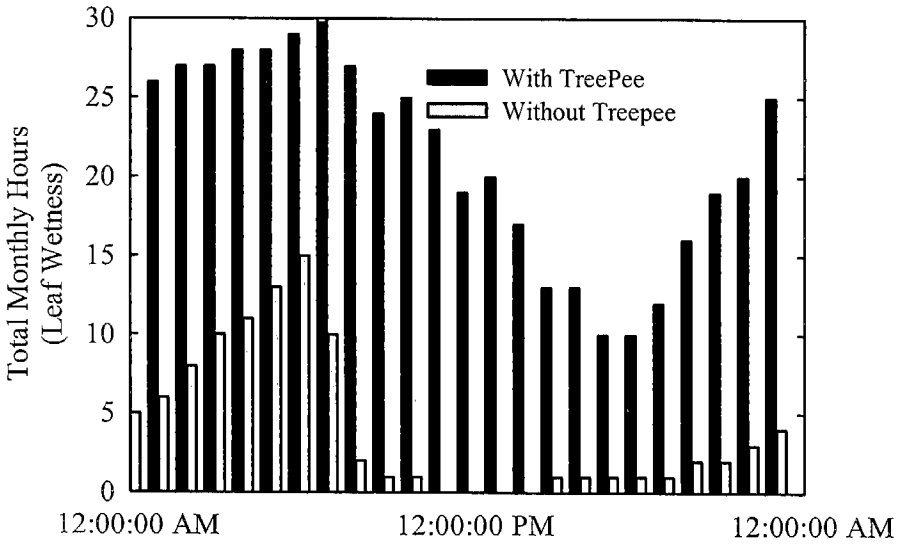
February, 2000



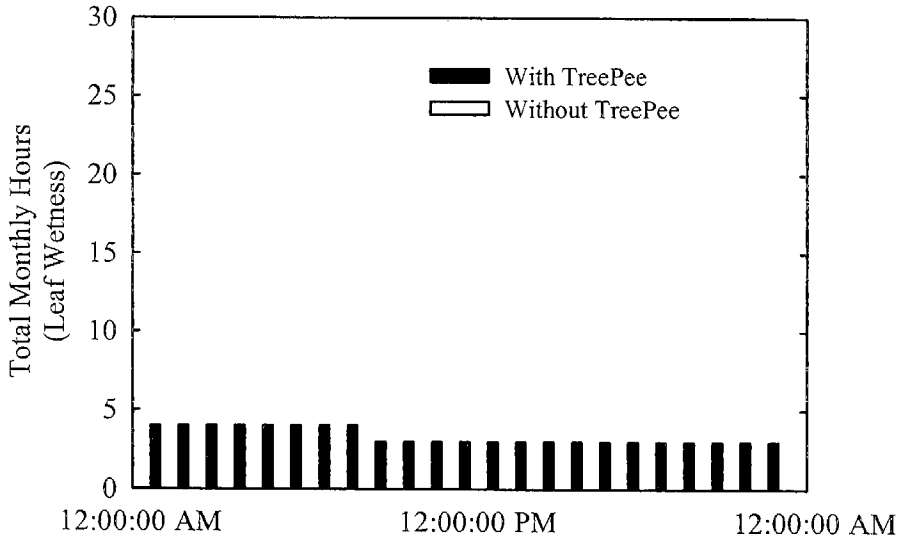
March, 2000



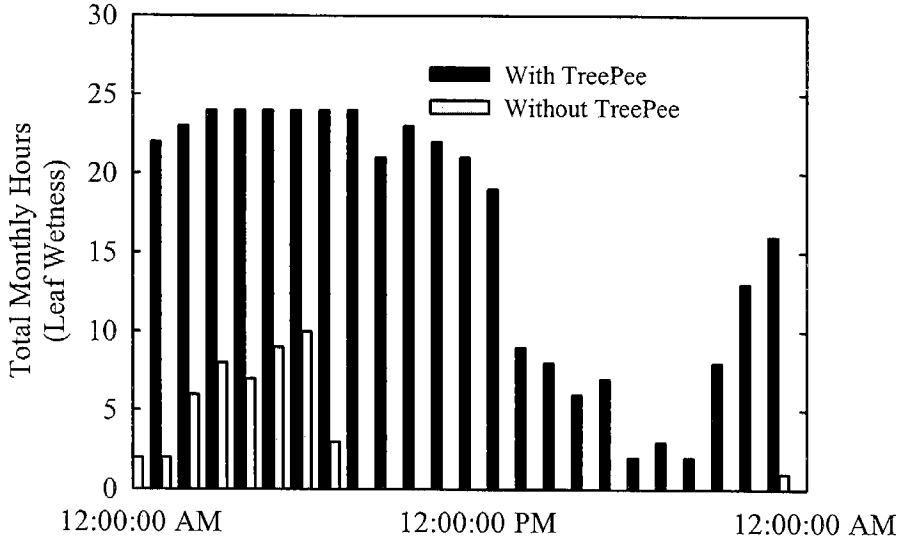
April, 2000



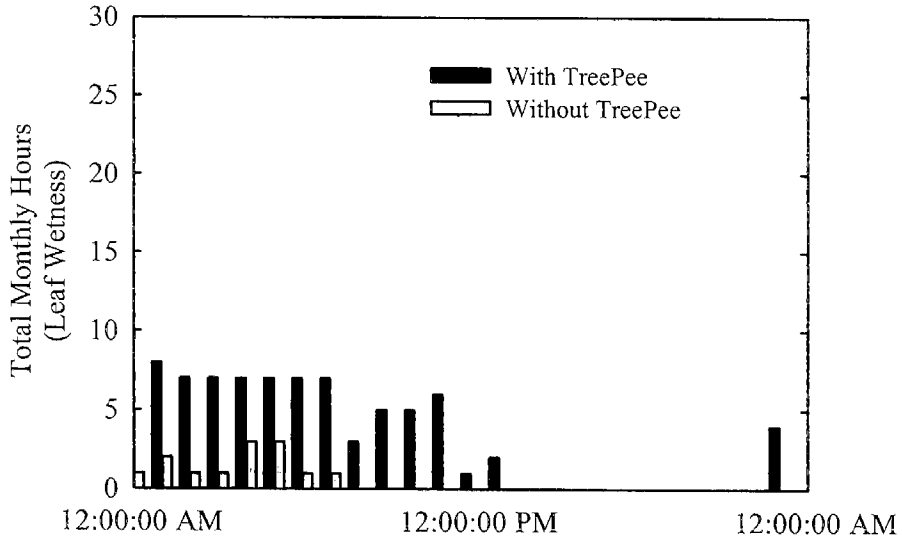
May, 2000



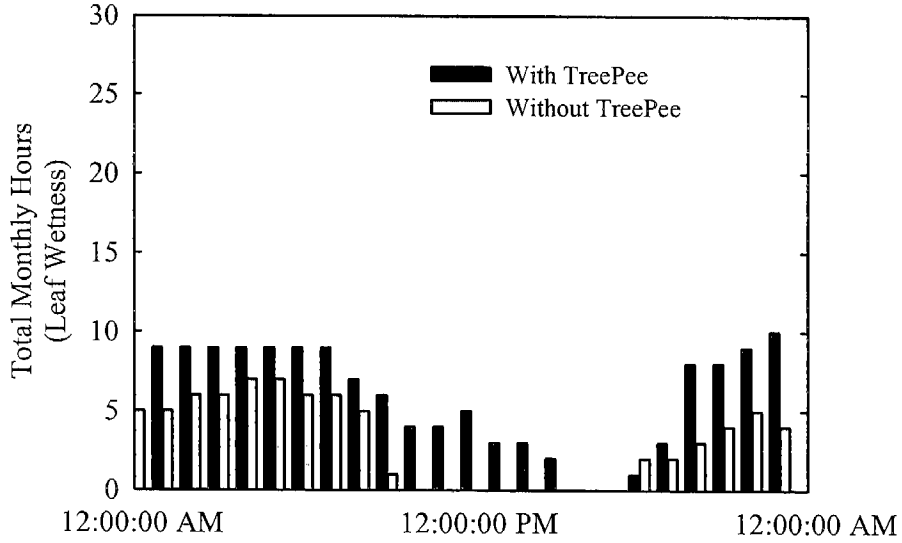
June, 2000

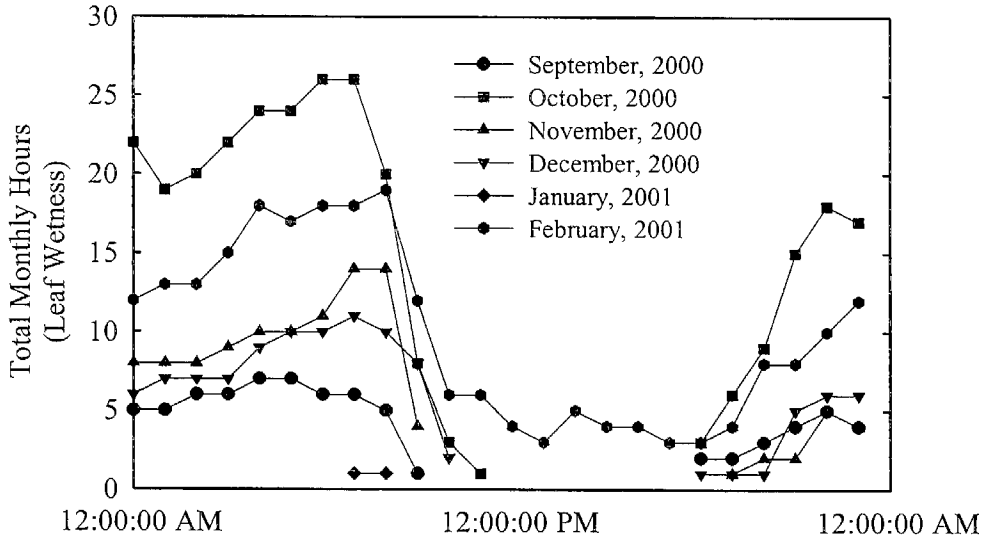


July, 2000

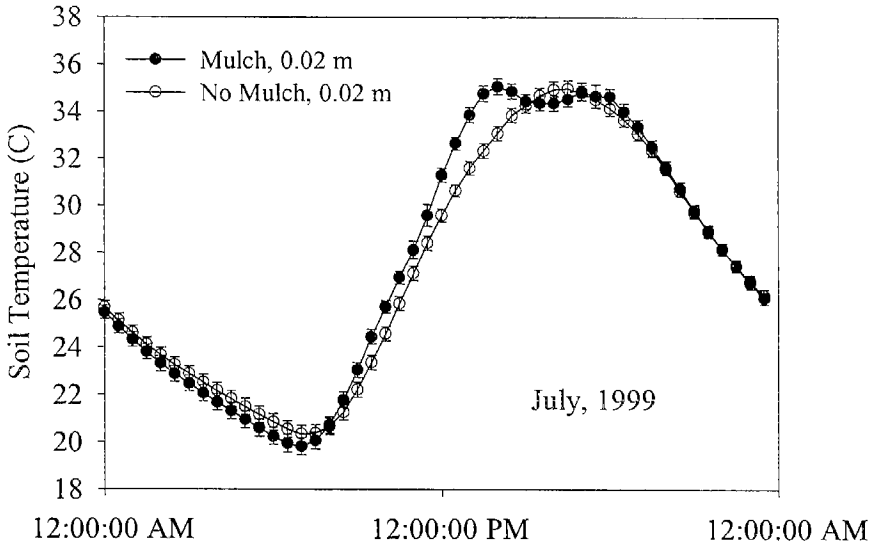


September, 2000




30
25
20
15
10
5
0
Total Monthly Hours
(Leaf Wetness)
September, 2000
October, 2000
November, 2000
December, 2000
January, 2001
February, 2001
12:00:00 AM
12:00:00 PM
12:00:00 AM

Appendix H



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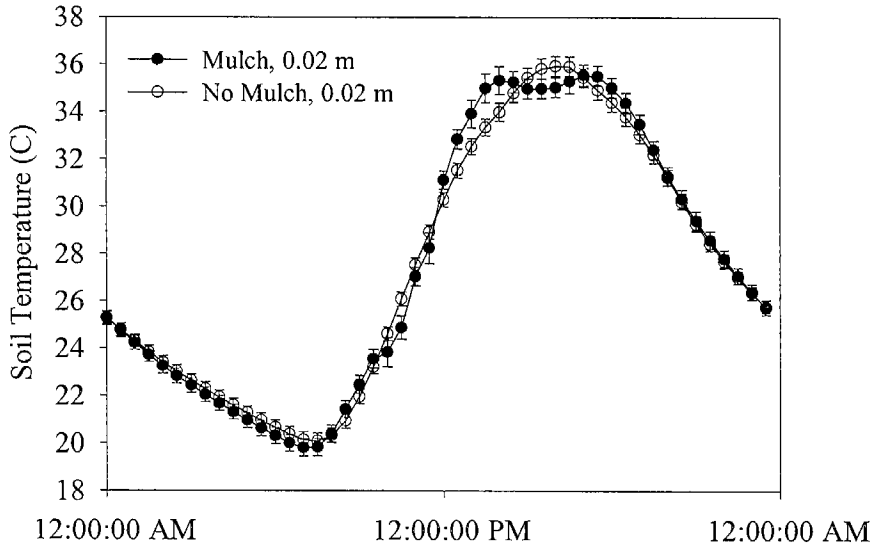

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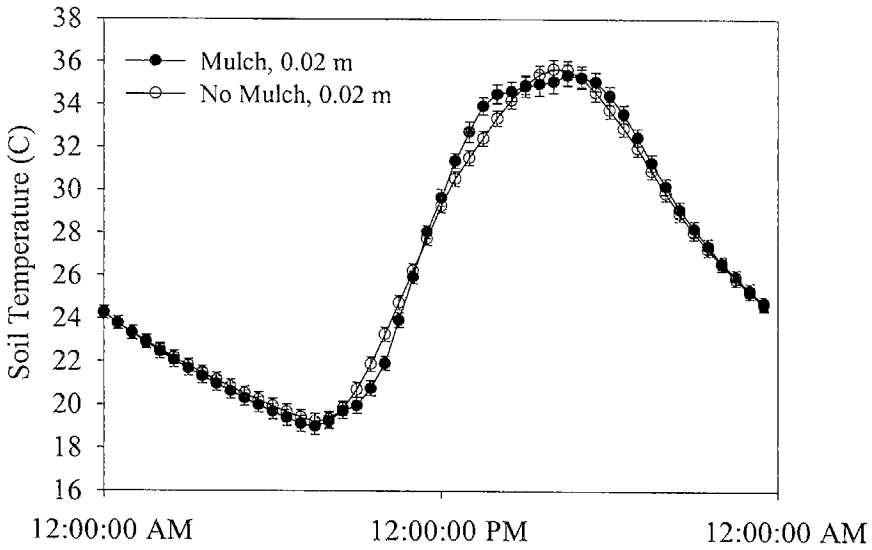

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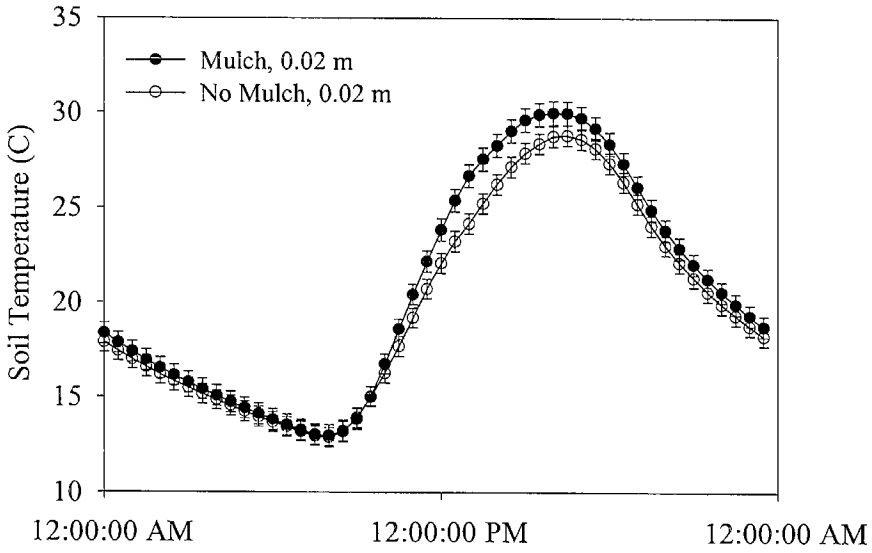

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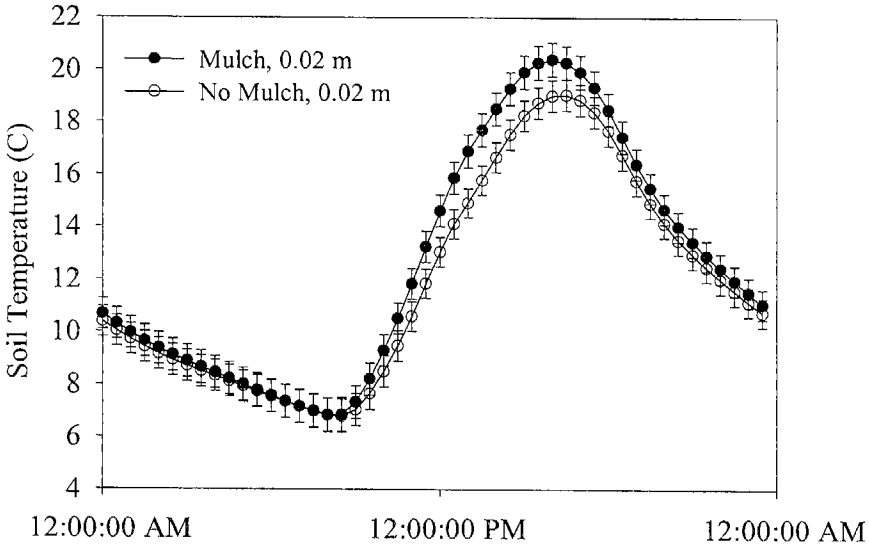
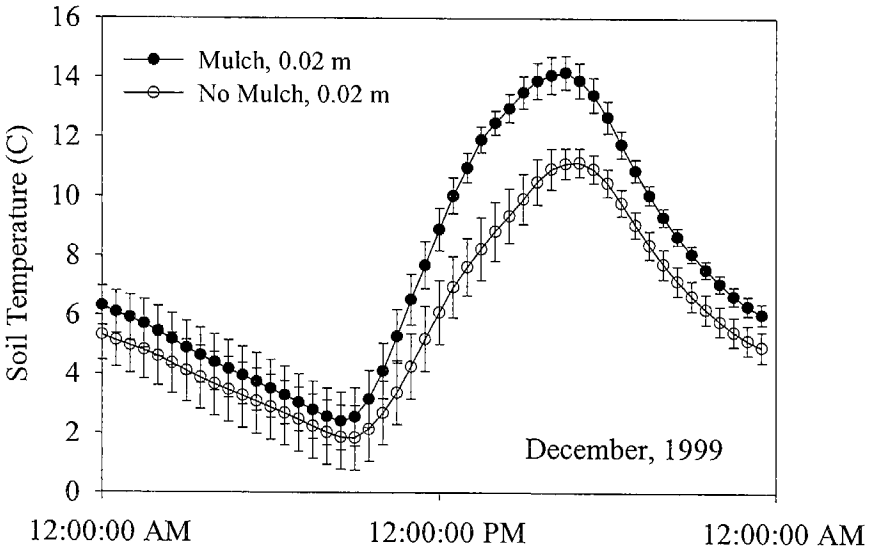
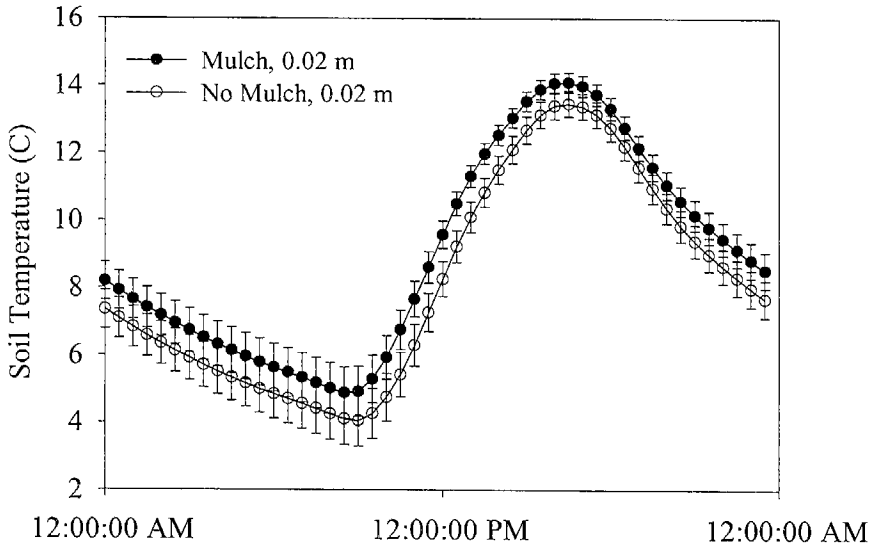




January, 2000



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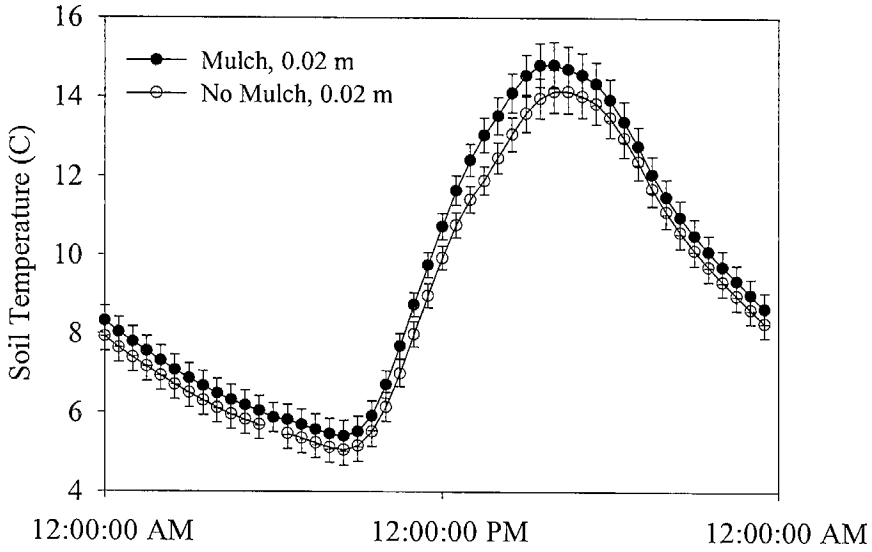

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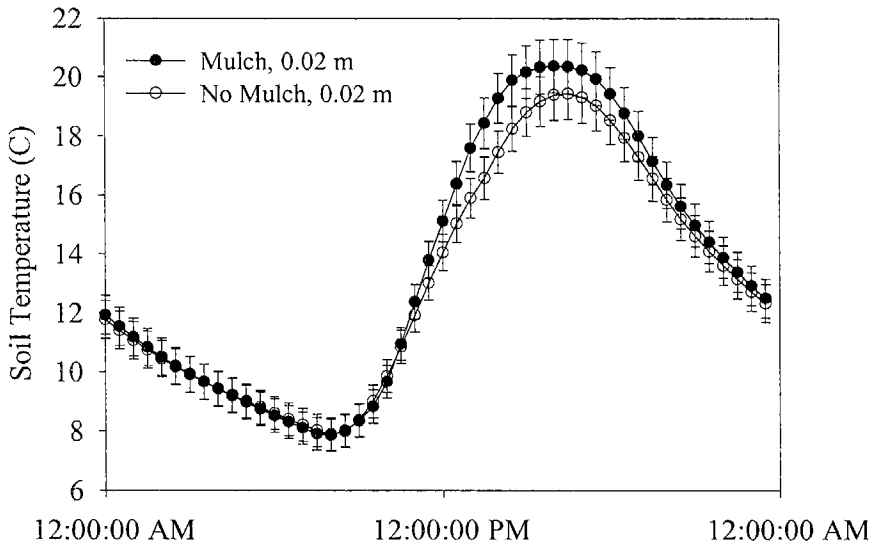

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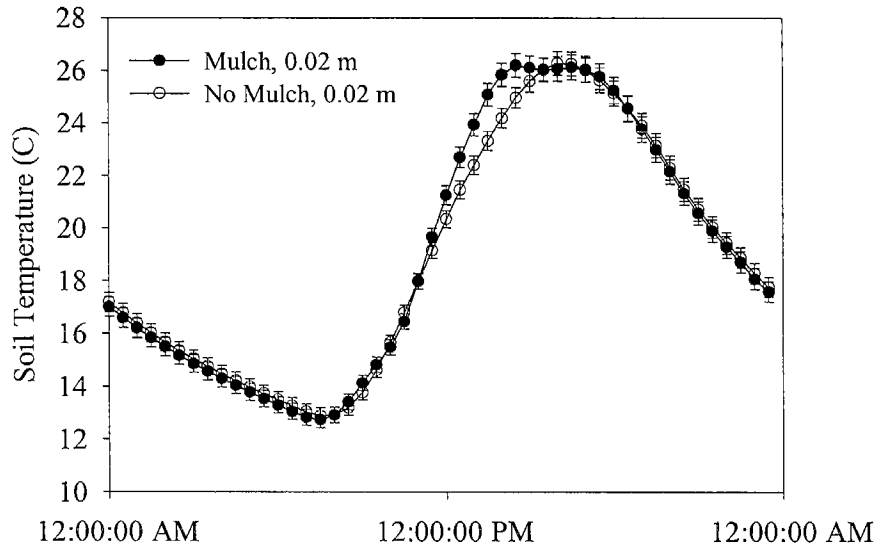
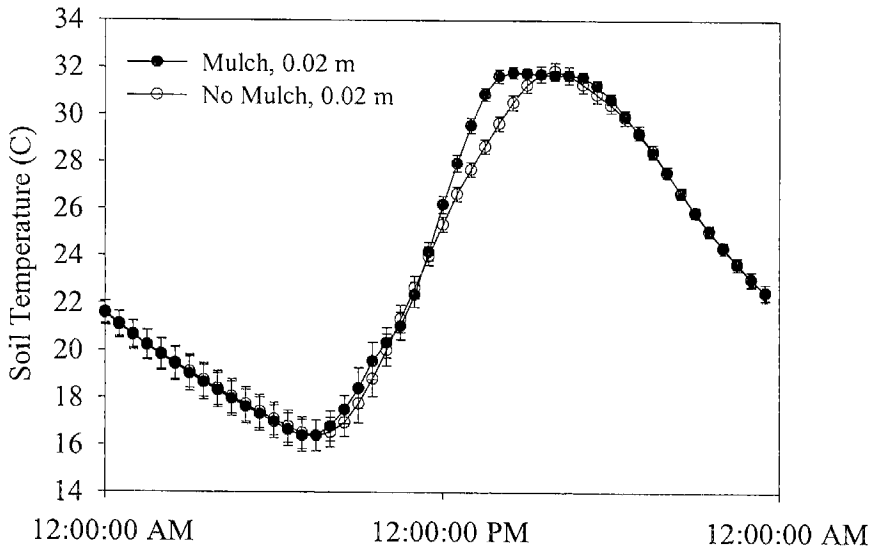


May, 2000



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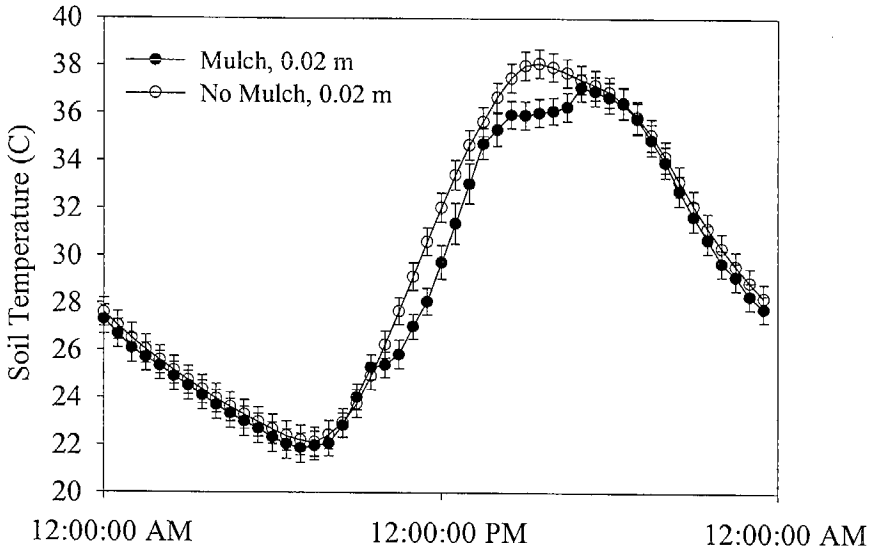

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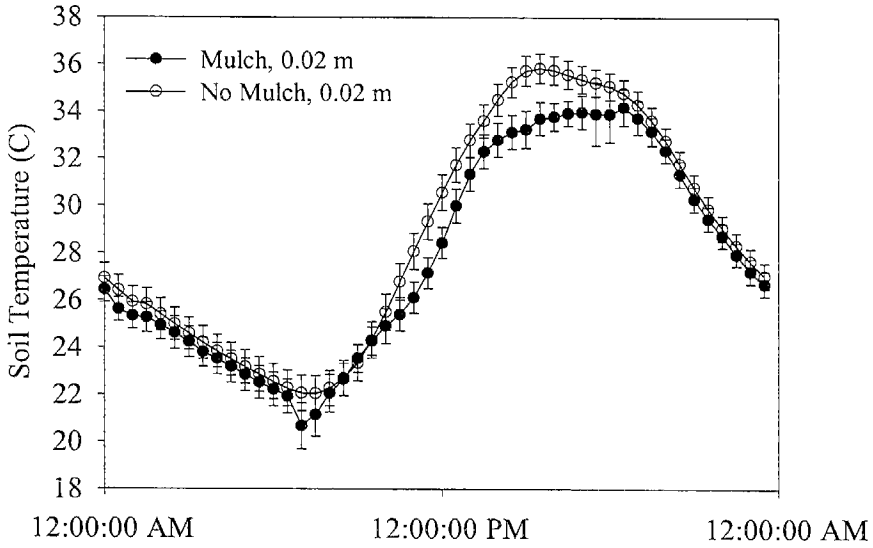

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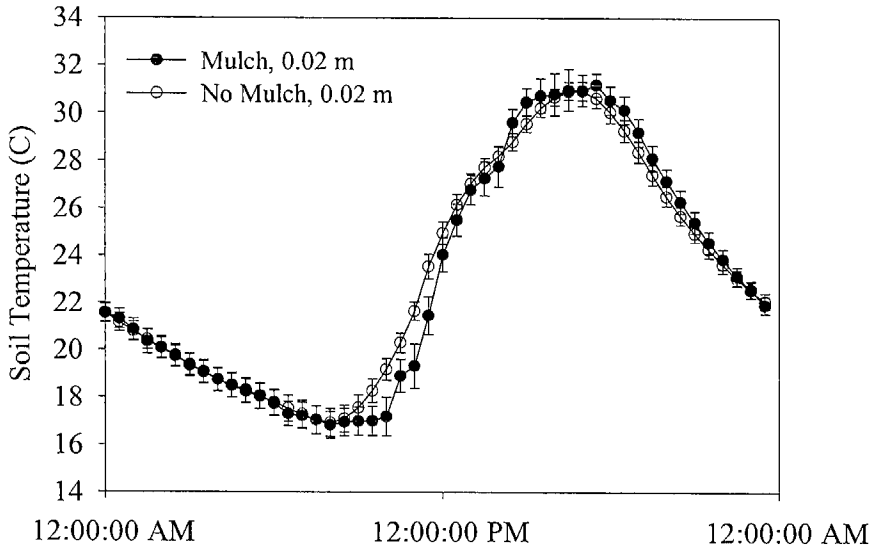

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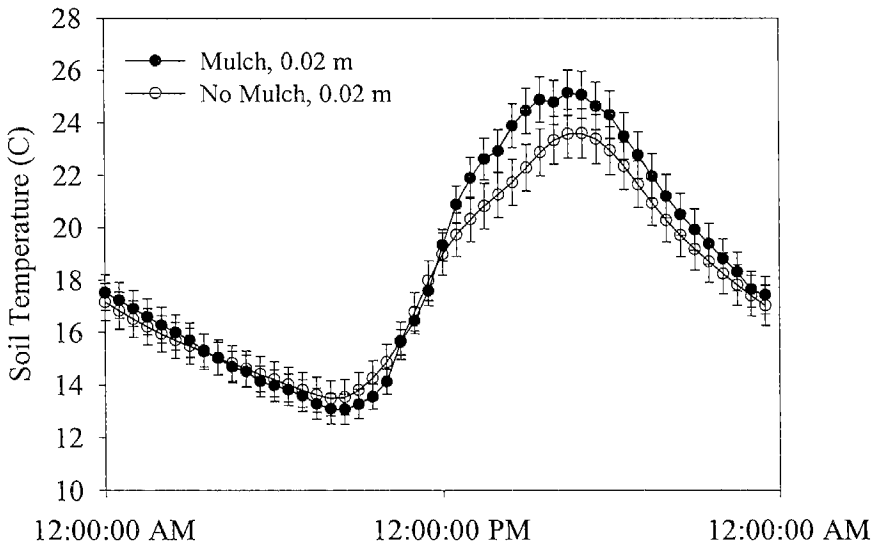

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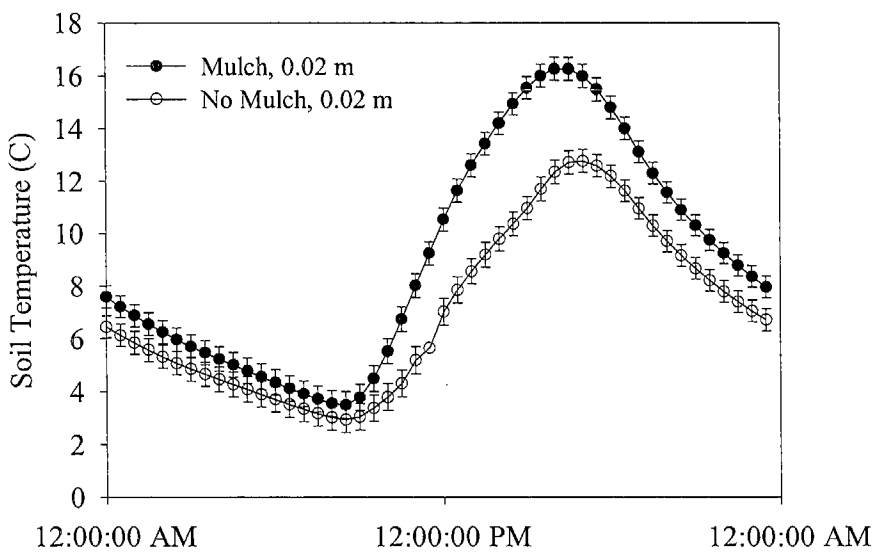
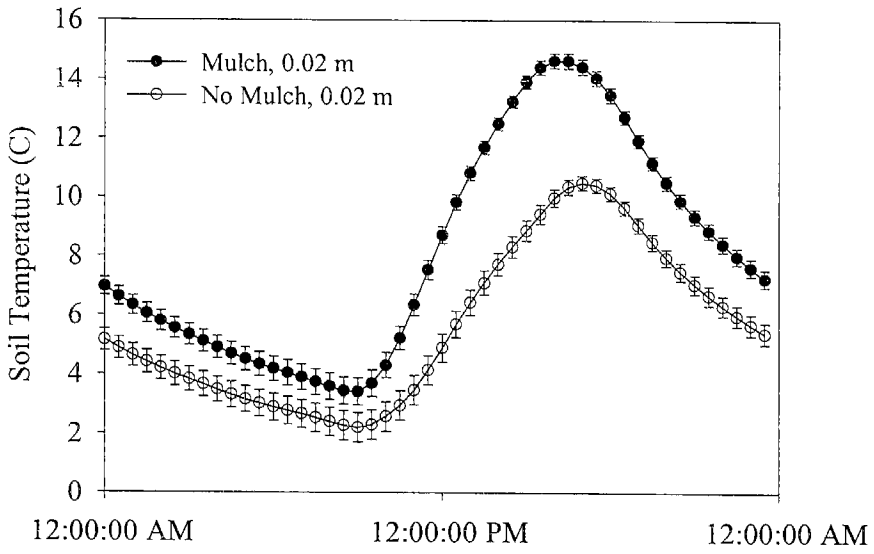
December, 2000