A PORTABLE INSTRUMENT TO INVESTIGATE
THE TEMPERATURE PROFILE
ABOVE A SORGHUM CROP

By

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CHAPTER I

INTRODUCTION

Climatic conditions which exist in the Panhandle of Oklahoma are unique. During the summer months, evaporation from a U. S. Weather Bureau evaporation pan commonly exceeds 1-inch per day. Energy requirement for this amount exceeds the amount of energy which can be accounted for by net radiation alone, leading to the belief that advection is responsible for the difference. One can calculate evapotranspiration by the aerodynamic method for which temperature gradient is a component which should be known.

Nothing was known about the temperature regimes which existed in grain sorghum fields at Goodwell, Oklahoma. It was thought, that by utilizing thermistors and transistorized operational amplifiers, investigations of the regimes could be made with a portable system.

The objective of this study was to develop a portable system to study the temperature regime within a grain sorghum field. The temperature regime would be used to characterize the turbulent boundary layer phenomenon.

CHAPTER II

LITERATURE REVIEW

In accounting for the energies to which a field is exposed, the energy budget can be used. This energy budget is formulated to be:

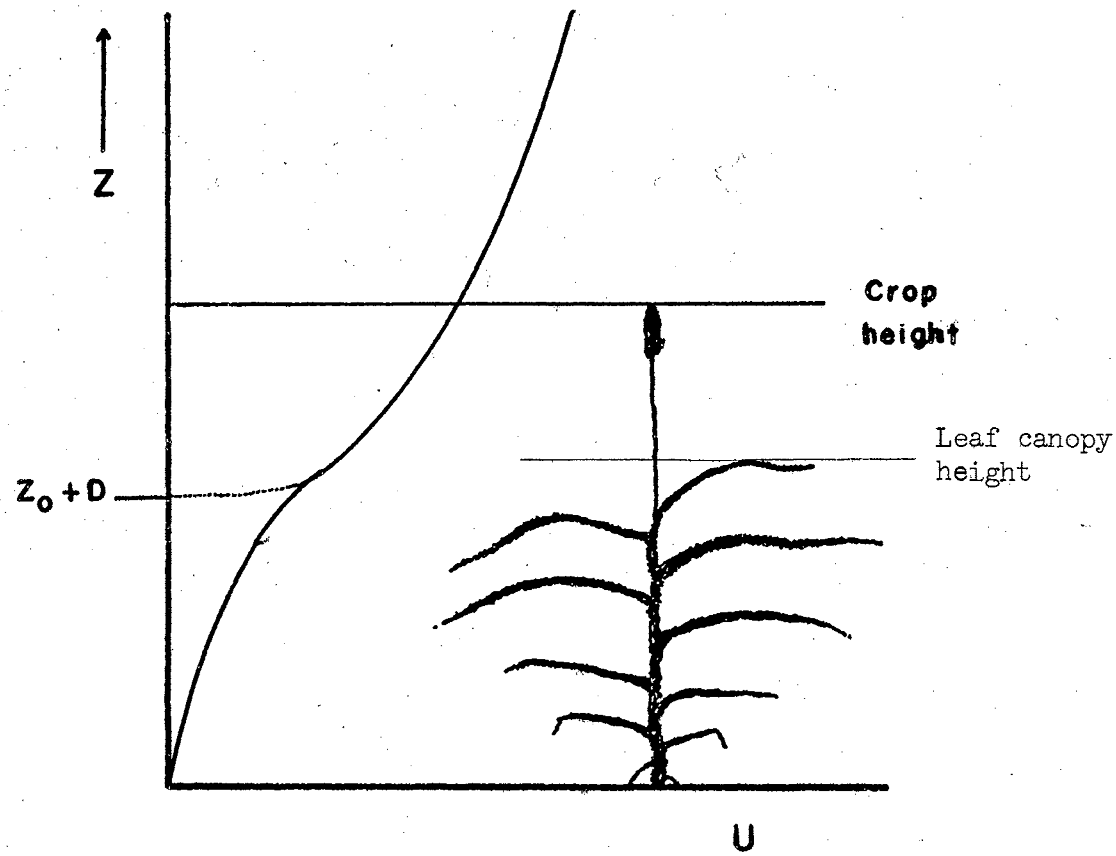
$$Rn = S + A + E$$

where Rn is the net radiation, S is the soil heat flux density, A the sensible heat flux density and E the latent heat flux density (5, 10, 19). These terms account for the majority of energy to which a plant or a bare surface is subjected. The energy used in photosynthesis or which is stored in the plant is assumed to be negligible, compared with the magnitude of the values of the above terms. In this thesis, primary interest lies in the value of the sensible heat flux, A, as it is believed that this value is an important factor in evapotranspiration in the Panhandle region of Oklahoma (6).

The sensible heat flux density refers to energy transported by the wind. An equation for the wind above a field, with the leading edge of the field at least 10 meters upwind, has been proposed and proven to be:

$$U_Z = \frac{U_*}{K} \ln\left(\frac{Z - D}{Z_o}\right)$$

where U_Z is the windspeed at some specified height Z, K is von Karman's constant, U_* is the friction velocity, D is the zero-plane displacement and Z_o is the roughness length (4, 8, 18). The parameters D and Z_o are are shown in Figure 1.



(Note: $Z_o + D$ is the point where the logarithmic curve would meet the Z axis upon extrapolation.

Figure 1. Some Parameters of the Logarithmic Wind Profile

The zero-plane displacement is the lower limit of the logarithmic wind profile, while the upper limit is recognizable by a discontinuity in the wind velocity profile. The zone of this logarithmic wind profile is called the turbulent boundary layer, or boundary layer, and wind is responsible for its formation.

In investigation of the zero-plane displacement, Stoller and Lemon, (17), found that for wheat, this logarithmic profile started about halfway between the soil surface and the top of the crop. For corn, they found that the logarithmic profile started about 200 cm, the crop height being 245 cm. In both of these cases, the logarthmic profile was characterized by windspeed, with the crop surface being relatively uniform, that is, no heads or tassels present. Where short grasses and bare surfaces have been used, the zero-plane displacement was assumed to be near or above the surface, not being located exactly (13, 15, 4).

The boundary layer has unique properties. These properties include: (1) independence of the prevailing windspeed (4, 15); (2) it does not commence at the point where surface condition changes, but some distance downwind (4); and (3) within this layer, the profiles of temperature and humidity are similar, but of opposite slope to that of wind profile (15).

In the characterization of the boundary layer, since the wind was responsible for transfers, temperature and humidity profiles would assume a profile comparable to that of the wind. Confirmation of temperature and humidity profiles to the logarithmic law was shown conclusively by Rider and Robinson (15). Although these profiles were negative with respect to that of wind, it confirmed earlier results above bullrush millet (1) and corn (10).

A question in the characterization of the boundary layer is the minimum distance downwind from the leading edge of the field where the conditions reflect that of the field. This minimum distance is called the minimum fetch. For short grass, 16 m was found to suffice (15); while with corn, a distance of about 60 m away from the leading edge was sufficient (9).

Controversy of the height to distance-downwind ratio exists and the values range from 1/20 to 1/200 (14). Among empirical equations, that of Elliot (4) is worth mentioning. He found that the growth of the boundary layer, with respect to the x axis on the horizontal plane, varied with the terrain. On an airfield, he found the equation $0.75\ x^{0.8}\ z_o^{0.2}$ fitted the results. Lemon modified this equation to $0.75\ x^{0.8}$ to fit the result obtained above a cornfield (10). No value for grain sorghum was found in the literature. Assuming that the parameters for grain sorghum would be between corn (10) and bare surface (4), the foregoing equation would predict the height of the boundary layer to be about 15 m at a point 100 m into the field.

It should be noted that because of its irregularity, wind movement above a surface has to be treated statistically (4, 20). By averaging, a somewhat steady state can be obtained. This steady state, or quasi-steady state (18), is assumed to be a sustained local wind with a wavelength of about 1,000 meters.

In the consideration of vertical movement above the crop, but within this boundary layer, the transfer of mass and momentum from the crop, or bare surface, is of the equation:

$$f = K\left(\frac{dq}{dz}\right)$$

where f is the flux density, K is the Eddy transport coefficient, dq/dz is the vertical gradient of the entity in question. The Eddy transfer coefficient is the result of turbulent motion above the crop. Turbulent motion is a result of the frictional drag (9).

If momentum flux density, or shearing stress (τ), is the entity considered, then the above equation becomes:

$$\tau = \rho K_m \left(\frac{du}{dz}\right)$$

du/dz being the wind velocity gradient, ρ the air density (16). Other transfer coefficients due to the same turbulence will be of similar form (16). Thus:

$$A = \rho C_p K_a \left(\frac{dt}{dz}\right)$$

where A is the heat flux density, C_p is the specific heat, K_a is the Eddy diffusivity or transport of sensible heat and dt/dz is the gradient of temperature. Vertical transfer of moisture would have a similar equation (16).

A question which arises is whether the Eddy transport coefficients for air, moisture and other similar masses are the same. Crawford (3) has shown evidence that the assumption that they are of equal magnitude is valid.

Within the boundary layer, horizontal transfer of momentum and mass has also been found to occur, with the magnitude of transfer dependent upon the prevailing windspeed (17). It has been postulated that point rates of evaporation at 32 m and 48 m from the leading edge of the field would be 7% and 12% less than point rates at 16 m over short, closely cropped grass (15). Furthermore, it was extrapolated that the point rate of evaporation would be relatively constant between 100 and 1,000 m downwind from the leading edge of the field (13).

In studies of advective energy above sudan grass 100 to 400 cm in height, it was found that the seedheads absorbed the radiant energy, converting it into sensible heat (5). This transformation of energy would tend to make the air in the vicinity of the seedheads hotter than that of the prevailing conditions. Similar results were obtained with high corn plants, as it was found that the temperature was the greatest at about 250 cm above the ground - the crop being 350 cm high (17).

Beggs, et al. (1), have clearly shown that the character of the temperature profile can vary diurnally. The temperature immediately above the crop was higher than the air further up at midday. In the evening, the opposite was true. Hence a negative slope of height versus temperature prevailed near midday and a positive slope prevailed in the evening. At an intermediate time, a vertical profile was noted.

In applying the flux equations, evaluation of the eddy transport coefficient (K) factors is difficult. A method which can be used to ascertain the relationship between evapotranspiration and sensible heat involves the Bowen ratio (15). The Bowen ratio relates the fluxes such that the K factor for heat and moisture cancel (since they can be assumed equal). Furthermore, no wind profiles are needed.

A relatively complete description of instrumentation used up to 1953 is given by Lettau and Davidson (11). In the description, discussions on the various types of heat sensors and shields are made.

Recently, the utilization of an electrically operated, permanently based apparatus for recording environmental conditions above a crop has been described by Tanner (21). This apparatus was modified and improved by Lemon (7). Their devices were of a fixed installation and required an A. C. line. Ambient temperature was measured from an aspirated sample. This aspirated system was also used by Rider, et al. (13, 15).

Beggs, et al. (1) used a portable potentiometer to determine the resistance of the thermocouples. These thermocouples were shielded by a half-cylinder of polished aluminum foil, being supported by plexiglass to ensure thermal insulation. Lagging of the instruments was provided by imbedding the sensors in blocks of metal.

In experiments where average values and low sensitivity of instruments are needed, hygrothermographs, set within Stevenson screens, have been found to suffice (22).

CHAPTER III

METHODS AND MATERIALS

Temperature Sensing

Thermistors[1] - represented as T1 to T6 in Figure 2 - were used for temperature sensing. A 1.5 volt dry cell served as a power supply for the thermistors. These thermistors had a 5 cm glass stem, tipped with an orb of 2 mm radius. The functional circuit of Figure 3 shows the bridge used for detecting voltage differential due to temperature change.

Amplification of the incoming voltage differential was accomplished by the use of operational amplifiers[2]. These amplifiers - A1 and A2 in Figures 2 and 3 - were powered by 10 dry cells connected to provide +7.5 and -7.5 volts. No sacrifice of operating characteristics would be expected to occur when as little as 1/2 the rated voltage supply for the amplifiers was used[3].

A1 in Figures 2 and 3 detects the unbalance bridge of the thermistor system. It provides an amplification of about 99 times - the ratio

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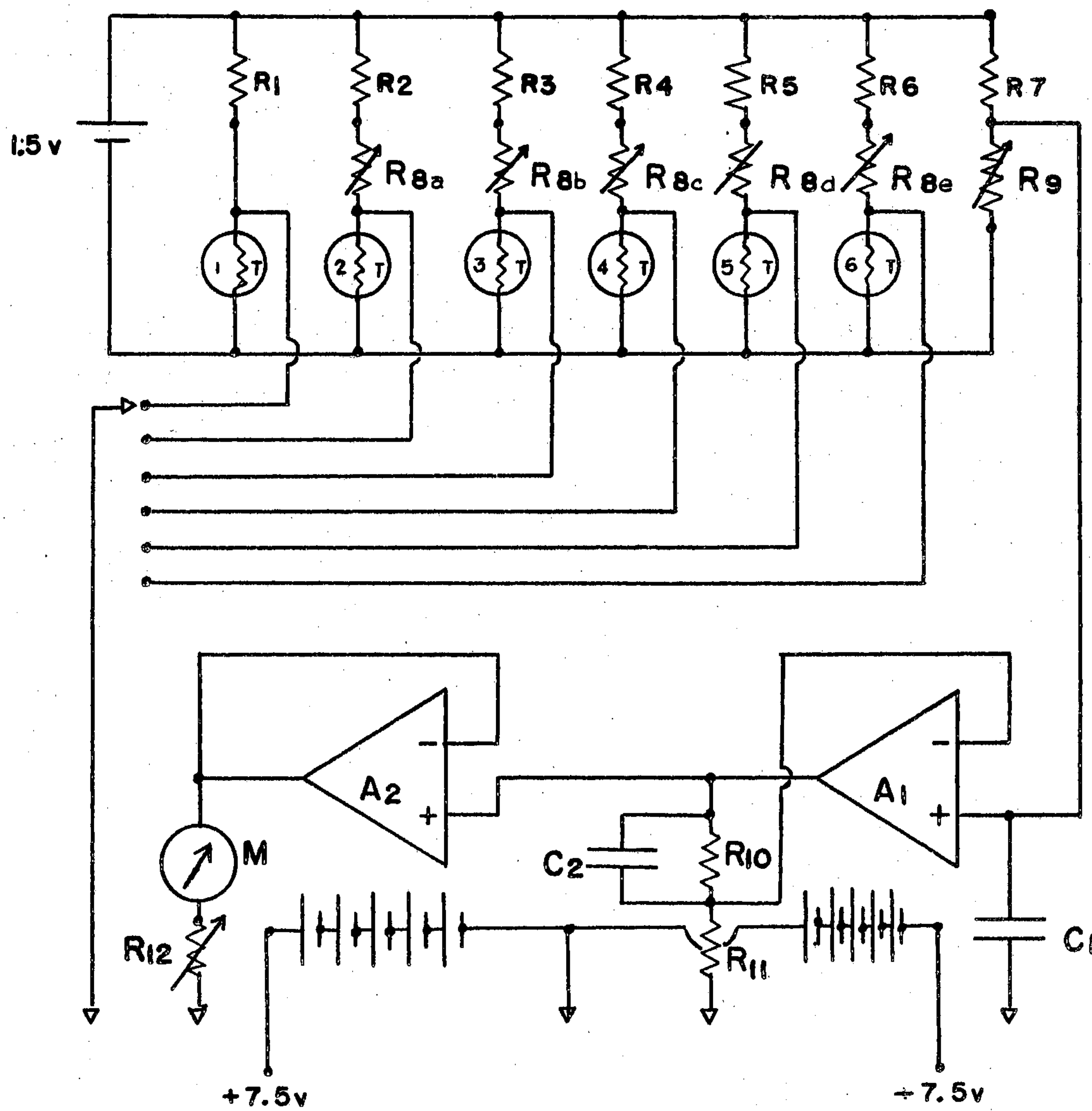
[1]Glennite - Model 32PBI obtainable from Allied Radio Corporation, Chicago, Illinois.

[2]Philbrick - Model P65AHU manufactured by Philbrick Researches, Inc., Dedham, Massachusetts.

[3]Personal communication with J. L. Stewart, Philbrick Sales Representative, Applied Science Associates, Tulsa, Oklahoma



R_1 = 20.0K
R_2 = 17.7K
R_3 = 19.4K
R_4 = 19.5K
R_5 = 19.5K

R_6 = 15.0K
R_7 = 20.0K
R_8 = .75 K
R_9 = 2.7 K

R_{10} = 19.8 K
R_{11} = .20K
C_1 = .001μfd
C_2 = 200 pfd

Figure 2. Schematic of the Thermistor-Amplifier Circuit

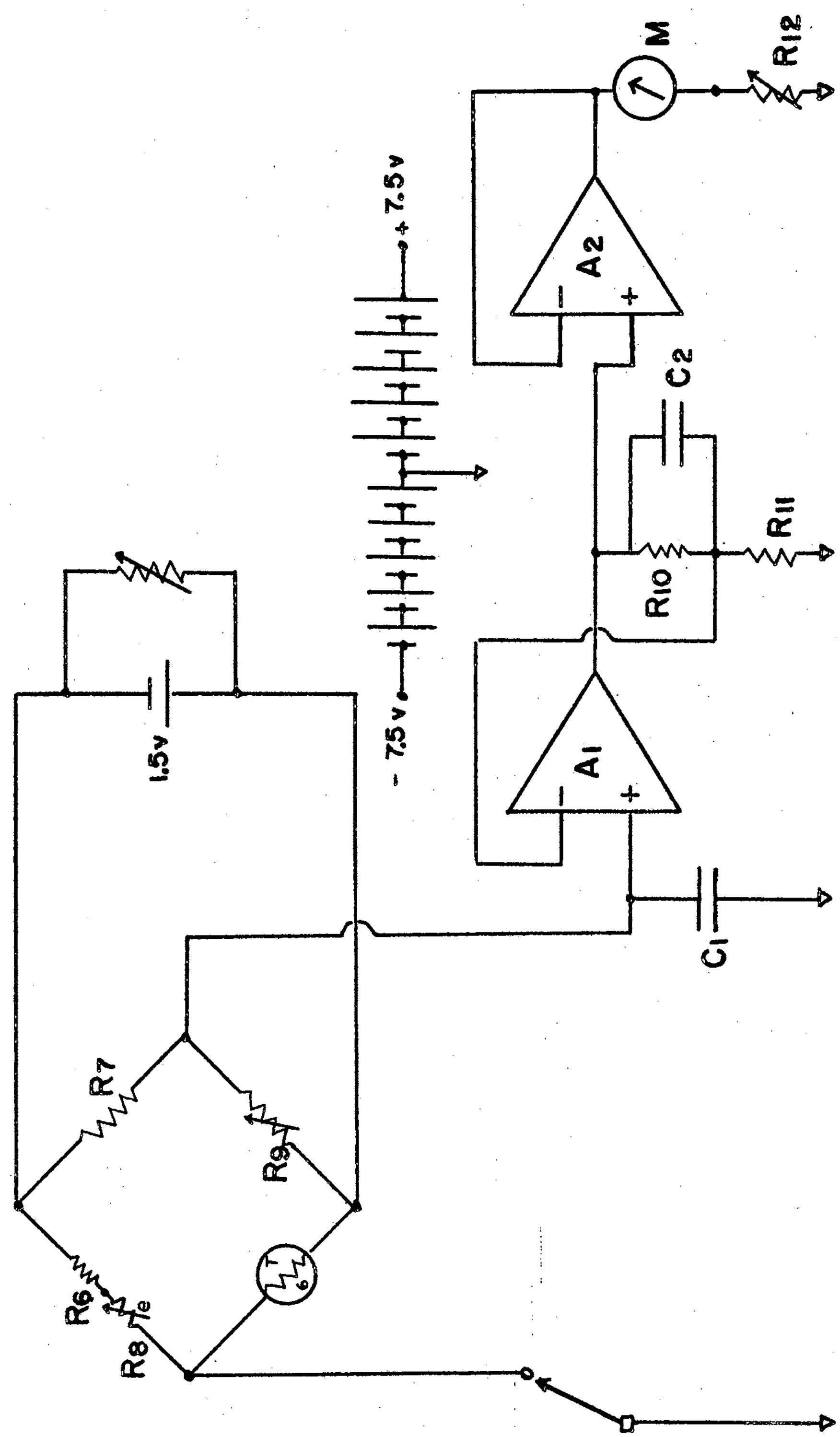


Figure 3. Functional Diagram of Thermistor-Amplifier Circuit

of R10 and R11. A2, is a follower to A1. This amplifier provides no gain. The output of A2 is registered on the meter[4] - M in Figures 2 and 3.

The capacitor, C1, is used to isolate the input to A1 from the switching transients when the various thermistors are selected in reading. This capacitor provides a 5 second time constant for the circuit. Capacitor C2 is used to stabilize the amplifier, A1, from oscilation.

The resistor, R12, controls the output of A2. Thus it serves as a "sensitivity" control for the system. R9 serves to balance the bridge at a given temperature, and is called the "range" control. $R8_{a,b,c,d,e}$ are used to balance T2 through T6 so that they may read identical with T1 at a selected given temperature.

Any change of resistivity of the thermistors was registered on the meter. The range of temperature encompassed was from 18.50 to 30.00° C. Full scale deflection on the meter was 2.5° C, giving a unit value of 0.05° C. since the meter contained 50 divisions.

The assembled amplifying circuit was enclosed in an aluminum frame, measuring 20 x 19 x 12 cm. The total weight of the assembly, including 4 m of wire, was 3 kg.

The method of calibration of the thermistors was to randomly insert them into closely fitting holes - 1.5 cm deep - in a solid brass cylinder. A thermometer[5] was inserted in a hole at the other end of the cylinder. The cylinder was supported on a wooden platform and the

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[4]Simpson D. C. Milliammeter - Model 1327 obtainable from Allied Radio Corporation, Chicago, Illinois

[5]Fisher - Model 451 obtainable from Fisher Scientific Company, Houston, Texas.

entire assembly placed in a vacuum desicator. A vacuum desiccator was used for two reasons: (1) because it provided an outlet for the electrical wires; and (2) because the system could be sealed, thereby being relatively free from convection inside. The desiccator was wrapped with aluminum foil and placed in an environmental chamber where temperature could be accurately controlled.

Calibration of the device over the range of temperature encountered in the field was made. Whenever change in temperature was made during calibration, 12 hours was allowed for the system to equilibrate. Range adjustment was then made in order to bring the readings on the same scale as the #1 thermistor. The result of this calibration is shown in Figure 4.

Radiation Shield and Assembly

An attempt was made to duplicate the plate type radiation shield described by Portman (12). This shield was compared with a cylindrical one designed and constructed in the laboratory (see Figure 6). The cylindrical radiation shield was found to respond as fast to ambient conditions as the plate type, but it did not accumulate heat as fast, nor was it subjected to as much reflected radiation.

The outer radiation shield of the cylindrical type was constructed of cardboard. This shield was designated to shield out all reflected radiation greater than 35°. The outside was covered with aluminum foil and painted white, the inside was painted black and dusted with charcoal powder. The inner shield is of plexiglass and blocks out radiation at angles greater than 15°. It is painted white on the outside, black on the inside.

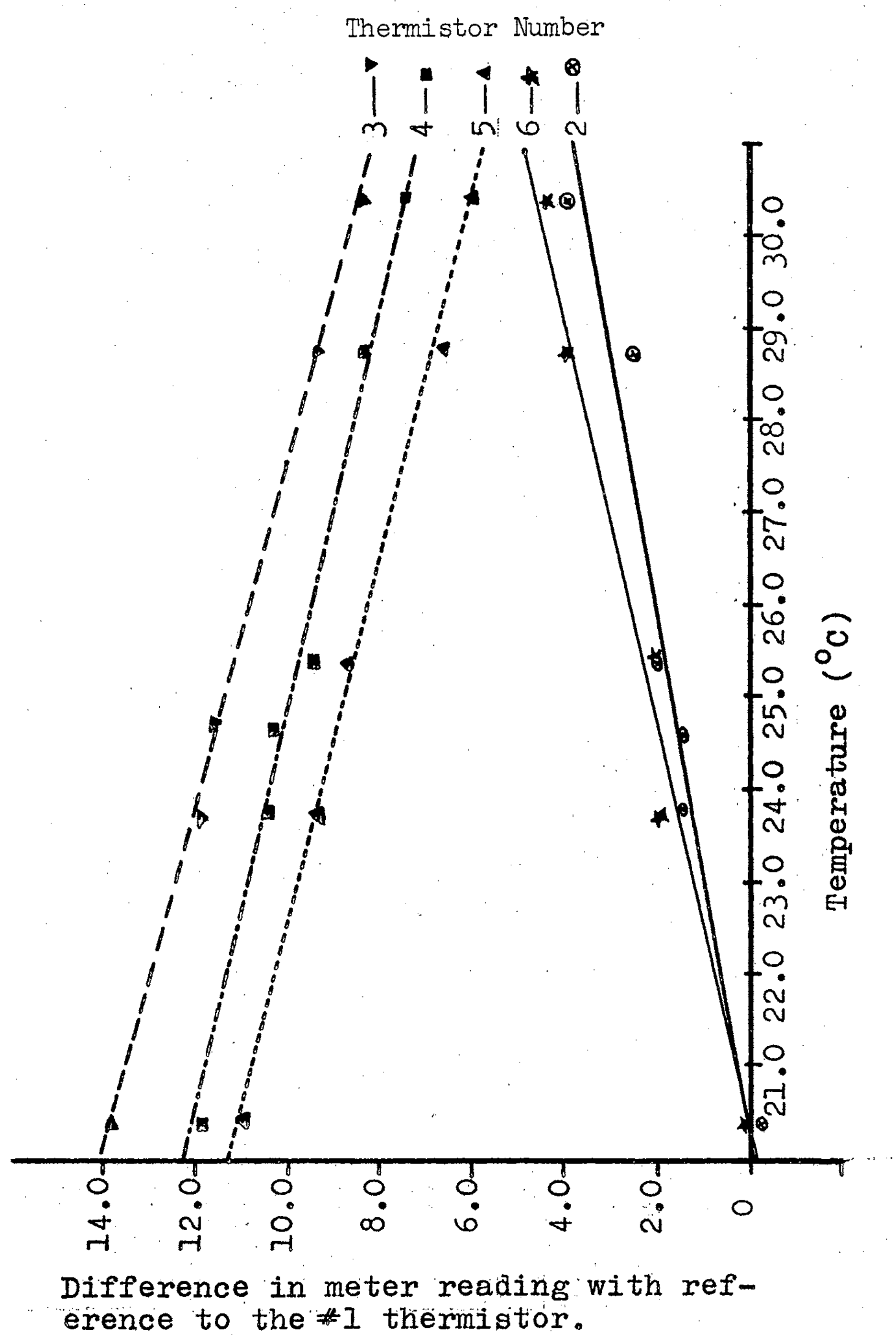

Figure 4. Calibration Curves

The supporting assembly is shown in Figure 6. The main stem is of aluminum tubing while the supporting stem is of steel conduit, 2 cm outside diameter. The main stem can be extended by attaching a larger diameter aluminum tube at the bottom, and telescoping to the desired height. The whole assembly was supported from the soil by a 4-vaned anchor.

The distances above the crop to where the shields were placed were: 8.5, 20.0, 30.0, 42.0, 150 and 200 cm. Crop height was found by aligning a point on the mast with the height of the crop. It should be noted that the shields were valid when the wind was normal to the direct radiation of the sun.

Method of Sampling

The thermistors were assigned to the radiation shield assemblies in a random manner.

Testing of the apparatus was performed in a grain sorghum field. An anemometer was placed at about 1 m away, laterally to the apparatus, at about 10 cm above the crop. Wind speed and temperature measurements were made within a 3-minute period. As many readings as possible were made during the quasi-steady state. The sequence of readings was to switch from 1 through 6 and then reverse the sequence. The average value which was obtained was plotted on 2 cycles semi-logarithmic paper. It should be noted that on the graphs, the nomenclature used is shown in Figure 1.

[6] Taylor - Model 3132 obtainable from Taylor Instrument Company, Rochester, New York.

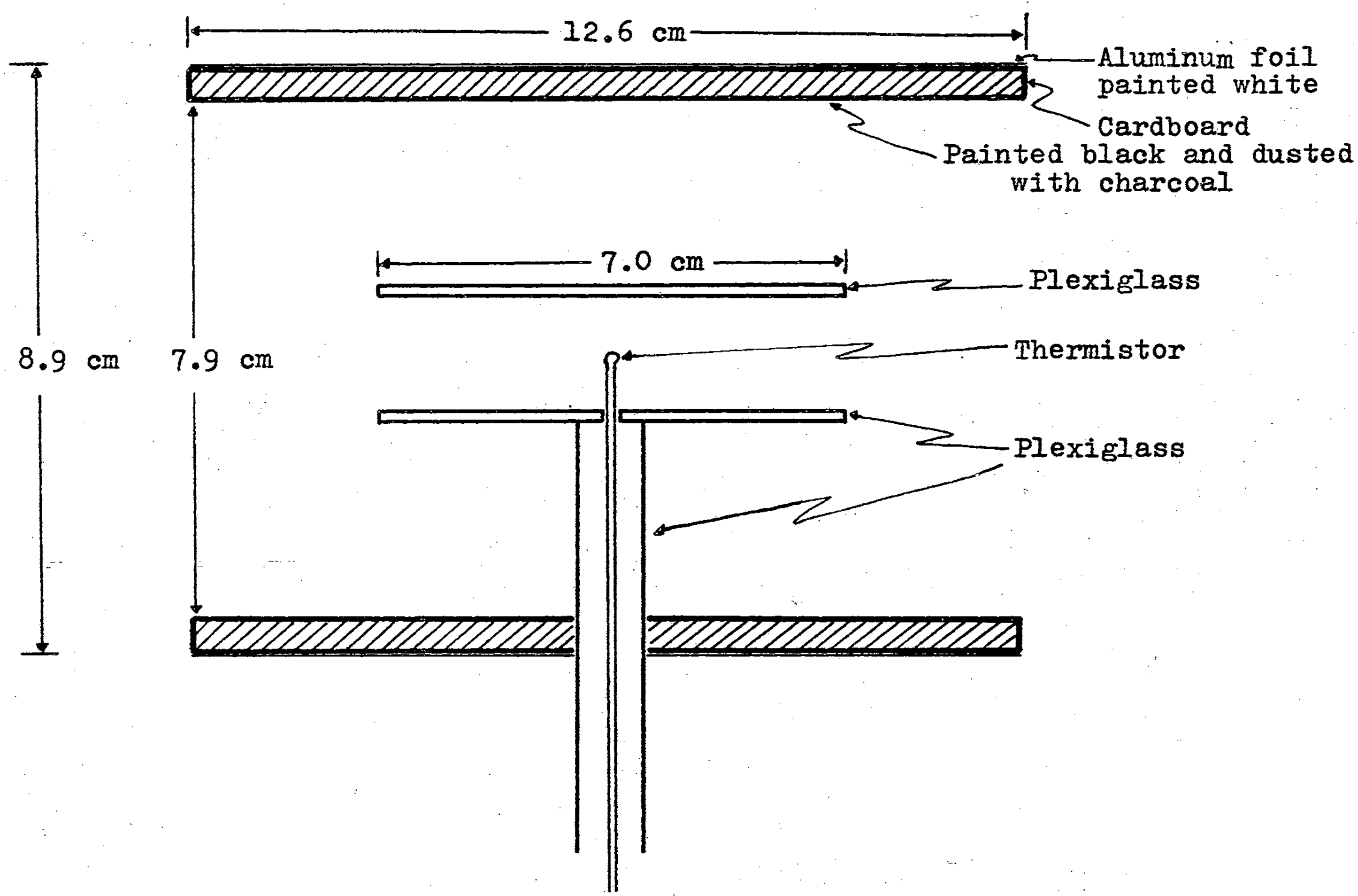

Figure 5. Scaled Diagram of the Radiation Shield

Figure 6. Profile Sensing Mast

The orientation of the mast into the wind was obtained with the aid of streamers placed between the 150 and 200 cm sensor. By electrical means[7], reference temperature was obtained. Corresponding reading of the thermistor was obtained. The field distances where temperature profile measurements were made were obtained.

The field layout is shown in Figure 7. The row orientation was from east to west. Grain sorghum (OK-612) were planted in 8-inch rows, on a 56-inch bed with 4 rows per bed.

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[7]Telethermometer - Model 43TC obtainable from Yellow Springs Instrument Company, Inc., Yellow Springs, Ohio.

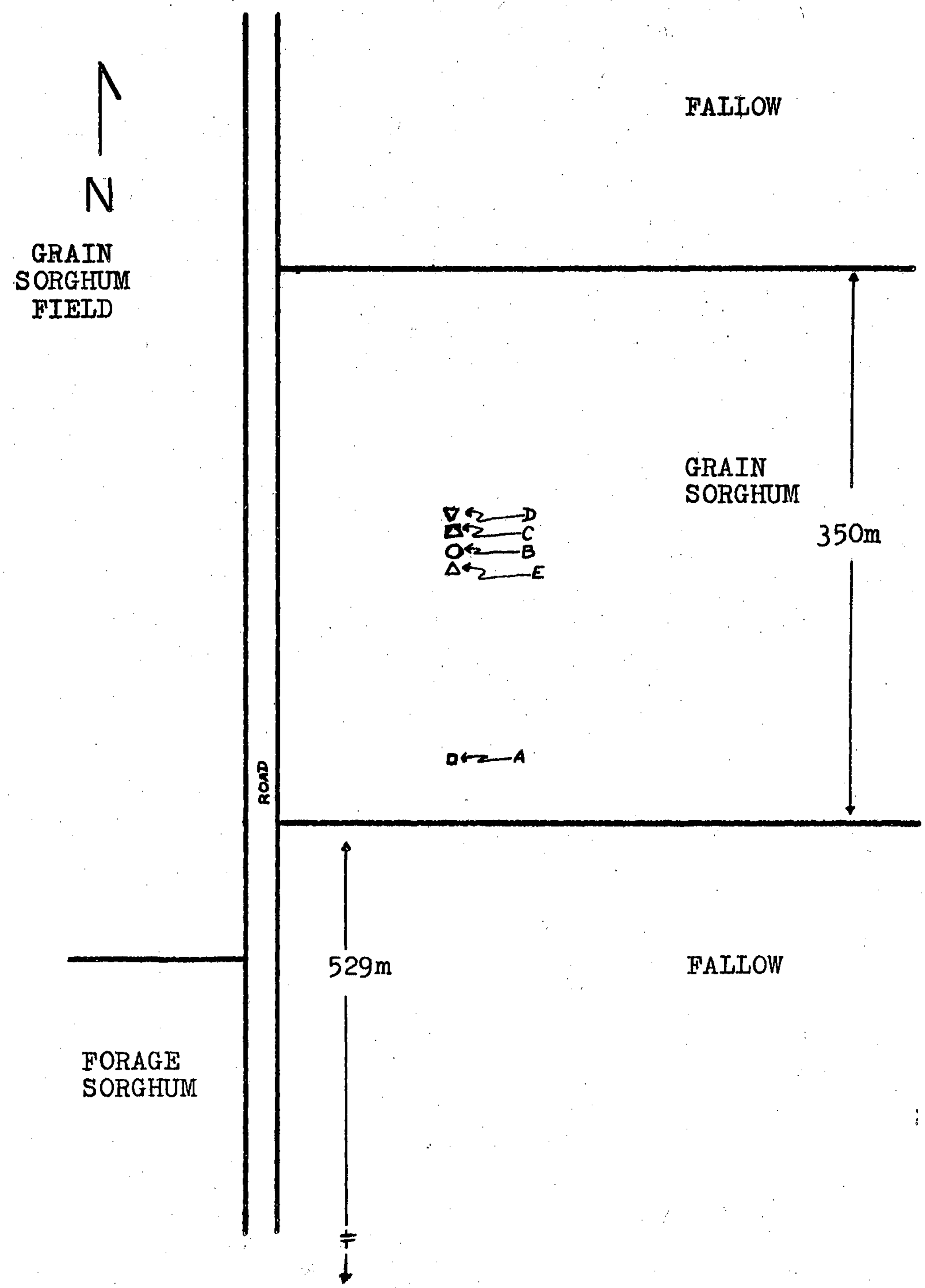

Figure 7. Layout of Field under Study

CHAPTER IV

RESULTS AND DISCUSSION

On September 3, 1966, a clear, cloudless day, readings were made at point A, Figure 7. The temperature sensing mast was lowered in increments of 10 cm into the crop after each 3 minute reading. The purpose of this was to check whether the results reflected temperature conditions or effects of the thermistors. The results are shown in Figure 8. The discontinuity shown between 80 and 90 cm was consistent. In general, the slope at a given height was consistent. This seems to confirm the validity of the thermistors for temperature profile sensors.

The temperature regime within the heads was found to be higher than above the crop. Similar results have been reported with corn (9) and sudan grass (5). Figure 8 also shows that the immediate turbulent boundary layer above the crop was relatively independent of windspeed.

On September 9, a series of readings was taken to further investigate the temperature regime which existed in the field. The times at which these measurements were taken were 1:15, 2:00, 2:45 and 4:00 p. m. Central Standard Time. The location where these were taken is shown as points B, C, D and E respectively in Figure 7.

The results are shown in Figures 9, 10, 11 and 12. These graphs show the diurnal fluctuation of temperature above the field. Figure 9 shows the profile at about a steady condition. Profiles 3 and 4 seem

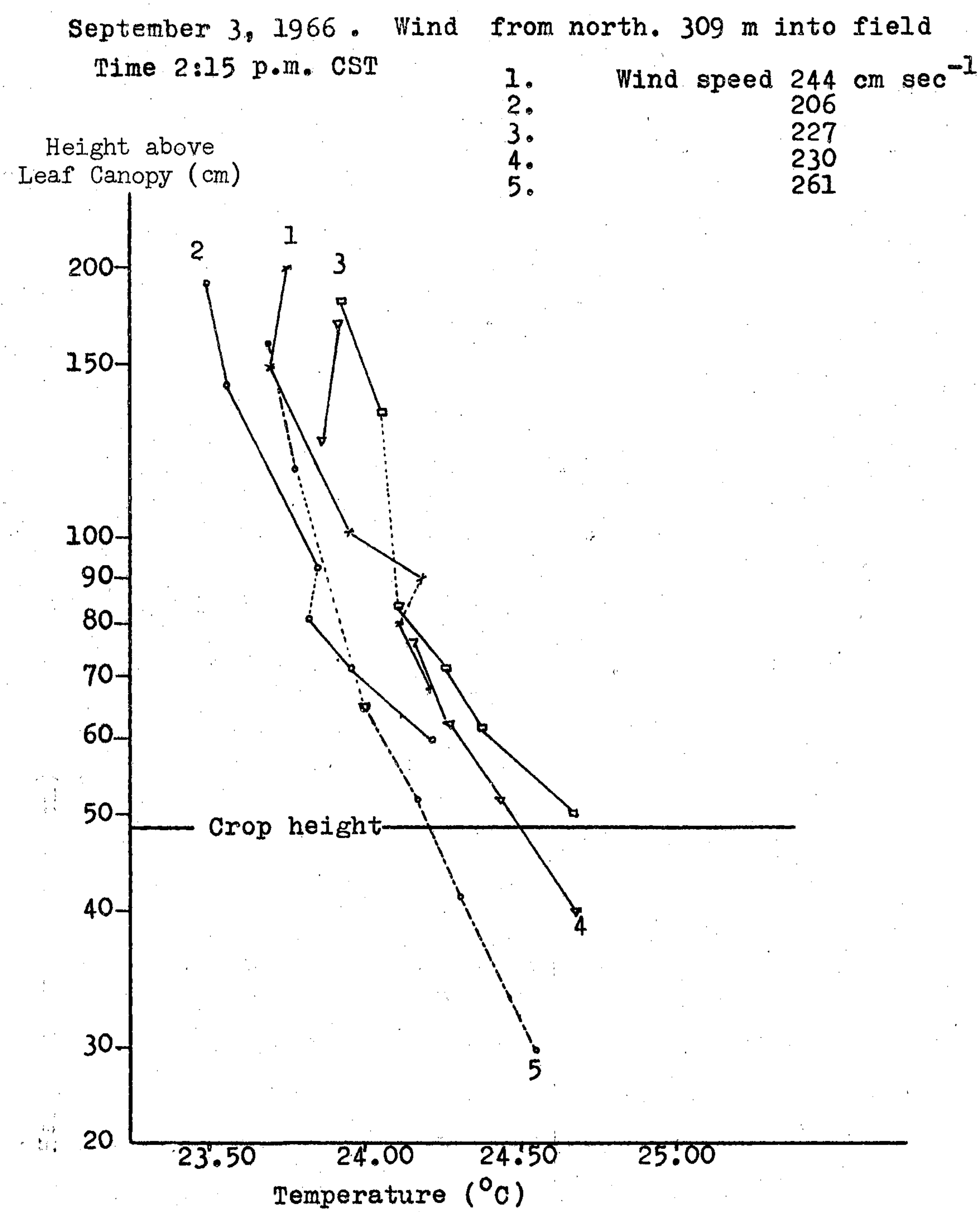

Figure 8. Temperature Profiles at Certain Levels in and above Crop

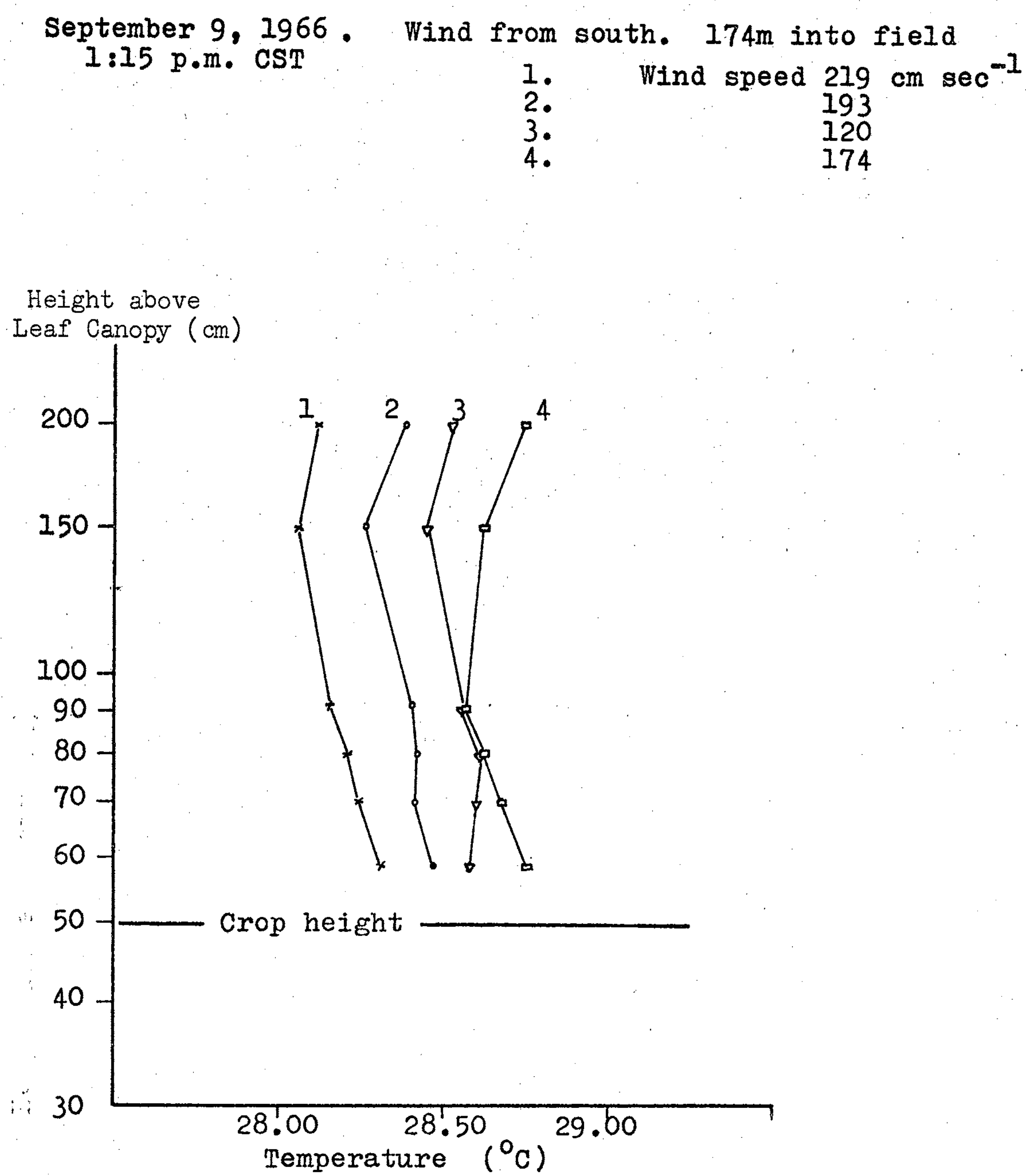

Figure 9. Temperature Profiles on September 9, 1:15 p. m., above Crop

September 9, 1966. Wind from south. 182m into field
2:00 p.m. CST

1.	Wind speed 204 cm sec^{-1}
2.	217
3.	147
4	183

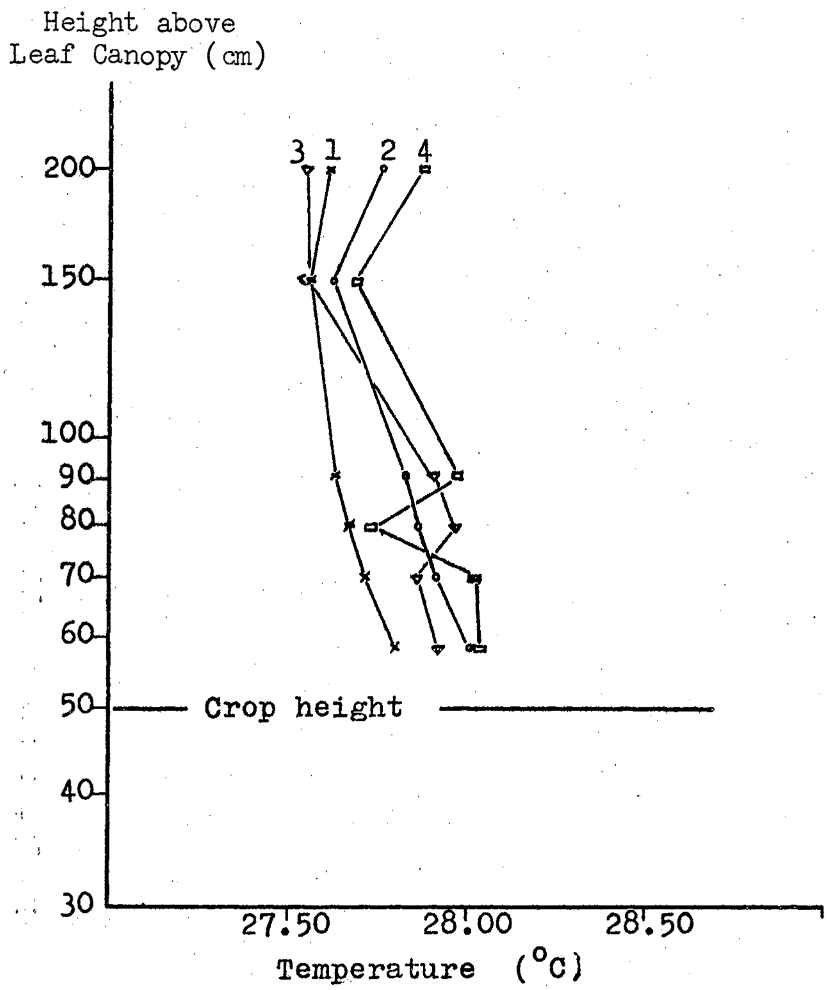

Figure 10. Temperature Profiles on September 9, 2:00 p. m., above Crop

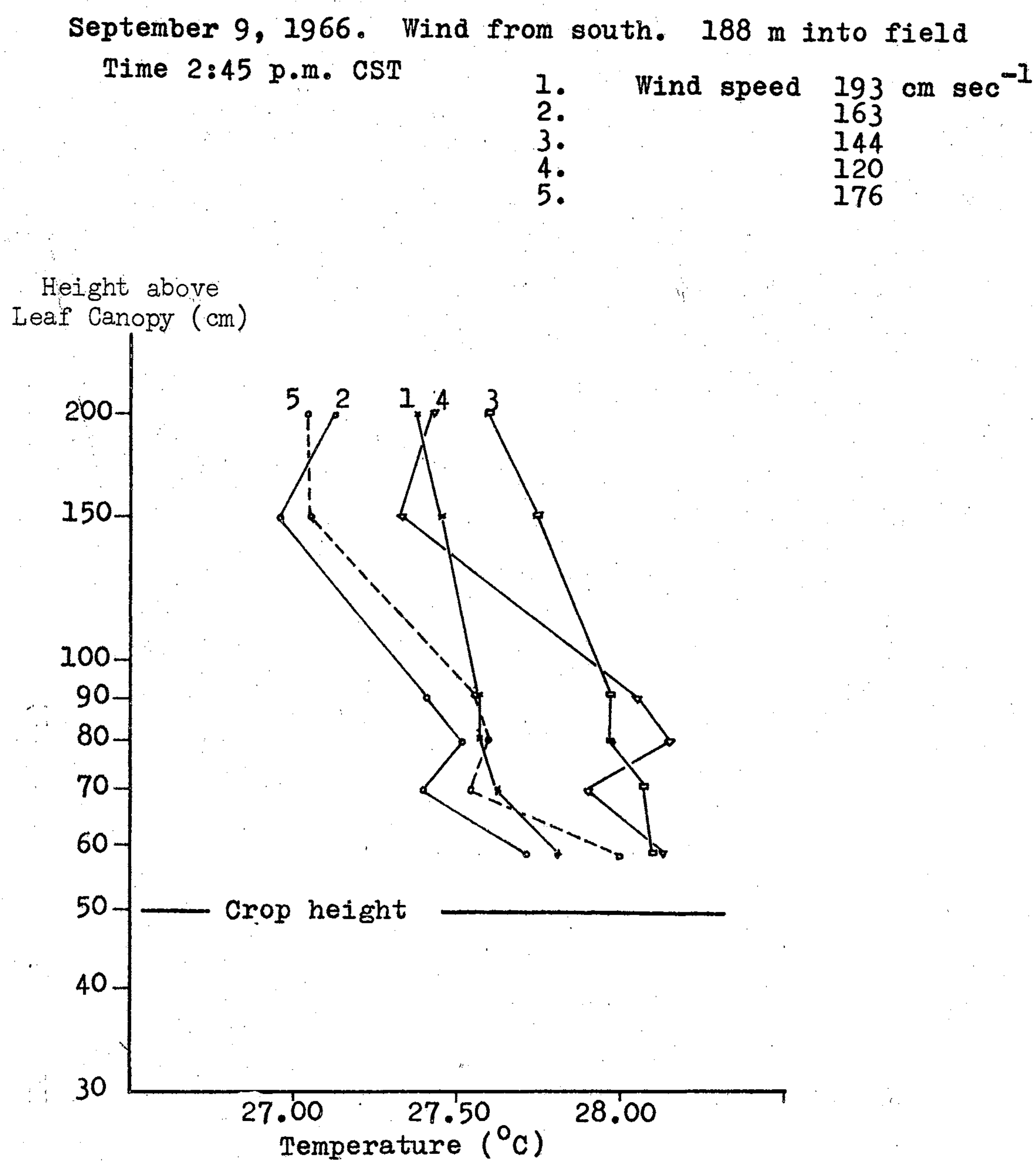

Figure 11. Temperature Profiles on September 9, 2:45 p. m., above Crop

September 9, 1966. Wind from south. 167m into field
4:00 p.m. CST

1.	Wind speed	183 cm sec^{-1}
2.		217
3.		183
4.		176
5.		138

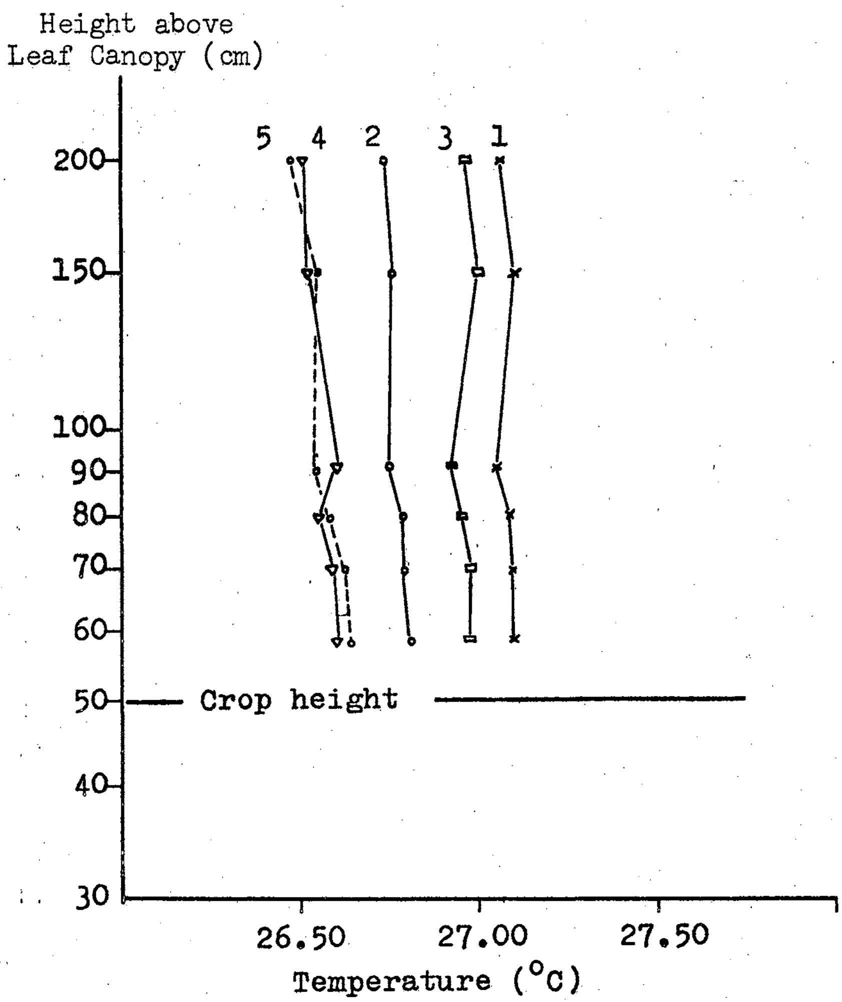

Figure 12. Temperature Profiles on September 9, 4:00 p. m., above Crop

to have a discontinuity at about the 80 to 90 cm height above the crop. Evidence of this condition is also seen in Figures 10 and 11.

At point C, 8 m from point B, 45 minutes after readings at point B commenced, profiles were again characterized. Noticable in this result, Figure 10, is profile #4. Between 70 and 80 cm above the crop there was a steep temperature gradient. This condition also was found in Figure 11. It seems as if at this time of the day, the maximum thermal instability existed. The gradient at profile 5 of Figure 11 was about .04° C/cm between 58 and 70 cm above the canopy.

Figure 12 shows where stable thermal conditions exist, making the profile vertical.

The portability of the apparatus showed that characterization of temperature profiles could be made at various places in a field within a short period of time. A factor to be considered in these studies is that the height of the crop hampered movement in the field. This is the factor which limits the number of places which could be measured in a given time.

CHAPTER V

SUMMARY AND CONCLUSIONS

A portable instrument, suitable to investigate the temperature regime in a field has been described. The temperature sensing apparatus weighed 3 kg; was small and sturdy enough for field work.

This instrument utilized 11 dry cells (1.5 volts each), 2 transistorized operation amplifiers and other electrical materials. Temperature sensing was done by using thermistors mounted on a portable mast at 8.5, 20.0, 30.0, 42.0, 150 and 200 cm above the crop.

The instrument was tested in a grain sorghum field at Goodwell, Oklahoma. The sensitivity of the instrument was good enough to sense temperature profiles consistent with those found in the literature.

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