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Influence of Irrigation on the Microclimate and Development of White Mold Disease in Dry Edible Beans

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INFLUENCE OF IRRIGATION ON THE MICROCLIMATE AND DEVELOPMENT OF WHITE MOLD DISEASE IN DRY EDIBLE BEANS

BY

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INFLUENCE OF IRRIGATION ON THE MICROCLIMATE AND DEVELOPMENT OF WHITE MOLD DISEASE IN DRY EDIBLE BEANS

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Production of dry edible beans in the western Great Plains is limited by white mold disease. Although the climate of this region is semi-arid, irrigation has apparently produced a microclimate favorable for the disease.

A study was conducted in 1976 near Scottsbluff, Nebraska which examined the effect of irrigation on the microclimate in dry edible beans. Also examined was the influence of irrigation frequency on the microclimate and development of white mold disease. Microclimate parameters measured in the canopy included; air and leaf temperature, vapor pressure, stem temperature, soil temperature, dew intensity and duration and soil moisture. Leaf areas were also determined regularly.

The results indicated that the immediate effects of irrigation on the microclimate include: decreasing daytime air temperatures 3 to 4° C; reducing leaf temperatures up to 5 to 6° C; lowering daytime soil temperature as much as 10° C; increasing daytime vapor pressure up to 10 mb; and increasing percent soil moisture by as much as 10%. These effects persisted for several days. Little effect of irrigation on the microclimate was observed at night. These results suggest that irrigation increased transpiration rates, and reduced soil heating, and sensible heat flux to the air from the soil and plant.

Results also indicated that irrigation frequency significantly affected the microclimate. As a result of modifying the energy balance, the heavy irrigation treatment resulted in lower air, leaf and soil temperatures, and higher soil moisture values than those in the normal irrigation treatment. These effects were also influenced by the more dense canopy that developed under heavy irrigation.

Soil temperature and soil moisture values were more favorable for the production of apothecia in the heavy irrigation treatment than in the normal irrigation treatment. These results may explain the larger number of apothecia observed in the heavy irrigation treatment. Larger amounts of infection were observed in the heavy irrigation treatment, apparently becuase results suggest that it induced a more favorable microclimate for disease development than did the normal irrigation treatment.

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Lawrence E. Hipps

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CHAPTER I

INTRODUCTION AND OBJECTIVES:

Great Northern dry edible beans, *Phaseolus vulgaris* L., are grown extensively in portions of the western Great Plains. The semi-arid climate in this region with hot days and cool nights, coupled with ample irrigation water provides ideal conditions for growing dry edible beans.

Production of beans in this region is often limited by white mold disease caused by the fungus *Sclerotinia sclerotiorum* (Lib.) dBy = *Whetzelinia sclerotiorum* (Lib.) Korf and Dumont (1972). This pathogen also attacks many other vegetable crops, especially when these crops are grown in humid regions such as in the eastern part of the United States. The semi-arid climate of the western Great Plains should not be favorable for white mold. Nevertheless, it does exist there, and in some years economic loses to the dry edible bean producers are substantial.

Researchers have related severity of white mold infection with the amount of irrigation. Heavy irrigation has been associated with greater disease severity. Thus, irrigation has apparently produced a microclimate within bean canopies which promotes the disease. Modification of the microclimate by altering irrigation practices offers one possibility for disease control (Steadman, Blad and Schwartz, 1976).

During the summer of 1976 research was conducted to evaluate the effect of irrigation on the microclimate in dry edible beans. The study utilized the design of Blad, Steadman and Weiss (1977). Subsidiary objectives required to achieve the main objective include: 1) determination of the difference between the microclimate of two plots of one cultivar which were irrigated at the same frequency, but where the irrigation of one plot was always delayed three days; 2) evaluation of the effect of different irrigation frequencies on the microclimate, soil moisture regime and canopy development in plots of the same cultivar. The effects of the irrigation modified environments on the various stages in the development of white mold disease are also examined.

CHAPTER II

REVIEW OF LITERATURE

A plant disease can only exist in a favorable environment. Thus, the development and spread of a plant pathogen will be governed, to a large extent, by the microclimate in a plant canopy. Relationships between microclimate and plant disease have been examined in numerous investigations. However, most researchers have not measured microclimate parameters which control the development of disease, but have only related the severity of a disease to one or more climatic features.

2.1 Temperature and Moisture:

Plant diseases are influenced by several environmental factors, particularly the factors of temperature and moisture. Wallin and Loonan (1971), found that the most favorable temperature for sugar beet spot, *Cercospora beticola*, in a controlled environment was 29° C. The number of spots produced after a 48 and 72 hour leaf wetness period was respectively 30 and 80 times the number produced after a 24 hour period of wetness. Boll rot in cotton was favored by high relative humidity, the presence of free moisture, and low light intensity (Ranney, et al. 1971). The severity of white mold disease in vegetables in Florida correlated well with amounts of precipatation, and was greatest when air temperature was 21° C. (Moore, 1955).

Dew affects the development of plant diseases, expecially in semi-arid climates where dew may provide a major source of moisture. An extensive review of the effects of dew on plant disease is given in Wallin (1967). Wallin states that "dew deposition will favor any plant pathogen whose spores or cells require a water film to germinate or divide." Prabhu and Wallin (1970) reported that the development of wheat stem rust was favored by days with 8 or more hours of dew when average temperature was greater than 10° C, during and for 24 hours after the dew period.

Many researchers have attempted to correlate plant disease severity with conventional and readily available meteorological data obtained some distance away from the study site. These data are easier to obtain than data within the crop canopy. Minimum temperature greater than 20° C and relative humidity of 100% for six hours or more on several consecutive nights were found to provide favorable conditions for severe outbreaks of Southern Corn Leaf Blight

(Schenck and Stelter, 1974). In their study, meteorological data was recorded over sod located several hundred meters from the corn crop under observation. Periods of high humidity after rains measured at weather stations in England and Wales were found to correlate well with apple scab development (Preece and Smith, 1961).

Upper air flow patterns at 500 mb were associated with both favorable and unfavorable surface weather conditions for sugar beet leaf spot development in Iowa by Gullach and Wallin (1970). Stable upper air longwave patterns with wave numbers of 3 to 5 were associated with unfavorable surface conditions, while instability of the longwave pattern resulting in numerous shortwave upper air disturbances passing over Iowa, resulted in surface conditions favorable for leaf spot development. Favorable conditions were defined as temperatures between 10 and 32° C, and relative humidity of 90% or greater for 12 hours or more.

The relationships between meteorological data and disease development and severity have been used to forecast the outbreak of plant diseases. Some problems encountered when attempting to forecast plant disease epidemics or schedule disease control operations in a semi-arid climate have been discussed by Palti and Rotem (1973). They noted that regional forecasting of plant disease is impractical in warm semi-arid climates due to the dominance of microclimatic factors.

2.2 Development of White Mold Disease:

There are several distinct stages in the development and spread of white mold. The life cycle as shown in Figure 1 was reported for Nebraska by Cook, Steadman and Boosalis (1975). The development of the disease is shown schematically in Figure 1. Each stage is governed by specific environmental requirements. Sclerotia, which are formed by the fungus during the latter stages of the disease, are the major source of inoculum. Sclerotia are very resistant to adverse conditions and may overwinter in the soil (Hungerford and Pitts, 1953; Partyka and Mai, 1962).

The germination of sclerotia to form spore producing bodies, known as apothecia, is governed by soil moisture and soil temperature. Abawi and Grogan (1975) found that soils must be nearly moisture saturated before apothecia formation can occur. The soil temperature range for apothecia production was found to be 10 to 25° C, with the optimum temperature range between 10 and 15° C. Duniway, Abawi and Steadman* (1977-unpublished data) found that germination occured in a soil moisture range of 14 to 32%. The optimum value was 25%. Morrall (1977) found that

*Personal Communication

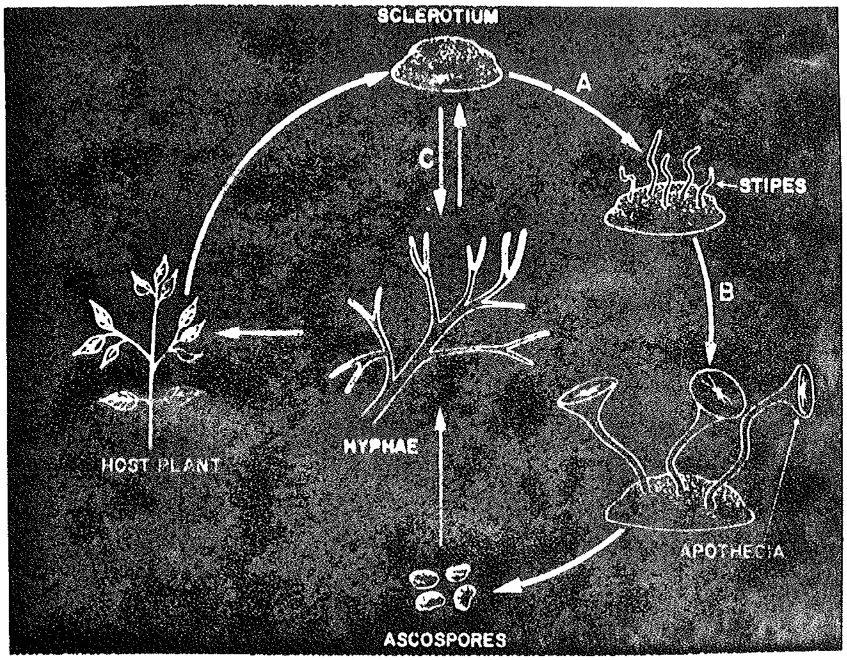

FIGURE 1. SCHEMATIC OF THE LIFE CYCLE OF SCLEROTINIA SCLEROTIORUM. FROM STEADMAN AND NICKERSON (1975).

germination occurred between 0 and -7.5 bars, but not at lower water potentials. The effect of moisture fluctuations on the germination of sclerotia has not yet been examined.

Apothecia periodically emit showers of ascospores. These ascospores may survive adverse conditions until the environment becomes favorable for germination to occur. Partyka and Mai (1962) and Grogan and Abawi (1975) found that ascospores survive longer at low rather than high relative humidity. Ascospores can only germinate and colonize on injured plant parts or senescent tissue. Free water must also be present on these surfaces (Abawi and Grogan, 1975). Ascospores will not infect healthy plants unless an exogeneous energy source, such as senescent tissue is available. Abawi and Grogan (1975) found 25° C to be the optimum temperature for ascospore germination.

After colonization of senescent tissue the disease may infect healthy plants with mycelial threads. The disease may then spread rapidly under favorable conditions. Mycelial growth and lesion initiation and development were found to be maximal at 20 to 25° C (Abawi and Grogan, 1975).

2.3 Cultural Practices and Plant Disease:

Many cultural practices affect the microclimate of a crop. Hence cultural practices may influence disease development. White mold in dry edible beans has been shown to be favored by the existence of a dense plant canopy (Coyne, et al., 1974; Haas, 1973; Blad, Steadman and Weiss, 1977; Moore, 1955; Partyka and Mai, 1962).

Haas (1973) observed that beans planted in north-south rows perpendicular to prevailing winds, sustained more white mold infection than those in east-west rows. However, Crandall, et al. (1971) found lower relative humidity and higher temperatures in bush beans planted in rows perpendicular to the prevailing wind than in those in rows parallel to prevailing winds. These conditions would be less favorable for a fungal disease such as white mold. In Washington State, pole beans planted in rows parallel to the prevailing wind were associated with less gray mold, _Botrytis cinerea_, than those in rows perpendicular to the prevailing wind (Campbell, 1949). Campbell observed that gray mold was most severe where rows were closest together, as was also reported by Steadman, Coyne and Cook (1973).

The fungus _Sclerotinia trifoliorum_ was severe in five forage species grown on north-facing slopes, but was not observed on the south-facing slopes in a study conducted in West Virginia (Bennett and Elliott, 1972).

It has been demonstrated that windbreaks can modify the microclimate of a sheltered crop (Rosenberg, 1967;

Brown and Rosenberg, 1972). Windbreaks cause higher relative humidity, lower evaportranspiration rates and less turbulence. White mold disease was severe in a vigorous growth of dry edible beans grown adjacent to a windbreak (Coyne, et al., 1974).

Irrigation is a cultural practice which exerts a major influence on the microclimate of crops. Mist irrigation lowered leaf temperatures up to 20° C, air temperatures as much as 5° C, and soil temperature up to 2° C in potatoes (Sanders and Nylund, 1972). Hobbs (1973) demonstrated that intermittent sprinkler irrigation reduced canopy air temperature by an average of 3° C in potatoes and bush beans. Researchers working with bush beans found that mist irrigation lowered canopy air temperatures 2° C, and increased relative humidity up to 20% (Crandall, et al., 1971). The effects varied with differing row widths.

Kemp, et al., (1974) found that low volume sprinkler irrigation, for cooling purposes when air temperature exceeded 27° C, increased the quality of snap beans. Anderson, et al. (1975) found that intermittent sprinkler irrigation when air temperature exceeded 7° C, reduced bud temperatures of apple trees up to 34° C. The irrigation treatment also delayed blooming 17 days, which indicated that this method may be a viable technique for the prevention of frost damage.

Sprinkler irrigation reduced leaf temperature by as much as 10 to 12° C, and increased transpiration in potatoes (Lomas, et al., 1972). Kohl (1973) determined that soil temperature at the 10 cm depth of a plot irrigated every 14 days was 2° C above that of a daily irrigated plot with cover, and 4° C above a daily irrigated plot without cover, on the 7th day after irrigation. The study was conducted in sprinkler irrigated potatoes. Lomas and Mandel (1973) studied the effects of below and above canopy sprinkler irrigation on the microclimate of an avocado plantation. Above canopy irrigation was more effective in decreasing air temperatures and increasing relative humidity during the period following irrigation.

Sprinkler irrigation of alfalfa reduced downwind air temperatures less than 1° C, and increased vapor pressure less than 1 mb downwind from a sprinkler lateral (Kohl and Wright, 1974). These researchers noted that the observed changes would not significantly influence plant growth or evapotranspiration.

Furrow irrigation of soybeans reduced air temperatures as much as 11° C, and increased relative humidity up to 40% (Downey and Caviness, 1973). Vertical gradients of temperature and humidity were also affected.

Thus, researchers have shown that plant diseases are influenced by several environmental conditions such as temperature and moisture. Favorable environments for disease development may be provided by macroclimatic or microclimatic conditions. The microclimate has been shown to be influenced by certain cultural practices such as irrigation.

Reichert and Palti (1967) reviewed the climatic conditions under which white mold will occur. They concluded that white mold will not be a problem in regions where rain falls only when temperatures are greater than 25-27° C or in semi-arid regions. Based on those findings white mold should not be a threat in the semi-arid climate characteristic of the western Great Plains. Since dry beans in this region are all irrigated, the microclimate in a bean canopy is apparently modified by irrigation to produce a suitable environment for white mold disease.

CHAPTER III

MATERIALS AND METHODS:

3.1 Experimental Design:

The study was conducted at the University of Nebraska Agricultural Meteorology field laboratory located near Scottsbluff, Nebraska (10° 57' N; 103° 41' W; 1225 m above msl). The experiment utilized the design of a larger continuing study by Blad, Steadman and Weiss (1977). Six plots of 30 rows each were assigned to the study (see Figure 2). Each plot was 19.7 meters by 18 meters. Three cultivars of beans were grown: Great Northern "Tara," which has a dense growth habit and high yield potential, occupied the two plots at the south end of the field; "Aurora," a cultivar with a more upright growth habit and a porous canopy, was planted in the middle two plots; Great Northern "U. I. No. 59," a cultivar with a canopy structure that is rather upright, was grown in two plots at the north end of the field. All of the plots were immediately adjacent to one another. This was the third consecutive year that this design was utilized. The beans were planted June 2, 1976, in 56 cm rows.

The plots were bordered by alfalfa on the west, and a gravel road and sugar beet field on the east. Elevation

TARA - DENSE GROWTH HABIT
AURORA - UPRIGHT GROWTH HABIT
GN NO. 59 - UPRIGHT GROWTH HABIT

NORMAL IRR. = 5.5 CM OF WATER EVERY 10 DAYS
HEAVY IRR. = 5.5 CM OF WATER EVERY 5 DAYS

#1 TARA NORMAL IRR.	#2 TARA HEAVY IRR.	#3 AURORA HEAVY IRR.	#4 AURORA NORMAL IRR.	#5 GN 59 NORMAL "LATE"	#6 GN 59 NORMAL "EARLY"

FIGURE 2. LAYOUT AND DESIGN OF THE STUDY.

of the sugar beet field was about a meter higher than the bean plots.

The plots were furrow irrigated in alternate rows. All of the beans received equal amounts of water up to July 21. After that date, two irrigation frequencies were applied. "Heavy" irrigation-approximately 5.5 cm of water applied every 5 days, and "normal" irrigation-5.5 cm applied every 10 days. Water was applied at the rate of 0.694 cm per hour for about 8 hours.

One plot each of Aurora and Tara beans received the heavy irrigation. The other plot in each pair received normal irrigation, as illustrated in Figure 2. Both plots of G. N. No. 59 received normal irrigation; however, plot 6 was always irrigated three days ahead of plot 5. This allowed examination of the effects of irrigation on the microclimate within the bean canopy during the three day lag periods. Table I is a listing of the irrigation schedule utilized during the study.

3.2 Microclimate and Instrumentation:

Microclimatic parameters measured in the canopy included air temperature, leaf temperature, stem temperature, vapor pressure, soil temperature, soil moisture, and dew intensity and duration. Leaf areas were also determined weekly.

TABLE I.

IRRIGATION SCHEDULE - SUMMER 1976

PLOT NO.	DATE	TIME PERIOD
PLOT 2 and 3	AUGUST 5	10:55-19:55
PLOT 6	AUGUST 7	11:30-19:45
PLOT 1 and 4	AUGUST 10	13:30-22:10
PLOT 2 and 3	AUGUST 11	22:30-08:00
PLOT 5	AUGUST 11	08:00-17:00
PLOT 2 and 3	AUGUST 15	13:30-21:00
PLOT 6	AUGUST 17	09:50-20:00
PLOT 1 and 4	AUGUST 19	15:00-23:00
PLOT 2 and 3	AUGUST 20	23:00-08:00
PLOT 5	AUGUST 20	08:00-16:00
PLOT 2 and 3	AUGUST 25	11:00-22:30
PLOT 6	AUGUST 26	22:30-08:30
PLOT 5	AUGUST 28	10:15-17:45
PLOT 1 and 4	AUGUST 30	11:00-19:30
PLOT 2 and 3	AUGUST 31	23:00-08:30

Air temperature was measured at 10 and 25 cm above the cultivated furrow in each plot with 5 mil evanohm-constantan thermocouples. Evanohm is a nickel base alloy of 20% chromium, 2.5% copper and 2.5% aluminum. The electrical properties of evanohm are similar to those of copper, except the thermal conductivity of evanohm is less than that of cooper. Thus, less heat is conducted to or from a thermocouple junction by evanohm than by copper. Starr (1974) has shown that the emf signal generated by an evanohm-cooper junction is too small to be measured by the data logger used in the study. Therefore, the thermocouples were connected to copper-constantan extension wires.

The air temperature thermocouples were mounted on dowel rods and shaded from solar radiation by an aluminum sun screen in each plot. All thermocouples were coated with a thin layer of epoxy.

Leaf temperatures were measured at 10 and 25 cm above the base of a bean plant in each plot. Two evanohm-constantan thermocouples, wired in parallel to provide an integration of temperature, were attached to the underside of two trifoliate leaves at each level.

Stem temperatures were measured in each plot with two evanohm-constantan thermocouples wired in parallel. These were attached to two separate stems several centimeters above the base of a plant.

Soil temperature was measured in each plot with three copper-constantan thermocouples wired in parallel and placed at a depth of 1 cm beneath an irrigated furrow. One thermocouple was placed in the middle and one at each side of the furrow.

All of the thermocouples except the soil and 10 cm air sensors, were wired differentially for greater resolution. This was accomplished as follows: the air temperature at 10 cm was determined by referencing the output against a 0° reference. Four additional evanohm-constantan thermocouples were attached to the dowel under the sun screen such that they were adjacent to this thermocouple. Thus, it was assumed that they were all the same temperature. These four thermocouples were wired in series to the thermocouples measuring stem temperature, air temperature at 25 cm and leaf temperatures at 10 and 25 cm. Since each of the above measurements utilized a separate reference, they were all electrically isolated. By determining temperatures differentially a resolution of 0.025° C was achieved for differences in temperature.

Vapor pressures in the canopy was determined in each plot with a model SP129A Honeywell dewprobe placed 10 cm above a cultivated furrow. These consisted of a lithium chloride treated cloth sleeve bobbin under an aluminized shield. Wire was bifilar wound around the bobbin. An operating temperature was measured in the bobbin, which was related to the dewpoint (see Figure 3).

Dew intensity and duration were determined in each plot from dew plates similar to those described by Davis and Hughes (1970). These consisted of a metal grid covered with gray latex paint. The amount of water present on a dew plate is proportional to the amount of current that can be passed through the grid at a given voltage. However, instead of recording the current on a strip chart recorder as was done by Davis and Hughes, the voltage drop across a resistor was measured. Voltage was applied to the dew plates only when their output was to be sampled. This precaution was needed to prevent a capacitance action in the dew plates which would reduce the amount of current that could be passed through them. Further, the heat generated by a continuous current flow could have evaporated some of the water on the dew plate leading to error in the recorded dew intensity and duration. The dew plates were calibrated by thoroughly wetting them with distilled water and adjusting their output under known voltage to

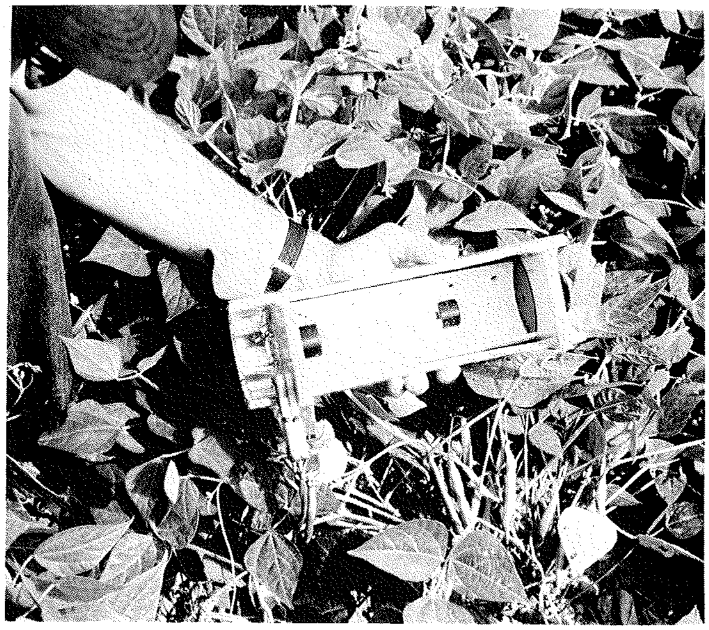

FIGURE 3. DEWPROBE OF THE TYPE USED IN THE STUDY.

full scale. Two dew plates separated by about 45 cm were wired in parallel and placed at a height of 10 cm above the surface of a cultivated furrow in each plot.

Conductors from all of the instruments were routed to a small junction box near the center of each plot. All instruments were located within one meter or so of these junction boxes. The junction boxes were linked to a large junction box which was linked to an 80 channel data logger located in a building 50 meters north of the plots. Measurements were sampled at 10 minute intervals and their output recorded on punch-paper tape. The data was converted to parametric form through a series of computer programs and was plotted with a Cal Comp plotter (Brown and Rosenberg, 1969).

Leaf area was determined weekly for each plot in order to arrive at a quantitative measure of the canopy structure. A one meter square wire grid was placed over two locations in each plot. Plants were segmented in 10 cm height increments, and were differentiated to within and between row components. A Lambda model L13050A area meter was used to measure the leaf area.

Soil moisture was measured gravimetrically on a daily basis from August 1 until the conclusion of the study. Four locations were sampled in each plot. These included the irrigated furrow, the side of the irrigated furrow, adjacent to the plant and the cultivated furrow. Figure 4 illustrates the locations of the samples. Samples were taken to a depth of 4 cm since most sclerotia which germinate to produce apothecia do so in the upper few centimeters of the soil. Samples were taken from three selected areas in each plot. Samples from all three areas in each plot were combined so that average values of the three samples were obtained for each of the four locations in each plot.

As part of the overall study Schwartz (1977) periodically determined the number of sclerotia which germinated to produce apothecia for sample areas in each plot.

3.3 Modification of the Energy Balance to be Expected by Irrigation:

The energy balance at the earth's surface can be written:

$$Rn + LE + A + S = 0$$

where Rn is the net radiation, S is the soil heat flux, A is the sensible heat flux to or from the air, and LE is the latent heat flux.

Furrow irrigation would be expected to modify the energy balance by increasing the magnitude of LE, and decreasing A

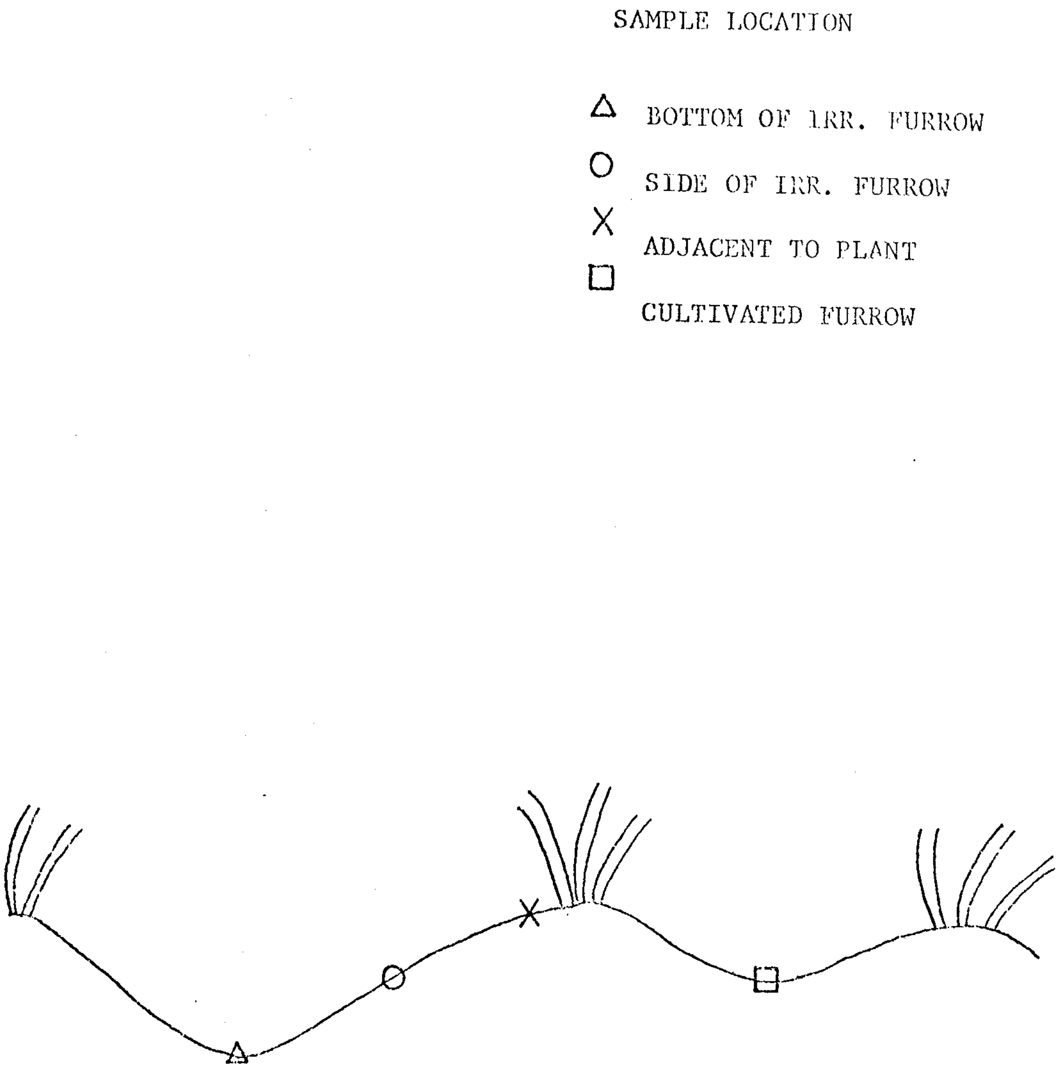

FIGURE 4. LOCATIONS OF SOIL MOISTURE SAMPLES.

and S. The wet soil surface resulting from irrigation will cause an increase in the proportion of energy consumed in evaporation and a corresponding decrease in the proportion of energy available to heat the soil, thereby causing a decrease in the soil heat flux and sensible heat flux to the air. Transpiration increases may be expected to occur after irrigation if water has been limiting (Lomas, et al., 1972; Lemon, et al., 1957). An increase in the transpiration by the plant will reduce the amount of sensible heat generated by the plant. The plant may even act as a heat sink under these circumstances. Thus, the reduction of sensible heat flux to the air caused by irrigation will result from increases in transpiration and evaporation from the soil. Figure 5 illustrates these processes.

The degree of modification of the energy balance in a canopy due to irrigation will depend on the density of the crop canopy. Very little solar radiation will reach the ground surface under a very dense canopy. Under these circumstances, sensible heat to the air from the soil and soil heat flux may be influenced more by the dense canopy than by the irrigation. Thus, the major effect of irrigation will be manifested either by the direct effects on the energy balance of the plants or indirectly on the energy balance of the soil through promotion of a dense canopy.

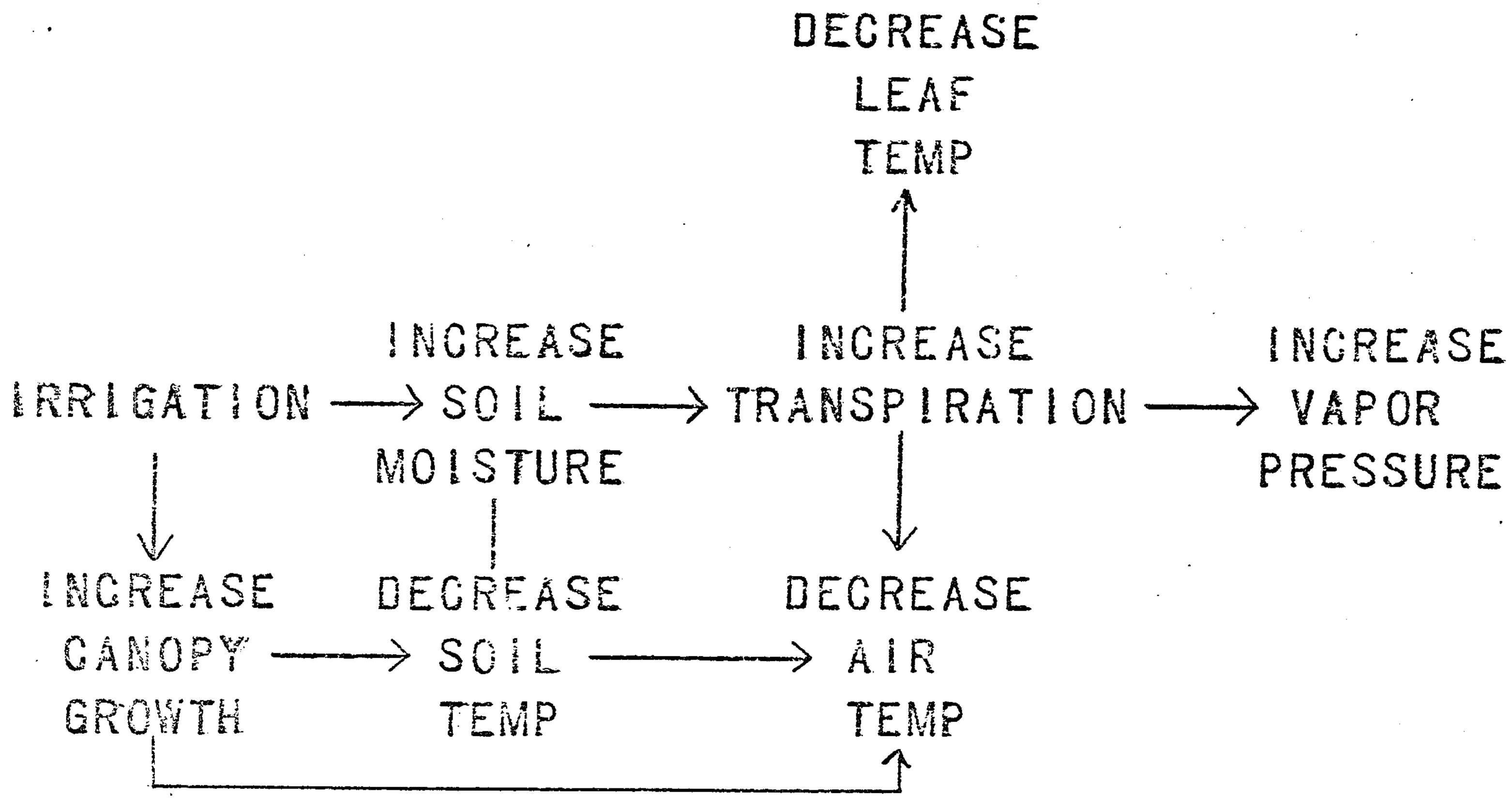

FIGURE 5. HYPOTHESIZED SCHEMATIC OF EFFECTS OF IRRIGATION ON MICROCLIMATE

In summary, irrigation will result in increased evapotranspiration, which will cause a reduction in sensible heat flux to the air from the soil and plants. If irrigation has promoted a dense canopy, the decrease in sensible heat flux from the soil to the air will be largely the result of the reduction of radiation penetration into the canopy.

CHAPTER IV

RESULTS AND DISCUSSIONS:

EFFECT OF IRRIGATION ON MICROCLIMATE:

Data from the two G. N. No. 59 plots were analyzed to determine effects of irrigation on the microclimate. Both plots were treated alike except that plot 6 was always irrigated three days ahead of plot 5. Plot 6 will be referred to as the "early" plot, and plot 5 as the "late" plot.

4.1 Irrigation and Soil Moisture:

The change in soil moisture after irrigation is shown in Figure 6. Soil samples taken adjacent to the plant showed a similar response to irrigation as those in the other locations. The horizontal bars below the x axis denote the three day periods when it was possible to study the influence of irrigation. Increases of percent soil moisture as great as 10% persisted for several days. An increase in soil moisture should affect other parameters such as soil and air temperature and vapor pressure.

4.2 Irrigation and Soil Temperature:

The response of soil temperature to irrigation is illustrated in Figures 7 and 8. The results indicate that soil temperature in the irrigated or "early" plot began to decrease relative to the other plot immediately after the

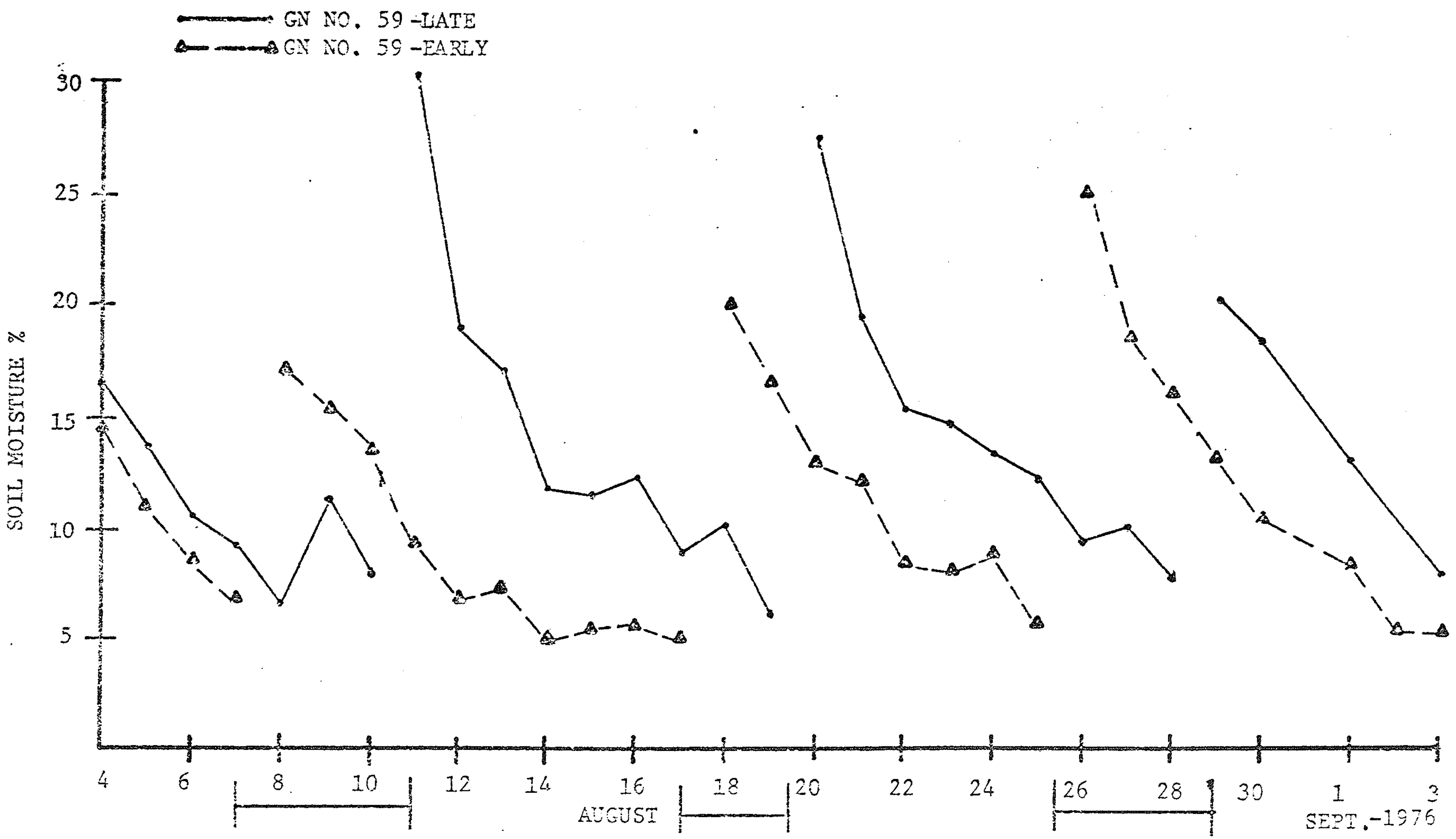

FIGURE 6. DAILY PER CENT SOIL MOISTURE ADJACENT TO PLANT IN GN NO. 59 PLOTS. BARS DENOTE PERIOD OF TIME BETWEEN EARLY AND LATE IRRIGATION.

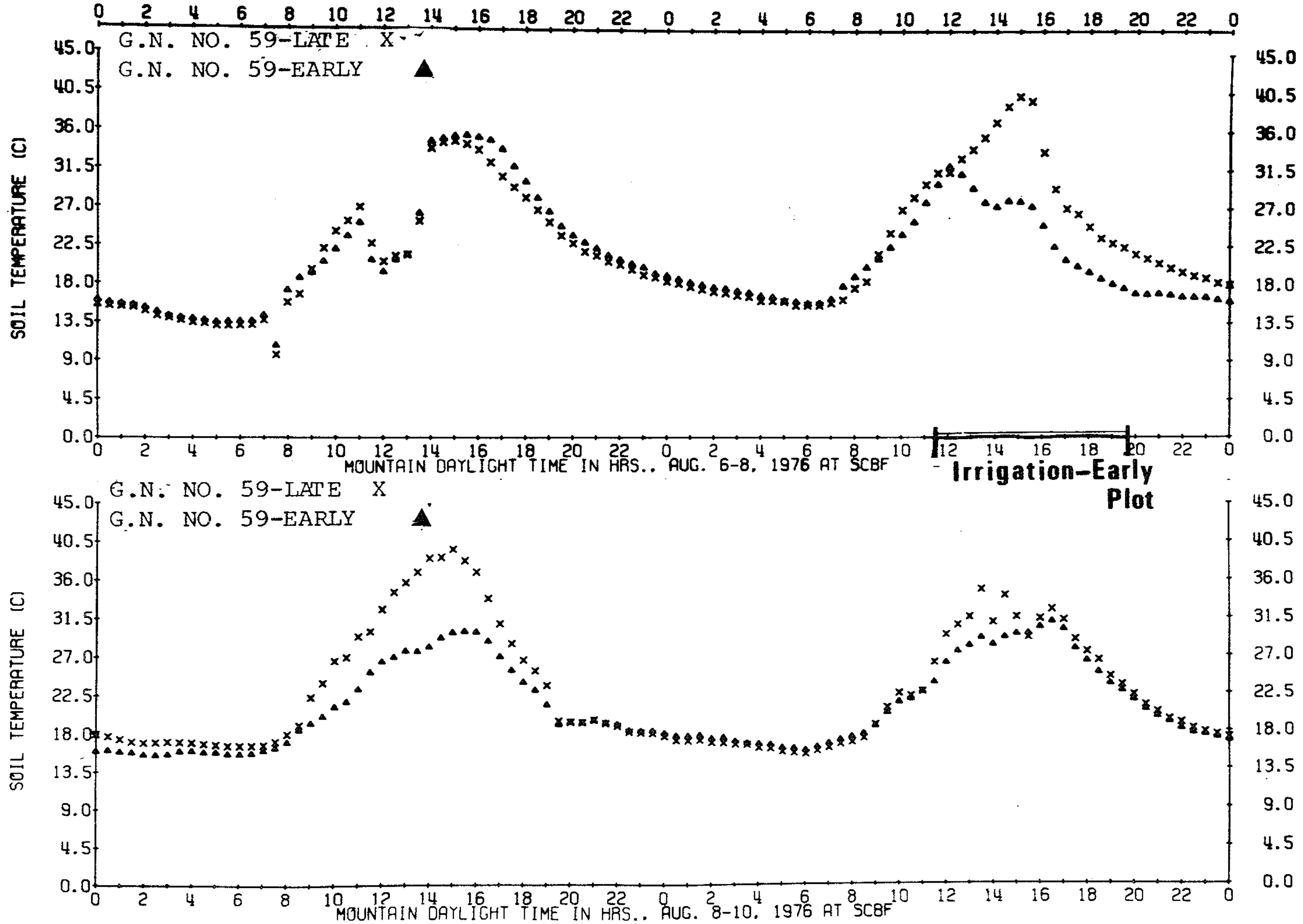

FIGURE 7. SOIL TEMPERATURE IN GN NO. 59 PLOTS, AUGUST 6-10,1976.

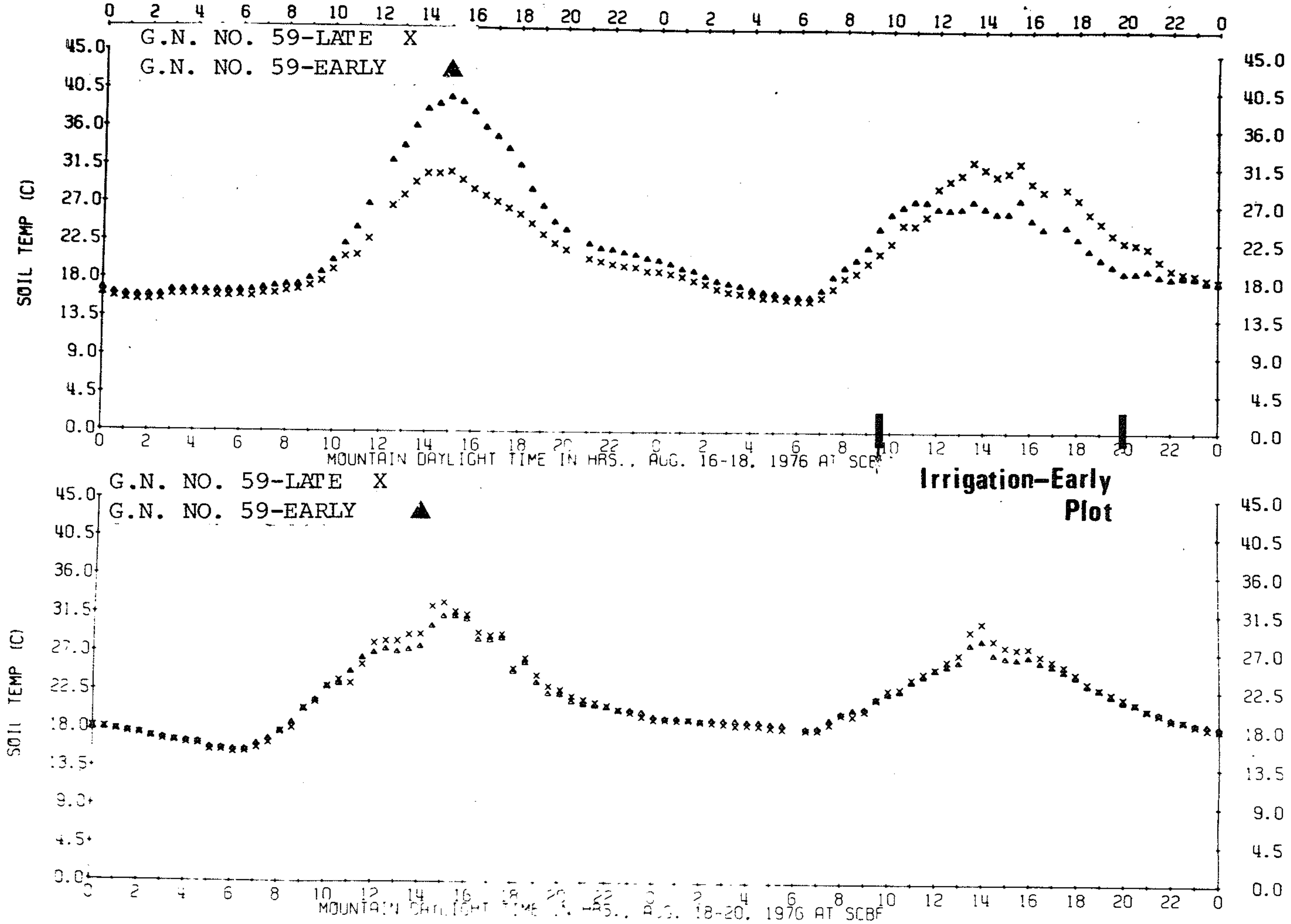

FIGURE 8. AS IN FIGURE 7, FOR AUGUST 16-20,1976.

first irrigation commenced on August 7. Soil temperature in the early plot slowly decreased during the day and leveled off when irrigation ceased in the early evening. The canopy was very porous in these plots throughout the study. Thus, a significant amount of solar radiation must have reached the ground surface in both plots. Soil in the late plot was much warmer than in the early plot during the day. Most of the radiant energy at the surface would be consumed in evaporation in the early plot. However, more of the available energy in the late plot would be used to heat the drier soil surface.

Soil temperature differences between the plots gradually diminished during the first night after irrigation. Closer examination of the data reveals that soil temperature decreased most rapidly in the late plot, while that in the early plot decreased very little. The disparity in the rate of cooling occurred because the irrigated plot was cooler to begin with. Also since water has a high heat capacity, slower cooling would be expected in wet soil than in dry soil.

During the two days following irrigation, the soil in the early plot was cooler than that in the late plot. The difference between the plots during the daytime hours was as much as 10° C on the day after irrigation. The reasons for this effect were discussed in section 3.3. Nighttime soil temperatures were similar in both plots. This is because there is no solar radiation load at night.

The effect of the second irrigation, which occurred August 17, on soil temperature, is shown in Figure 6. Soil temperature in the early plot was significantly warmer than that in the late plot during daytime periods before irrigation. Since the effect had not been evident before the first irrigation, it was probably caused by differences in canopy structure above the soil temperature sensors. Additionally, it is possible that one or more of the soil thermocouples in the early plot may have become exposed. The second irrigation lowered soil temperatures a similar amount as the first irrigation.

4.3 Irrigation and Vapor Pressure:

The influence of irrigation on vapor pressure is shown in Figures 9 and 10. The consistently small difference in vapor pressure between the plots before irrigation is likely a measure of instrumental error or resolution.

Both figures indicate that no immediate change in vapor pressure was recorded after irrigation. The time

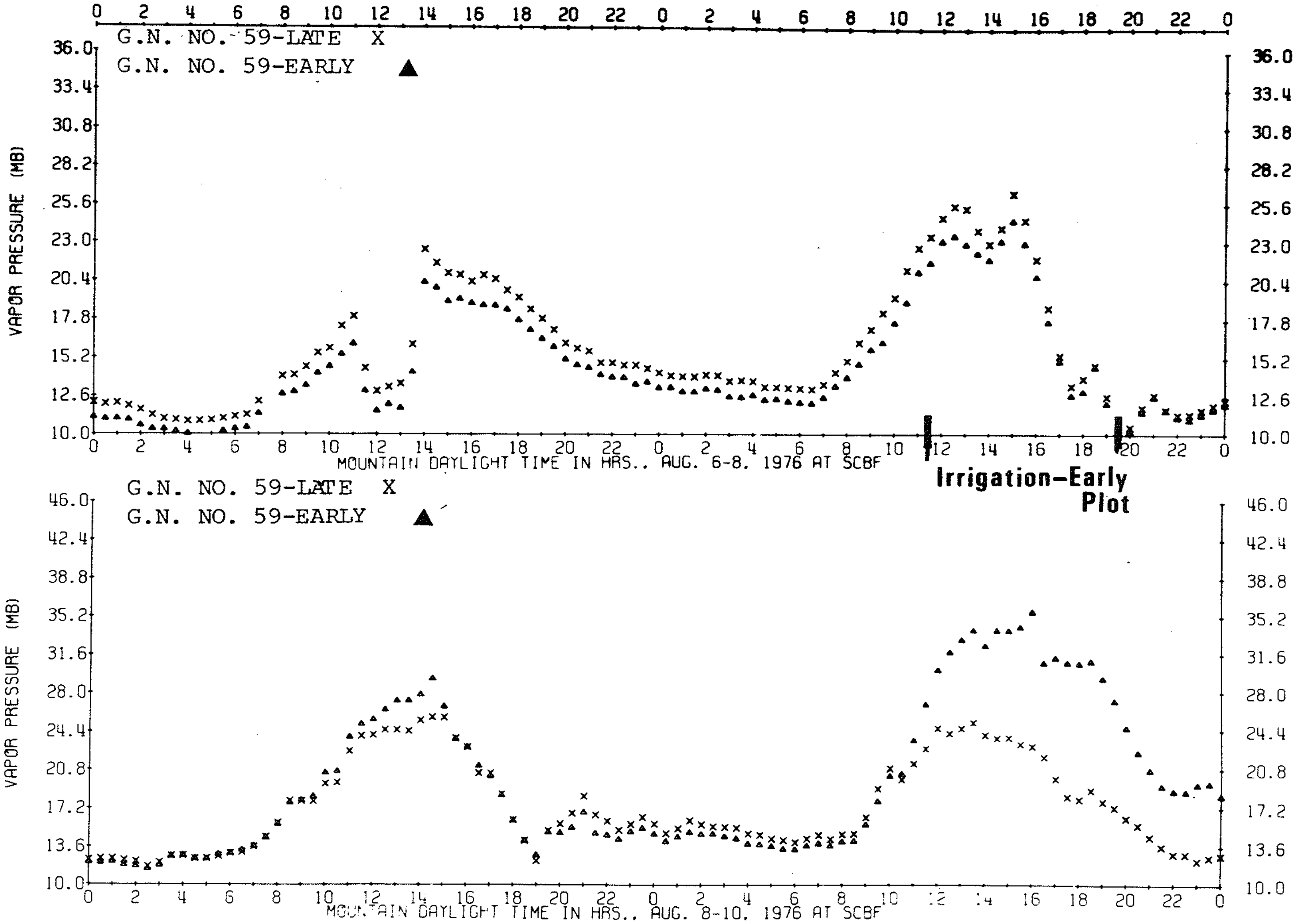

FIGURE 9. VAPOR PRESSURES AT 10 CM IN GN NO. 59 PLOTS, AUGUST 6-10,1976.

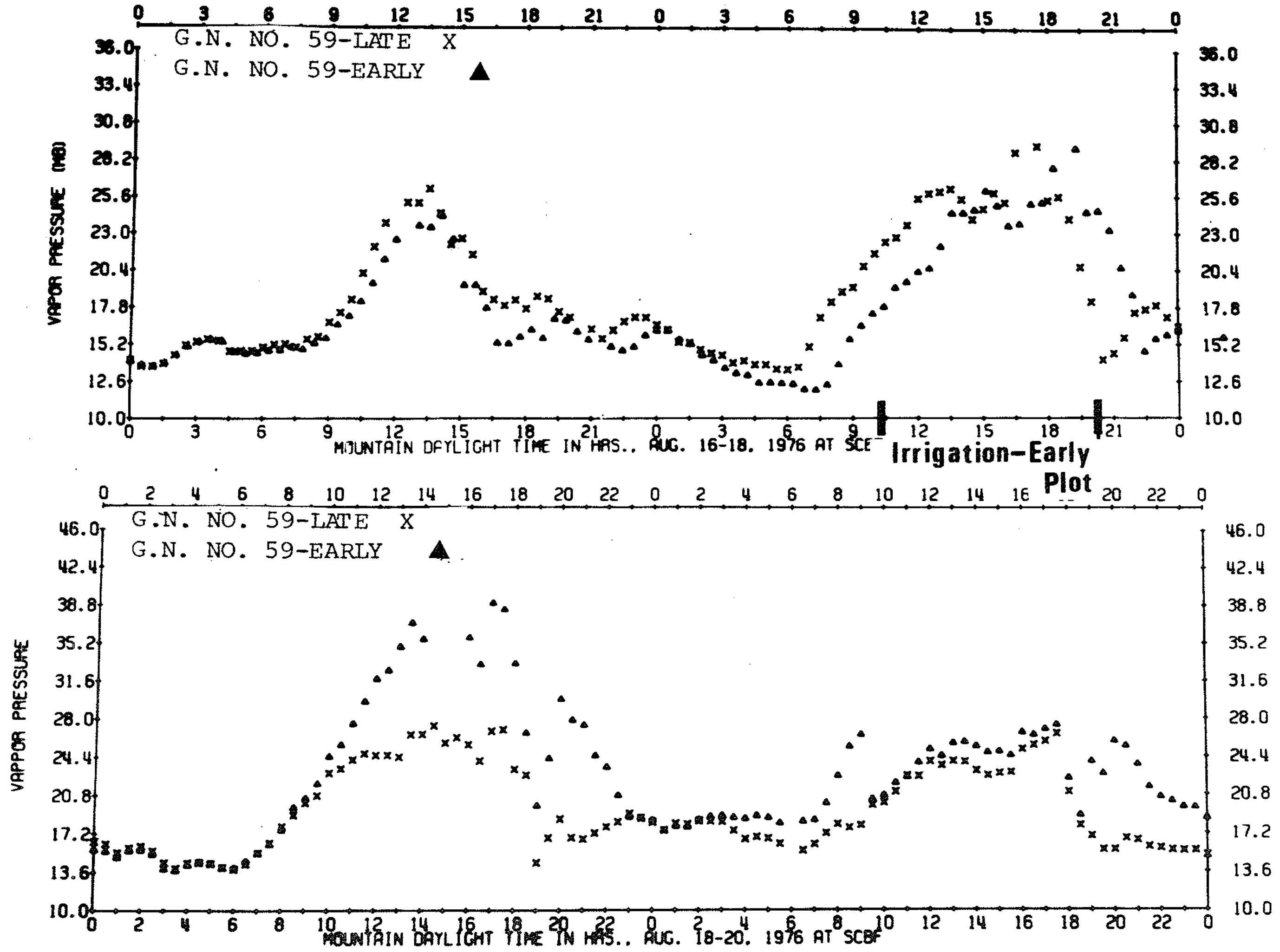

FIGURE 10. AS IN FIGURE 9, FOR AUGUST 16-20, 1976.

lag involved in water reaching the root zone and subsequent increase in transpiration may account for this delay. Vapor pressure in the early plot increased dramatically by as much as 10 mb during daytime hours for two days after irrigation. This suggests that the transpiration rate was increased in the irrigated beans. Little effect was observed at night when transpiration is negligible. Similar results were reported in potatoes by Lomas, et al. (1972). Evaporation of water from the wet soil may also have contributed to the vapor pressure increase observed after irrigation. Both plots shared visible symptons of moisture stress proir to irrigation. The stressed condition of the plots would accentuate the changes in vapor pressure caused by irrigation.

Very little difference in vapor pressure existed between the plots on August 19, which was the second day after irrigation (Figure 10). This was due to low solar radiation flux densities on that day (Figure 11). Hence, transpiration rates were reduced in the early plot by limited solar radiation, despite the increase in availability of water to the plants.

The results indicated that the increase in vapor pressure caused by irrigation was maximal on days

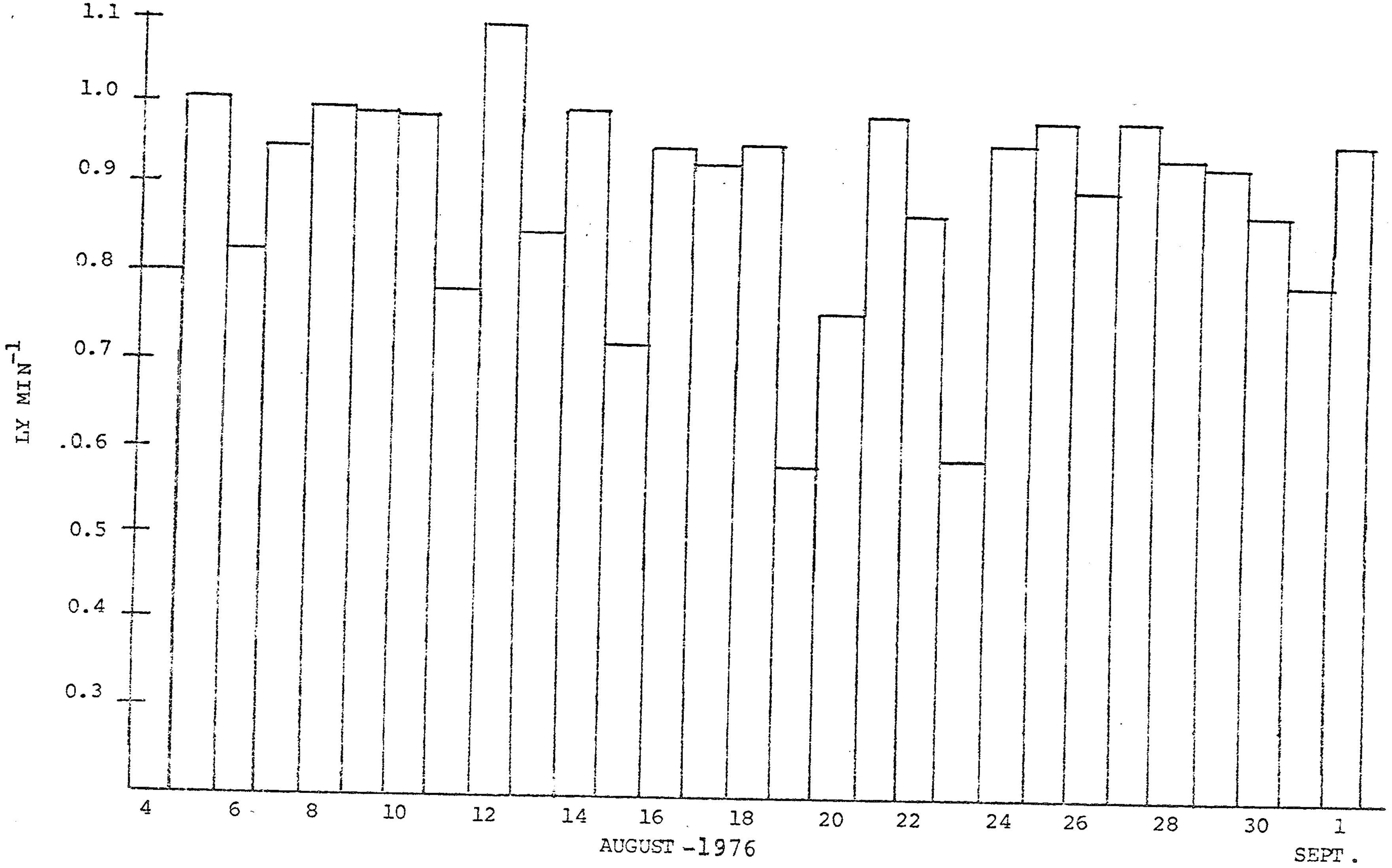

FIGURE 11. AVERAGE SOLAR RADIATION FLUX DENSITIES BETWEEN 0900 AND 1800 HOURS EACH DAY.

with the greatest flux density of solar radiation. Thus, the results indicate that vapor pressure will increase after irrigation only if adequate solar radiation is available to supply energy needed to transpire the additional water.

4.4 Irrigation and Air Temperature:

Two cases which demonstrate the influence of irrigation on canopy air temperatures are shown in Figures 12 and 13. Temperatures in the early plot were significantly higher than those in the late plot during the daytime on days preceding irrigation. This difference was consistent during sunny days but disappeared at night and during cloudy periods. Reasons for the temperature differences are somewhat uncertain. Reflected solar radiation may somehow have been incident on the thermocouple in the early plot but not on the one in the late plot since shielding was only above the sensors. It is more likely that the temperature difference was caused by canopy structure differences which affected the penetration of radiation into the plots.

Knowledge of air temperature differences between the two plots before and after irrigation permits one to evaluate the influence of irrigation on air temperature. The difference in temperature between the plots decreased

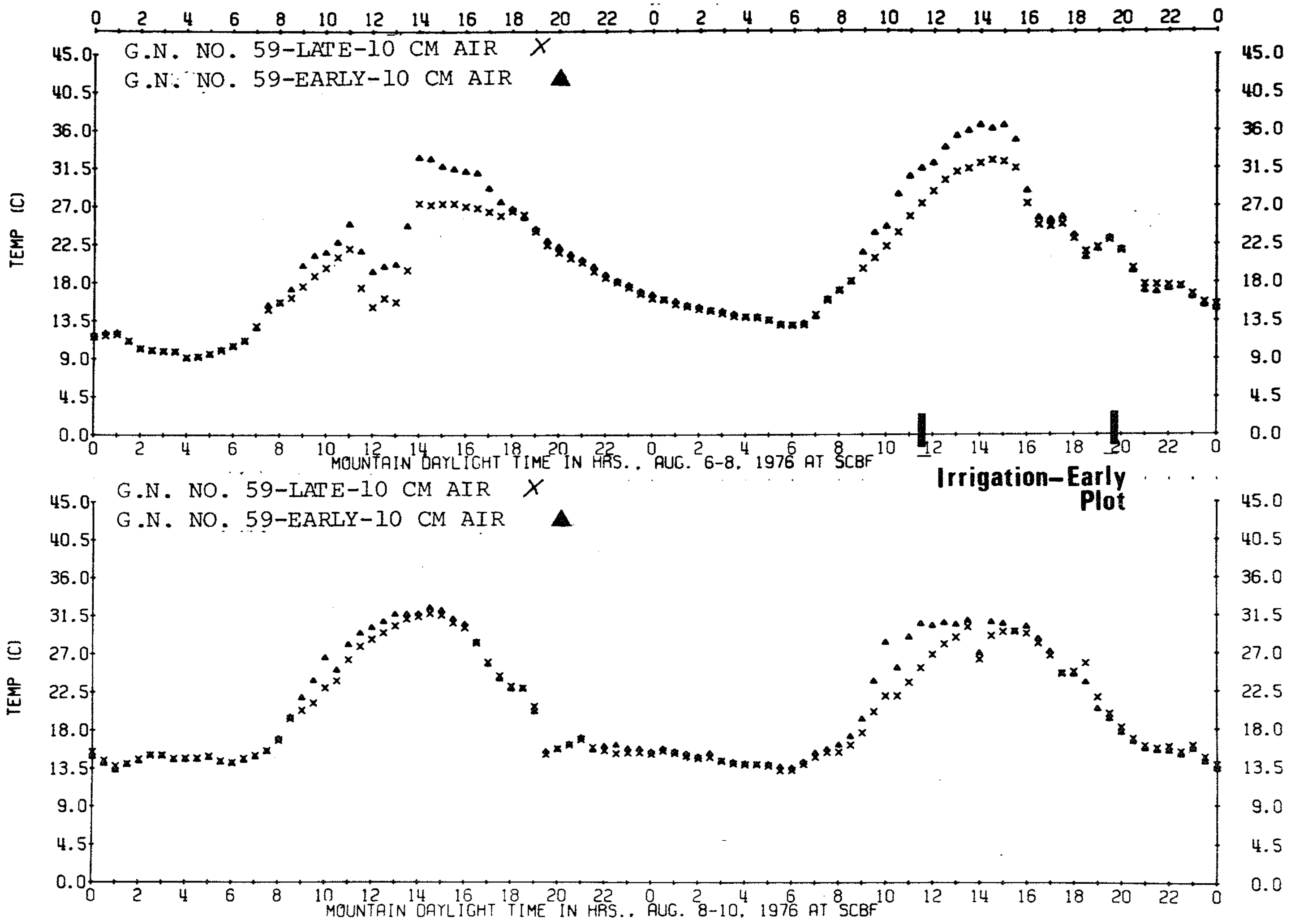

FIGURE 12. AIR TEMPERATURE AT 10 CM IN GN NO. 59 PLOTS, AUGUST 6-10, 1976.

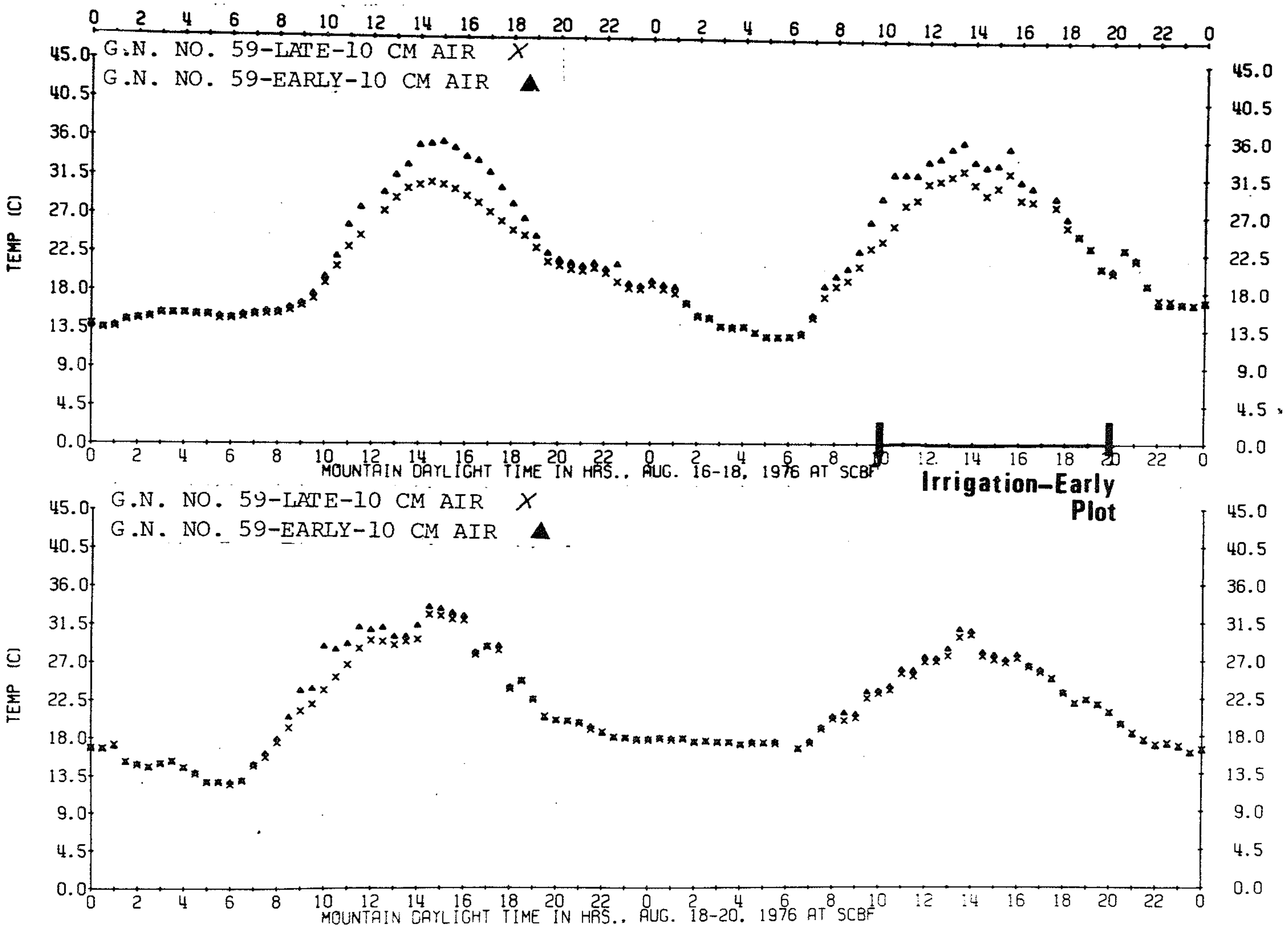

FIGURE 13. AS IN FIGURE 12, FOR AUGUST 16-20, 1976.

during the daytime for several days after the first irrigation on August 7. Since solar radiation values were similar before and after irrigation (see Figure 11), any change in the air temperature difference between the plots may be ascribed to irrigation. Close examination reveals that temperatures of the late plot remained nearly the same from day to day. The decrease in the temperature difference between the plots was caused by a reduction of air temperatures in the early plot due to irrigation. Statistical tests (paired t-tests) indicate a significant reduction, at the .001 probability level, in the average air temperature difference between the plots from 0900 to 1800 hours on August 7 and the same time period on August 8 and 9.

The decrease in daytime air temperature after irrigation resulted from the modification of the energy balance by irrigation. Irrigation apparently reduced the canopy air temperature by as much as 3 to 4° C during the daytime. The effects persisted for several days. No effects were observed at night.

The second irrigation produced similar results (Figure 13). The low solar radiation flux densities on

August 19 caused the temperature of the two plots to be similar and masked any effects of irrigation.

4.5 Irrigation and Leaf Temperature:

Leaf temperatures were recorded at two levels in each plot. Some of the data appeared to be questionable, perhaps because of difficulty experienced in keeping the thermocouples attached to the leaves. Two cases which presented realistic data, and which demonstrated the influence of irrigation on leaf temperatures, are shown in Figures 14 and 15.

Daytime leaf temperatures were higher in the early plot than in the late plot prior to irrigation. This suggests that leaves measured in the early plot were more exposed to solar radiation, and were probably under more moisture stress. Irrigation had no effect on leaf temperature until the following day when leaf temperatures decreased in the early plot. This reduction in leaf temperature probably resulted from transpiration increases after irrigation. Vapor pressure increases during these periods indicate that transpiration had been increased. Hence, the contention that the decreases in leaf temperature in the early plot was the result of irrigation seems supportable.

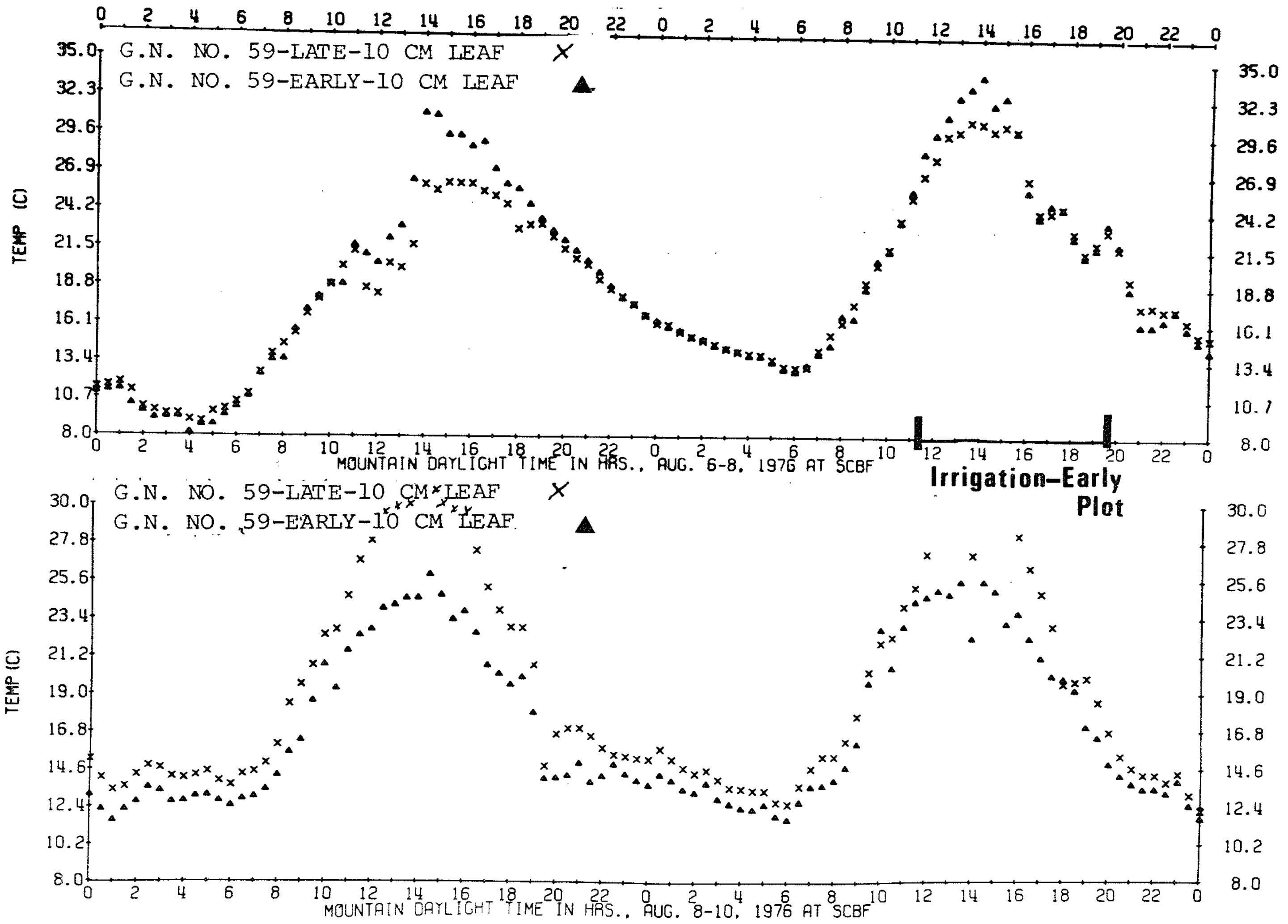

FIGURE 14. LEAF TEMPERATURES AT 10 CM IN GN NO. 59 PLOTS, AUGUST 6-10, 1976.

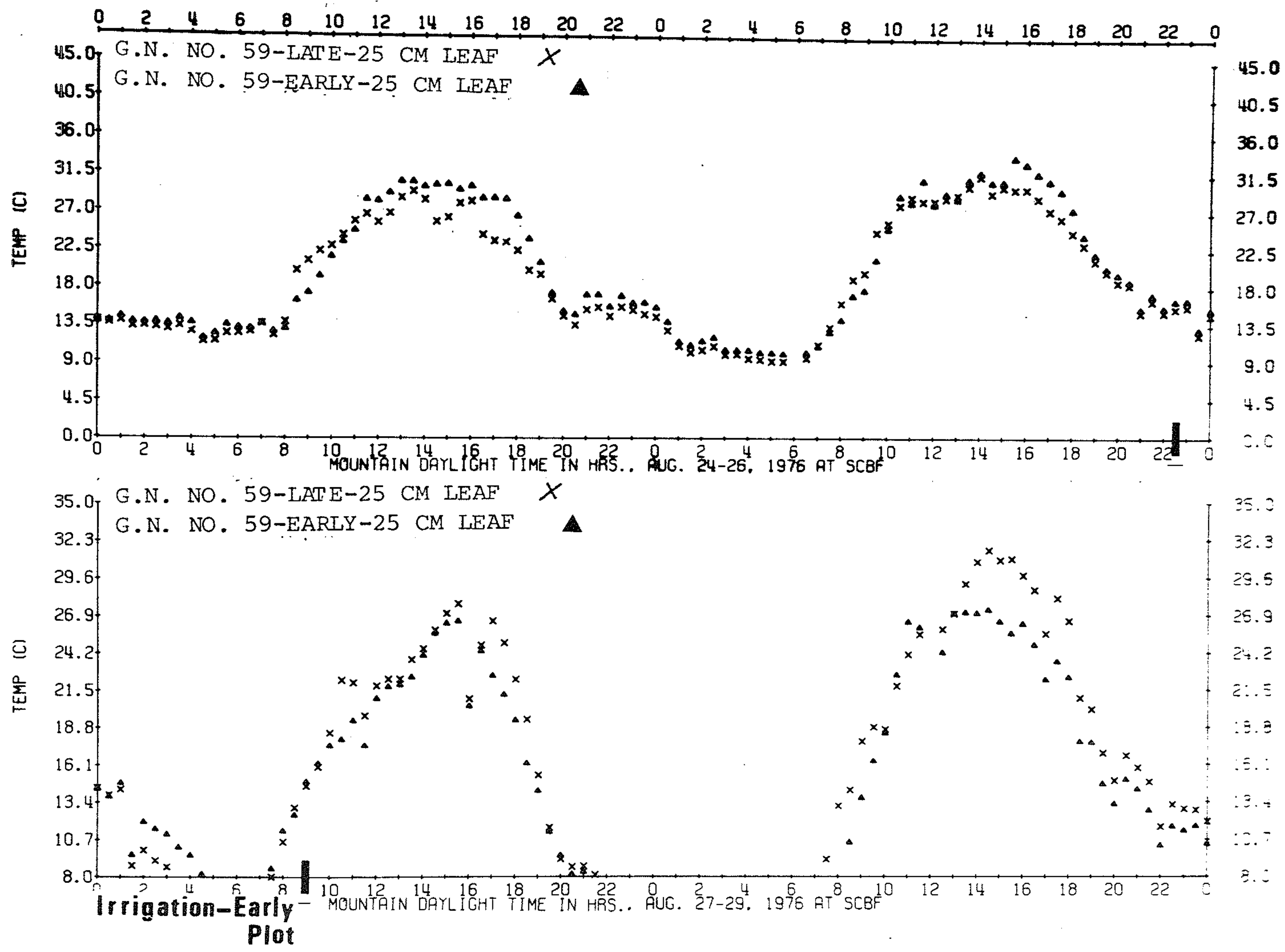

FIGURE 15. AS IN FIGURE 14, EXCEPT AT 25 CM, FOR AUGUST 24-29.

The reduction of leaf temperature after irrigation was as great as 5 to 6° C during mid-day. This effect persisted for several days. No effect was observed at night.

4.6 Stem Temperature and Dew Intensity and Duration:

No effect of irrigation on stem temperature was observed. The results also indicated that irrigation did not appear to influence dew intensity or duration, despite apparent small increases in nighttime vapor pressure after irrigation.

CHAPTER V

INFLUENCE OF IRRIGATION FREQUENCY ON THE MICROCLIMATE AND DEVELOPMENT OF WHITE MOLD DISEASE:

Heavy irrigation has been associated with large amounts of white mold infection. Therefore, increasing the irrigation frequency should be expected to create a more favorable microclimate for the development of white mold. For those reasons the influence of irrigation frequency on the microclimate in dry edible beans was examined and related to the development of white mold disease.

5.1 Irrigation Frequency and Canopy Development:

Since both irrigation and canopy density will modify the energy balance and influence the microclimate in the canopy, it is desirable to examine the influence of irrigation frequency on the canopy structure of dry edible beans.

Figure 16(a)-16(e) illustrates the development of the canopy structure in each cultivar and treatment during the study.

Tara developed the most dense canopy particularly between the rows. On August 4 the heavily irrigated Tara plot (henceforth referred to as Tara heavy) had already developed a more dense canopy than the normally irrigated

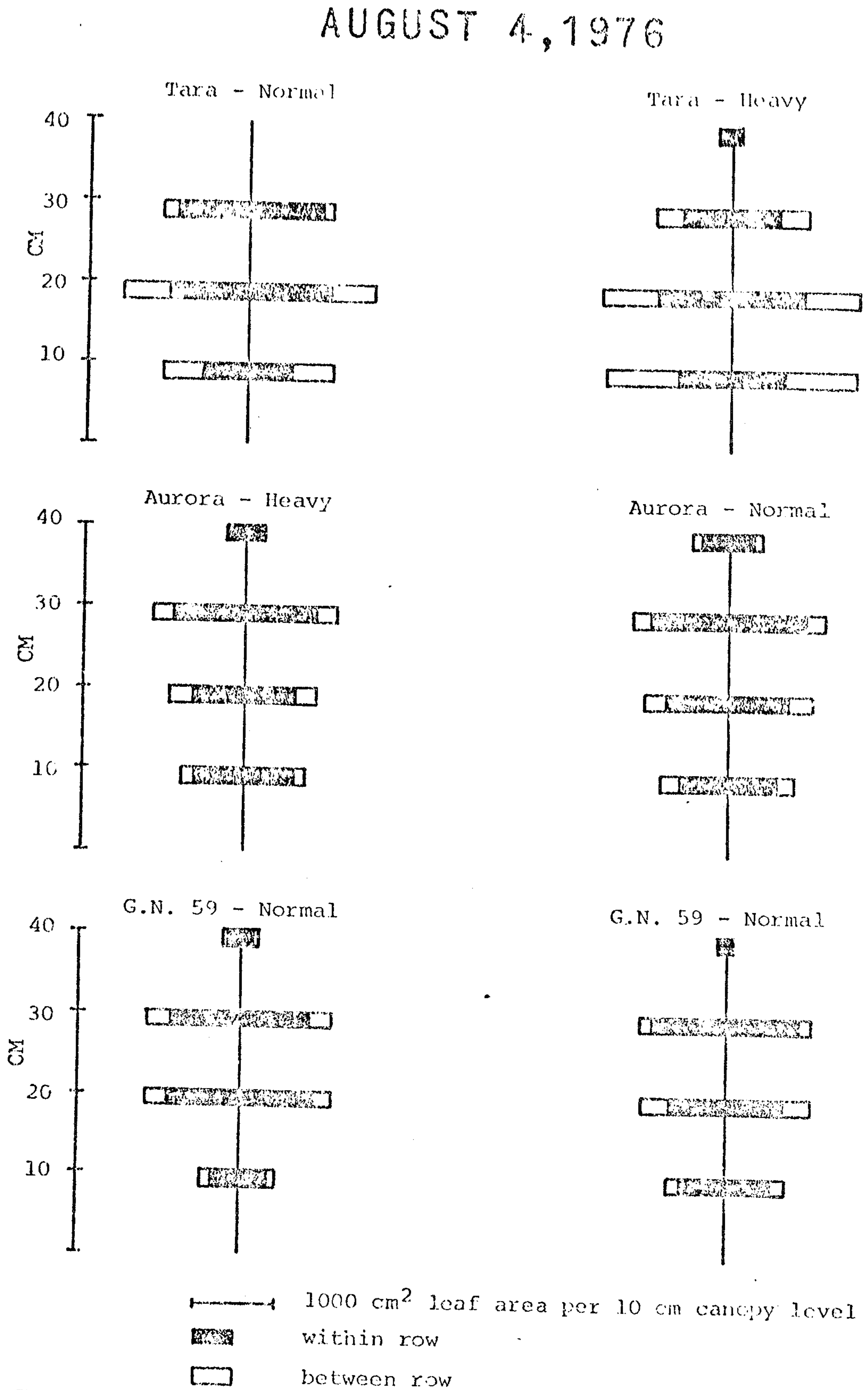

FIGURE 16 (a) - DISTRIBUTION OF LEAF AREA PER 10 CM IN CANOPY, ON AUGUST 4,11,18,25, AND SEPTEMBER 2, 1976.

AUGUST 11, 1976

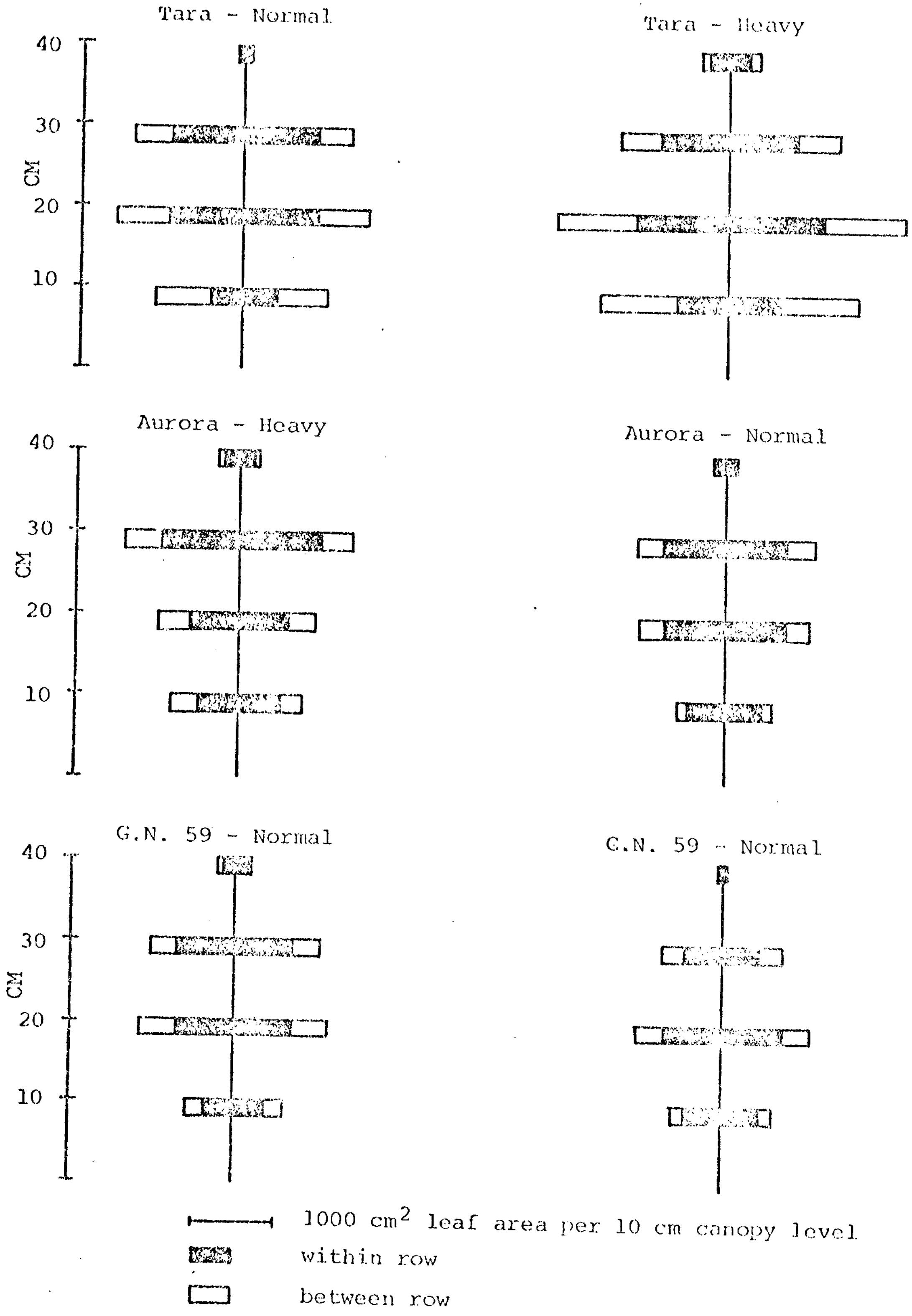

FIGURE 16 (b)

AUGUST 18, 1976

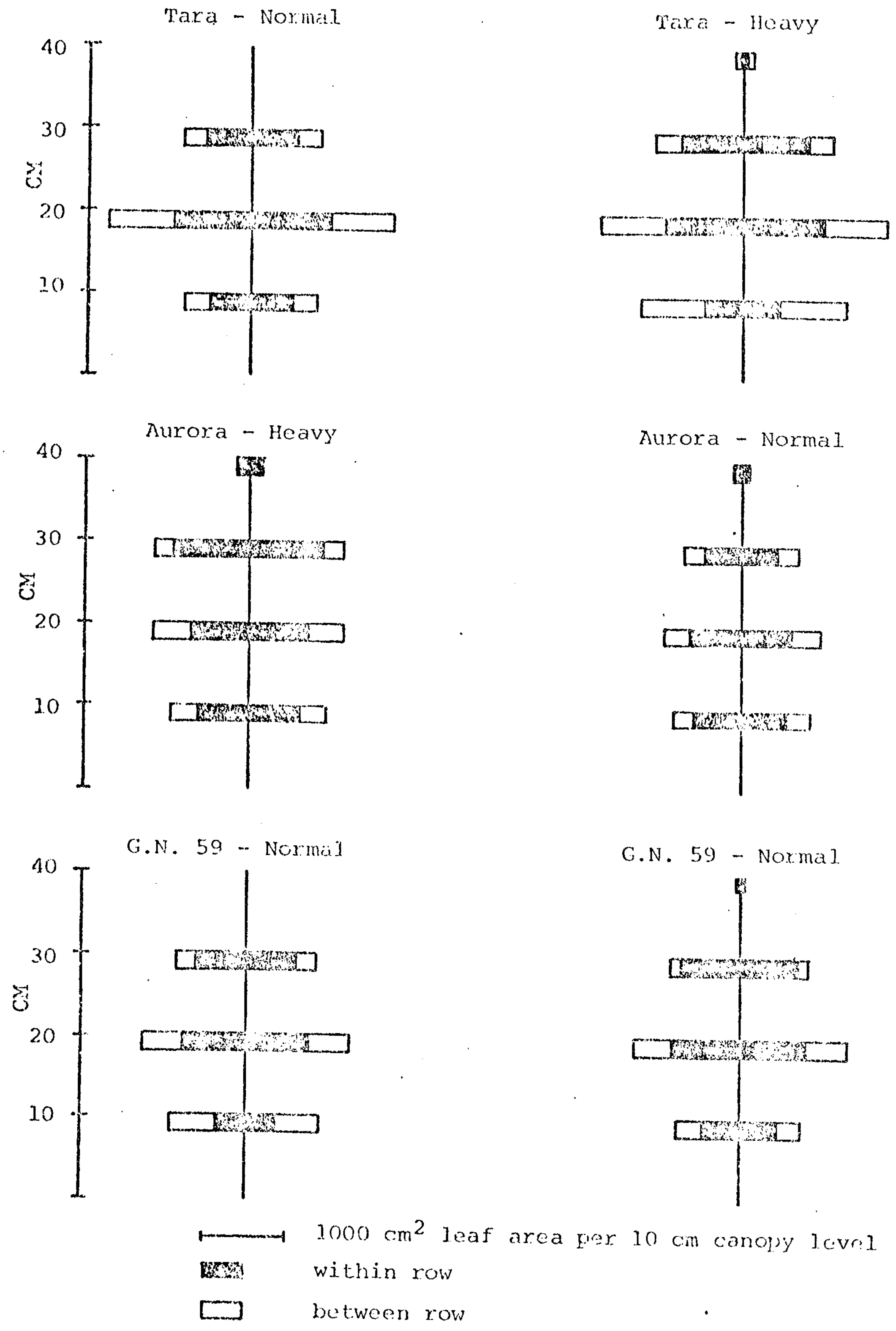

FIGURE 16 (c)

AUGUST 25, 1976

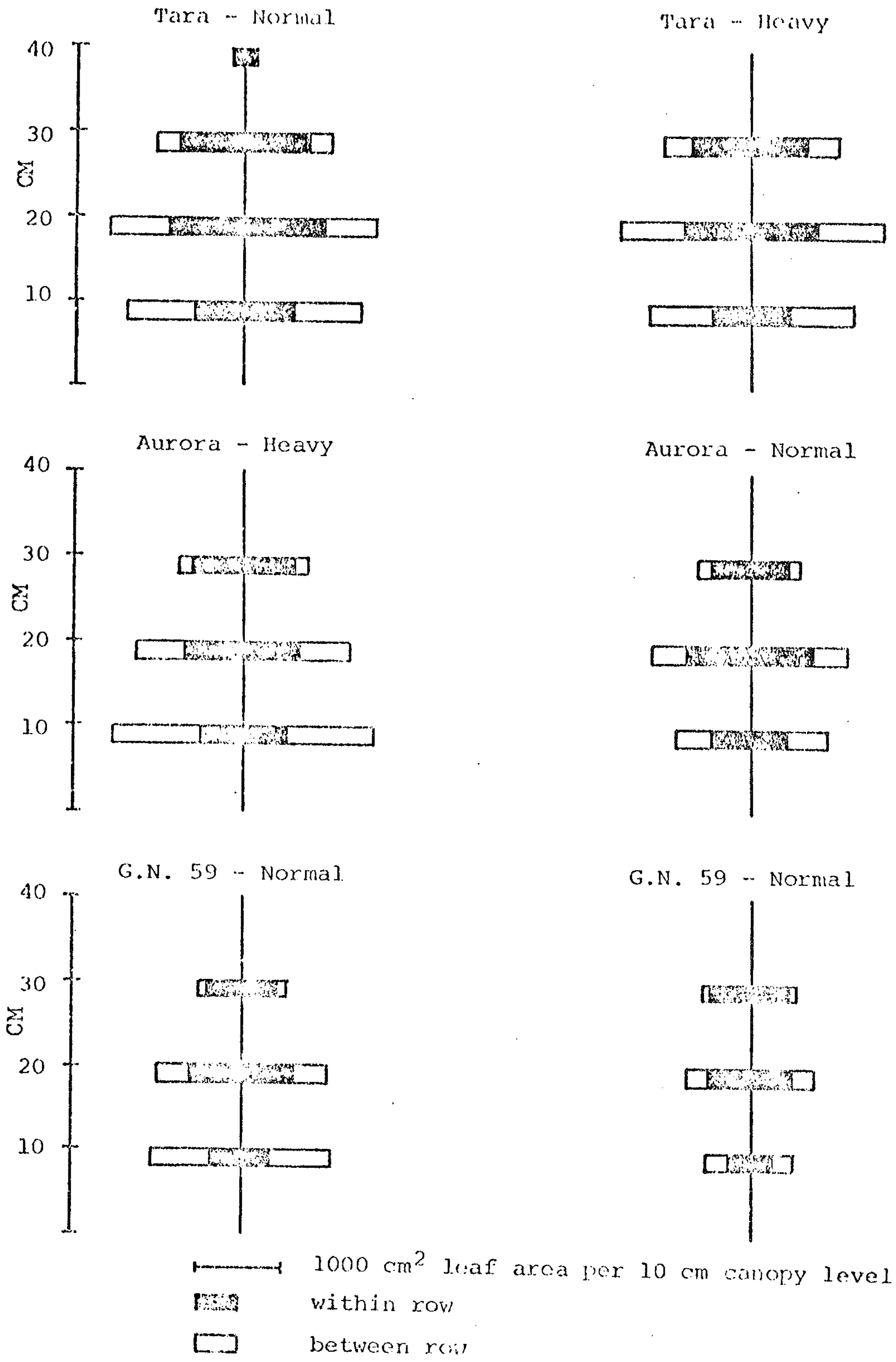

FIGURE 16 (d)

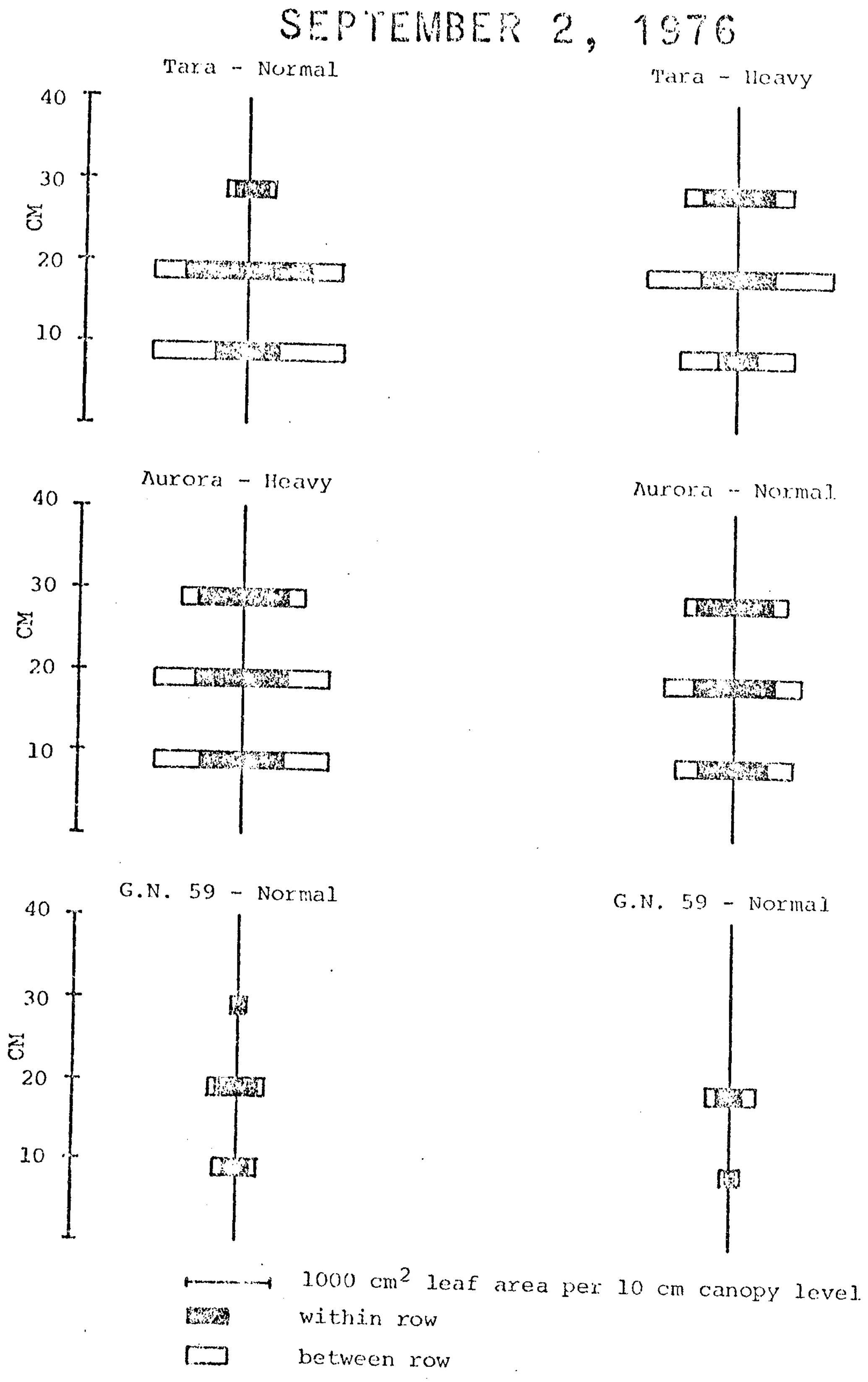
SEPTEMBER 2, 1976
Tara - Normal
Tara - Heavy
Aurora - Heavy
Aurora - Normal
G.N. 59 - Normal
G.N. 59 - Normal
CM
40
30
20
10
1000 cm2 leaf area per 10 cm canopy level
within row
between row

FIGURE 16 (e)

Tara (henceforth referred to as Tara normal). No effect of irrigation frequency on canopy density was evident in the Aurora plots at this time. The canopy data for the plots of G. N. No. 59 are shown for comparitive purposes. By August 11, irrigation-induced canopy structure differences between the plots became more accentuated in both Aurora and Tara. Figure 17 shows photographs of the Tara plots taken August 9, 1976, which illustrate these effects.

On August 18, leaf area diminished slightly in the Tara heavy plot, while canopy density in the Tara normal plot changed little. Leaf areas in the Aurora remained unchanged during this period. Data collected August 25, indicated similar leaf areas in both Tara plots. The canopy in the Aurora heavy plot became much more dense than that in the Aurora normal plot during this period.

By September 2, when the study was ending, the canopy had deteriorated in all of the plots. This was the result of both maturation of the beans and of white mold damage, especially heavy in the Tara.

Heavy irrigation promoted a more dense canopy, especially between the rows, until late in the study.

FIGURE 17. ILLUSTRATION OF CANOPY STRUCTURE DIFFERENCE BETWEEN TARA NORMAL AND HEAVY IRRIGATED PLOTS, ON AUGUST 9, 1976.

5.2 Irrigation Frequency and Air Temperature:

The influence of irrigation frequency can more readily be seen by the examination of daytime average temperatures, since nighttime air temperatures were similar in all plots. Average daily air temperatures were determined in the Tara and Aurora plots for the period 0900 to 1800 hours on each day of the study. 0900 to 1800 hours were used because data indicated that the influence of irrigation on the microclimate was significant only during that time period. Results for the 10 cm level are presented in Figures 18 and 19. Similar temperature patterns were observed for air temperature at the 25 cm level.

The results indicate that air temperature was consistently lower in the plots receiving heavy irrigation. The difference in air temperature between the normal and heavy irrigated plots appeared to be greatest on very warm days. Temperatures remained moderate in the heavily irrigated plots during very warm days. This result is important since an increase in temperature might have limited white mold development. The lower air temperature in the heavy irrigation treatments probably resulted from a reduction of sensible heat flux to the air from the soil and plant due to the wetter soil and more dense canopy, as has been previously discussed. Abawi and Grogan (1975)

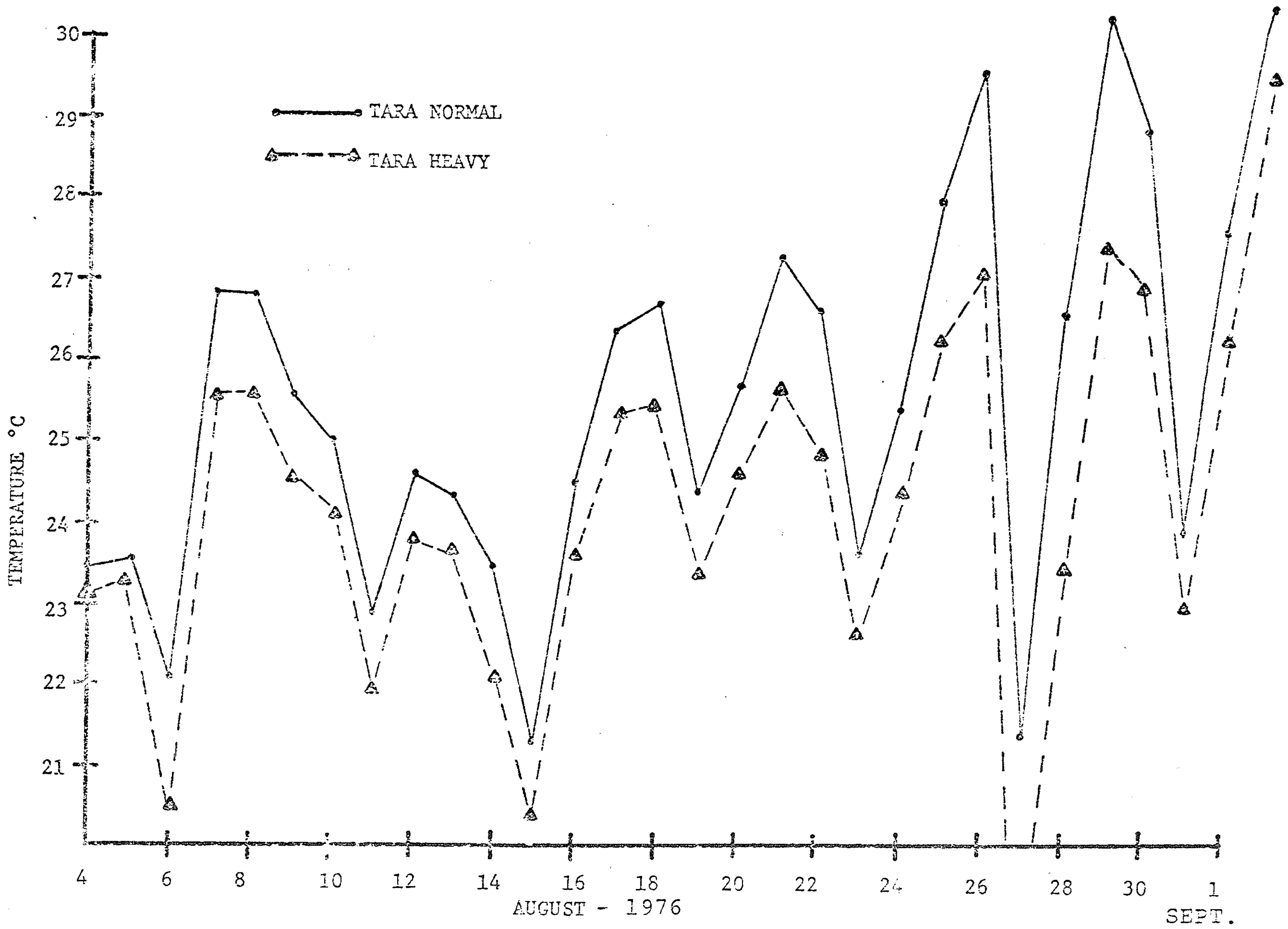

FIGURE 18. AVERAGE AIR TEMPERATURE AT 10 CM IN TARA, FOR 0900 TO 1800 HOURS EACH DAY.

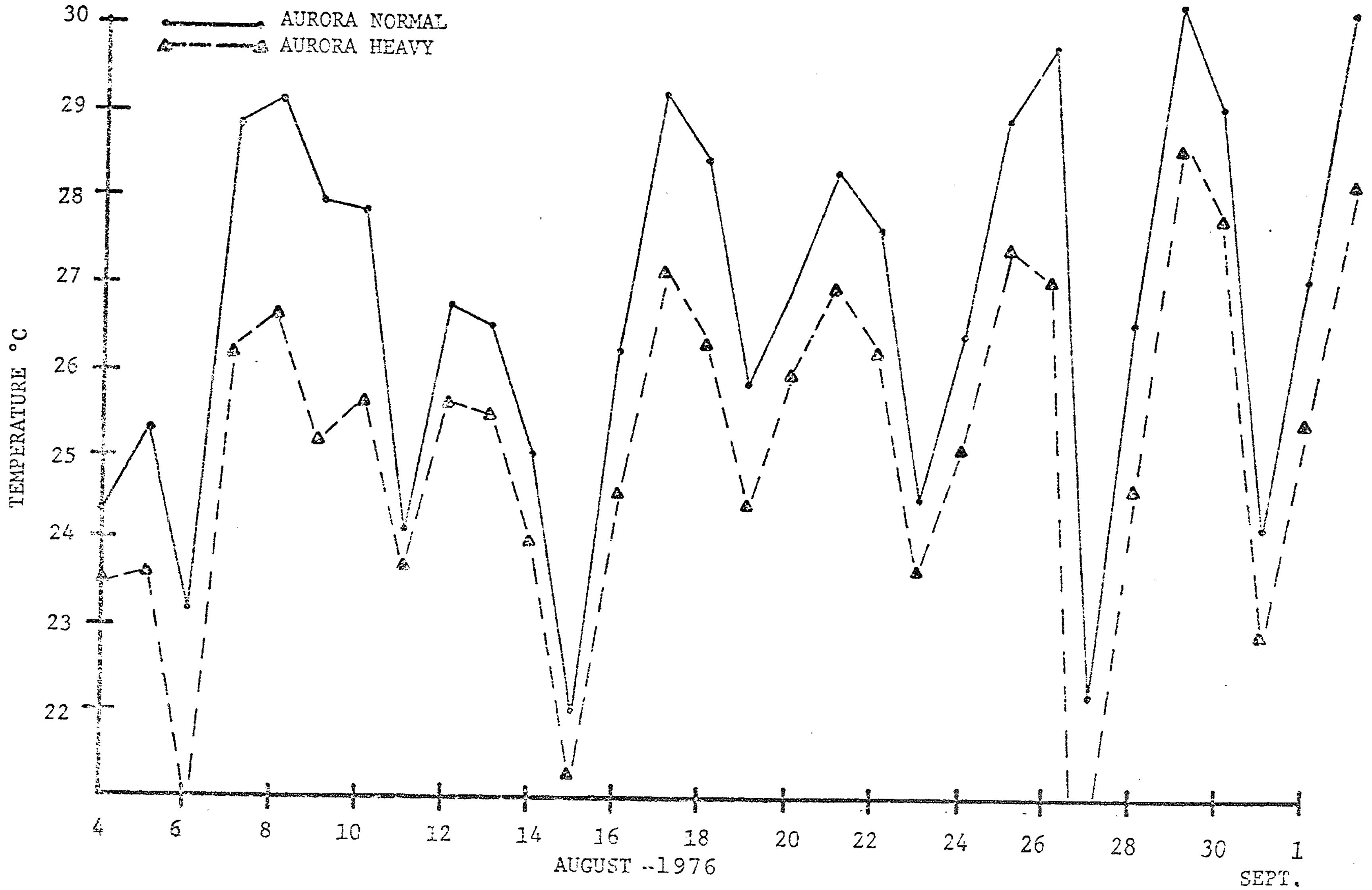

FIGURE 19. AS IN FIGURE 18, FOR AURORA.

found 25° C to be the optimum temperature for ascospore germination. Temperatures in the heavy irrigation treatmtnes appear to have been more favorable for colonization than those in the normal irrigation treatment.

5.3 Irrigation Frequency and Leaf Temperature:

Leaf Temperatures measured at 10 and 25 cm in the Tara and Aurora canopies were averaged in the same manner as were the air temperatures. The results were similar at both levels, and are shown only for the 10 cm level in Figures 20 and 21.

Leaf temperatures were consistently lower in the plots receiving heavy irrigation. The temperature depression was most evident during very warm days when temperatures might otherwise have become unfavorable for the development of white mold. Since most of the leaves measured were sunlit, the major cause of the temperature reduction was probably increased transpiration. If the leaves would have been shaded, then the cooler leaf temperatures under heavy irrigation would be the result of the cooler environment persent under the more dense canopy.

The difference in transpiration rates between the normal and heavily irrigated plots should be greatest just prior to irrigation of the normal plots, since plants in those plots were usually observed to be under moisture

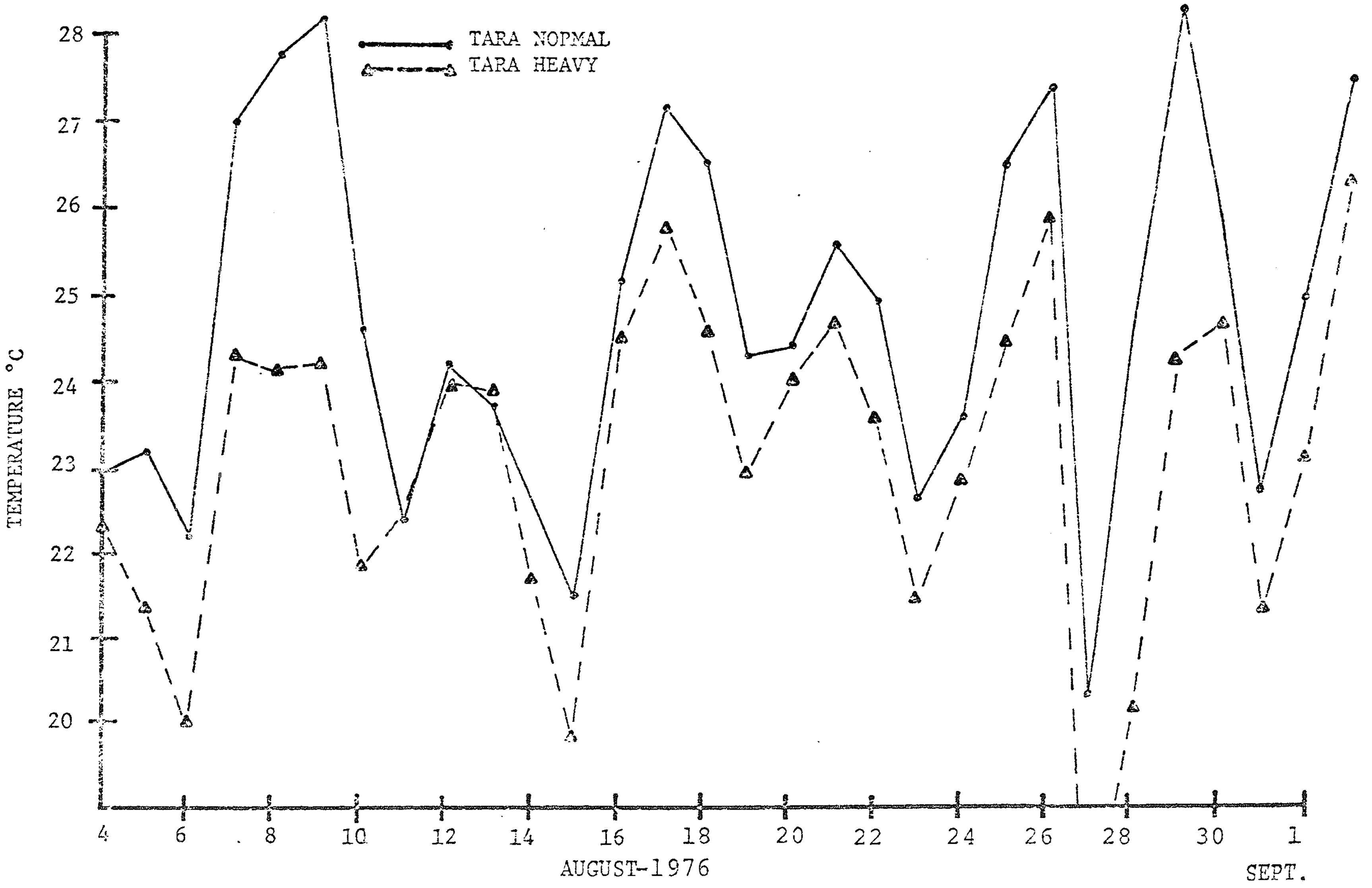

FIGURE 20. AVERAGE LEAF TEMPERATURE AT 10 CM IN TARA, FOR 0900 TO 1800 HOURS EACH DAY.

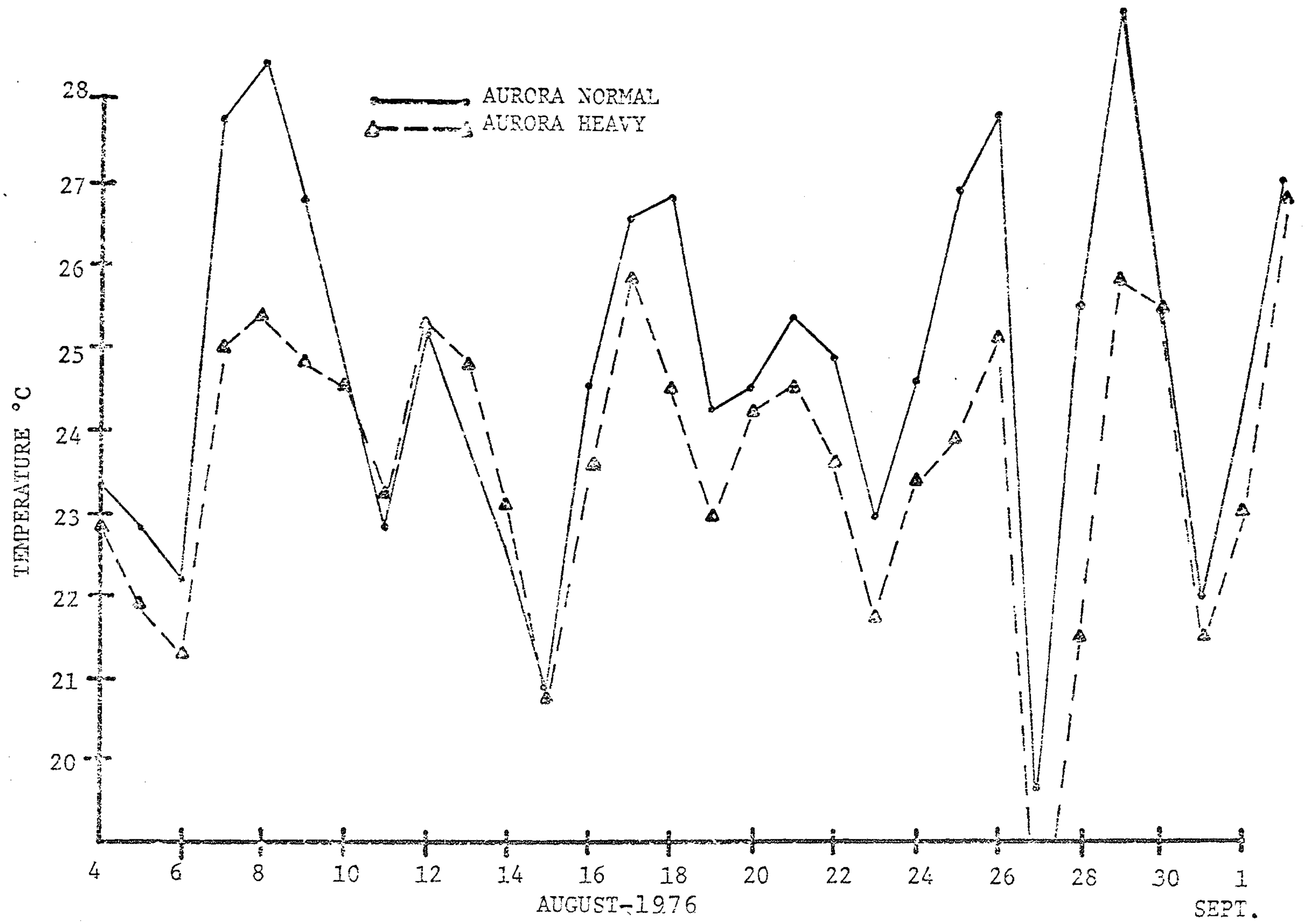

FIGURE 21. AS IN FIGURE 20, FOR AURORA.

stress at that time. Thus, differences in leaf temperature between the two irrigation treatments should be greatest shortly before irrigation of the normal plots when flux density of solar radiation were great and air temperature was high. Leaf temperature data for August 7-10 and 27-30, shown in Figures 20 and 21, support this reasoning.

Leaf temperature in the heavily irrigated plots appeared to be closer to the optimum temperature for ascospore germination. Thus, if these data are representative of the temperatures of senescent tissue, which was often observed laying on leaf surfaces, colonization would appear to be enhanced by heavy irrigation, given adequate wetness conditions.

5.4 Stem Temperature, Vapor Pressure and Dew Intensity and Duration:

No effect of irrigation frequency on stem temperature was observed in the Aurora or Tara, as transpiration rates of stems are negligible. Vapor pressure data are not available in those plots because of apparent malfunctions of the dewprobes.

Dew intensity and duration were also found to be unaffected by irrigation frequency. This latter result was unexpected and may have been due to large sampling or instrumental errors. The two sample locations in each plot may not have been representative sites.

Data indicated that heavy dew occurred for prolonged periods of time in all of the plots. As much as 12 hours of dew occurred on some days. This would seem to suggest that enough free moisture was available for ascospores to germinate and colonize on senescent or injured tissue, although the duration of surface wetness required for colonization has not yet been well established.

5.5 Soil Temperature:

Average daily soil temperatures for the period 0900 to 1800 hours in the Aurora and Tara are shown in Figures 22 and 23. No effect of irrigation frequency on soil temperatures was observed at night.

Irrigation frequency had a profound effect on soil temperature in the Tara plots. Soil temperature was depressed as much as 8° C by heavy irrigation. This decrease was likely the result of soil moisture and canopy density increases caused by heavy irrigation. Penetration of radiant energy to the surface would be reduced by an increase in canopy density. Data indicates that soil was consistently wetter in the heavy irrigation treatment. This suggests that

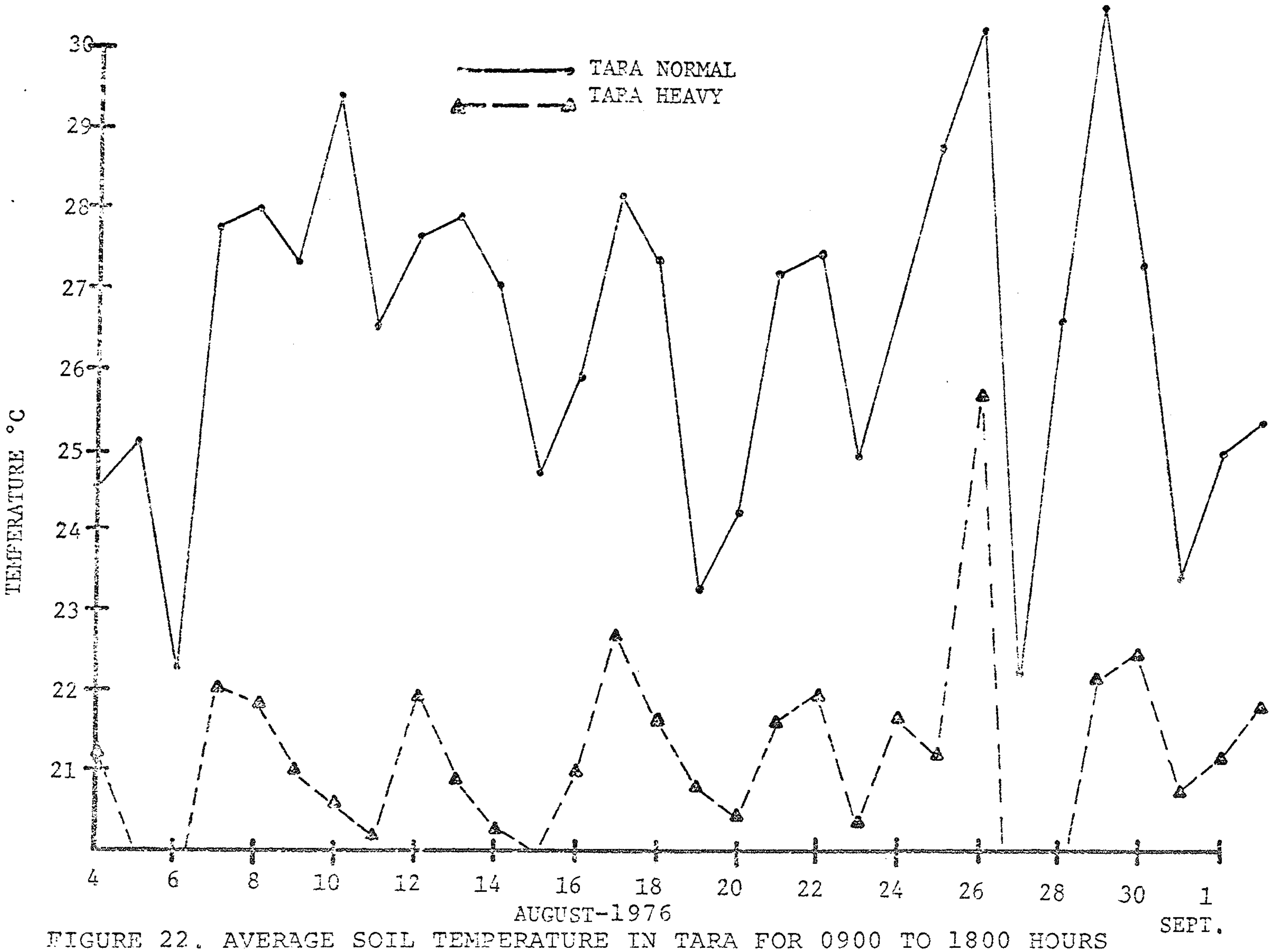

FIGURE 22. AVERAGE SOIL TEMPERATURE IN TARA FOR 0900 TO 1800 HOURS EACH DAY.

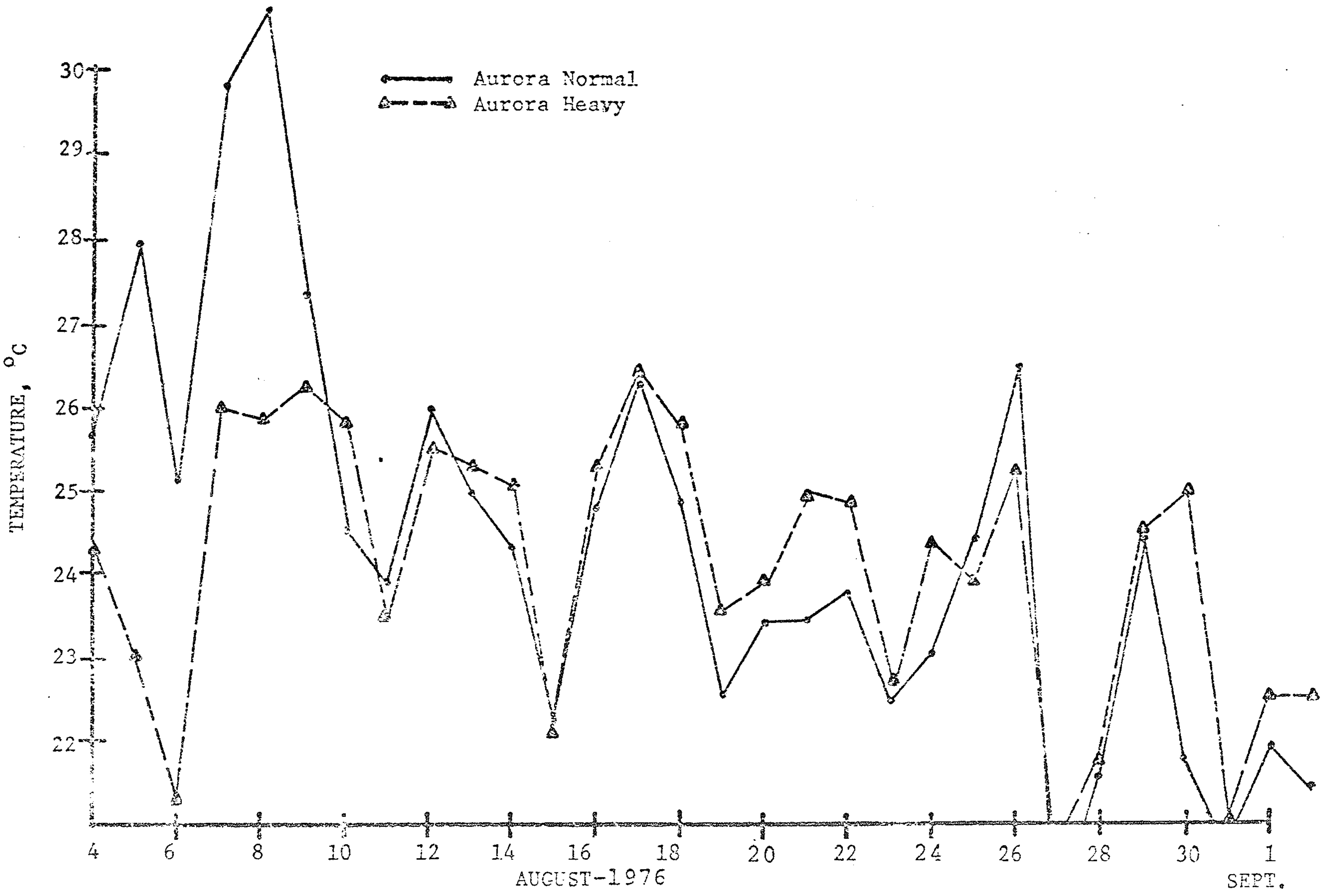

FIGURE 23. AS IN FIGURE 22, FOR AURORA.

radiant energy that was available at the soil surface would be largely consumed in evaporation, resulting in lower soil temperatures.

Almost no effect of irrigation was observed in the Aurora plots, especially after August 9. The Aurora normal plot often had lower soil temperatures than did either the Aurora heavy or Tara normal plots. Soil temperatures recorded in the Aurora normal plot may have been lower than the true representative values perhaps because the canopy structure above the sensors may have been more dense than in the plot as a whole.

Soil temperature fluctuated over a much smaller range than did air or leaf temperatures. The damping effect was most prevalent in the Tara heavy plot, where soil moisture and canopy density were greatest. The variability of soil temperature increased during the latter part of the study, when the canopy density decreased in all of the plots.

The lowering of soil temperature associated with heavy irrigation may have had an important influence on the germination of sclerotia. Abawi and Grogan (1975) found that the temperature range was 10 to 25° C, with 10 to 15° C the optimum for germination. Twenty-four hour averages of soil temperature would be several degrees lower than are shown in Figure 22. Soil temperatures in the Tara heavy plot are closer to this optimum temperature than are those in Tara normal. Figure 22 indicates that daytime soil temperatures in the Tara normal plot were often higher than 25° C. Thus, soil temperature during these times may have become inhibiting for germination of sclerotia in the normal irrigation treatment.

5.6 Soil Moisture:

Soil moisture conditions adjacent to the plant in the Tara and Aurora plots are shown in Figures 24 and 25. Conditions adjacent to the plant are displayed since most of the apothecia were observed in that location.

The results indicate that soil moisture was consistently greater in the heavy irrigation treatment, particularly during the 5 day period prior to irrigation of the normal plots. During these times the percent soil moisture was as much as 10% greater in the Tara heavy plot, and up to 16% greater in the Aurora heavy plot, than their normal irrigated counterparts. Figure 26 is the moisture release curve for the soil at the study site (Felch, 1965). By examining Figure 25 it is evident that there was often no moisture available for sclerotia germination in the normally irrigated plots.

These results have important implications concerning apothecia development. Duniway, Abawi and Steadman (1977)

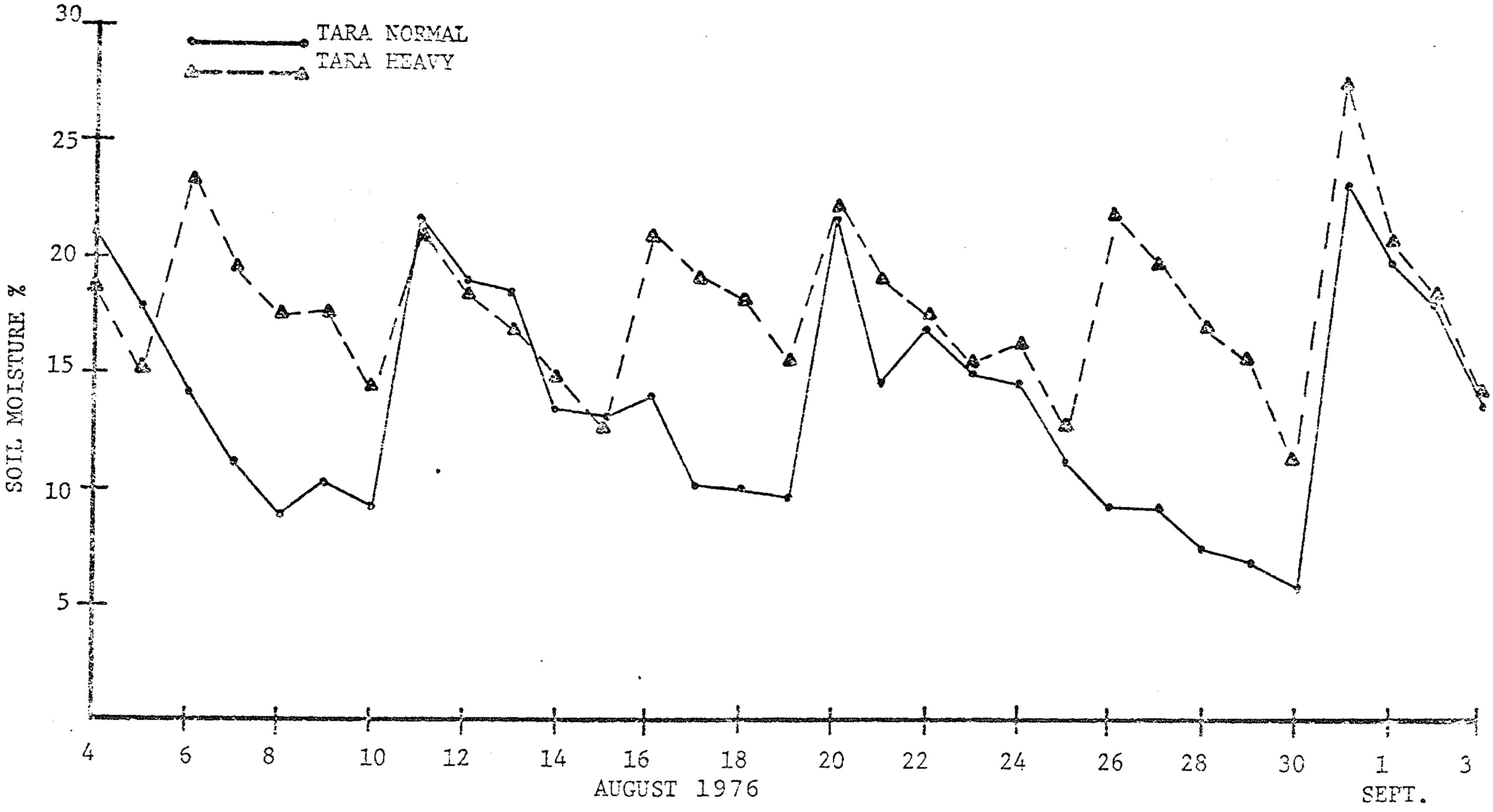

FIGURE 24. PER CENT SOIL MOISTURE ADJACENT TO PLANT, DETERMINED DAILY IN TARA.

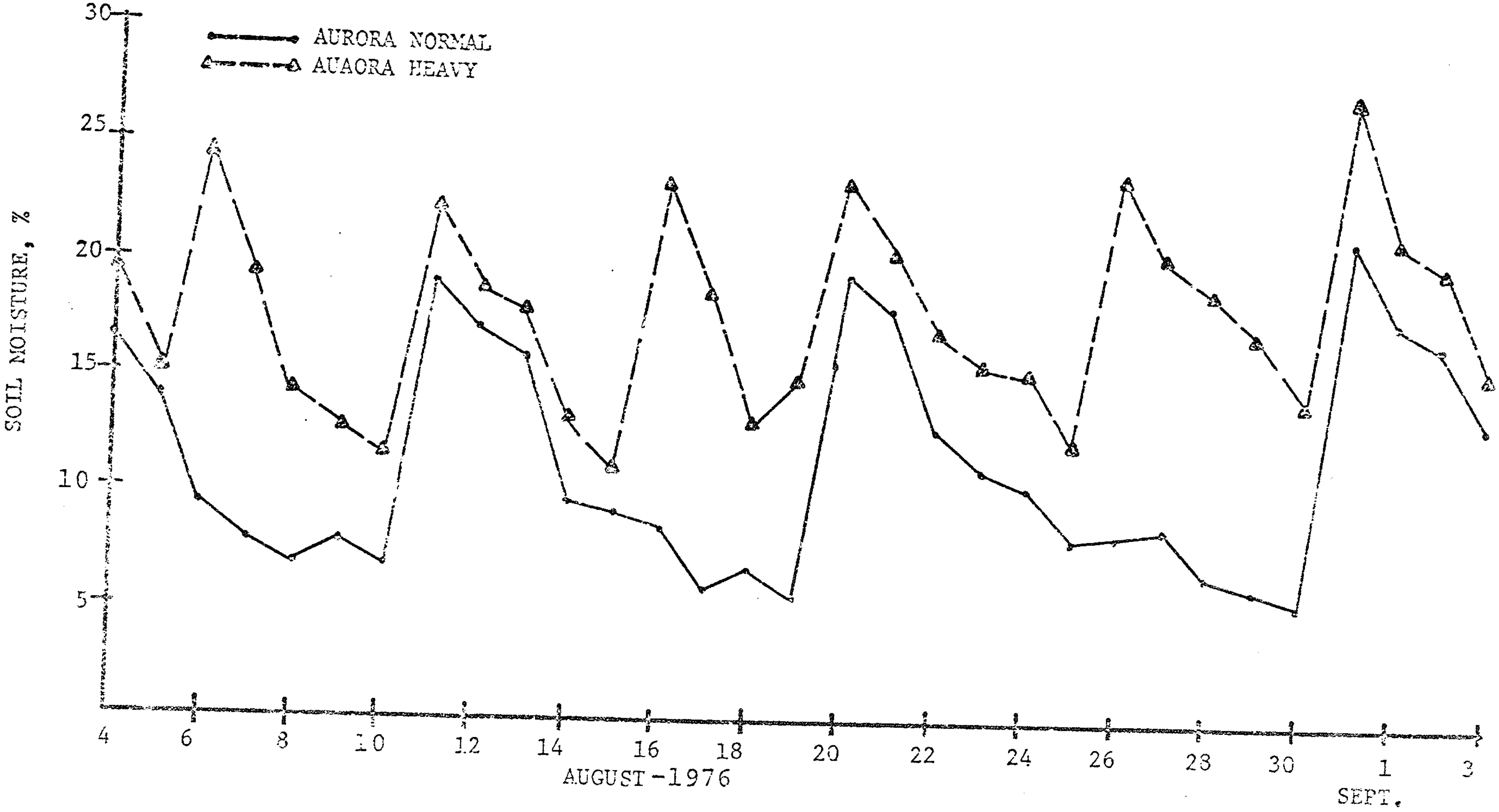

FIGURE 25. AS IN FIGURE 24, FOR AURORA.

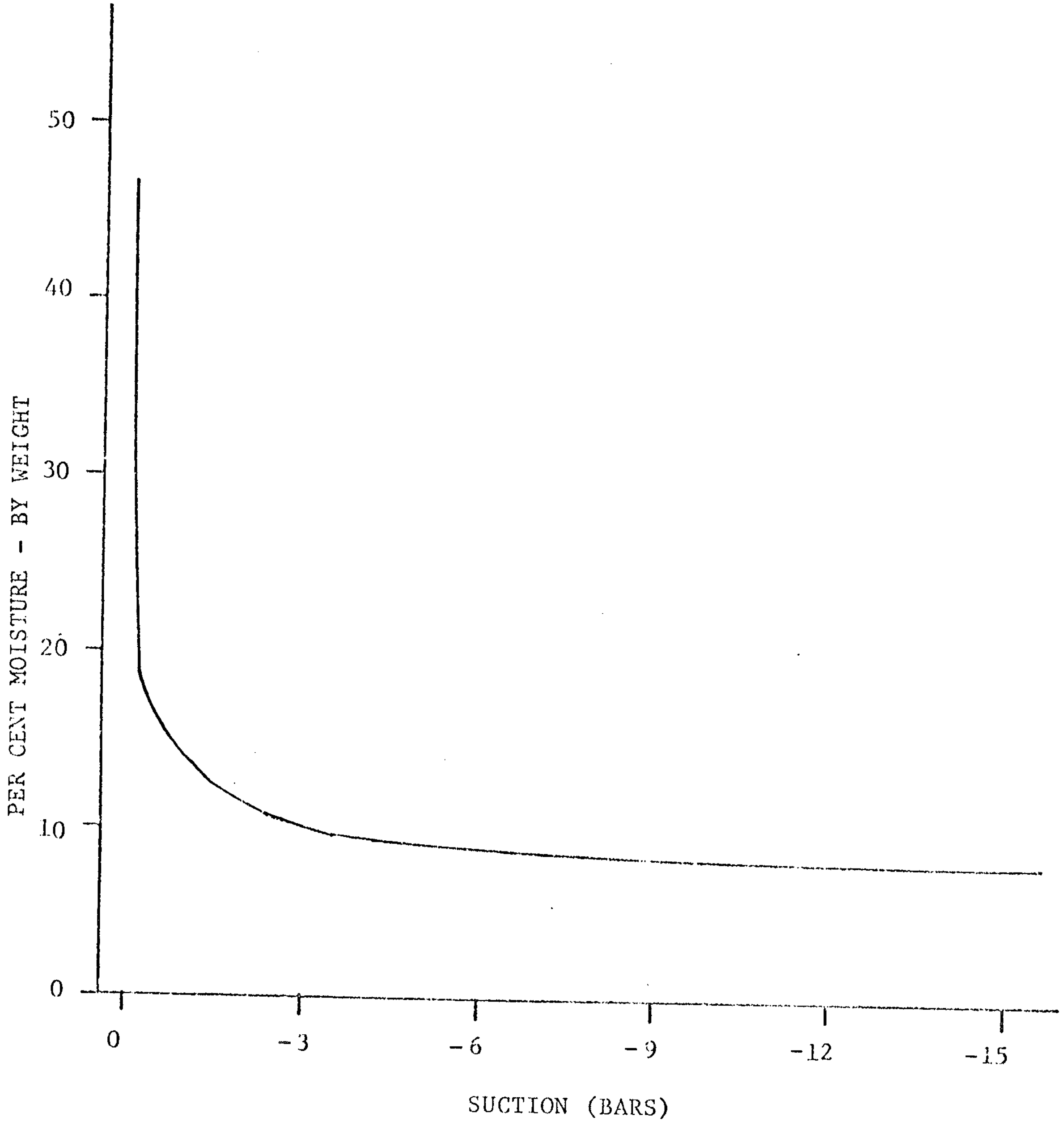

FIGURE 26 SOIL MOISTURE RELEASE CURVE FOR TRIPP VERY FINE SANDY LOAM SOIL AT STUDY SITE. FROM FELCH (1965).

established the relationship between soil water potential and the germination of sclerotia for the soil from the study site. They found soil moisture values of 20% (-.25 bars) to be optimal for germination. Soil moisture values less than 14% (-1 bar) or greater than 32% (-.08 bars), were found to be inhibiting for germination. Morrall (1977) found that germination did not occur at water potentials lower than -7.5 bars, in a clay soil. Figures 25 and 26 demonstrate that soil moisture in the heavy irrigated plots stayed near the optimum value for sclerotia germination whereas soil moisture values in the normal irrigation treatment were often below the critical 14%. These results suggest that water potential in the normally irrigated plots often become inhibiting for germination of sclerotia.

5.7 Apothecia Production:

Figure 27, from Schwartz (1977), indicates the number of sclerotia which germinated to form apothecia in the Aurora and Tara. Observations are based on samples taken on three different dates. No apothecia were observed in the G. N. No. 59 plots.

Apothecia production was greatest in the Tara heavy plot, followed by Tara normal, Aurura heavy and Aurora normal, respectively. Most apothecia were observed adjacent to the

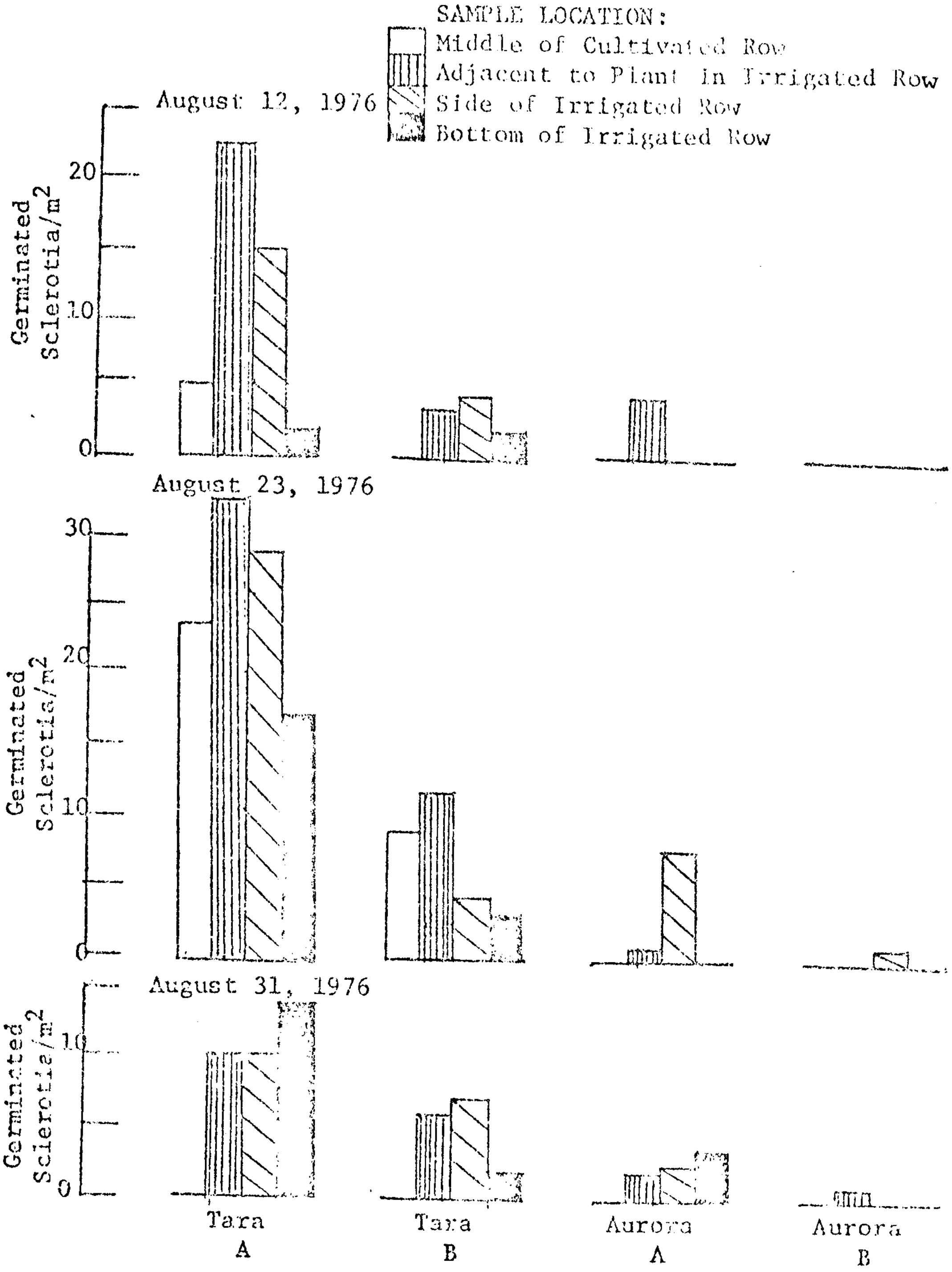

FIGURE 27. GERMINATED SCLEROTIA OBSERVED IN SAMPLE LOCATIONS, FROM SCHWARTZ (1977).

plant and on the side of the irrigated furrow. Figure 28 is a photograph of apothecia that were observed during the study.

Samples taken at planting time indicated similar numbers of sclerotia in both plots of Tara. However, much fewer sclerotia were found in the Aurora plots relative to the Tara. The smaller number of apothecia in the Aurora may have been at last partially due to the low inoculum level. The difference in inoculum level between the Tara and Aurora was likely the result of the history of the plots. As noted before, this was the third consecutive year this design has been utilized.

Since the inoculum levels were similar in both plots of Tara, the difference in observed numbers of apothecia between these plots may be the result of differences in soil temperature and soil moisture caused by different irrigation treatments. It was previously shown that values of soil temperature and water potential in the heavy irrigation treatment were more favorable for germiniation of sclerotia than those in the normal irrigation treatment. These effects may explain the larger number of apothecia observed in the Tara heavy plot.

The low number of apothecia observed in the Aurora may be related to the low inoculum levels in the Aurora plots. Other unknown factors, such as light intensity may be involved as well.

FIGURE 28. APOTHECIA OBSERVED NEAR BEAN PLANTS AT STUDY SITE.

5.8 Results of White Mold Infection:

The final amounts of white mold infection found in each plot are listed in Table II. The heavily irrigated Tara clearly sustained much more infection than the Tara normal or either of the Aurora plots. No white mold infection was observed in the plots of G.N. No. 59.

TABLE II. SEVERITY OF WHITE MOLD DISEASE IN TARA AND AURORA DRY EDIBLE BEAN CULTIVARS UNDER NORMAL AND HEAVY RATES OF IRRIGATION ON SEPTEMBER 8,1976. FROM STEADMAN (1977-UNPUBLISHED DATA).

CULTIVAR	IRRIGATION TREATMENT	% WHITE MOLD*
TARA	NORMAL	15.2%
TARA	HEAVY	50.0%
AURORA	NORMAL	0.6%
AURORA	HEAVY	5.4%

* % OF ABOVE GROUND PLANT INFECTED.

CHAPTER VI

SUMMARY AND CONCLUSIONS:

The results of this study indicate that irrigation exerts a considerable influence on the microclimate in dry edible beans. The immediate effects of irrigation on the microclimate included: decreasing daytime air temperatures 3 to 4° C; reducing leaf temperatures 5 to 6° C; lowering daytime soil temperatures as much as 10° C; increasing daytime vapor pressure up to 10 mb; and increasing percent soil moisutre by as much as 10%. These effects persisted for at least two days. No effect of irrigation on the microclimate was observed at night.

The results suggested that irrigation modified the energy balance of a bean canopy. Soil heating and sensible heat flux to the air from the soil and plant would be reduced after irrigation. These effects would result from the wet soil surface and increase in transpiration rates following irrigation.

The results of the study also demonstrated that irrigation frequency significantly affected the microclimate. As a result of modifying the energy balance, the heavy irrigation treatment resulted in lower air, leaf and soil temperatures, and higher soil moisture values, than those in the normal irrigation treatment. These effects were probably also influenced by the more dense canopy that developed under heavy irrigation, which would have reduced the penetration of radiant energy into the canopy.

Soil temperatures and soil moisture values in the heavily irrigated plots remained near the optimum values for germination of sclerotia. However, results suggested that soil temperatures and soil moisture in the normal irrigation treatment often become inhibitory for germination. These results may explain the larger number of apothecia observed in the heavy irrigation treatment.

Air and leaf temperatures were made more favorable by heavy irrigation for ascospore germination and subsequent colonization.

Larger amounts of infection were observed in the heavy irrigation treatment. This was apparently because heavy irrigation induced a more favorable microclimate for the disease than did the normal irrigation treatment.

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