MICROMETEOROLOGICAL INSTRUMENTATION

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SUMMARY

The instrumentation, data acquisition and analysis systems installed at the Plant Physiology Division, D.S.I.R., Palmerston North, microclimate field plots are described.

Results from one day's observations are presented showing diurnal changes in the energy budget, soil and crop temperatures, and evapotranspiration rates.

INTRODUCTION

The last decade has seen many advances in instrumentation used for measuring the physical environment of crops and pastures. These developments have made it practical to apply theory describing the mechanisms of mass, momentum and energy exchange between the crop and the atmosphere, to the measurement of crop processes such as transpiration and photosynthesis in the field. These micrometeorological techniques eliminate the need to destructively sample the crop, and they do not modify the crop environment in any way. The techniques have been used over the past 10-15 years by meteorologists and soil physicists in many countries; and they are now being used frequently in agronomic research overseas.

In this paper the instrumentation which has been used to measure the evapotranspiration rates of pastures and crops is described. Much of this instrumentation can be used in other areas of biological research where a description of the environment is required. For this reason approaches used and experiences gained are given in detail.

INSTRUMENTS AND METHODS

Field Site:

Several of the micrometeorological techniques used require that measurements be made within the boundary layer of the crop. It is widely accepted that the fetch to measurement height ratio should be at least 50 : 1. Therefore, a measurement made 1 m above the crop surface, requires 50 m of crop upwind from that point. These fetch requirements dictate the minimum plot size for each crop. A permanent field of four hectares has been developed on part of the Massey University farms. The soil is a Manawatu silt loam.

Measurement of Evapotranspiration:

The experimental objectives were to measure the field evapotranspiration rates of pastures and crops under different long (weeks) and short-term (hours) weather conditions, and varying soil water status.The energy budget method (Tanner, 1960) of measuring evapotranspiration has been used. This technique is the most proven and reliable of the above crop methods. Comparative measurements can be made over time intervals as brief as 30 minutes. The method integrates spatially over the crop surface and the equipment is relatively portable, so that it can, if necessary, be used at field sites away from the home base.

The energy budget for any surface can be written as follows:

$$R_N + E + H + G_o + P + V = 0 \qquad (1)$$

where R_N - net radiation

E - latent heat flux

H - sensible heat flux

G_o - soil heat flux at soil surface

P - energy exchange for photosynthesis and respiration

V - energy storage in vegetation.

For most agricultural crops both P and V are small (2%), so that where the method is being used to measure evapotranspiration, these terms can be neglected.

Net radiation and soil heat flux can be measured directly. However, it is technically difficult to measure the sensible and latent heat fluxes directly. An alternative approach is to measure the ratio of these two fluxes.

This is called the Bowen ratio:

$$\beta = H/E \qquad (2)$$

$$\equiv f\,(T_W, \Delta T_D, \Delta T_W, P_a) \qquad (3)$$

where T_W - mean wet bulb temperature

ΔT_D - dry bulb temperature gradient

ΔT_W - wet bulb temperature gradient

P_a - atmospheric pressure

Therefore, the following components are measured directly:

$$R_N, \quad G_o, \quad T_W, \quad \Delta T_W, \quad \Delta T_D, \quad P_a$$

INSTRUMENTS (SENSORS)

The field sensors used to measure the key parameters are discussed below. The instrumentation used to measure all the necessary environmental parameters is outlined in Table 1.

Net Radiation

Net radiation comprises the net flux of both the long-and short-wave radiation components above the crop surface. This flux can be measured with a Funk type radiometer comprising a horizontal black plate with the two surfaces forming a thermopile (Funk, 1959). The head is enclosed in thin polyethylene domes which are kept inflated by passing dry air through them and then into a bubbling column giving a pressure of about 2 cm WG inside. They are supported on a tripod (or mast) at about 1 m above the crop surface.

Soil Heat Flux

Equation (1) requires the heat flux at the soil surface. This cannot be measured directly because the flux plates would disturb the soil surface.

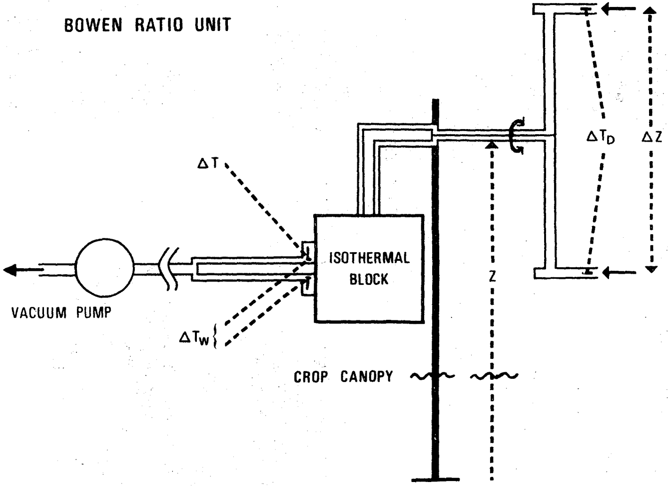

FIG. 1. Schematic Diagram of Bowen Ratio Unit.

Therefore, the plates are buried at 5.0 cm depth and the changes in heat stored in the 0 - 5.0 cm soil layer are calculated from temperature and soil heat capacity measurements.

$$\text{Therefore, } G = G_{5.0\text{ cm}} + \begin{pmatrix}\text{Changes in heat storage} \\ \text{of C - 5 cm layer}\end{pmatrix} \quad .. (4)$$

The soil heat flux plate comprises a thermopile wound on a section of fibreglass circuit board (Tanner, 1963) and potted in epoxy. Spatial integration is achieved by burying three plates beneath each crop.

The rate of change in soil temperature at 1.85 cm is used to calculate the heat storage term in equation (4). The temperature at this depth represents the average temperature of 0 - 5.0 cm soil layer. Germanium diodes (1N2326) potted in epoxy, to which a constant forward current of 1 mA is applied, are used as soil temperature sensors. Soil temperatures are also measured at depths of 10, 40 and 80 cm.

Bowen Ratio

The Bowen ratio is computed from measurements of T_w, T_W, and T_D made above the crop but within its boundary layer. These measurements have been made with the machine shown schematically in Figure 1. At the end of each arm a shielded silicon diode measures the dry bulb temperature. The shields are so arranged that both the upper and lower sensors look at the same radiation environment. To reduce errors (Fuchs and Tanner, 1970) the air which is drawn over the sensors is then taken to a pair of labyrinth ducts in an aluminium block which brings the two airstreams to the same dry bulb temperature before passing the two wet bulb sensors (Slatyer and Bierhuizen, 1964). These are a modified design using subminiature silicon diodes to measure the temperature. Snowtex tissue wicks are used.

To eliminate any systematic errors in the gradient data the arm carrying the dry bulbs is inverted 180° every 15 minutes and the average value over 30 minutes is taken as the error term.

Experience has shown that it is essential to check all instrumentation at least three times per day.

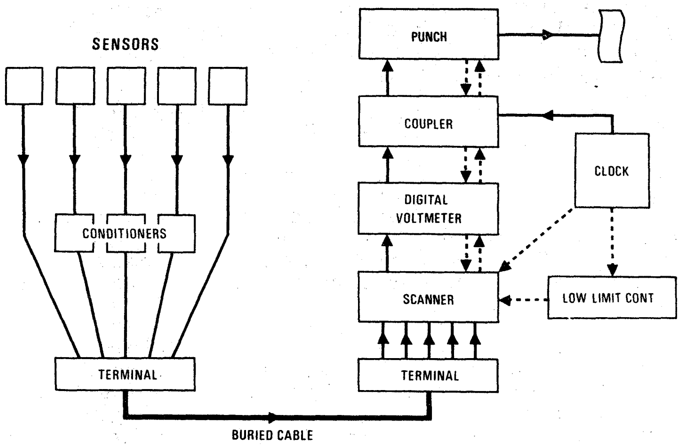

FIG. 2. Schematic Diagram of Field Sensors and Data Logging System.

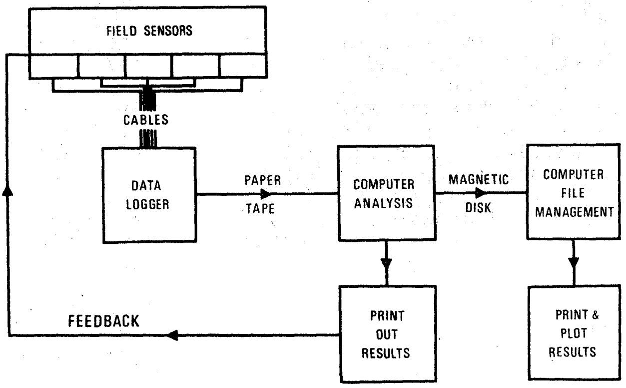

FIG. 3. Block Diagram of Data Logger and Computing System.

A bevy of faults, not all of which could have been anticipated has been experienced, e.g., magpies occasionally pecked through the polythene hemispheres of the net radiometers, wet bulb wicks can be broken or water reservoirs dried out, airflows over sensors may change due to blockages, birds may break light wires, leaf thermocouples become dislodged or rabbits burrow through underground wires.

DATA LOGGING SYSTEM

The logging system is based on a Hewlett-Packard 2012B system with a few local modifications. It is shown schematically in Figure 2. All the signals fed to the data logging system are in voltage form. Some sensors, e.g. wind speed, require a conditioner to convert their fundamental output to a proportional voltage.

Signals are fed one at a time to the digital voltmeter (DVM) which selects the most appropriate range and takes a reading. The DVM is of the integrating type which eliminates most of the interference from mains hum. The encoded data is fed via the coupler to the tape punch.

A scan is initiated by the clock at selected intervals (usually 1 minute or 1 hour) and the first and last channels scanned can be selected by thumbwheel switches. The scanner has been modified so that the first channel scanned can be programed to change on command from the clock so that both short and long scans can be intermixed. For example, one might scan channels 20 to 60 for 9 minutes and on the tenth minute scan channels 1 to 60. This feature can be used to conserve tape by skipping those channels which are recording slowly changing parameters, e.g. soil temperature.

The system can operate at a speed of about 10 channels/sec. This means that the system is only operating about 10% of the time. For this reason it is highly desirable to have a solenoid operated tape punch that does not require a motor running all the time, e.g. FACIT 4070 model. A block diagram of the data logger and computing system is shown in Figure 3.

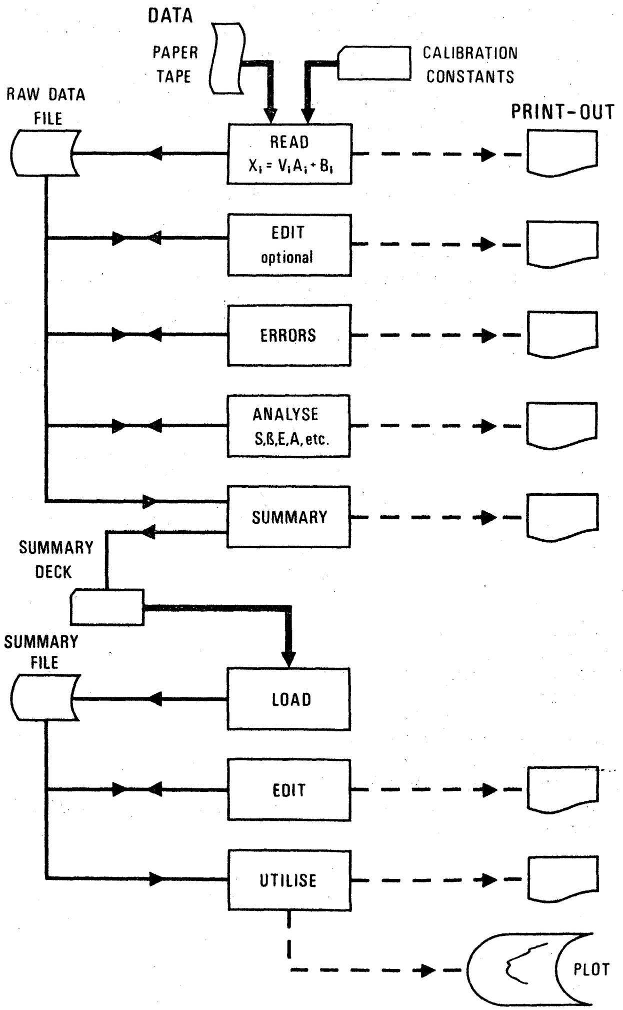

FIG. 4. Flow Diagram of Computer Programs.

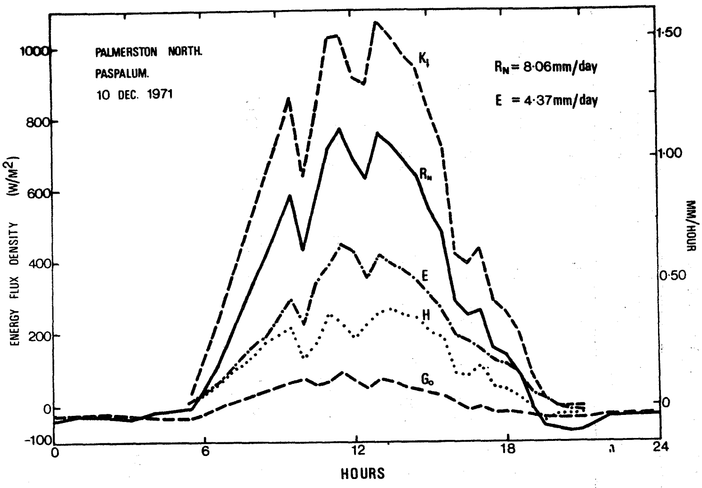

FIG. 5. Energy balance Components Recorded on Paspalum, December 10 1971.

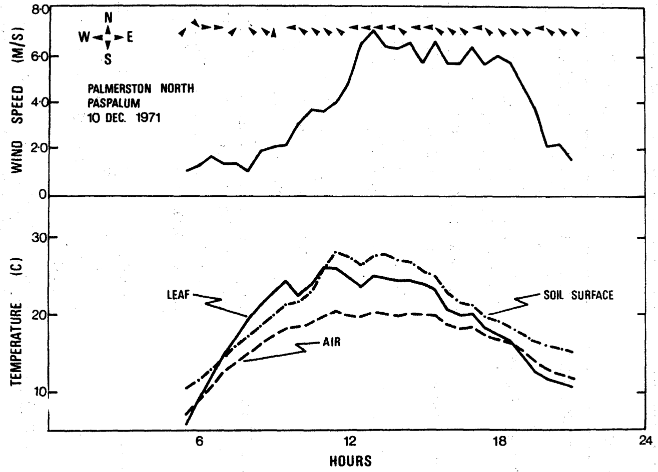

FIG. 6. Paspalum Leaf-, Air- and Soil Surface Temperatures; Global Radiation; Windspeed and Wind Direction Data for December 10 1971.

TABLE 1. Type and Output Characteristics of Instruments Used to Measure Various Environmental Parameters.

			Output	
Parameter	Instrument Used	*	Typical Range	Sensitivity
1. Net radiometer	Funk type net radiometer (Funk, 1959).		-7 to +70 mV	9 to 26 wm^{-2}/mV
2. Soil heat flux	Soil heat flux plates (Tanner, 1963).	P (C)	-1.0 to +1.0mV	120 wm^{-2}/mV
3. Soil temperatures	Germanium diodes (1N2326) potted in epoxy resin.	P	90 to 170 mV	0.5 C/mV
4. Air temperatures	Aspirated subminiature silicon diodes (BAW56) in radiation shields.	P	650 to 730 mV	0.5 C/mV
5. Leaf temperatures	Fine (0.004 in) copper-constantan thermocouples referenced to ice.		-0.2 to 2.0 mV	25 C/mV
6. Soil surface temperature	Copper-constantan thermocouples referenced to ice. Potted in epoxy resin and covered with heat shrink tubing (0.125 in O.D.).	P	-0.2 to 2.0 mV	25 C/mV
7. Windspeed	Casella cup (5.4 cm) anemometer at 2 m. Rate meter required for signal conditioner to data logger.	C/P		
8. Wind profiles	Small C.S.I.R.O. cup (3.2 cm) anemometers at intervals on 2 m mast, driving pulse counters.	C		

TABLE 1 (continued)

			Output	
Parameter	Instrument Used		Typical Range	Sensitivity
9. Wind direction	Wind vane on 360° potentiometer	P		
10. Global radiation	Eppley pyranometer.	C	0 to 15 mV	80 wm^{-2}/mV
	Integrating silicon solar cell pyranometer (Kerr et al, 1967)	P	100 w hr m^{-2} $\equiv$	100 counts
11. Rain	Unit detects the onset of rain. Interleaved conductors on a printed circuit card.	P		
12. Soil water	Gravimetric sampling.			
	Tensiometers (Barrie, 1963).	P(C)	0 to -0.8 bars	
	Thermocouple psychrometers (Rawlins and Dalton, 1967).	C	0 to -40 bars	0.47 uV/bar
13. Stomatal resistance	Diffusion porometer. Modified design of Kanemasu et al (1969). Modifications include use of stainless steel cup and electronic stop watch.	P	0 to 30 sec/cm	

* C - available commercially, P - made at Plant Physiology Division

COMPUTING SYSTEM

Before using a computer for data analysis one must be able to state exactly what one wants to do. In this respect a computer is a good aid to planning these types of experiments.

All computation has been done on the Massey University IBM 1620 system which supports two disks drives, line printer, card reader/punch, tape reader/ punch, incremental plotter and typewriter.

The processing procedure consists of seven main programs and a number of supporting programs. shown in Figure 4. (Talbot, 1972).

READ reads paper tapes, applies scaling factors to bring values to engineering units and prints out and stores the values on to magnetic disk, scan by scan. This incorporates an error detection routine which reports all tape format errors found (mainly due to tape punch faults) on the typewriter.

EDIT may be used if required to printout selected channels and correct errors (e.g., due to open circuit sensor, etc.)

ERRORS computes the systematic errors of the wet and dry bulb gradient measurements and stores these back to disk.

ANALYSE computes half-hour mean values and energy balance equations. All values used are printed out together with the means and balance values.

SUMMARY prints out on two pages per crop all the values of means and balances and also the spot readings taken on the hour. A deck of cards is punched with the same information.

LOAD sorts and loads the summary card deck on to another disk for use as a summary file.

UTILISE allows access to any part of the filed data for listing, plotting, regression analysis, etc., i.e., the file is a data base for a number of utility programs.

RESULTS

The system was run on 66 days during summer 1971-72. About 3500 ft of tape per day was punched. The tape was processed on the computer as soon as possible, up to the point of the SUMMARY program. Usually the tape was processed within 24 hours of recording; but there was never more than one week's delay. This gave an immediate feedback to the operator in the field so that faulty sensors could be detected and repaired. Experience has shown that this feedback of information is essential in order to reduce data losses to a minimum.

Energy balance data over paspalum for a typical day (10 December 1971) are presented in Figure 5. Total energy for the day available as net radiation was equivalent to 8.06 mm water. Evapotranspiration was 4.37 mm.

Temperature, windspeed and direction, and global radiation data for the same day are presented in Figure 6.

FUTURE INSTRUMENTATION

Several instruments at present in various stages of development have potantial for environmental studies in agronomy. We are particularly interested in the measurement of CO_2 and momentum fluxes.

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