AGRICULTURAL METEOROLOGY

CAgM REPORT NO. 16

REQUIREMENTS FOR THE STANDARDIZATION OF INSTRUMENTS AND METHODS OF OBSERVATION IN THE FIELD OF AGRICULTURAL METEOROLOGY

by

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REPORT OF THE RAPPORTEUR ON STANDARDIZATION OF INSTRUMENTS AND METHODS OF OBSERVATION IN AGRICULTURAL METEOROLOGY

This report has been approved by the President for circulation to the members of CAGM. A copy of the report is attached for information.

Reproduced from the English translation of the Russian report
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1. **Introduction**

1.1 At its Seventh Session (Sofia, Bulgaria, 1979) the WMO Commission for Agricultural Meteorology authorized the President of CAgM to appoint a Rapporteur on the Requirements for the Standardization of Instruments and Methods of Observation in the Field of Agricultural Meteorology. The President of CAgM accordingly appointed Dr. V.N. Strashny (USSR) as rapporteur on the subject. The terms of reference of the rapporteur include:

- critical study of the requirements for the standardization of instruments and methods of observation in the field of agricultural meteorology
- defining the requirements of CAgM in this field including description of instruments and their purposes

1.2 The rapporteur with the help of WMO Secretariat circulated a questionnaire seeking information on the agrimeteorological observations made from Members of WMO. A sample questionnaire is included in the appendix. The following countries sent in their reply:

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* no regular observations
+ observations during experiments
§ observations during research projects
1.3 From the information received it was apparent that in many countries
agrometeorological observations are well organized, but that, also in many countries,
there is a requirement for the organization of observations on agrometeorological
parameters.

2. Soil Moisture

2.1 General Considerations

2.1.1 Information relating to soil moisture is of very great practical interest
for agriculture. Moisture in the layer occupied by roots is practically the only
source of water supply for crops and is often a limiting factor in obtaining a
good crop. The amount of moisture in the soil is continually varying both in space
and in time, and, consequently, in order to assess the conditions for obtaining the
yield, has to be regularly calculated under field conditions during the entire
growing season. It is necessary to make observations at various depths in the
layer occupied by roots since, due to the limited movement of the moisture, there
may be appreciable differences in soil moisture, in the vertical. In view of
the significance of soil moisture, scientists have long devoted much attention to
developing methods for determining this parameter. Very many methods have been
proposed for the measurement of soil moisture, but only some of them have been
found to be suitable in the long term for use under field conditions.

2.2 Gravimetric Method

2.2.1 At present, the most widely used method for determining soil moisture, in
various countries, is by drying samples of the soil (gravimetric method); this is
the standard method, for comparing all other methods of determining soil moisture.
In essence, this method consists of extracting periodically samples of soil from
various layers by means of a drill. These samples are transferred to a drying
vessel, are weighed, dried out and again weighed. Drying of the sample takes place
at a temperature of 105\(^\circ\)C until the weight remains constant. This usually happens
after about 8-12 hours. The soil moisture is determined from the difference in the
weights of the sample before and after drying out and is calculated as a percentage
of the absolute weight of dry soil:

\[
W = \frac{(P_1 - P_2)}{P_2} \times 100\% 
\]

where \(W\) is the soil moisture in percent, \(P_1\) is the weight of the moist soil and
\(P_2\) is the weight of the dry soil. In order to speed up the drying process, the
samples of soil may be dried out in a thermostat under vacuum conditions by infrared
rays, by high-frequency currents, by a current of hot air, etc. The method of dry-
ing samples is simple and reliable, but there are inherent and important shortcomings:
there is no continuity in the observations of soil moisture since, each time, the
sample is taken from a fresh boring; the moisture of only a small sample is deter-
minded and, in order to obtain a representative value, the operation has to be
repeated a large number of times (8 to 20); the process of selecting samples is
very time-consuming; the results of the measurements are not known immediately but
only after drying out and calculations. The magnitudes of the error of observation of soil moisture expressed as a percentage of the absolute weight of dry soil under non-irrigated conditions are: the mean error in determining the moisture of separate samples with a probability of 68% is 0.5% and the maximum error with a probability of 95% is 1.0%; the mean error (with probability 60%) in determining the moisture of loamy soils, which are uniform as regards mechanical composition, on an observing plot of area 1 ha, the observation being repeated four times, varies within the limits 0.6 - 1.5%, while the maximum error (with probability 80%) varies within the limits 1.0 - 2.5%.

2.3 Indirect Methods

Indirect methods of determining soil moisture may be sub-divided into three groups: tensiometric, electrical and neutron methods.

Among the indirect methods which have been developed, the following may be mentioned: thermal capacity, distillation, extraction, carbide, optical, picnometric methods and reflectometric method with contraction of the soil under pressure, the method of additional moistening of the soil and the dielectric method. These methods do not eliminate the most time-consuming part of the work, viz. the selection of samples in the field.

2.3.1 Tensiometric methods

There are many variants of this type of instrument and many works setting out methods of their use for the measurement of moisture and the capillary tension of moisture in the soil. Tensiometers are used for the measurement of capillary forces in the soil and consist of porous vessels (or ceramic filters) filled with a liquid (usually water) hermetically connected to a manometer or vacuum meter. Measurement of soil moisture by this method consists of measuring the vacuum created in the instrument as a result of extracting from it the water in the soil. Depending on the amount of moisture in the soil and the differences of tensions in the ceramic and the soil, moisture moves from the soil to the instrument or from the instrument to the soil which creates or increases the vacuum and this is observed by the change of pressure in the instrument.

2.3.1.1 A short description is given below of some instruments of this type:

(i) the portable tensiometer for the measurement of soil moisture has a long tubular form with a hollow porous tip. Part of the internal surface of the tip inserted into the soil forms the walls of the first chamber inside the body of the instrument. A shaft is provided at the end of the tubular part at a point which is far away from where the tip is attached. There is an aperture in the shaft communicating with the interior. The manometer for the vacuum is attached at one end of the shaft. A cylinder is attached to the other end of the shaft. A plunger is placed inside the cylinder forming the second chamber of the regulated volume. The first chamber is connected to the second by means of the first part of the
capillary which is situated inside the body and aperture of the shaft. The second part of the capillary, situated in the aperture of the shaft, connects the second chamber with the manometer for the vacuum. These parts of the capillary minimize the volume of water in the tensiometer and reduce the error of measurement to a minimum. These errors arise due to the difference of expansion and pressure of the water caused by temperature variation. Readings of the manometer are made rapidly and accurately by adjusting the plunger in the cylinder.

(ii) The main working part of the instrument is a funnel-shaped ceramic filter providing the connexion between the water filling the instrument and the soil moisture. The bottom of the filter is porous with the diameter of the pores not exceeding 1.0-1.5 mm. The lateral walls of the filter are covered with glaze and are impermeable to water and air. A copper and brass pipe with an internal diameter of 8-10 mm is used to place the filter in the soil at a given depth and connects the filter to the glass bulb air-lock. This latter is used to fill the instrument with water and to free it of air which has penetrated the instrument, for which purpose in the upper part of the air-lock there is an aperture closed by a rubber cork. Two branch pieces in the air-lock serve to connect it to the pipe and to the manometer. The manometer consists of a V-shaped thick-walled glass tube, 800 mm in height and with an internal diameter of 1.5 mm, filled with well-purified mercury. All parts of the instrument are hermetically connected to each other by vacuum-safe rubber tubing. The ceramic vessel, the copper pipe, the air-lock and the mercury-free part of the manometer pipe connected to the air-lock joint, are filled with water.

(iii) - Equipment for measuring and regulating soil moisture

It comprises a moisture sensor and a measuring system. In order to increase the accuracy of measurements when there is surface spreading, the equipment is provided with a permeable porous block, with a hygroscopic capacity which is greater than that of the soil, and located above the moisture sensor. The upper surface of the block is at a distance of 1.5 times the radius of the effective zone of action of the sensor, from the upper surface of the sensor. The area of the lower surface of the block is 10 - 12 times more than the upper surface of the moisture sensor.

(iv) - Moisture sensor

This comprises a cylindrical part made of a capillary material of given porosity, one end of which is open to the action of moisture from the soil entering through a
wick. This part is provided with capillary ducts. The moisture is extracted from the wick through these ducts under the action of the capillary effect, forcing out air which moves to the other end of the cylinder. The casing, with a diaphragm, joined to this part, has an internal space in which the displaced air is compressed. The resulting pressure is transferred to the diaphragm, controlling a valve cutting off irrigation water.

(v) - Detector for determining soil moisture

The detector comprises a hollow rigid probing device. At one end of the probing device there is a porous moisture sensor covering the end of the probing device. The moisture sensor is filled with a non-organic substance of the capillary type with a large number of pores of given diameter. The sensor acts as an air valve and limits the movement of air from the layer occupied by vegetation through the porous element when the layer occupied by vegetation adjacent to it reaches a given high level of moisture content and moisture covers the pores. When the layer occupied by vegetation reaches a given low level of moisture content, air starts to move through the porous element. At the other end of the probing device there is an indicator which shows the soil moisture according to the state of the moisture sensor. In addition, at the other end of the probing device is attached a casing having a central aperture situated on the axis of the sensing device. At this same end of the sensing device is attached a moveable reversing valve containing a plunger and a membrane. By means of the reversing valve between the moisture sensor and the indicator, a difference of pressure is maintained or built up determining the operation of the sensor.

2.3.1.2 In recent years, definite progress has been made in the construction and operation of such instruments. The advantages of this method are: continuous observations at any one place, simplicity of taking readings, rapid response of the instrument to moistening of the soil, the instruments can easily be put into the soil. Disadvantages are: the instruments provide only an indirect measurement of soil moisture and it is therefore necessary to calibrate them for each type of soil, they often get broken when setting them up, the range of quantities measured is from 0 to 0.8 - 0.9 atm, which means that they cannot be used for low values of soil moisture.

2.3.1.3 Tensiometers are most suitable for observations of soil moisture under irrigated conditions, since the values do not usually then exceed the operational limits of the instrument.
2.3.2 **Electromagnetic methods**

2.3.2.1 Methods enabling the effect of moisture on the electrical properties of the soil to be evaluated, can be regarded as electromagnetic methods:

(i) - conductometric (resistor) method, based on the relationship between the electrical resistance of the soil and its moisture content

(ii) - dielectric (capacity) method, based on the measurement of the dielectric permeability of the soil.

2.3.2.2 A large number of sensors have been developed which are sensitive to specific resistance, to polarization or to both. The specific resistance of the soil depends on the soil moisture content, and it is therefore possible, either to measure the specific resistance between electrodes plunged into the soil, or to measure the specific resistance of a substance which is in equilibrium with the soil. One of methods for the future involves working with frequencies of 10 - 100 MHz and using an electro-measuring bridge.

2.3.2.3 **Brief description of some of the instruments:**

(i) The sensor consists of a pair of parallel electrodes placed in a porous plaster block. The electrical resistance between the two electrodes varies according to the amount of water absorbed by the block. A pair of non-insulated parallel leads about 3 cm in length at the end of a cable at a distance of 1 cm from each other is placed at the centre of the mould. The plaster is mixed with distilled water and poured into the mould and kept until hard. A calibration curve is necessary for each type of soil.

(ii) - equipment for the measurement of the moisture of substances

This equipment comprises an auto-generator with a system for amplifying positive backward signals which, in turn, comprises a resonance system with a dielectric sensor. In order to increase the accuracy of the measurements, the equipment also comprises a filter connected in series and consisting of hormone components, a frequency auto-generator and a detector. The output of the auto-generator is switched to the filter, while the amplifier of a positive backward signals is connected to the output of the detector.

(iii) - moisture sensor

This comprises a sensitive element in the form of a quartz resonator switched to the unit for transforming resistances to equivalent electrical signals. The radiating grains of the quartz resonator are placed in damping devices in the form of hollow vessels.
(iv) - absorption moisture sensor

This comprises electrically insulated electrodes and a moisture-sensitive coating, electrodes in the form of twisted wires with the intervening space between them filled with the moisture-sensitive coating.

(v) - instrument for determining soil moisture by means of an electrical resistance element. The sensor has a pair of spaced external electrodes in direct contact with the ground and a spring device for creating a constant pressure between each of the electrodes and the ground. The spring device is a unit containing each of the electrodes, rubber-like material and a dielectric pipe. Each electrode is a flexible conducting strip in the shape of a ring on this pipe. Such an arrangement is most effective if, between each electrode and the pipe, there is an aperture at an acute angle which is filled with a rubber-like substance. This arrangement also includes the spring device.

(vi) - moisture detector and instrument in which such a detector is used

The moisture detector contains 2 resistances one of which is under conditions of thermal conductivity with the material absorbing moisture, and the second, with the material not absorbing moisture. As a consequence of this, the difference in the value of the thermal conductivity of these materials, due to the fact that one material absorbs heat while the other does not, can be used to determine the amount of moisture.

(vii) - moisture meter with a linear scale and temperature compensator

This instrument gives measurements of the moisture content by measuring the specific electrical conductivity, which depends on the moisture content of the sample. The relationship between the specific electrical resistance of the sample and its moisture content is non-linear in one of the ranges of moisture content and linear in the other. The instrument comprises a device for the measurement of the specific resistance of the sample and a linearizing device for receiving electrical signals, which within the one range of moisture content mentioned, varies in proportion to the variation of the moisture content of the sample. There is an indicator for switching in the linearizing device between the aforementioned equipment for measuring the specific resistance, and also for switching off. In addition the instrument comprises a temperature compensator displacing the zero of the indicator depending on the temperature measured.
(viii) - moisture meter

This instrument generates an electric current under the action of moisture on it. It comprises an electrically insulated plate on the surface of which the moisture acts. On this plate, two electrically conducting electrodes are fixed, which are both simultaneously affected by the moisture, so that they generate an electric current proportional to the moisture.

(ix) - resonance method of measurement

The instrument for measuring moisture comprises a dielectric material surrounded by a screen, which screens the material from electro-magnetic radiation. This screen in the form of a cylinder, comprises a wire grid and also input and output antennae, inside the screen at some distance for the dielectric material.

(x) - moisture meter in which moisture variations alter the electrical resistance

The meter consists of an outer plate, whose dimensions are altered by variations of relative humidity and an inner plate (core) whose dimensions are altered in the same way as that of the outer plate. A large part of the surface of the inner plate is connected to the outer plate. A large number of joined conducting carbon particles is introduced into the inner plate. A feature of the meter is that the carbon particles are hydrophobic, and with changes of relative humidity they absorb water and changes in weight.

(xi) - method of measuring moisture

The moisture is determined by measuring the dielectric permeability coefficient of the moisture-sensitive element in the low-frequency band, with the ratio of the orientation of the dipoles of a space charge increasing as compared with the orientation of the molecular dipoles of water absorbed on the moisture-sensitive element.

(xiii) - soil moisture meter

The principle of the instrument is to measure the modules of the impedance of the sensor for two frequencies, and then undertake processing by means of the algorithm:

\[ N = \frac{Z_{LF}}{Z_{HF}} \frac{Z_{HF}}{Z_{LF}} = \frac{Z_{LF}}{Z_{HF}} (\text{soil}) \]

where \( Z_{LF} \) = modules of sensor impedance with the soil at low frequency
\( Z_{LF} (\text{empty}) \) = modulus of empty sensor impedance at low frequency
\( Z_{HF} \) = modulus of impedance at high frequency
\( K = a \text{ constant} \)
2.3.2.4 The main advantages of instruments of the resistor or capacity types are: possibility of continuous observations at the same site; remote sensing observations; simplicity and rapidity of taking readings; diversity of sensor configurations - from small to large - which gives some control of the sphere of influence of the sensor. The main disadvantages are: need to calibrate for each layer of soil for which the moisture is determined; calibration varying with time due to variations in the concentration of ions; need to apply corrections to soil temperature on which the dielectric permeability depends; the accuracy of measurements does not always meet the requirements of agricultural specialists and agro-meteorologists.

2.3.3 Nuclear methods

2.3.3.1 Dispersion of neutrons method

2.3.3.1.1 This is an indirect method for determining the soil moisture content. When inserting the source of neutrons into the soil, the high-energy neutrons are slowed down as a result of resilient collisions with the nuclei of hydrogen atoms of the soil moisture and are dispersed. The density of the resulting cloud of slow neutrons is a function of the moisture and liquid, in the solid or gaseous state, in the soil. The number of slow neutrons returning to the detector in unit time is determined from graduated curves. Two types of neutron sensor have been developed. The first is a depth sensor which is inserted into the soil by means of a pipe to the depth at which it is desired to measure the moisture content. The second type is a surface sensor measuring the moisture of the topmost few centimetres.

2.3.3.1.2 It is considered that each instrument should be calibrated separately for each type of soil, since the presence of chlorine, barium, zinc, iron, cadmium, organic or other substances, the nuclei of which have high neutron absorption properties, has an effect on the calibration. Graduation depends also on the intensity of the source, the type of detector, configuration of the source and detector in the sensor, materials used for the sensor and the dimensions and composition of the pipe.

2.3.3.1.3 Calibration of neutron instruments may be carried out, either under laboratory conditions using samples of various types of soil (in which case the volume of soil should be sufficiently large), or under field conditions by determining the moisture at the same time as taking readings.

2.3.3.1.4 The merits of the neutron method are: soil moisture measurements can be made over a long period at the same site, i.e. the time-variations of soil moisture can be monitored; the moisture can be measured independently of the physical state (state of aggregation) of the water; the average moisture content through a given depth can be measured; automatic recording can be arranged; the whole range of values of soil moisture can be measured.

2.3.3.1.5 The shortcomings of the neutron method are: insufficient resolution by depth; the readings of the instrument depend on many physical and chemical properties of the soil which are difficult to measure; it is impossible to obtain correct readings for the top layers of the soil (0-20, 0-30 cm) as a consequence of dispersion of part of the slow neutrons to the atmosphere; health hazard; less accurate than the gravimetric method.
2.3.3.2 Method using the attenuation of gamma-rays

2.3.3.2.1 This is a radioactive method based on the fact that gamma-rays passing through a layer of the soil are attenuated. Attenuation takes place due to the constant attenuation caused by the soil, and varies with the amount of soil moisture. Hence, it follows that the variation in the water content of a layer of soil can be determined from the attenuation of gamma-rays passing through the layer. Gamma-rays can be concentrated in a narrow beam so that representative data can be obtained in any part of the soil. The basic equipment comprises a source of gamma-rays and a nuclear particle counter.

2.3.3.2.2 The drawbacks of the method are: in highly stratified soil there may be substantial fluctuations in the weight and moisture by volume of the soil, limiting spatial resolution; field equipment is expensive and difficult to use; radioactive sources constitute a health hazard and strict safety measures have to be observed, which complicates their use.

2.3.3.2.3 Instruments operating on this principle have been developed in Bulgaria, France, German Democratic Republic, Federal Republic of Germany, USSR, UK, USA, and are also used in a number of other countries for measuring soil moisture.

2.4 Remote Sensing Methods

2.4.1 Visible band of the spectrum

The spectrum may be divided into 4 main bands, which are used to determine soil moisture by remote sensing methods: visible band (λ = 0.4 - 0.7 μm), infrared band (λ = 0.7 - 15 μm), microwave band (λ = 0.8 - 10 cm) and gamma-radiation. Determination of moisture using the visible band of the spectrum is based on a correlation between spectral coefficients of the brightness of the soil and its moisture content. The correlation is fairly reliable for achromatic soils with little humus (less than 30-40%) and also for the topmost layer of the soil (5-10 cm) in view of the negligible thickness of the active layer determining the magnitude of the reflected signal. However, the relationship is not rectilinear and specific for soils having various mechanical compositions. Threshold values of soil moisture, between which there is a relationship between the spectral coefficient of brightness and soil moisture are the value of maximum hygrosopicity - which is the lower threshold - and values of capillary moisture - which is the upper limit.

2.4.1.2 In these intervals, the curve for the relationship between brightness (γ) and moisture (f) is described by the exponential function:

$$ \gamma = e^{-Z \Delta f} $$

where Δf is the difference between the measured and initial soil moisture (usually between the measured moisture and the maximum hygrosopicity); Z is a coefficient reflecting the influence of the mechanical and organic composition of the soil. A decrease in the brightness of the soil with increased moisture is associated with the replacement of air, as the connecting medium between particles of soil, by water with a large coefficient of refraction and increased transparency.
2.4.1.3 A prospect for remote sensing from space to give readings of soil moisture, is the measurement of reflected light. An advantage of the use of polarized light is: increased intensity of the signal; it is unaffected by the daylight factor, cloud amount, angle of viewing, etc. The degree of polarization increases with increasing soil moisture, and to a greater extent in the case of soils with a heavy mechanical composition, than in the case of light soils.

2.4.1.4 Spectrophotometric, photographic and television systems are used for observation of the surface moisture of the soil in the visible band of the spectrum of reflected solar light.

2.4.1.5 Space photography enables the spatial non-uniformity of soil moisture to be seen particularly clearly. From photographs obtained from "Gemini" and "Sojuz", parts of deltas, valleys and depressions, with differing moisture and hydrological regimes, in arid zones of the world, could be distinguished. However variations in soil moisture, since these are, to a large extent, determined by the state of the vegetation, the mineral composition of mountain rocks and humus in the soil. Consequently, in space photographs, the most clearly distinguishable features are the ephemeral non-uniform patterns of soil moisture associated with the erratic rainfall in arid zones on days and times preceding photography.

2.4.1.6 Thus, in the visible band of the spectrum there are quite a few methods for determining soil moisture. However they are all at the stage of being developed and need to be checked carefully. Nevertheless most of them make it possible to undertake a qualitative analysis of the moisture conditions of the surface of the soil in territories which can be photographed.

2.4.2 Infrared band of the spectrum

2.4.2.1 The infrared band of the spectrum, according to the physical laws and remote sensing methods, is divided into two parts: the near infrared band of the spectrum (with $\lambda = 0.7 - 2.5 \mu m$), where the long-wave reflection of light from the sun is recorded, and the intermediate and far infrared band of the spectrum (with $\lambda \geq 3 \mu m$) where the radiant heat of the earth's surface itself is recorded. The general laws governing the relationship between brightness and moisture in the near part of the infrared band are the same as those for the visible band of the spectrum, i.e. with increasing moisture of the surface of the soil, the coefficient of brightness is most pronounced is displaced towards intermediate and high values of moisture. As a result, a high degree of moisture not discernible in the $\lambda = 0.4 - 0.7 \mu m$ band, is discernible in the $\lambda = 0.7 - 1.3 \mu m$ band. However, unlike the visible band of the spectrum, the interval of values of soil moisture over which the relationship between moisture and the coefficient of brightness is most pronounced is displaced towards intermediate and high values of moisture. As a result, a high degree of moisture not discernible in the $\lambda = 0.4 - 0.7 \mu m$ band, is discernible in the $\lambda = 0.7 - 1.3 \mu m$ band. However the range itself of values of moisture in infrared pictures is less than in synchronous pictures in the red visible band due, in the first place, to the increased degree of contrast. In various works an analysis is given of evaluations for territories with various moisture conditions from infrared pictures in the range $\lambda = 0.7 - 1.3 \mu m$ with a maximum of $\lambda = 1.1 \mu m$. 

2.4.2.2  The possibilities of aerial and space surveys in the thermal infrared band of the spectrum are limited by two windows of transparency of the atmosphere in this range: $\lambda = 3.4 - 5.6 \mu m$ and $8 - 12 \mu m$ but being disturbed by the presence of narrow bands of absorption at about $\lambda = 4.3 \mu m$ and about $10 \mu m$. A remote space reading of the moisture of the surface of the soil in these regions of the spectrum is based on the relationship between the moisture and thermal properties of the soil. The thermal properties of the soil depend on many factors: the mechanical and mineral composition, exposure and structure, but first and foremost, on the moisture. The presence of many factors influencing the thermal properties of the soil, means that variations of soil moisture and temperature are inadequate. But the main factor determining the considerable variability in the thermal characteristics is the non-equivalence of daily and seasonal fluctuations in the temperature of soils with different amounts of moisture. This has an effect, not only on the form, but even on the sign of the relationship between temperature and soil moisture at different times of the year. All this complicates and renders incorrect any solution to the reverse geophysical problem - that of obtaining soil moisture from values of radiation temperature measured by satellite. All this experience shows that, in solving certain problems such as the occurrence of enormous amounts of soil with high moisture content, following the variations with time, infrared surveys from space can be used successfully. However, all the shortcoming inherent to the method of evaluating moisture in the visible spectrum, apply also to the infrared band of the spectrum.

2.4.3  Microwave band spectrum

2.4.3.1  The microwave band of the spectrum ($\lambda = 0.3 - 30 \ cm$) enables information to be obtained concerning the moisture of the earth's surface (regardless of cloud cover) by measuring the polarization and intensity of the radio-thermal characteristics of soils of various moisture content are determined in the first instance by such parameters as dielectric permeability, temperature and depth of scanning. The dielectric permeability increases exponentially with increasing soil moisture. At the same time, with increasing, the influence of soil moisture on changes in dielectric permeability increases.

2.4.3.2  The depth of the radiating layer, making the main contribution to the radiation, increases with increasing wavelength and varies from a few tenths of a wavelength in the case of an environment with high absorption, to half a wavelength for an environment with low absorption.

2.4.3.3  It should be mentioned that the temperature of the soil influences the magnitude of the radiation and the degree of polarization; also the temperature correlates with the dielectric permeability. Radio-brightness temperatures ($T_B$) of the surface of the soil, measured under field conditions at experimental sites and from aircraft, in the ranges $0.8$ and $3 \ cm$, decreases appreciably with increasing moisture of the underlying surface. The dry, ploughed land of the steppes, the soil of the desert with sparse vegetation and also the denser vegeta-
tion of forest areas, show a comparatively high value, $T_B = 250-300$ K during the entire growing period. Areas of high moisture and areas with precipitation show values of $T_B$ which are lower by 50-80 K as compared with dry soils. Reservoirs have the lowest values of $T_B$—about 100-170 K. Soils with a cover of vegetation have an increased radiating capacity and an increased radio-brightness temperature, as compared with bare soil. In fact the increase in $T_B$ is proportional to the density and height of the vegetation cover.

2.4.3.4 On 23-24 September 1968, with $\lambda = 3.4$ cm, using the radiometer on the satellite "Kosmos-243", the spatial and temporal mean radio-brightness temperature was determined in an ellipse $25 \times 33$ km with centre at the sub-satellite point and area about $2600$ km$^2$ (Basharinov, Gurvic, Shutko, Beljakova, Matveev, Mironov).

2.4.3.5 In order to establish relationships between $T_B$ K, measured from a satellite, and surface moisture, satellite radio-brightness measurements were compared with observations of soil surface moisture at agronomical stations and with areas of precipitation on the day of making the survey and the preceding 24 hours. Recordings on charts of radio-brightness measurements (with $\lambda = 3.4$ cm) for geographical zones, satisfactorily reflect the temperature and moisture of the surface of the soil. A large part of the surface of the snow-free belt from the Black Sea to the eastern pre-Urals has a high $T_B$ (about 280-290 K). The highest $T_B$ are found in the driest watersheds of the Manchusky ranges with dry chestnut soils, ploughed or occupied at this time of the year by harvested grain crops (steppe) ($T_B = 300$ K). River valleys have relatively low $T_B$ (Volga, Kama, Ob), also marshy lowlands (pre-Surinski plain, upper Kamenski plain). Low values (for a land area) of $T_B$ occur in regions of recent rainfall in forest-steppe, the northern steppes and in the south of the forest area of the pre-Volga uplands. Low rainfall (up to 4 mm) decreased $T_B$ to 270-275K (i.e. by 10-20) and intensive rainfall (more than 4 mm) decreased $T_B$ to 260-265 K (i.e. by 20-30). The lowest values of $T_B$ occur near large sheets of water (Black Sea - 125 K).

2.4.3.6 The experimental unit for land resources on board "Skylab" comprised a radiometer with a wavelength of 21 cm. This was not a scanning sensor; it had a field of view of 115 km between points at which the energy was halved. With such a coarse spatial resolution it is difficult to compare directly the response of the sensor and measurements of soil moisture. However there are two reports on indirect comparisons. McFarlane showed that there was a steady ratio between the brightness temperature on "Skylab" with a wavelength of 21 cm and readings of previous rainfall for data obtained at the same time, starting from the extremity of Texas and Oklahoma and further to the southeast towards the Gulf of Mexico.

2.4.3.7 Igman and Lin carried the analysis of "Skylab" data a stage further, comparing the brightness temperature with evaluations of moisture from the print-out of the radiometer. Evaluations of soil moisture were based on a combination of actual surface measurements and calculations of soil moisture using a climatic model of the water balance. They obtained a correlation of 0.96 from data obtained during five occasions when "Skylab" passed over Texas, Oklahoma and Kansas. This result is very good, in view of the difficulty of obtaining information on soil moisture from a print-out of these dimensions, and in view of the fact that the brightness temperature was measured over a wide range of crop conditions existing over
the area. These results from space, supported by more detailed aircraft and surface measurements, presented earlier, give considerable support to proposals that it may be possible to use microwave radiometers for sensing soil moisture. A difficulty associated with this method is that the spatial distribution is limited by the size of the antenna permissible for such satellites. An advantage of a microwave survey, as compared with surveys using the infrared and visible bands of the spectrum, is that it is possible to obtain data relating to the vertical profile of soil moisture, by comparing measurements in various ranges of the spectrum.

However, the question of the practical use of this method can only be decided after an assessment has been made of the influence of various factors, mentioned above, on the value of the radiation and degree of polarization, which is made more difficult due to the lack of experimental data.

2.4.4 Active microwaves

2.4.4.1 Back scattering with such a space target as the soil is characterized by a scattering coefficient of the target of $\sigma_0$. Thus $\sigma_0$ characterizes the relationship between the properties of the object and the response of the instrument for measuring scattering. For the given set of parameters of the sensor (wavelength, polarization and adjusting angle relative to $0^\circ$) $\sigma_0$ for bare soil is a function of the roughness of the surface of the soil and dielectric properties depending on the amount of moisture. Fluctuations of with variations of soil moisture, roughness of the surface, the adjustment angle and frequency of observations, were extensively studied in surface experiments carried out by students at Kansas University, using an active microwave system, mounted on a truck, and operating on frequencies of 1 - 18 GHz (wavelength from 30 to 1.6 cm).

2.4.4.2 The presence of a vegetation cover above the surface of the soil decreases the sensitivity of radar back scattering to soil moisture by weakening the signal as it passes through the vegetation cover and back and increases the component itself of back scattering. Furthermore, both factors in general are functions of certain parameters of the vegetation cover, including the shape of the plants, their height and moisture content and also the density of the vegetation. The effect of a vegetation cover on the radar response to soil moisture is to decrease the sensitivity by approximately 40% as compared with bare soil.

2.4.4.3 The two microwave methods of sensing soil moisture have much in common, e.g. the ability to penetrate cloud and moderate vegetation and probing limited to only the upper 2-5 cm of the soil. The main difference is the spatial resolution. For passive systems, the resolution is limited by the size of the antenna, and for practical purposes this means 5-10 km. On the other hand, using a radar method it is possible to achieve from space a resolution of 100 m or less, e.g. by means of the radar on the "Siset" satellite with a wavelength of 18 cm, a resolution, a resolution of 25 m was obtained. The problems associated with the latter method are the difficulty of obtaining absolute graduations, high sensitivity to roughness of the surface and angle of view, and the large amount of data which has to be examined for any operational purposes.

2.4.4.4 The sensitivity to soil moisture of remote sensing methods was used in field or airborne experiments and, to a certain extent with satellites. These
experiments also presented some difficulties associated with each method. Some of
the limitations mentioned are of a fundamental nature, e.g. the effect of cloud in
the thermal infrared band, while others may be decreased or eliminated by using more
recent technology, e.g. larger antennae for improving the resolution of the radio-
meter or developing methods of graduating. There is a fundamental limitation to all
the methods of graduating: it is evident that they sense the moisture content in
only the 5-10 cm upper layer of the soil. This limitation means that the method of
remote sensing cannot be used satisfactorily in cases when a knowledge is required
of the moisture regime in the layer of soil occupied by roots.

2.4.5 Gamma-radiation

2.4.5.1 In the USSR a method has been extensively used involving a gamma-
survey of snow cover and moisture of the upper layer of the soil by aircraft. The
method consists essentially of determining the variations in intensity (I) of gamma-
radiation of natural radio-active elements, everywhere present in soils, depending
on soil moisture. Sources of gamma-radiation are radio-active elements of families
of Uranium-238, Thorium-232 and the isotope Potassium-40, which determine the use-
ful radiation, comprising 60-90% of the total flow of gamma-quanta.

2.4.5.2 If gamma-radiation of the isotope is distributed uniformly in the soil
of the ground and if the relative soil moisture by weight (f) is everywhere constant,
then the intensity of the gamma-radiation of these isotopes at a height, h, above
the soil will be:

\[ I = I_0 \frac{1}{1 + kf} \]

where \( I_0 \) is the intensity of gamma-radiation at a height \( h \) when \( f = 0 \); \( k \) is a
constant coefficient reflecting the various interactions between gamma-radiation
and the soil and water, and is equal to 1.11. The value \( I_0 \) is determined either by
measuring simultaneously the intensity of the gamma-field and the soil moisture,
under the same conditions, or by selecting directly a sample of soil and measuring
\( I \) under laboratory conditions with \( f = 0 \).

2.4.5.3 The contribution of layers of soil at various depths to the total flow
of gamma-quanta, \( I \), decreases nearly exponentially with depth. In practice, the
main contribution comes from the layer of soil at 30-40 cm. For this reason the
soil moisture is also determined in this layer. In order to select a useful signal
when undertaking surveys, the background radiation is measured separately and
subtracted from the total radiation. Scintillating counters with NaI monocrystals
with diameter 150 mm and height 100 mm are used as sensors.

2.4.5.4 By means of gamma-surveys by aircraft it is possible to obtain, opera-
tionally, sufficiently reliable information on soil moisture in a 0- 30 cm layer
over large areas. This method may become extensively used not only for operational
surveys of soil moisture but also for determining dates for turning on irrigation.
3. **Least Field Capacity**

3 Plants cannot use all the moisture contained in the soil. In order to estimate the conditions of water supply for agricultural crops, we can compare only the amount of moisture which is used by the plants for building up the yield and, for this purpose, the agro-hydrological properties of the soil are determined.

3.2 The least field capacity is the amount of moisture the soil can retain in suspended state when there is deep groundwater.

3.3 The most reliable method of determining the least field capacity is considered to the the method of flooding the ground and determining, by a gravimetric method, the moisture in each layer of soil after the water has drained away by gravitation.

3.4 A membrane press or centrifugal method may also be used.

4. **Wilting Point of the Plants**

4.1 The value of the soil moisture at which the turgor of a plant is not restored, even in air which is near to saturation, is called the wilting point. The wilting point is determined:

(i) - by a laboratory-vegetation method, i.e. cultivating various plants in vessels with soil until there is a steady loss of turgor and subsequently determining the soil moisture in the vessel;

(ii) - by a membrane (or lamellar) press under constant pressure above the surface of a soil sample, after which the remaining soil moisture is determined;

(iii) - by a centrifugal method in which the moist soil sample is subjected to the action of the centrifugal force. The number of revolutions necessary is determined, after which the residual moisture content of the soil sample is determined

(iv) - by a method of calculation, taking the maximum hygroscopicity and multiplying it by 1.34.

5. **Mass of Soil by Volume**

5.1 In order to determine the mass of soil by volume, a special drill (sample extractor) is used, designed to take samples from the undisturbed soil every 5 or 10 cm. The volumes of the samples of soil may be different. The mass of the soil by volume is calculated by dividing the mass of dry soil of each sample by its volume.
6. **Soil Temperature on Land with Winter Crops**

6.1 In order to estimate the hibernation conditions of wintering crops, the soil temperature is measured at the depth of the tillering node of winter grain crops, at a depth of 3 cm on land with grass several years old and in orchards at various depths.

6.2 Remote sensing instruments are used based on the property of metals that their electrical resistance is altered with changes of temperature. Various types of sensor are used:

(i) - sensor consisting of a non-inductive coil of very pure platinum wire, the electrical resistance of which varies linearly with changes of temperature within the limits of $-30^\circ$ to $70^\circ$C. It has an accuracy of $\pm 0.3^\circ$C.

(ii) - copper wire resistance thermometer placed in a hermetically sealed jacket. Measurements of temperature can be made in the range $+45^\circ$ to $-30^\circ$C. The accuracy is $\pm 1^\circ$C.

(iii) - hermetically sealed thermal system filled with toluene under pressure consisting of a thermometer bulb, manometer spiral spring with bimetallic compensator and connected capillary tube. Readings of the sensor are taken by means of a portable panel or recording device.

7. **Depth of Snow Cover**

The depth of snow cover is measured by means of a scale, graduated at 1 cm intervals.

8. **Depth to Which the Soil is Frozen**

8.1 Instrumental measurements of the depth to which the soil is frozen are made by observations of the depth of zero temperatures with the following instruments:

(i) - the main working part of the frozen ground meter is a rubber tube filled with water and tightly closed at each end. Inside the rubber tube along its length there are uniformly tight nylon threads with knots for retaining pieces of ice melting from above. On the outer surface of the tube are hermetically connected to the upper and lower capillaries. Plugs hermetically seal the ends of the capillaries. The upper plug with a rubber tube is fixed to the lower end of a wooden rod. At the upper end of the rod there is a cap with a ring. A protective plastic tube is inserted into the soil and the meter is put inside it in
such a way that the zero of the scale is at the level of the surface of the soil. In order to determine the depth of the frozen soil the meter is taken out of the protective tube and the level of the piece of ice is found by feeling. The depth of the lower limit of the piece of ice is taken as the lower limit of frozen soil. This gives an accuracy within 1 cm.

(ii) - the instrument consists of two plastic tubes with an internal diameter of 2.2 and 1.6 cm and is 91.5 cm in length. The internal tube is filled with 0.1% of fluorescent solution together with small pieces of quartz and then sealed. The bottom of the outer tube is closed and put into the soil. Both tubes are installed 15 cm above the level of the ground and protected from light and moisture. When necessary the inner tube is taken out to make a measurement. The yellow-green colour of the solution changes to light brown at frozen locations. A reading is taken on the scale on the inner tube to an accuracy of 13 cm.

9. **Estimating the State of Agricultural Crops**

9.1 This is usually done visually by comparison with the state of crops in years with a good yield. When making a visual estimate of the state of a crop, the state of the plants themselves, the uniformity of the crop, the degree of damage due to meteorological phenomena, pests and diseases, etc. are taken into account.

9.2 Research has shown that in order to obtain information on the state of pasture-type vegetation, it is possible to use photographic systems (Vinogradov 1971; Carnegie 1968). They make it possible to select the most suitable combination of films and light filters, to examine and measure photographs stereoscopically, and they give a high resolution. A de-coder receives information readily and rapidly and also a quantitative assessment of photographs is possible (by measuring optical density). Large-scale aerial photography makes it possible to study the specific composition of pasture-type vegetation.

9.3 Spectrometric surveys make it possible to identify very accurately the composition and quantitative characteristics of grass and undergrowth (Vinogradov 1971; Harik 1965).

9.4 By means of aerial photographic surveys, the indications of the following main types of plant disease have been successfully identified: brown rust of rye and wheat, grass rust, yellow grass rust, phytophthora of potatoes, root rot of cotton, nematode of cotton, circus mosaic of maize, etc (Volvach and Fedchenko 1976; Brenchley 1968; Colwell 1965; Hope 1966). They obtained space and other remote sensing methods of identifying damage: spectrometric survey, television multispectral scanning, thermal survey.
10. **Phases in the Development of Agricultural Crops**

   The phases in the development of agricultural crops are determined visually. There is a report from Canada that infrared methods using aircraft and surveys from satellites (in the infrared and visible bands) are used to determine the phases of development of crops. However a brief description of the methods is not given.

11. **Height of Plants**

   The height of plants is measured by means of a graduated scale.

12. **Density of Plants**

12.1 The density of crops is measured by counting the number of plants per unit area. We may also point out that there is a method for determining the sparsity of agricultural crops based on temperature contrasts in the vegetation cover, measured by radiometric sensors in the infrared region of the spectrum (Orlov, Utva).

13. **Biomass of Plants**

13.1 The biomass of plants is usually determined by cutting down the plants over unit area and weighing both moist and dry masses by means of scales.

13.2 In the USSR, an estimate of the productivity of pasture land is made from an aircraft making a spectrometric survey in two spectral intervals (Rachkulik, Sitnikova, 1976). The standard error in determining the biomass of the plants is 0.5 - 1.0 cent/ha. This method is assumed as the basis of a method for estimating the productivity of pasture land from satellite pictures, developed in the USSR (Rachkulik, Sitnikova, 1974). The main point of this method is that it partially eliminates the influence of the atmosphere on the results of space measurements. This is achieved by calibrating satellite pictures by aircraft, viz.: a relationship is established between the optical density, D, or the transmissivity of the picture, P, of calibration regions, and the coefficient of brightness, R, of these regions. The calibration regions are selected so that their coefficients of brightness cover the whole range in which R of the masses under consideration photographed by satellite may fall. The coefficients of brightness of regions are determined from aircraft by a photometric method in those spectral intervals in which the satellite picture was obtained. D and P are determined by a microphotometer under laboratory conditions. If a map showing the distribution of R is available it is possible to proceed to values of the vegetation mass, m, using graduated curves of the relationship between R and m. The values obtained of vegetation mass are presented in the form of a map, divided into squares corresponding to an actual area of 50 x 50 km, in each of which is marked the mean yield of desert vegetation for that square. Thus this method makes it possible to
obtain in 1 - 2 days detailed maps of the distribution of the yield of desert pasture-land over an area of 30-50 million hectares.

13.3 Carnegie (1968) notes that in order to study pasture-land in regions having a constant cloud cover, a radar survey may be undertaken. A drawback to the method is the low resolution.

13.4 A particular case of the spectrometric method is the photometric method, and this has been widely used in the USSR. The method is based on the relationship between the productivity of agricultural crops and their structural characteristics (projective covering, density, leaf index) on the one hand, and the coefficients of spectral brightness on the other. The closeness of the relationship between the reflecting properties of the vegetation cover and its parameters (and consequently the method as a whole), depends on the values of the contrast between the soil and the vegetation. In the case of contrasts of 0.5 or more, the relationship between the coefficient of brightness and the parameters of the vegetation cover may be expressed by the formula:

\[ K_{VS} = K_v + (K_s - K_v) 1^{-\alpha m} \]

where \( K_v \) is the ratio of the coefficients of brightness of the vegetation in two regions of the spectrum, \( m \) is a parameter of the vegetation cover, and \( \alpha \) is a constant. \( K_s \) is the ratio of the coefficients of brightness of the soil in two regions of the spectrum. In order to reduce the influence of conditions of illumination, the state of the atmosphere, degree of tillage and moisture of the soil on this relationship, the ratio of the coefficients of brightness in two regions of the spectrum are now used instead of coefficients of brightness. In order to use the method, a calibration is carried out on the soil, consisting of simultaneous measurements of \( K_{VS} \), \( K_s \) and \( m \) at the same site, and drawing curves based on these data. Then, having set up the instrument on an aircraft, \( K_{VS} \) and \( K_s \) are measured over any given territory and, by means of the curves, the state of the agricultural crops is effected visually on the basis of a series of observations. Recording on an aircraft is automated. The results of the survey gives the value of the vegetation mass above the ground for individual agricultural crops, along an itinerary or averaged over an area. The value of the mass of vegetation above the ground, being an inertial characteristic, is widely used both for estimating the state of crops and for estimating the expected yield of agricultural crops. The research which has been undertaken shows that there is a fairly close relationship between the value of the mass of vegetation for grain crops in the earing phase and the value of the expected yield. The correlation coefficient fluctuates between 0.75 and 0.85, depending on the crop and the territory.

14. Photosynthetic Active Radiation

14.1 In the process of photosynthesis, not the whole of the spectrum of solar radiation is used, but only that part of it which is in the interval of wavelengths 0.38 - 0.71 \( \mu m \). Of the radiation absorbed in this interval of the spectrum, up to 28% is used in the process of synthesis to produce a variety of organic substances (Ross 1975).
In order to measure photosynthetic active radiation, the following instruments are used:

(i) - sensor with microvolt output (Canada)

(ii) - a pair of identical pyranometers provided with filters (In one of them the filter transmits in the range 395 - 2800 nanometres, in the other, in the range 715 - 2800 nanometres. The photosynthetic active radiation in the range 395 - 715 nanometres is measured by balancing the outputs of these pyranometers

(iii) - photometer (Australia)

(iv) - multi-purpose agroclimatic unit with sensor T-SRF provided with automatic self-recording, for measuring the intensity of radiation in the range 42 x 85 (mm) (South Korea)

(v) - measurement by means of special pyranometers with wavelengths 315, 400, 446, 545, 646, 730, 816, and 914 nanometres (Belgium)

(vi) - silicon elements (China)

(vii) - quantum sensor LT - 1905 in the range 400 - 700 nanometres (Norway)

(viii) - two "Precision Eppley" pyranometers; the first has a clean cupola receiving wavelengths from 0.258 to 2.8 micron; the second has an RG-8 filter receiving wavelengths from 0.258 to 0.56 micron. In order to obtain the photosynthetic active radiation, the readings of RG-8 are subtracted from the readings of the first pyranometer (USA)

(ix) - tubular solarimeter (A) sensitive to radiation of 350-2500 nanometres and tubular solarimeter (B) sensitive to radiation of 750-2500 nanometres. The electrical output is recorded on magnetic tape by a battery data recorder. The photosynthetic active radiation is determined as the difference between the readings of A and B (Ireland)

(x) - quantum radiometer/photometer LI.185A with sensors LI-COR measuring in the range 400-700 nanometres (Malaysia)

(xi) - in view of the fact that the ratio of photosynthetic active radiation to global radiation is very constant (of the order of 0.48) it is preferable to measure global radiation (France).
15. **Temperature of the Surface of Leaves**

15.1 In order to measure the temperature of the surface of leaves, the following instruments are used:

(i) - Barnes PRTS or Heimann KT-24 radio-thermometers with accuracy from ± 0.25° C to ± 0.50° C (France)

(ii) - platinum temperature resistors-detectors (platinum detector enclosed in a ceramic jacket. Accuracy ± 0.5% (Ireland)

(iii) - thermocouple. Infrared thermometer (Australia)

(iv) - hot junction of a thermocouple formed by a thin copper wire and a thin constantan wire with a diameter of 0.1 mm and about 5 cm in length. The ends of both wires are cleaned, twisted and then soldered. The thin hot wire is attached to the leaf surface by glue, while the cold wire is in a thermo-flask with water at 0°C. The difference between the thermo-electric potentials of the two wires is recorded by a self-recording device. The readings are converted to temperatures by means of calibration curves (Japan)

16. **Duration of Retention of Moisture on Leaves**

16.1 This is measured by the following instruments:

(i) - sensor (blotting paper) the length of which is altered by moistening, thus showing the duration of the period with moisture on the vegetation organs. An INRA/STEFCE self-recording device is placed above an ordinary thermometer. Sensor (thin copper leaf with gold coating), the conductivity of which varies with the presence of water, closing an electrical circuit, thus indicating the duration of moisture (France)

(ii) - dropometer, consisting of a rectangular wooden block 32 x 5 x 2.5 cm, covered with paint enhancing the retention of dew. The dropometer is exposed after sunset, and the size, shape and the dew deposited on it are observed after sunrise by comparison with a collection of photographs of each type of dew (India, Jordan)

(iii) - the system consists of 5 sensors, power unit, timer, calibrated potentiometer and self-recording device. The moisture sensors form a grid of 5.8 x 7.8 cm, and are covered with a thin coating of black paint and several coatings of grey latex paint. The timer provides an instantaneous supply of current from the power unit to the sensors. The current flows through the sensors if there is a film of water on any of the sensors (USA
the sensor consists of pairs of interlocked platinum electrodes in the form of a comb, with support of filter paper. The conductivity of the sensor is appreciably increased if dew forms on the filter paper, and this change is recorded by the self-recording device.

17 Conclusions

17.1 A brief survey of a wide variety of instruments and methods of observation, used in agrometeorological observation and research, based on information provided by member countries of the World Meteorological Organization is given in the above paragraphs. This survey could not completely cover all the different types of instrument and methods of observation used for agrometeorological research in various countries. Each of the instruments and methods of observation used has its advantages and disadvantages.

17.2 Methods of measurement at a given location, with some accuracy, be used to estimate the complex conditions for the build-up of the yield of agricultural crops on a specific piece of land. However, in order to achieve any degree of accuracy for an area, it is necessary to have a large number of observations at various locations, with the result that the amount of work (mainly manual) involved in obtaining the observations becomes very great.

17.3 Remote sensing methods (aircraft, satellites) enable data to be speedily collected from large areas, but at present these methods are mainly at the development stage, and are only used to a limited extent by hydrometeorological services. The main problems in remote sensing are spatial resolution and the accuracy of measurements. It seems that remote sensing will always require calibration for the location, so that requirements, as regards the accuracy of measurements of agrometeorological parameters at a given location, will increase.

17.4 At the same time it may be noted that in order to measure agrometeorological parameters few instruments are used, visual methods are frequently used, while much effort goes into manual work.

17.5 Information relating to the moisture of the layer occupied by roots and the state of agricultural crops are of the greatest significance for estimating the complex agrometeorological conditions, from the point of view of the expected yield.

17.6 For the measurement of soil moisture, in various countries, very many instruments and methods of observation are used, developed on different principles and leading to differing errors of measurement. Coupled with this, there is no reliable soil moisture meter, by means of which the amount of productive moisture in the soil can easily be determined, and which could be used as a standard. The remote sensing methods which have been developed have not, so far, been widely used, due to the inadequate spatial resolution and depth of measurements.

17.7 Observations on the state of agricultural crops and damage to them due to unfavourable hydrometeorological conditions, pests and diseases, are mainly made visually.
17.8 With a view to ensuring uniformity and reliability in the measurements, and also common methods and instruments for measurements, it would seem to be desirable to ask the WMO Commission for Instruments and Methods of Observation to give the most serious attention to the need to develop, as soon as possible, instruments and methods of observation for agrometeorological purposes. Priority to be given for the development of:

(i) a reliable non-stationary soil moisture meter, by means of which it would be possible to determine quickly the soil moisture on agricultural land at various horizons of the layer occupied by roots, with an error not exceeding 1.0 percent of the weight of absolutely dry soil (or 5-10 mm of productive moisture in the layer of the soil 0-100 cm) and not constituting any health hazards

(ii) method for remote sensing of the moisture of various horizons of the layer of soil occupied by roots

(iii) instruments and methods of observation of the characteristics of the general state of various agricultural crops (both on a specific piece of land, and over large areas.

17.9 With a view to speeding up technical progress in the field of agrometeorology, to ensure uniformity of methods and instruments, for measurements used in various countries, and to achieve a wider distribution of information, the hydrometeorological services of member countries of WMO should inform other Members concerning the development of new instruments and methods of observation in the field of agrometeorology in their countries, the results of using them and the advantages as compared with other instruments and methods of observations already available.