AGROCLIMATOLOGY
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A MANUAL FOR COLLECTION OF RELEVANT DATA SETS FOR AGROCLIMATOLOGICAL STUDIES

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NOTE TO THE READER

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1. INTRODUCTION

Existing agricultural research strategies rely heavily upon the analogue concept for the transfer of information (Nix 1983). This suggests the necessity of establishing a network of experimental sites. Analysis of agroclimatic data of these sites thru systems approach would help interpretation, generalisation and extension of research results. This requires an interdisciplinary research effort for identification and collection of minimum data set for the soil-crop-weather and management system.

The minimum data set requirement would, however, change depending upon the objectives and the nature of questions that need to be answered. Nix (1983) defined the minimum data as those which are required for simple genotype X environment interaction and comparative analysis of crop performance at widely spaced sites and/or seasons. The data set is just sufficient for calculation of biophysical indices, for initialising and verifying runs of the simple crop models, and for development and testing of empirical yield prediction equations.

Proposals for collection of minimum data sets for field experiments have been made by Collis-George (1972), Frere (1972), Nix (1973), Angus (1980), and Huda et al. (1980). The principle of collecting minimum data set is implicit in several national and international field research programs such as the Australian National Soil Fertility Project, the Asian Cropping Systems Program, the World Meteorological Organisation Wheat Crop Ecology Project, and the International Benchmark Sites for Agrotechnology Transfer (IBSNAT).

The Farming Systems Research Program of ICRISAT has been working on multilocation crop modeling experiments since 1979 in cooperation with scientists from eight locations in India (11-31°N) and one location (Khon Kaen) in Thailand. A minimum data set was identified in a meeting of the cooperating scientists from these locations held at ICRISAT Center in 1979. A manual for collection of meteorological, crop, soil and management data was prepared to maintain the uniformity in data collection across locations. We now consider it appropriate to revise the manual based on our experience and publish it for the of scientists/technicians involved in agroclimatological research.

The manual deals with a list of minimum data sets. A list of additional data sets that would be desirable to collect is also included. Methods of data collection and the use of required instruments are also described. The name, make and the approximate price of some of the instruments are given in Appendix I.

2. DATA SETS

2.1 Meteorological

2.1.1 Minimum

Rainfall, maximum and minimum temperature, solar radiation, potential evaporation, relative humidity.

2.1.2 Desirable

Wind speed, bright hours of sunshine, net radiation, canopy interception of photosynthetically active radiation (PAR), measurements of leaf temperature, stomatal conductance, transpiration, leaf water potential.

2.2 Crop

2.2.1 Minimum

Genotype name, plant density, dates of emergence, anthesis and physiological maturity, total number of leaves (non tillering crop), maximum and final leaf area index, total dry matter, grain yield, number of effective tillers and their contribution to grain yield (tillering crop).

2.2.2 Desirable

Partitioned dry matter and canopy cover (leaf area index) sampled at or close to critical growth stages e.g., panicle initiation, anthesis and physiologicl maturity, monitoring of phenological stages, seed weight and seed number.

Appearance dates for each effective tiller, leaf area, and total dry matter for tiller and main plants at few critical growth stages (for tillering crop).

2.3 Soil

2.3.1 Minimum

Available water holding capacity and initial available water content.

2.3.2 Desirable

Available soil water as a function of depth and time, bulk density, upper and lower extractable water storage values, pH, initial nutrient status, soil temperature.

2.4 Management

2.4.1 Minimum

Records of all treatments, their timing, and level of inputs (e.g. Fertiliser, irrigation, herbicide etc.), row spacing, depth of sowing etc.

2.4.2 Desirable

Records of land use history, monitoring of pests and diseases.

3. METHODS OF DATA COLLECTION

3.1

If the experimental plot is not located near a meteorological observatory, rainfall should be measured on site. Other meteorological data can be obtained from an adjacent meteorological station. A brief description of the instruments required for meteorological and micro-meteorological observation is given. Reddy (1977) described some of the instruments required for meteorological observations.

3.1.1 Rainfall

There are two types of raingauges for measuring the amount of rainfall received:

i) Non-recording

ii) Recording

Non-recording type: The non-recording raingauge (Symon's pattern) consists of collector, with a gun metal of 200 cm^2 (diameter = 159.6 mm), a base, and a 4 litre polythene bottle of 200 mm of rainfall capacity. Both the collector and the base are made of fibre glass reinforced polyster (Fig. 1). The collector has a deep set funnel and the complete raingauge has slight taper with the narrower portion at the top. The gauge should be placed on level ground. The raingauge should be fixed on a masonary or concrete foundatin 60 x 60 x 60 cm sunk into the ground. The base of the gauge should be embeded in the foundation so that the rim of the gauge is exactly 30 cm above the surrounding ground level. The rim of the gauge should be kept perfectly level. The amount of the reiinfall collected by the gauge is measured with the aid of graduated measuring cylinder known as a rain measure supplied with the raingauge at specified routine hours of observation.

Recording type: The natural syphon recording raingauge (Fig.1) is instrument designed to give a continuous recording of the rainfall. In addition to the total amount of rainfall, the times of onset and cessation of rain and therefore the duration of rainfall are also recorded.

Rainwater entering the gauge at the top of the cover slide via a funnel to the receiver consisting of float chamber and a syphon chamber. The pen is mounted on the stem of the float and as the water level rises in the receiver, the float rises and the pen records the level of water in the chamber. Syphoning occurs automatically when the pen reaches the top of the chart, i.e., 10 mm mark and then the pen comes down to zero line of the chart. The pen arises again with the onset of rainfall. In case there is no rain, the pen traces a horizontal line.

The gauge should be so installed that the rim of the funnel is horizontal and set at a height of exactly 75 cm above the ground level. For setting the pen to zero mark pour sufficient water into the receiver till the pen reaches the top and water syphons out. After all the water is drained out the pen should be on the zero line. If not, the adjustment of the pen should be done.

3.1.2 Air Temperatures

The standard air temperatures are measured by using dry bulb, wet bulb, maximum and minimum thermometers. These are exposed under similar conditions in a shelter of approved pattern called the Stevenson Screen (Fig. 2).

Dry and wet bulb thermometers indicate the instantaneous temperature and humidity condition of the air at the time of observation, while the maximum and minimum thermometers indicate the highest and lowest temperatures of the day.

The bulb of wet bulb thermometer is always kept wet by means of a one fold of thin and soft muslin sheath fed by water from a bottle through a wick.

The four thermometers are read twice daily i.e. at the time of the routine morning and afternoon observations.

3.1.3 Solar Radiation

A pyranometer (Fig. 3) is suitable for measuring global sun and sky radiation. The silicon photodiode has made possible the construction of simple pyranometers of reasonable accuracy. The photodiode is stable and the response of the silicon photodiode sensor does not cause serious error provided the photodiode is used only for solar radiation. An LI-200S pyranometer (LI-COR Inc, Lincoln, Nebraska, USA) is useful for this purpose. The pyranometer should be set up on a level surface free from any obstruction to either diffuse or direct radiation. The sensor could be conveniently levelled through the use of a mounting and levelling fixture. The vertical edge of the sensor should be kept clean to maintain appropriate cosine correction. A calibration certificate supplied by the manufacturer can be used to calculate the daily solar radiation in langleys/day from the integrator counts for each day.

3.1.4 Evaporation

Pan or tank evaporimeters are the most widely used instruments for evaporation measurement from free water surfaces. The standard mmended evaporimeter is class 'A' pan (Fig. 4). The class 'A' evaporimeter (mesh covered, fixed point gauge) is an instrument for measuring the amount of water lost by evaporation per unit area in a given time interval from a shallow container. The amount of water lost by evaporation from pan in any given interval of time is measured by adding known quantities of water to the pan from a graduated cylinder till the water level touches the reference point.

Observations with the evaporimeters should be made twice daily at 0830 and 1430 hrs IST. Clean the pan as frequently as necessary, about once a fortnight or more often, to keep it free from sediments, scum and oil films. When heavy rains threaten to overflow the pan, remove enough water to lower the level.

3.1.5 Wind Speed and Direction

The wind direction is given by an instrument called the windvane. It is balanced lever which turns freely about a vertical axis. In the most common type, one end of the lever exposes a broad surface to the wind, whilst the other end is narrow and points to the direction from which the wind blows. Under this moveable system is fixed a rigid cross, the arms of which are set to the four cardinal directions - North (N), East (E), South (S) and West (W). The wind direction is to be read from the wind vane to the nearest of the sixteen points of the compass. Wind direction is always to be recorded as the point from which the wind comes.

The wind speed or wind force is given by an instrument called the ...ieter. It consists of four hemispherical cups attached to the ends of two crossed metal arms. The cross is pivoted to a vertical spindle passing through a brass tube attached to the anemometer box. The foot of the spindle rests on a steel ball placed inside a hallow at the base of the box. The rotation of the upright spindle is transferred by means of a gear to a counter called the cyclometer. To determine the wind speed at the time of observation, take two successive readings of the anemometer at an interval of 3 minutes. Substract the first reading from the second one and multiply the difference by 60/3, and the wind speed will be obtained in miles per hour. (1 mile/hr = 0.9 Knot). The average wind speed per day in miles/hr is given as the difference between the two successive readings at 0830 hr IST separated by 24 hrs divided by 24. The wind instruments are fixed at a height of about 10' above ground level.

3.1.6 Sunshine

The Campbell sunshine recorder is an instrument for recording the duration of bright sunshine. It consists essentially of a glass sphere of 10 cm diameter mounted centrally on a spherical bowl. The diameter of the bowl is such that when exposed to the sun's rays the sphere focusses the rays sharply on a card held in grooves in the bowl. Three overlapping pairs of grooves are provided in the bowl to curved cards suitable for different seasons. Long curved cards are used during summer 12 April to 2 September; short curved cards for winter 15 Octoebr to 28 February and straight cards at equinoxes i.e. for the remaining period. The action of the recorder depends upon the charring of the cards by the heat of the sun rays which are focused on the card by the glass sphere. The sunshine recorder uses the movement of the sun instead of clock to form the time basis of the record. The whole instrument is mounted on a marble stone which in turn is set up on a firm and rigid support. This recorder can be used from 5°S to 45°N.

3.1.7 Net Radiation

Net radiation on the crop canopies can be measured by net radiometer (Fig. 5). It measures all radiation on a horizontal surface, between wavelengths of approximately 300 nm and 60,000 nm (0.3-6.0 μm), from the upper and lower hemispheres. The resultant can be recorded by any integrator such as LI-510, LI-550 etc. Both horizontal black surfaces (sensing elements normally constantan-silver thermopiles having resistance of 180-200 ohms) have been shielded from the effect of wind and weather by a pair of polyethylene domes which are optically transparent from 0.3 to approximately 60 μm.

The higher the net radiometer is mounted, the larger is the area covered by the measurements and less they are influenced by the variations in the characteristics of this area. But an excessive height leads to the effect of radiation of the layer between the surface and the instrument.

Net radiometer measures difference of global radiation (solar + sky) and longwave radiation reflected from earth's surface and crop canopies.

3.1.8 Albedo Radiation

Albedo is the percentage energy reflected by a surface in a specified band of wavelength. The instrument used for measuring albedo radiation is called Albedometer (Fig.6).

The albedo meter consists of high sensitivity sensing element consisting of copper-constantan thermopile to which a blackened sensor plate is attached and its spectral response is from 0.3 to 2.6 microns (300 nm to 2600 nm). The signal generated is directly proportional to the amount of radiation falling on the sensor plate. For measuring albedo radiation, the Albedometer is fitted with a specially designed shield so that the instrument cannot see its own shadow, or depending upon the use, area of the shadow is reduced to an absolute minimum. Albedometer has to be mounted on a tripod stand such that it covers the crop and soil at the ratio of 50:50 and can be connected to integrators such as LI-510, LI-550 etc.

3.1.9 Canopy Interception of PAR

The ultimate source of practically all energy for the physical and biological processes occurring on earth is solar radiation. Although 99% of the solar radiation lies between the limits of 0.2 and 4 microns, different wavelength bands may cause differetn biochemical effects. Of all the wavelength bands, the region between 0.4 to 0.7 microns is of most importance in terms of plant photosynthetic efficiency, and the radiation in this wavelength band is called Photosynthetically Active Radiation (PAR).

A quantum sensor could be used to measure the number of photons, in the 400-700 nm (visible wavelength) range, received on plane surface. The sensor may be most conveniently levelled through the use of the mounting and levelling fixtures and can be connected to integrator such as LI-510 or LI-550.

Profile measurement of PAR (plant canopy PPFD) can be done by using portable angle iron framework with 4 small diameter quantum sensors and integrators (LI-COR inc., USA).

LI-191 SB line quantum sensor along with LI-188 B integrator effectively averages (PPFD) over its one meter length, eliminating the need for averaging readings from many small diameter sensors as stated above (Fig. 7). Stronger evidence of the relation between radiation interception during entire growing season and annual dry matter production of several crops grown in England was reported by Monteith and in those studies solar radiation (KJ m^{-2} min^{-1}) was generally converted to PPFD, which is the preferred measurement for radiation interception.

PPFD is the number of photons in the 400-700 nm waveband incident per unit time on a unit surface. The ideal PPFD sensor responds equally to all photons int he 400-700 nm waveband and has cosine response.

3.1.10 Leaf Temperature

Leaf temperature could be measured by using "Instatherm" Infrared thermometer (Fig. 8).

At any temperature above absolute zero (-459.72°F) infrared energy (thermal energy) is emitted by all objects and materials. The amount of thermal energy emitted is proportional to the 4th power of their absolute temperature. The infrared thermometer collects the thermal energy emitted from a surface by means of fixed focus optics and converts it into an electrical signal by sensitive detector which is then electronically conditioned for reading in temperature units (°C or °F). It is fast because it collects IR energy at the speed of light, and the detector has a very low mass. The time constant is 0.1 second, about 10 times faster than conventional contact methods.

3.1.11 Stomatal Conductance and Transpiration

Steady state porometer (Fig.9) LI-1600 manufactured by LI-COR, USA, is a battery operated portable instrument and is primarily used for measuring different plant parameters such as leaf temperature, relative humidity, transpiration, and diffusive resistance along with cuvette temperature, air flow into cuvette, PAR at the point of measurements.

Definition of Steady State Condition: A steady state condition (null balance) is the one when the humidity in the cuvette is maintained at the ambient value of humidity, or another chosen value of humidity desired for the null point. A steady state condition where the humidity is either equal to, or very near the null point, is a general condition that will give accurate diffusive resistance measurements.

Principle of Operation: A leaf sample is placed on to the cuvette aperture of the sensor head and held in place by a clamping action (Fig. 10). The relative humidity of the cuvette, in contact with the sample, is held constant steady state condition. The diffusive resistance or water loss (transpiration) is determined by the instrument under this steady state condition.

Many factors namely light level, CO_2 level, relative humidity, ambient temperature, leaf temperature, leaf water potential, and wind will effect in finding stomatal resistance. LI-1600 minimise disturbing the light level, relative humidity, ambient temperature, and leaf temperature. Prevention of alteration of the wind environment - "boundary layer resistance" is impractical and is approximately 0.15 sec cm^{-1}. To avoid CO_2 level effect, the observations are taken within a period of 30-60 seconds.

3.1.12 Leaf-Water Potential

The technique of measuring leaf-water potential using pressure chamber (Fig.11) has been briefly discussed here. A leaf or leafy twig is cut from the transpiring plant and is sealed into the pressure chamber with the cut surface open to the atmosphere. The pressure in the chamber is increased until the xylem sap just begins to exude from the cut surface. This pressure is equal to the negative hydrostatic pressure in the vessels connected with the leaf cells. When conditions of equilibrium are established between these two pressures, l_w, the leaf water potential, can be expressed as

$$l_w = P + l$$

Where P represents the pressure applied by the chamber and l_s is the osmotic effect of the solutes in the xylem samp. If l_g is negligible, then l_w is estimated directly by P.

The leaf sample should be cut from the plant only once, preferably with a sharp knife or razor blade close to the midrib. All temptations to make a second, smooth cut should be resisted, as these invariably lead to excessively high water potential values. It will be normally easier to get a quick leaf sample by making approximately a 2-cm cut at right angles to the midrib and tear off the sample quickly. The sample could then be introduced into a split rubber stopper. The stopper acts as a compression gland fitting securely in the pressure chamber.

The next step is the insertion of the rubber stopper into the chamber top. After the insertion, application of a thin film of vaseline on the chamber top and around the stoper was found useful for easy sealing of the chamber top and for prevention of any gas leakages.

The final step is the quick sealing of the chamber top so that the cut surface protrudes above the chamber top. The pressure from the cylinder is applied by turning the valve to chamber position. The rate of application of the pressure is regulated by the rate value taking care to see that the pressure is applied slowly and steadily. The surface of the leaf or petiole is carefully observed through a low power (20 x) lens and when the meniscus of the sylem sap just returns to the cut surface, the pressure in the chamber is observed on the pressure gauge. At this stage, the valve should be turned on to the off position to facilitate the recording of the reading on the pressure gauge. Then the pressure in the chamber is released by turning the valve on to the exhaust position.

The above steps are described in the order in which they are carried out in the field. The whole procedure starting from cutting the sample from the plant to recording the reading, usually takes about 2-3 minutes.

3.2 <u>Crop</u>

A suggested layout depicting the sample design of field experiment is shown in Figure 12. The cooperating scientists could vary the plot size depending upon the availability of area. Three replications are suggested as a minimum. A brief description of the method of crop data collection is given taking our sorghum modeling experiment as an iple.

Ten consecutive plants of each genotype are tagged in each replication. Every two to three days observations on the dates for emergence of each leaf, its development and senescence as well as the general growth and development of the plant are taken. In addition to these ten plants, sufficient number of plants in each replication are marked in fifth, tenth and fifteenth leaf when they are fully grown to determine total leaf number and to measure the leaf area for each leaf. Destructive samples from 1 m area at random are collected from each replication once a week for recording plant height, leaf area for each leaf in sorghum,dry weight of stem, leaf, leaf-sheath, head and grain. The sorghum growth stages described by Vanderlip and Reeves (1972) are monitored regularly. For example, in each replication, at least 10 plants are examined for the occurrence of a particular phenological event. It is suggested that at the cooperating centers at least the days from planting to certin critical growth stages such as emergence, panicle initiation, flag leaf, anthesis and physiological maturity be recorded. Approximately a week after physiological maturity, the crop is harvested. Data on grain and stover yield are recorded from the bulk areas as shown in the layout (Fig.12). The plant population is recorded at harvest time and at two or three other times during the growing season. Heads from ten consecutive plants are collected at random for yield component analysis such as number of grains per head and test weight.

3.2.1 Growth Stages of Sorghum

Sorghum growth and development stages could be divided into the following as suggested by Vanderlip and Reeves (1972).

0 - Emergence
1 - 3rd leaf

2 - 5th leaf
3 - Panicle initiation
4 - Flag leaf
5 - Boot stage
6 - Anthesis
7 - Soft dough
8 - Hard dough
9 - Physiological maturity

The above mentioned sorghum growth and development stages would be grouped into three (Eastin 1971):

GS-1 Covering stages 0-3

GS-2 Covering stages 3-6

GS-3 Covering stages 6-9

Short descriptions of how to identify each stage are given below:

0 - Emergence

During this phase, the following are observed:

(i)First cotyledon leaves; The tops of the leaves of shoots have opened upon some parts of the plot under observation:

(ii)General Emergence: The first opened leaves have appeared over most of the plot.

If due to drought or other unfavorable circumstances, the shoots have not appeared en masse, a note to that effect should be made in the observations register.

1 - Third Leaf

The sign leading up to this phase is the third leaf starting to open up.

2 - Fifth Leaf

The sign leading up to this phase is the fifth leaf starting to open up.

3 - Panicle Initiation

It is said that panicle has initiated when vegetative apex is converted to the reproductive stage. This is the most vital stage and at this time the shoot apex shows a sudden construction at the base. This stage can be identified by dissecting the shoot apex separating leaves one by one. By this time five to six leaves had already expanded but the remaining leaves had initiated covering the young panicle meristems.

4 - Flag Leaf

This stage is reached when the last leaf has emerged. This can be identified by examining no other leaf initiation.

5 - Boot Stage

Flag leaf has fully expanded and the base of the flag leaf completely covers the emerging panicle.

6 - Anthesis

This phase starts with the appearance of anthers on the principal branch of the ear.

7 - Soft Dough

The signs of this stage are as follows: The size of the grains is nearly normal, but their color still remains green; if a grain is pressed between the fingers, its casing breaks and the contents flow out like milk. For this operation, grains are taken from the upper part of the inflorescence from the main stem. During this phase plants are still green.

8 - Hard Dough

Milk has condensed into hardness and by pressing the grain liquid milk does not come out.

9 - Physiological Maturity

This phase could be identified by the appearance of a black layer at the hyla region which completely blocks the translocation of photosynthates to the grain.

3.2.2 Leaf Area

Individual leaf area of each plant could be measured by using a leaf area meter (LI-3100 Area Meter, LAMBDA Instruments Corporation, Lincoln, Nebraska). The leaf area meter utilizes an electronic method in which sample travel under the fluorescent light source, the image is reflected by a system of three mirrors to a solid state scanning camera. Length of travel information is determined from the line current frequency and motor speed and accumulating area in cm is displayed on the LED display with the options for 1.0 or 0.1 mm resolution.

Leaf area measurements are conveniently coupled with dry matter sampling. Ten consecutive plants are sampled randomly from each treatment. The leaves, stems, petioles and heads are separated from each plant.

The transparent belts supplied by the manufacturer can be mounted on the upper pulley assembly and the lower pulley assembly. The meter is then connected to a proper AC source and is ready for leaf area measurement (Fig. 13).

Sorghum leaves are cut into smaller pieces and are fed on to the transparent belt moving underneath the fluorescent light source.Care must be exercised to see that samples that are not folded while moving ion transparent belt and belts are to be cleaned with wet cloth frequently. When the samples are all fed, the leaf area in cm can be noted down from the LED display. Leaf samples can then be put in a brown paper bag for dry matter measurements.

Leaf area can also be estimated from measurements of leaf length and maximum width. Regression coefficients relating the product of leaf length and maximum width to leaf area for four genotypes of sorghum grown at ICRISAT Center is given in Table 1. The coefficients ranged from 0.67 to 0.71.

3.3 Soil

3.3.1 Soil Water

There are direct and indirect methods to measure soil moisture, and several alternative ways to express it quantitatively. There is, therefore, no universally recognized standard method of measurement and no uniform way to compute and present the results.

Soil moisture content is usually expressed as a dimensionless ratio of water mass to dry soil mass (g/g), or of water volume of total soil volume (cc/cc). These ratios are usually multiplied by 100 and reported as percentages by weight or by volume. We shall proceed to describe, briefly,some of the most prevalent methods for this determination.

Gravimetric: The traditional ("gravimetric") method of measuring the water content by mass consists of removing a sample (e.g. by augering) and of determining its "moist" and "dry" weights (the latter after drying the sample to constant weight in an oven at 105°C). The gravimetric water content is the ratio of the weight loss in drying to the dry weight of the sample.

The measurement of bulk density, particularly in the field, is difficult and subject to errors. The gravimetric method itself, depending as it does on sampling, transporting, and repeated weighings, entails inherent errors. It is also laborious and time-consuming, since a period of at least 24 hr is usually allowed for complete drying. The standard method of oven drying is also arbitrary. Some clays may still contain appreciable amounts of adsorbed water even at 105°C. On the other hand, some organic matter may oxidize and decompose at this temperature so that the weight loss may not be due entirely to the evaporation of water.

The errors of the gravimetric method can be reduced by increasing the sizes and number of samples. However, the sampling method is destructive and may disturb an observation or experimental plot sufficiently to distort the results. For these regions, many workers prefer indirect methods, which permit making frequent or continuous measurements at the same points, and,once the equipment is installed and calibrated, with much less time and labor.

Neutron Scattering: The advantage of this method is that it allows rapid and periodically repeated measurements in the same locations and depths of the volumetric wetness of a representative volume of soil.

The instrument known as a neutron moisture meter (Fig.14) consists of two principal parts: (a) a probe which is lowered into an access tube inserted vertically into the soil, and which contains a source of fast neutrons and a detector of slow neutrons; (b) a scaler or ratemeter (usually battery-powered and portable) to monitor the flux of slow neutrons, which is proportional to the soil water content.

The fast neutrons are emitted radially into the soil, where they encounter and collide elastically with various atomic nuclei, and gradually lose some of their kinetic energy. The average loss of energy is maximal when a neutron collides with a particle of a mass nearly equal to its own. Such particles are the hydrogen nuclei of water. The average number of collisions required to slow a neutron from 2 MeV to thermal energies is 18 for hydrogen, 114 for carbon, 150 for oxygen, and 9N + 6 for nuclei of larger mass number N (Weinberg and Wigner 1958). In practice, it has been found that the attenuation of fast neutrons in the soil is proportional to the hydrogen content of the soil. The slowed (thermal) neutrons scatter randomly in the soil, forming a cloud around the probe. Some of these return to the probe, where they are counted by a detector of slow neutrons. The detector cell is usually filled with BF3 gas. When a thermalized neutron encounters a 10B nucleus and is absorbed an alpha particle (the helium nucleus) is emitted, creating an electrical pulse on a charged wire. The number of pulses over a measured time interval is counted by a scaler, or indicated by a rate meter.

The effective colum of soil in which the water content is measured depends upon the concentration of the hydrogen nuclei, i.e., upon the energy of the emitted fast neutrons. With the commonly used radium-beyullium sources, the soil volume measured is in effect a sphere, which in a wet soil is perhaps 15 cm in diameter, but in relatively dry soil may be as great as 50 cm or more (de Vries and King 1961). This low degree of spatial resolution makes the instrument unsuitable for deterction of water-content discontinuities (e.g., wetting fronts or boundaries between layers), or for measurements close to the soil surface.

Methods of calibrating the neutron moisture meter were described by Holmes (1950) and Holmes and Jekinson (1959). In most soils, it is possible to obtain a nearly linear dependence of the count rate upon the volumetric wetness of the soil.

Improper use of the equipment can be hazardous. The danger from exposure to radiation depends upon the strength of the source, the distance from the source to the operator, and the duration of exposure. A protective shield (generally consisting of lead and paraffin or polyethylene in a cylindrically shaped unit with a central hole to acc te the probe) is an essential component of the equipment, and it also serves as a standard absorber for checking the readings. With reasonable care and attention to safety rules, the equipment can be used safely.

3.3.2 Soil Temperatures

Soil (or earth) thermometers serve for the measurement of the temperatures in the upper strata of the Earth. In depths down to approx. 30 cm (i.e., 1,5,15 and 30 cm) mercury-inglass thermometers can be used, vessel of which is arranged in the corresponding depth whereas its scale is situated above the earth's surface in order to facilitatre the reading. The instruments for depths of 100 and 150 cm are also mercury-in-glass thermometers. The thermometers consist of glass vessel filled with the mercury and of the glass capillary fused to it. As soon as the temperature rises, the mercury is pressed into the glass capillary. A scale support made of opal glass is arranged behind the capillary. Scale support and capillary are surrounded by an enclosing tube, the lower part of which is melted together with the mercury vessel. The immersion depth is calculated from the lower end of the thermometer bulb up to the middle of the bulge situated in the upper part of the stem. A metal frame is used as mounting support for each single earth thermometer. The measuring field should be bare ground. Weeds have to be removed. Walking on the measuring field gives rise to an undesired alteration of the ground conditions. The earth thermometers should be read at the two prescribed times (0830 and 1430 hrs IST).

3.4 Management

Relatively homogeneous and uniformly levelled fields should be selected for conducting the experiments. There should be adequate drainage facilities. Usually management is directed towards good crop establishment, control of weeds, pests, and diseases. If these are not controlled, then weed sampling (dry matter at anthesis and harvest) or time and rating of damage by pests and/or diseases be recorded. Land use history can be of diagnostic value.

Table 1. Regression coefficients relating the product of leaf length and maximum width to leaf area of sorghum.

Season	Genotype	No. of Observations	Regression* coefficient (b)	R^2
1979 rainy	CSH-1	512	.6973	.99
	CSH-6	447	.7111	.98
1979 postrainy	CSH-8	3135	.6829	.98
	M-35-1	3589	.6654	.92
1980 rainy	CSH-1	1728	.7017	.98
	CSH-6	2117	.7129	.98
1980 postrainy	CSH-8	2479	.6911	.97
	M-35-1	2101	.7101	.98

*Y=b.L.W. where Y, L, and W are leaf area, leaf length and maximum width respectively.

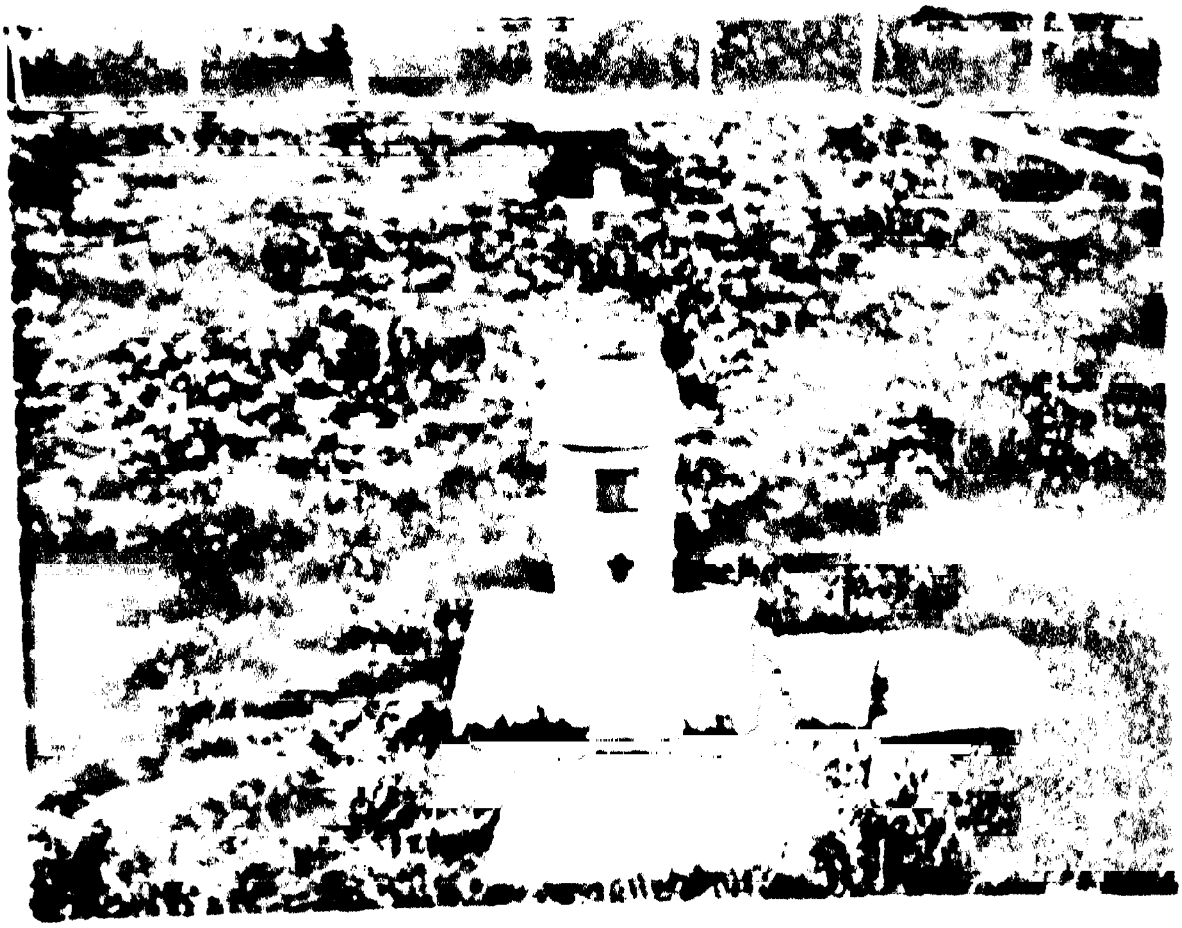


FIGURE NON-RECORDING RAINGAUGE (BACKGROUND)
RECORDING RAINGAUGE (FOREGROUND)

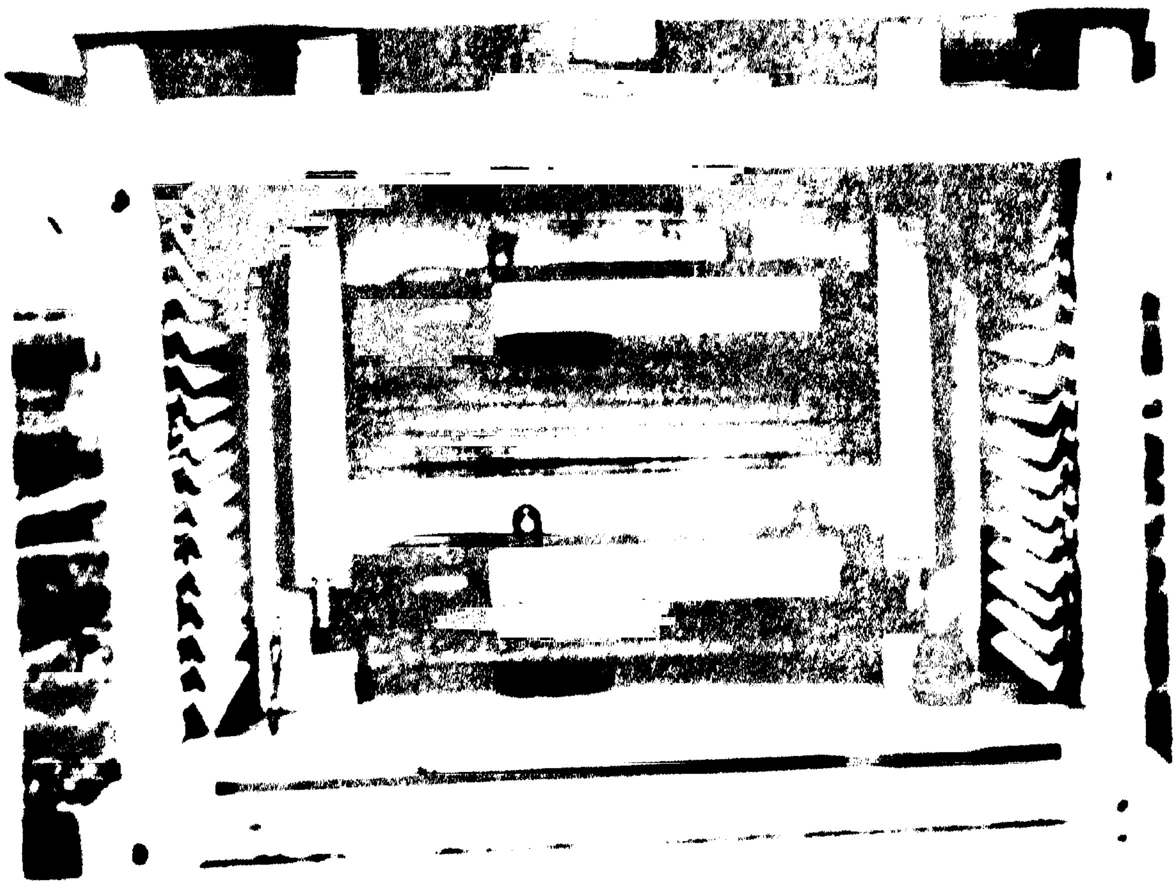


FIGURE 2. STEVENSON SCREEN

FIGURE 3. PYRANOMETER

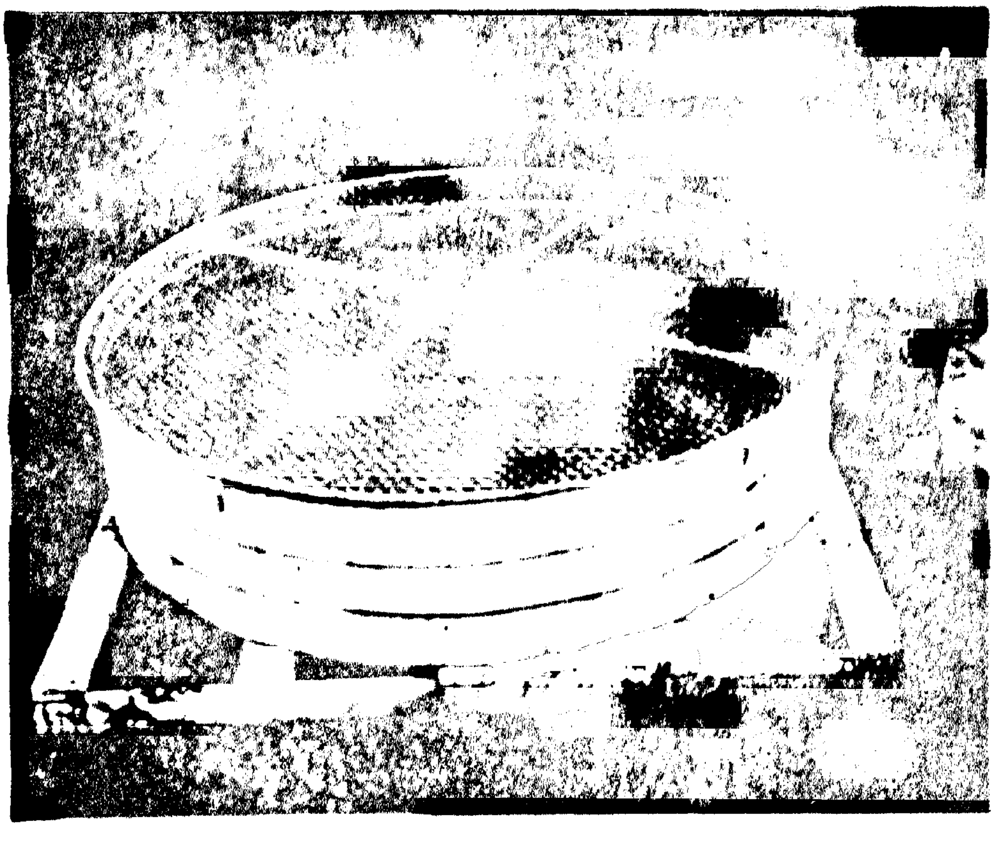


FIGURE 4. CLASS 'A" PAN EVAPORIMETER

FIGURE 5. NET RADIOMETER

A. ALBEDOMETER

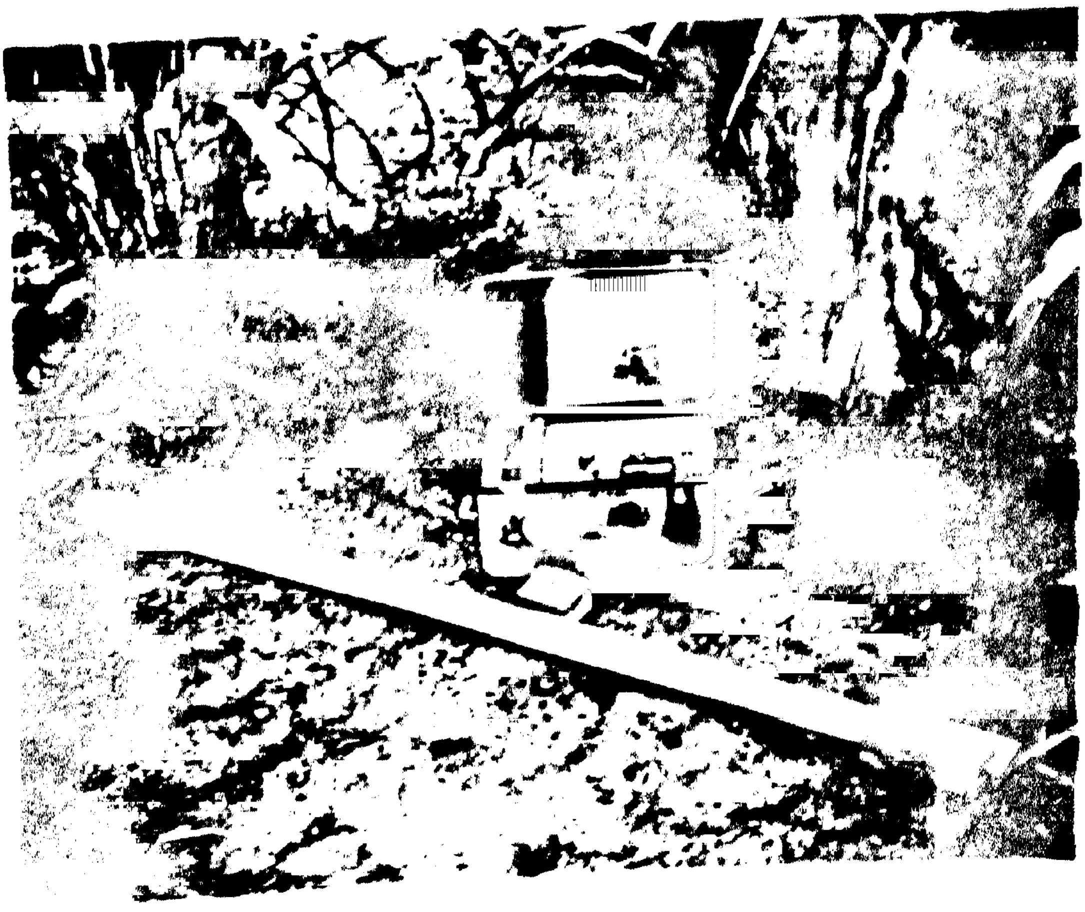


FIGURE 7. LINE QUANTUM SENSOR WITH LI-188B INTEGRATOR

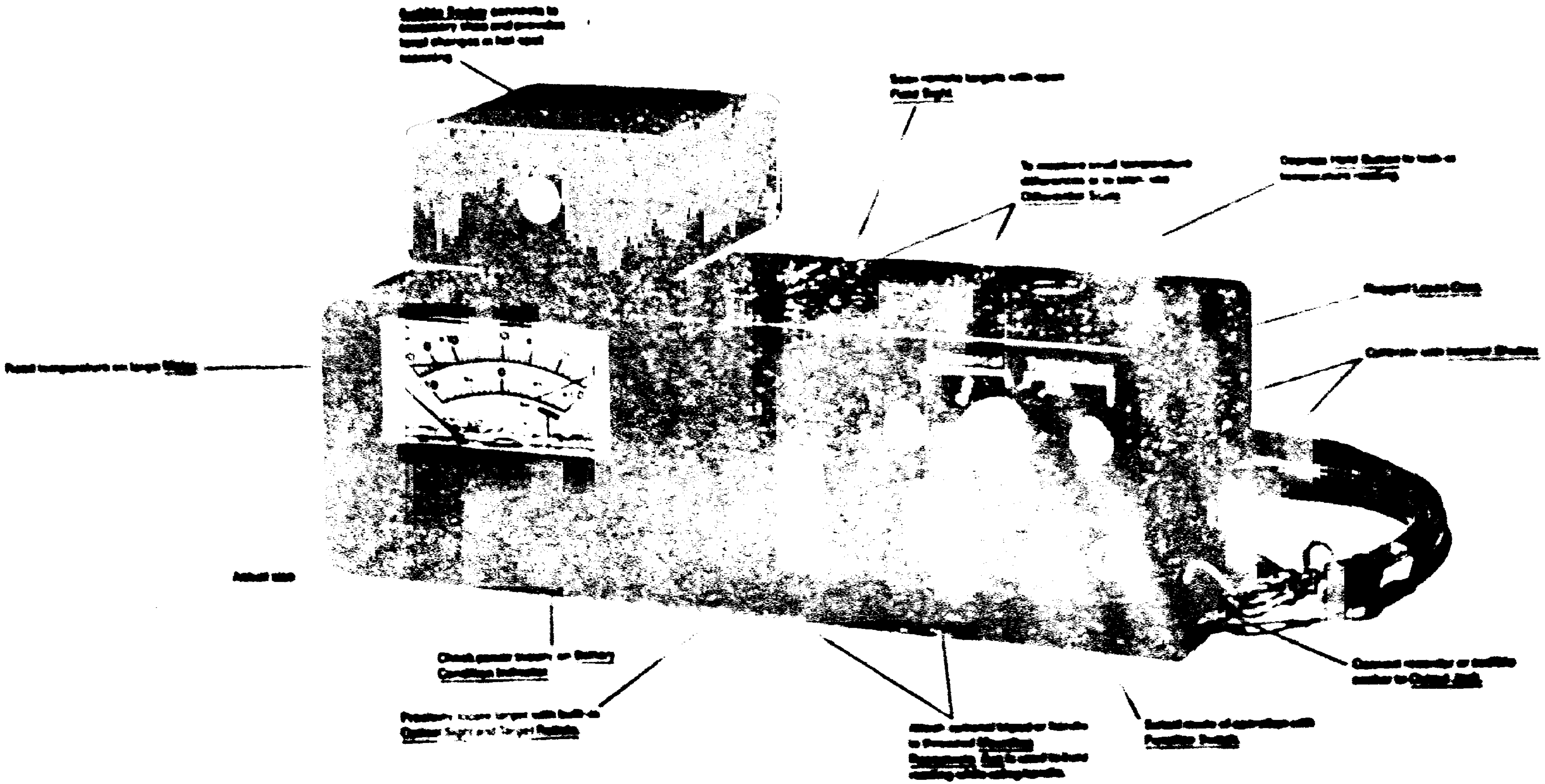


FIGURE 8. INFRARED THERMOMETER

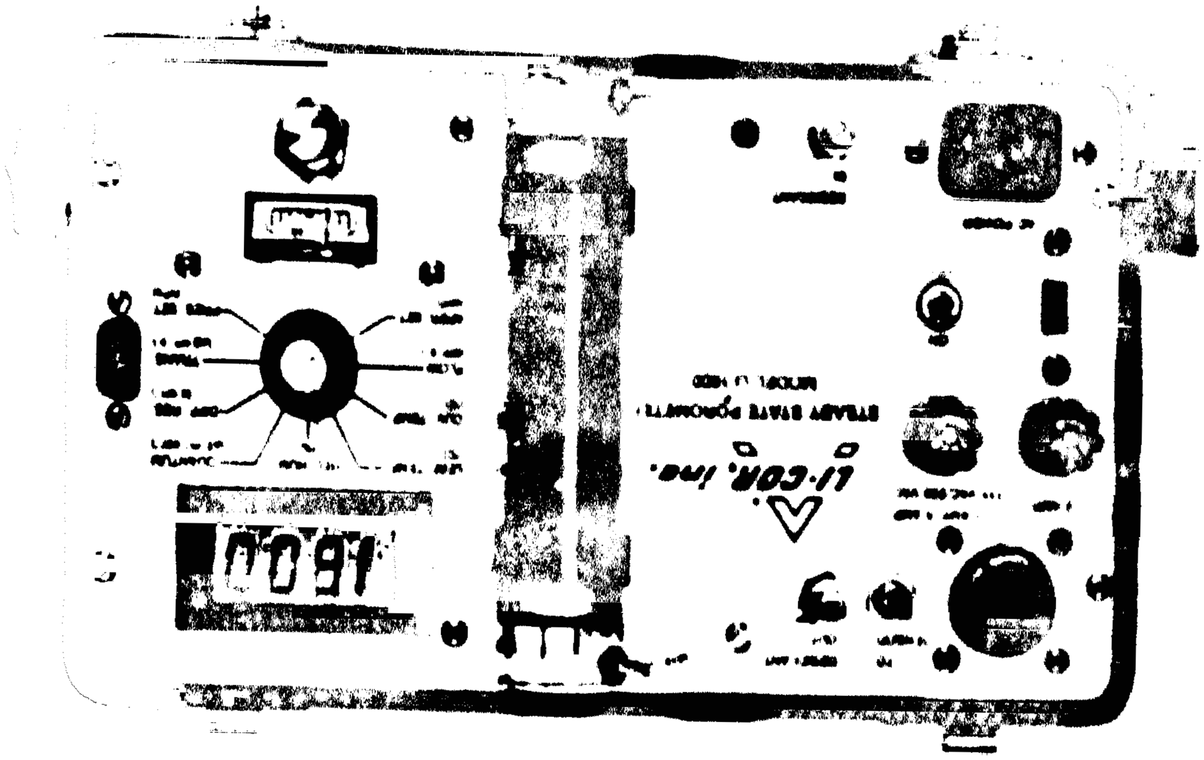


FIGURE 9. STEADY STATE POROMETER

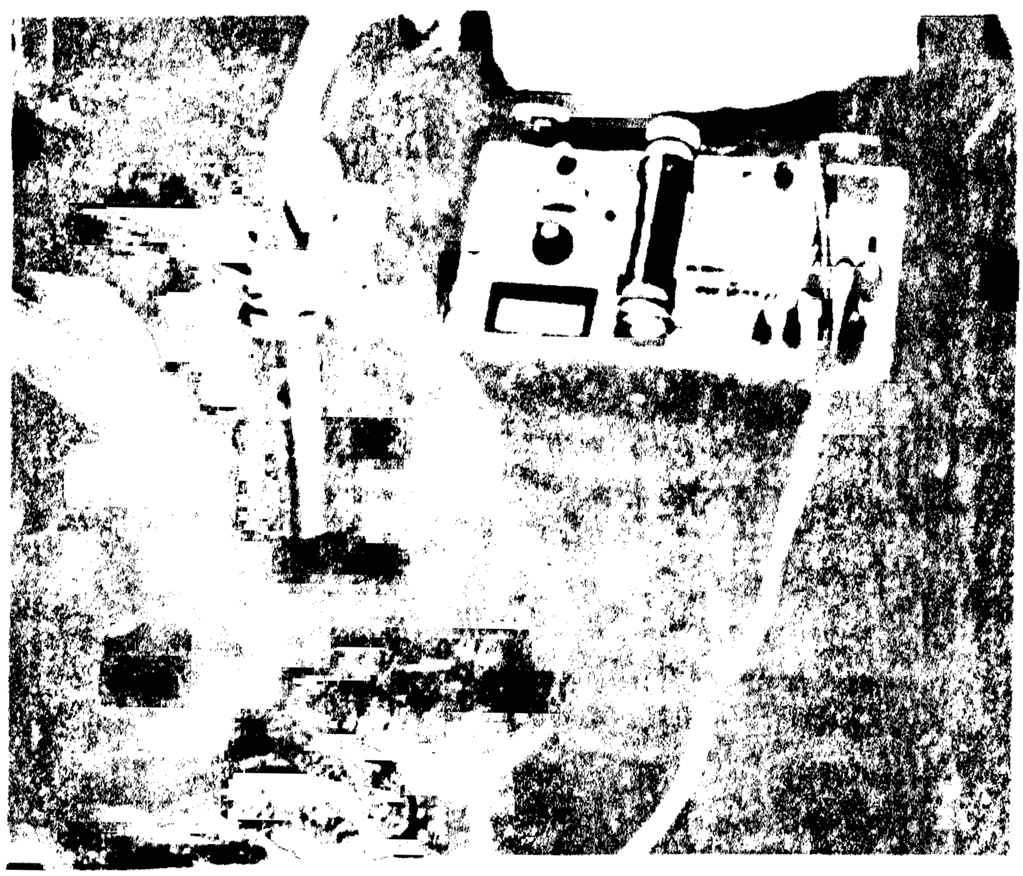


FIGURE 10. STEADY STATE POROMETER IN USE

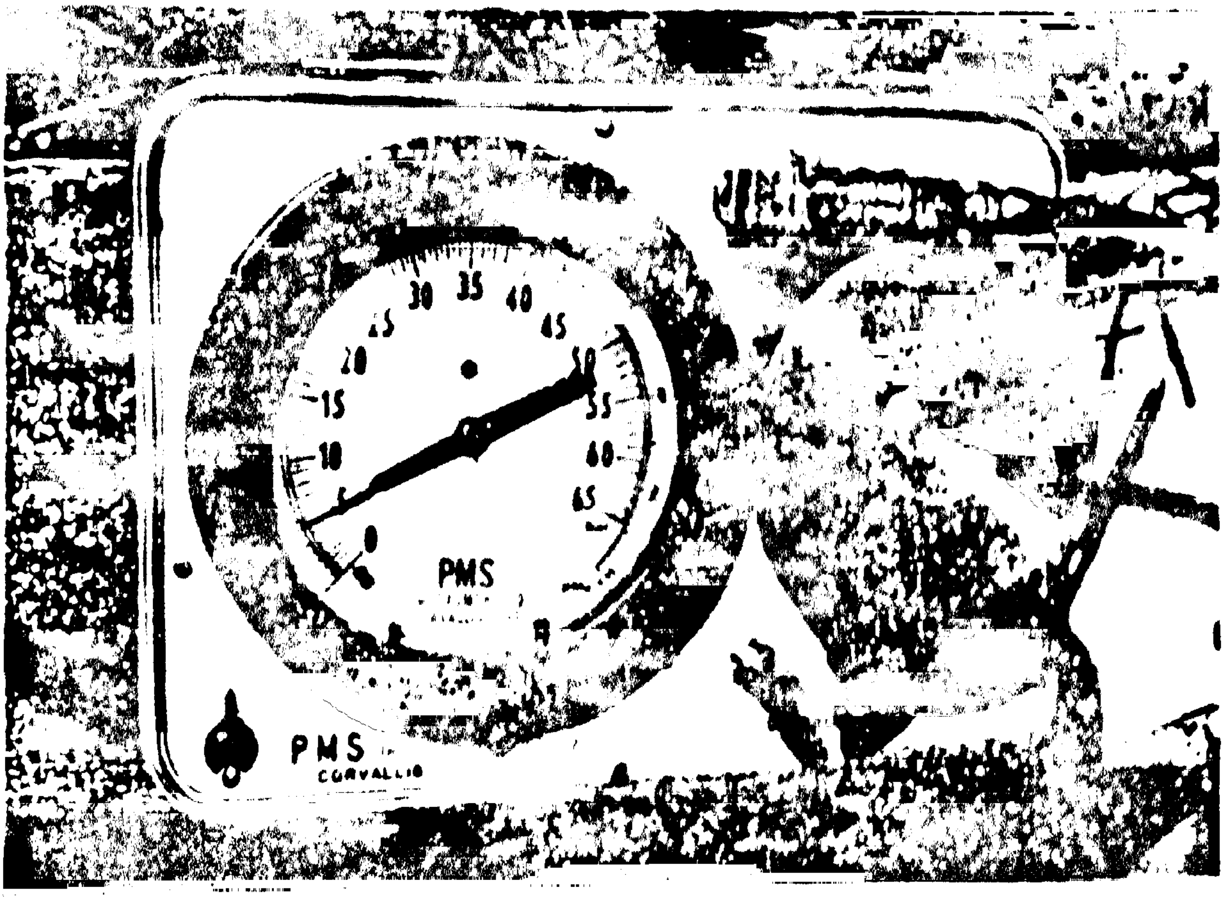
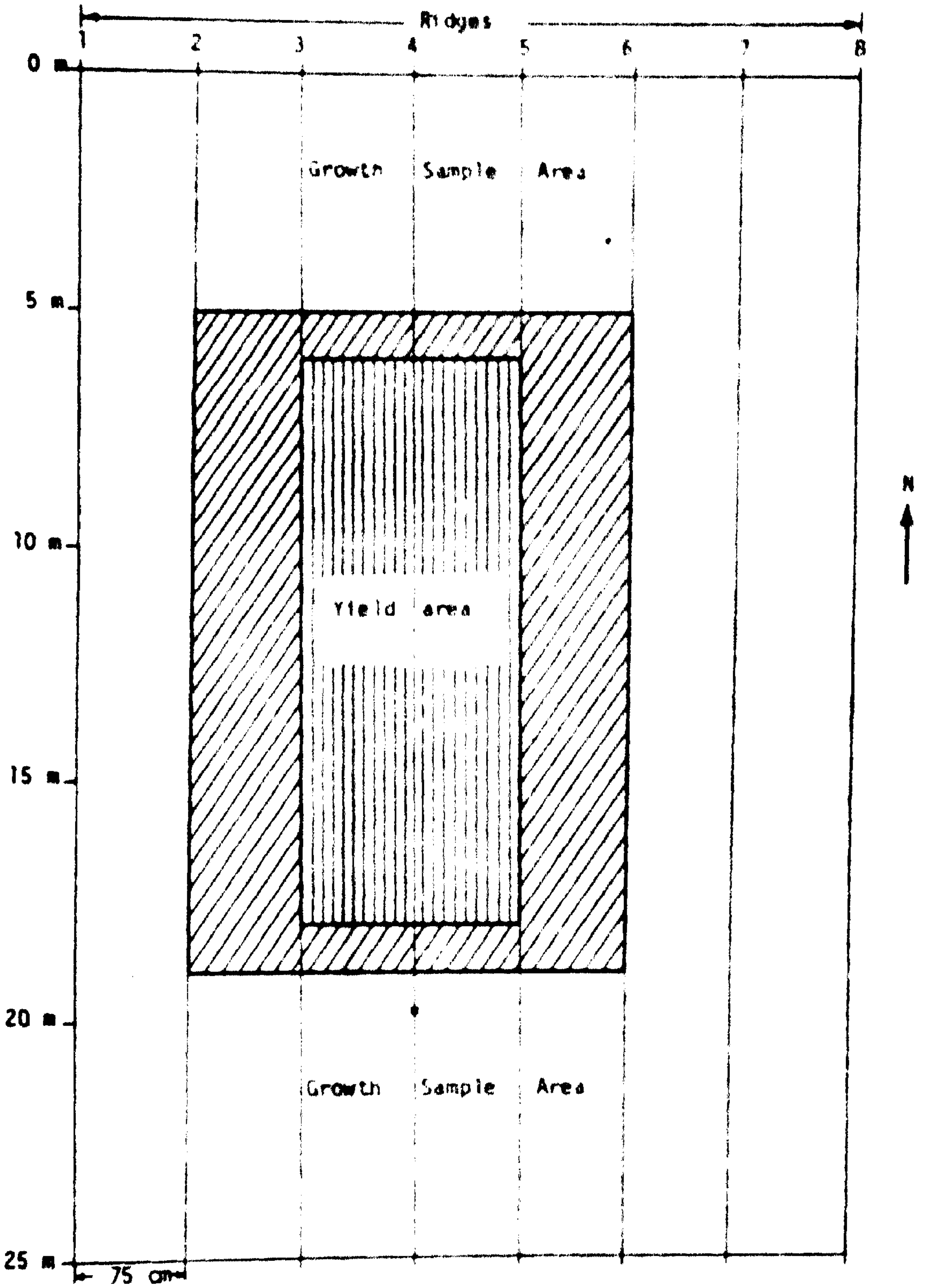


FIGURE 11. PRESSURE CHAMBER



RIDGES 1, 7, 8 - BORDER; RIDGE 2 - TILLERING STUDIES;
RIDGE 6 - MICROCLIMATOLOGICAL STUDIES; RIDGES 3, 4, 5 - YIELD AREA
* NEUTRON PROBE.

FIGURE 12. SUGGESTED LAYOUT FOR A FIELD EXPERIMENT.

FIGURE 13. LEAF AREA METER LI-3100

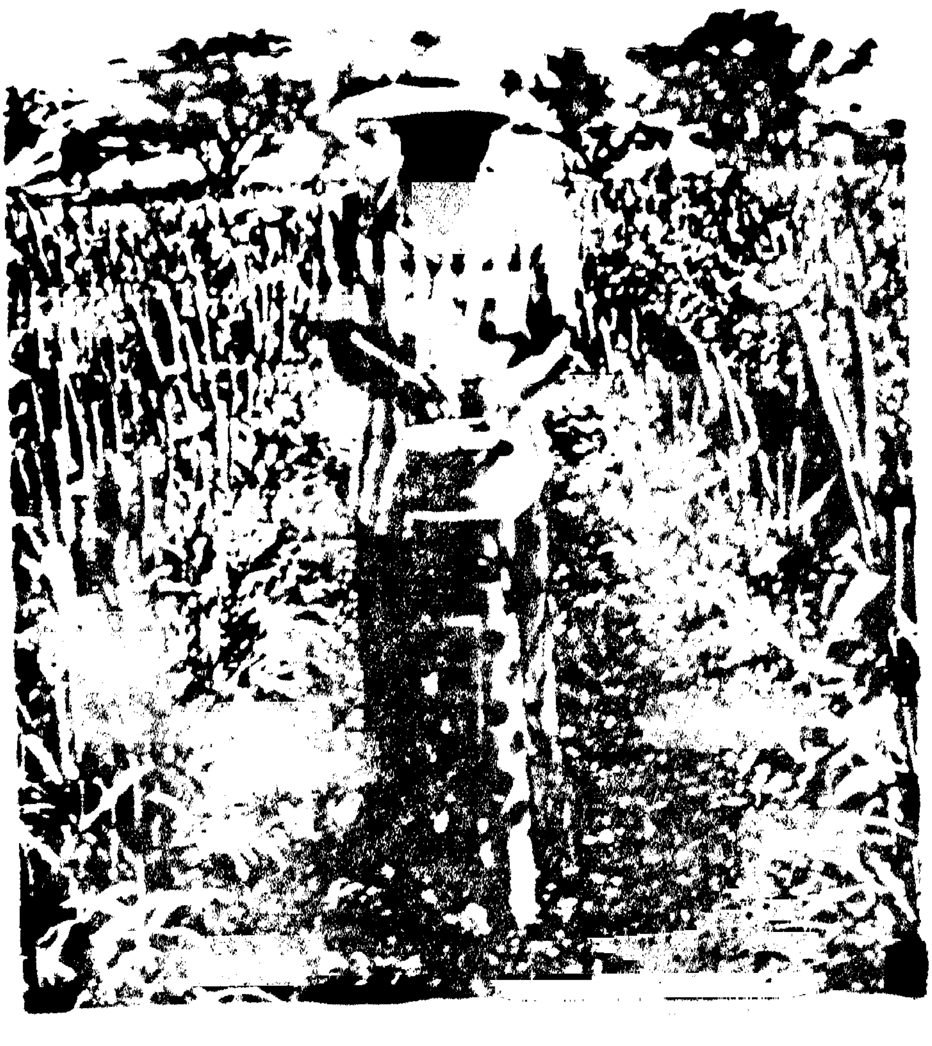


FIGURE 14. NEUTRON MOISTURE METER

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