Technical Manual no. 5

Methods and Management of Data for Watershed Research

International Crops Research Institute for the Semi-Arid Tropics
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Methods and Management of Data for Watershed Research

Technical Manual for the Training Workshop

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Contents

Preface

With financial support generously provided by the Asian Development Bank (ADB), ICRISAT has embarked upon a collaborative project which focuses on watershed-based management of natural resources (soil and water) in the seasonally dry tropics for sustained productivity of rainfed agriculture and prevention of land degradation. It addresses selected agroecologies and socioeconomic environments in South Asia (India) and Southeast Asia (Thailand and Vietnam) where available improved technologies can be transferred readily in partnership with national agricultural research systems (NARS), local communities, and non-governmental organizations (NGOs) to increase agricultural production and improve incomes of farm families now living in poverty.

Field experiments have been initiated at three sites in India and one each in Thailand and Vietnam in collaboration with the national programs and NGOs. Various participants in the project are collecting the required data-sets on physical, biological, chemical, and socioeconomic aspects of the study sites for planning, evaluation, and transfer of technologies. To enable cross-site comparisons and extrapolation of results to future development sites, a common set of standard and agreed-upon procedures and methods need to be followed for collection and management of data.

To achieve the objective of common data exploitation, a training program was held at the ICRISAT Center, Patancheru from 15-26 November 1999 to discuss and update the participating scientists and technicians in methods and management of data. The participants were provided with hands-on training in appropriate methods for collection, entry, and maintenance of different types of data from watersheds such as soil, crop, hydrology, climate, and other relevant natural resources data, as well as socioeconomics data. A standard set of procedures for storage and retrieval of data for subsequent analysis were also discussed.

This Technical Manual on "Methods and Management of Data for Watershed Research" is a record of the lectures and hands-on exercises used during the training workshop. The workshop faculty members have contributed by compiling all the relevant material together for different topics related to watershed management. The editors have ensured that this Technical Manual is compiled to serve as a ready source of reference information for the staff of NARS and NGOs involved in watershed management research. It is hoped that it will enhance the quality of the partnership watershed research through this project supported by the ADB, and will form the basis of future workshops for hands-on training.

B I Shapiro
Director
Natural Resources Management Program

Need for Database Management in Integrated Watershed Programs

S P Wani

The term "watershed" refers to the divide separating one drainage basin from another. However, over the years, the use of the term watershed to signify a drainage basin or catchment area has come to stay. Hydrologically, watershed could be defined as an area from which the runoff drains through a particular point in the drainage system. The watersheds exist naturally and due to human intervention for agricultural purposes the changed ecology and management practices affect the well equilibrated ecologies. If watersheds are not managed properly then the natural resources are degraded rapidly and in due course cannot be used for betterment of humans. Soil, water, air, and vegetation are the most important natural resources for the survival of human beings and animals.

For maximum production of vegetation all the resources have to be managed efficiently and effectively. For efficient management of these resources, one has to lopk for a suitable unit(s) of management so that these resources are managed and handled effectively, collectively, and simultaneously. Watershed management can be defined as rational utilization of all the natural resources for optimum production to fulfill the present need with minimal degradation of natural resources such as land, water, and environment. Water can be managed if a watershed is taken as a unit. Since soil and vegetation can also be conveniently and efficiently managed in this unit, the watershed is considered the ideal unit for managing the vital resources of soil, water, and vegetation. In the watershed, people and animals are the integral parts of the watershed community. They depend on the watershed and they in turn influence the good or bad happenings. Participation of people is essential for the success of the watershed programs. Participatory watershed management is a process which aims to create a self-supporting system essential for sustainability. The concept of participatory watershed management emphasizes a multi-disciplinary and multi-institutional approach. The process begins with the management of soil and water which eventually leads to the development of other resources. Human resource development and large-scale participation is essential since finally it is the people who have to manage their resources. People's or farmers' participation is the key to the success of any integrated watershed development program.

The project on "Sustaining Asian Rainfed Agriculture: Improving Management of Natural Resources" addresses the following issues:

- Enhancing crop production; and
- Minimizing degradation of natural resource base.

The overall objective of this project is to enhance and sustain crop productivity of medium-high water-holding capacity soils in the intermediate rainfall ecoregion of the semi-arid tropics (SAT) of Asia. The specific objectives are to:

- Introduce practices for sustained increases in agricultural productivity; and
- Reduce soil degradation and increase farmers' incomes through better management of natural resources.

To achieve these objectives, we need to conduct on-station strategic research and on-farm developmental research. From this research we need to collect necessary data-sets to draw valid conclusions from the experiments we conduct.

The primary requirements of any data-set are: quality, quantity, and timeliness. Unless these three parameters are fulfilled, valid conclusions cannot be drawn from the research conducted. This workshop is being conducted to address these issues and to decide and agree on (1) sets of data to be

collected; (2) standard and uniform methods to be used; (3) at what frequency and intensity to collect data; and (4) how to store, process, and analyze these data-sets. The objectives of this workshop are to:

- Equip the Asian Development Bank (ADB)-ICRISAT collaborating project scientists with necessary knowledge base and to provide them with hands-on computer-based training in appropriate methods for uniform collection, entry, and maintenance of different types of data from watershed such as soil, crop, hydrology, socioeconomics, climate, and other relevant natural resource factors.
- Develop and maintain a standardized uniform system for data storage and retrieval for subsequent watershed- and regional-level (spatial) analyses pertinent to the objectives of the ADB Project.
- Discuss various aspects of base-data analysis and their use for improving the management of natural resources for sustaining rainfed agriculture in South Asia.

The approach will be through a participatory workshop for joint learning and hands-on-training for handling different data-sets. Basically this course is a refresher course so that all of us have a common understanding about the problems and the solutions for collecting necessary data-sets from this multi-disciplinary, multi-institutional and multi-country watershed project supported by the ADB. At the end of this workshop the goals to be achieved are to:

- Agree on data-sets that should be collected from on-station and on-farm experiments conducted in this project.
- Identify standard and uniform methods to collect necessary data-sets .
- Become acquainted with entry and maintenance of data-sets through hands-on-experience on computers; and
- Understand the ways to process data-sets for drawing valid inferences from our research.

All the participants in this workshop have diverse expertise and are directly involved in conducting research in different countries and represent different institutions including state agricultural universities, state research institutions, and non-governmental organizations. Once we all decide what are the minimum data-sets to be collected from each experiment, which method to be followed, and how much and at what interval data need to be collected, we will be on a strong platform to undertake the research in the area of integrated watershed management. Our research is focused towards sustaining the productivity of rainfed agriculture in the SAT of Asia with minimal degradation of natural resources and for improving the wellbeing of the SAT people in general.

Data-sets for Site Characterization and Field Experiments

Piara Singh

Several kinds of data-sets and other relevant information would be required for the benchmark site characterization and from field experiments. These data-sets would be useful in interpretation of research results, modeling of the production systems, and extension of technologies within and across the research domains.

Types of Data-sets

Data-sets for site characterization

The data-sets for site characterization pertain to climate, soil, and the socioeconomic aspects of the site or region. These data would be required for short- and long-term assessment of constraints, opportunities, and production potential of benchmark sites and its application domain. Analysis of these data would have implications for the kind of technologies to be developed that will have relevance to the production system/region.

Data collection from field experiments

Data-sets from field experiments comprise the following elements.

Experimental details

This is general information which is normally collected by a scientist for his experiment. It pertains to site characteristics where the experiment is conducted and the details of the experiment required in the analysis of field or laboratory data.

Essential data-set (EDS)

The set of data is considered as minimum to be collected for all field experiments. This basic data is useful in comparing results between years for a site and across sites and is useful in the application of the system models in a production system domain. Therefore, this data must be available for each benchmark site.

Experiment-specific measurements

As a part of the strategic research some measurements would have to be taken in some field/laboratory experiments to understand various processes related to soil, climate, and plant to generate new knowledge or to provide supporting information. These measurements will not form part of each experiment and would be decided by the scientists involved in a particular type of research.

Data-sets and Measurements

Various kinds of data-sets/measurements and methods involved to obtain these data are discussed.

Site characterization data and analyses

Climatic characterization of the site

For climatic characterization of a site we need historical weather data and its analyses for various applications are required.

Daily values:

- Rainfall (mm)
- Maximum and minimum temperature (°C)
- Duration of bright sunshine (h)
- Solar radiation (MJ m^{-2} day^{-1})
- Wind speed (km h^{-1})
- Relative humidity (RH) (%) (am, pm) or wet and dry bulb temperatures (°C)

Analysis of data: The potential list of analyses that can be performed for the characterization of the environment are listed below:

- Rainfall (30 years - most recent)
  - Annual rainfall and its variability
  - Monthly rainfall and its variability
    Seasonal rainfall and its variability
  - Weekly rainfall and its variability
  - Probability analysis of weekly data
  - Characteristics of the rainy season
    Distribution of rainy days
    Duration of wet spells and quantum of rainfall
  - Duration of the storm, quantum of rainfall received, and peak intensity of rainfall (5-10 years)[1]
- Mean daily potential evapotranspiration (PET) and open pan evaporation for each week and month (5-10 years)[1]
- Mean maximum and mean minimum temperature for each month (5-10 years)[1]
- Mean duration of bright sunshine and solar radiation (5-10 years)[1]
- Non-crop specific water balance of the site (Keig and McAlpine method)[2]
- Probability analysis of water balance components[2]
- Length of growing season and its variability[2]

Soil characterization of the site as per soil taxonomy

Physical properties: Information/data would be required for soil physical characterization and to evaluate the water retention and release characteristics of the soil for water balance and crop growth modeling. This information/data comprises location, pedon number, soil series, soil classification, slope of land, no. of soil layers (horizons) in the soil profile, soil color, soil permeability, soil drainage, water table depth, and layer-wise information on:

- Upper and lower depth of each horizon
- % clay <0.002 mm

1. Database needed.
2. Derived parameters

- % silt 0.002-0.05 mm
- % sand 0.05-2.0 mm
- % coarse fragments >2 mm
- Soil water content at field capacity and permanent wilting point (cm^3 cm^{-3})
- Soil water content at saturation (cm^3 cm^{-3})
- Quantity of roots

Chemical properties: Layer-wise data would be needed on organic carbon, soil pH, carbonates, and on exchangeable bases (Ca, Mg, Na, and K).

Socioeconomic characterization

The following data-set would be needed for characterizing the socioeconomic environment of the production system:

- Land use pattern
- Area, production, and yield of important crops
- Input use
- Output and input prices
- Information on irrigation sources and area
- Economic variables
- Demographic information
- Rural infrastructure
- Degradation of natural resources

Data from field experiments

Experimental details

Each experiment should have the following details about the experiment and the site.

Site: Latitude, longitude, elevation, soil type and soil series name, soil classification as per soil taxonomy, and distance of the site from the weather station.

Experiment: Experiment description, treatments (factors and levels), design of experiment, replications, layout and treatment randomization, plot size and total area, and on-farm/on-station/ watershed based research.

Essential data set (EDS)

Climate: Daily values of rainfall, maximum and minimum temperature, wet and dry bulb temperature, solar radiation or bright sunshine hours, pan evaporation, and wind velocity.

Soil: Layer-wise data on field capacity, lower limit of water availability, soil moisture measurements (preplant and during the season) to the maximum rooting depth, soil fertility measurements (preplant and at harvest) pH, organic C, total and available N, P, and K, and maximum rooting depth.

Crop: Growth stages (vegetative and reproductive), growth analysis at important growth stages, crop yields (total dry matter and seed), type and extent of crop damage, and cultivars and their characteristics.

Management: Sowing date, inter and intra-row spacings, plant density, inputs of crop residues, manures and fertilizers, date, amount and method of irrigation, biocide applications, and harvest date.

Socioeconomics: Farmer's preferences/reaction to new technology, operational difficulties, resources required, and labour use.

Experiment-specific measurements

Some of these measurements are N budgeting, N-fixation, availability of N, P, K, and micronutrients, biomass C and N, activities of microbes and vesicular-arbuscular mycorrhiza, potential N mineralization, soil moisture dynamics and water extraction by crops, runoff and soil loss, soil quality measurements, and light interception by crops.

Data needs and format for recording data are given in Appendices I—III.

Monitoring of Weather

Piara Singh, Y V Srirama, and N J Shurpali

Weather information is needed for carrying out various farm activities as well as to know the potential of an environment for agricultural production. Weather is usually monitored by recording the output of various instruments placed in a weather observatory or by installing an automatic weather station. Weather observatory is useful for recording weather at the research station, whereas an automatic weather station can be used for both on-station and on-farm research. In this chapter, we have described the operation of various instruments usually installed in a class 'A' observatory and the operation of an automatic weather station.

Class TV Observatory

Daily rainfall

Non-recording gauge

The instrument used is Fibre Glass Reinforced Raingauge (FRP Raingauge). The raingauge should be fixed on a masonry or concrete foundation 60 x 60 x 60 cm sunk into the ground. The base of the gauge should be embedded 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 horizontality should be checked with a spirit level laid across the rim.

At the time of recording rainfall, remove the funnel of the raingauge and take out the polythene bottle. Place the measuring jar in an empty basin and slowly pour the contents of the receiver into the measuring jar taking care to avoid spilling. If, however, any water is spilled into the basin, add it to the water in the measuring jar before arriving at the total amount collected. While reading the amount of rain, hold the measuring jar, upright between the thumb and the first finger or place it on a table or other horizontal surface. Bring the eye to the level of the water in the measure glass and take the reading of the bottom of the meniscus or curved surface of the water. The amount of rainfall should be read in millimeters and tenths. It is extremely important to note that the correct type of measuring jar appropriate to the type of raingauge funnel in use should be used for measuring the amount of rainfall, to avoid errors in the results. Enter 0.0 for no rain and a 't' (meaning trace) for rainfall below 0.1 mm.

Ensure that the collector of the raingauge does not get choked with dirt and that the receiving bottle and additional cylinder, if any, are always clean. They should be emptied regularly of sediment or other material that may have fallen into them and cleaned periodically. The grass around the gauge should be kept short. No shrubs or plants should be allowed to grow around the gauge. Both the rain measure glasses should be kept spotlessly clean. They should be handled gently to avoid breakages and stored dry in a safe place when not in use.

Recording gauge

The siphon recording raingauge is an instrument designed to give a continuous recording of rainfall. In addition to the total amount of rainfall, the onset and cessation of rain (and therefore the duration of rainfall) are recorded.

The gauge should be installed in such a way that the rim of the funnel is horizontal and set at a height of exactly 75 cm above ground level. For setting the pen at the zero mark, pour sufficient water into the receiver till the pen reaches the top and water siphons out. After all the water is drained out, the pen

should be on the zero line; if not, it should be adjusted.

Rainfall enters the gauge at the top via a funnel and passes through a receiver consisting of a float chamber and a siphon chamber. A 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. Siphoning occurs automatically when the pen reaches the top of the chart, at the 10 mm mark, and then the pen comes down to the zero line of the chart. The pen rises again with the onset of rainfall. When there is no rain, the pen traces a base horizontal line of the chart.

The chart should be changed daily (in India at 0830 IST) as a routine observation irrespective of the rainfall occurrence.

The observer should see that the pen trace matches the base horizontal line of the chart without an error after every siphoning operation. The instrument should be checked daily once for correct siphoning operation.

Temperature

Maximum and minimum thermometers have to be kept apart horizontally with the bulbs being towards dry bulb thermometer, maximum thermometer at higher level, and minimum thermometer at lower level in the Stevenson Screen.

Maximum temperature

Maximum temperature is recorded by a mercury thermometer placed in Thermometer Screen (Stevenson Screen) at 4.5 feet above ground. The bore in the stem of the maximum mercury thermometer is made extremely fine near the neck of the bulb. When the temperature of the air rises, the mercury in the bulb expands and forces its way into the stem past this constriction; but when the bulb cools, the mercury above the constriction cannot get back into the bulb and the length of the mercuiy thread remains just the same as it was when the bulb was warmest (i.e., highest temperature of the day). Maximum temperature is read twice daily, i.e., at the time of routine morning and routine afternoon observations (in India, at ICRISAT, Patancheru at 0717 IST and 1417 IST). This is to be set after the routine morning observations.

Minimum temperature

Minimum temperature is recorded by a spirit filled thermometer placed in Thermometer Screen (Stevenson Screen) at 4.25 feet above ground. The liquid inside the minimum thermometer is spirit in which is immersed a dumb bell-shaped index. When the temperature falls, the spirit drags the index along with it towards the bulb end; but when the temperature rises the spirit expands and runs past the index without disturbing it. Thus the end of the index farthest from the bulb gives the lowest temperature attained by the instrument. This is to be read twice daily at the routine morning and afternoon observations (in India, at ICRISAT, Patancheru, 0717 IST and 1417 IST). This is to be set after routine morning and afternoon observations.

Relative humidity

Dry bulb thermometer is used for obtaining the temperature of the surrounding air. Wet bulb thermometer helps to find out the relative humidity of the surrounding air. These are exposed under similar conditions in a shelter of approved pattern called the Thermometer Screen (Stevenson Screen).

Observe the position of the end of the mercury column and note down the reading to the nearest tenth of a degree. Always use the graduations etched on the glass stem of the thermometer and not the bold graduations on the porcelain scale on the thermometer mount. The bulb of a wet bulb thermometer is always kept wet by means of a single fold of thin, soft muslin sheath, which is fed with distilled water from a bottle through a wick.

Relative humidity will be obtained using the hygrometric tables for the given dry bulb and wet bulb temperatures. These thermometers are read twice daily, i.e., at the time of the routine morning and afternoon observations.

Having let down the door of the Thermometer Screen, first read the dry bulb and wet bulb thermometers as quickly as is consistent with accuracy, so that they may not be heated by the presence of your body or your breathing directly on the thermometer bulbs. While taking a reading make sure that the straight line joining your eye to the end of the mercury column is at right angles to the length of the column. Examine the muslin and the wick of the wet bulb thermometer and fill its bottle with water, if necessary. The muslin and the wick may be changed if necessary.

Wind speed

The wind speed is measured by an instrument called the anemometer. To install the instrument, a metallic pipe is rigidly embedded in the parapet wall of the roof or any other suitable masonry structure selected or securely fixed to the side of the tower or masonry structure by means of strong iron clips. The length of the metallic pipe should be such that the cup wheel of the anemometer is at least 1.2 m above the supporting wall when the instrument is screwed to the metallic pipe.

The wind run in km during the day is obtained by the difference in the counter readings (in India at 0830 IST) on two successive days and rounding off the quotient to the nearest whole number.

The instrument should be inspected, cleaned, and lubricated at intervals of three months. Dust and other foreign matter may get into the instrument case and settle on the revolving parts. The bearings and gear also require thorough cleaning and lubrication once in a while. The instrument should therefore be carefully inspected and all the bearings thoroughly oil washed, cleaned, and lubricated at intervals of six months.

Duration of bright sunshine

Duration of bright sunshine is measured by using a Campbell sunshine recorder consisting of a glass sphere, 10 cm in diameter, mounted centrally on a spherical bowl. The diameter of the bowl is such that when exposed to the sun's rays the sphere focuses the rays sharply on a card held in the grooves of the bowl. Three overlapping pairs of grooves are provided in the bowl for positioning suitable cards for different seasons. The card is charred by the heat of the sun's rays, which are focused on the card by the glass sphere. The sunshine recorder uses the movement of the sun instead of a clock to form the time basis of the record of bright sunshine hours. The mounting of the recorder is such that both the ends of the cards face East and West directions and the semicircular card holder faces South direction. Daily card should be inserted into the groove before sunrise and should be removed after sunset. The semicircular card holder position is decided according to the latitude of the location and hence is supplied by the manufacturer. The whole instrument is mounted on a marble stone, which in turn is set up on a firm and rigid support free from obstruction to direct radiation from the sun.

Daily total radiation

Daily total radiation consists of global sun and sky radiation at the location. Silicon photodiode is extensively used in pyranometers along with cosine corrected diffuser to receive solar radiation between 0.4 μm and 1.0 μm band approximately contributing to about 98% of global radiation from the sun. The silicon photodiode is preferred over copper-constantan thermopile because of its fast response. The silicon photodiode generates current proportional to the solar radiation impinging on it and is converted to voltage by passing it through a standard resistor.

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 leveled through the use of a mounting and leveling fixture. The vertical edge of the sensor should be kept clean to maintain appropriate cosine correction. Daily solar radiation is recorded by an integrator or a data logger between sunrise and sunset. By using

the calibration certificate supplied by the manufacturer, we can get solar radiation for shorter durations, say hourly, in watts m^2 or daily solar radiation in MJ m^{-2} day^{-1}.

Daily photosynthetically active radiation

All the 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 µm, different wavelength bands may cause different biochemical effects. Of all the wavelength bands, the region between 0.4 and 0.7 µm is of most importance in terms of plant photosynthetic efficiency, and the radiation in this wavelength is called photosynthetically active radiation (PAR). PAR is measured with a quantum sensor which consists of a silicon photodiode and a pass band filter with cosine correction allowing radiation between 0.4 and 0.7 µm wavelength from all angles of hemisphere.

The sensor could be conveniently leveled through the use of a mounting and leveling fixture and free from any obstruction. The vertical edge of the sensor should be kept clean to maintain appropriate cosine correction. Daily PAR is measured by an integrator or a data logger between sunrise and sunset. By using the calibration certificate supplied by the manufacturer, daily PAR can be recorded in E m^{-2} day^{-1} units.

Automatic Weather Station

Weather station consists of a microprocessor based data logger, powered by dry battery, trickle charged with solar panel. The data logger is connected to different meteorological sensors as per the requirement. To monitor weather conditions prevailing at experiment station, minimum meteorological data should be collected by installing Pyranometer to measure solar radiation, anemometer to record wind velocity at 3 m height, wind vane to record wind direction with reference to true north, raingauge to record total rainfall during predetermined intervals, and psychrometer to record air temperature and relative humidity (Figure 1). Soil temperature sensors should be installed to monitor temperature at 5-cm, 10-cm, and 20-cm depths.

The data logger is programmed using different instruction sets provided by the manufacturer (Campbell Scientific Inc., USA) in recording the sensed information from different sensors (Met.did file). Five minutes logging interval is selected and final output is done at hourly intervals. Data storage period in a particular model data logger is decided by the number of meteorological parameters

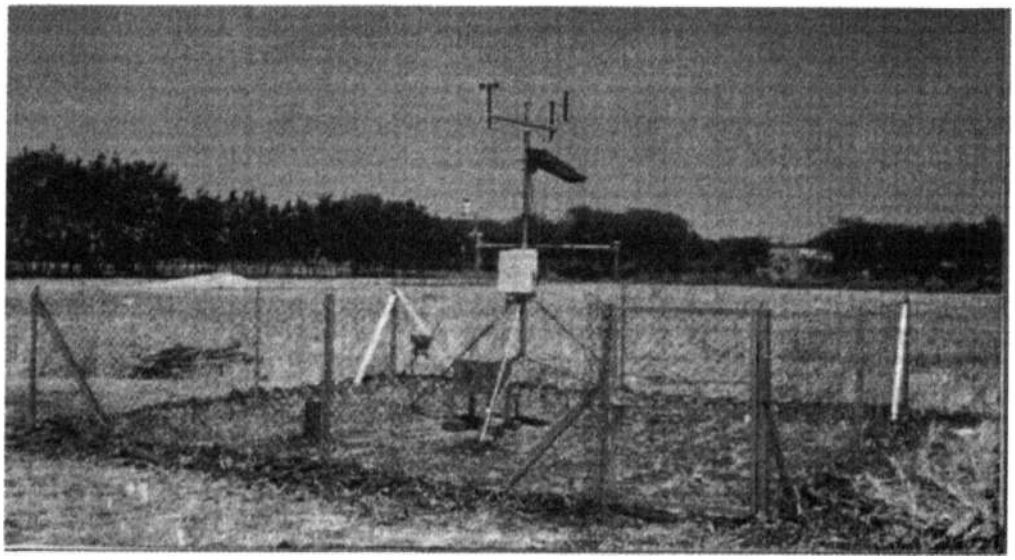


Figure 1. Automatic weather station at an experimental watershed.

collected and their output interval. After data has been collected in data logger, it can be retrieved using a laptop computer along with 32A modem or tape recorder with SC92A. Alternatively data can be continuously stored in a storage module (SM) by connecting it to the data logger. As and when the data is required, SM can be brought to the computer and data can be transferred using SC532A and 25P-9S cable along with SMCOM of PC208 software. Raw data in the computer can be processed to get the required data in a report format by using SPLIT option of PC208 or PC208W (report files of: rainfall events, hourly output, and meteorological daily output).

The storage capacity of SM ranges from 192 KB to 4 MB leading to approximately 0.1 to 2 million data points of low resolution or 0.05 to 1 million data points of high resolution. Since the basic meteorological data is available from the raw data files, different parameters can be derived from them such as rainfall events, rainfall and wind intensities, maximum and minimum values of all parameters along with time of occurrence. Preferred SI units should be used for reporting different parameters: energy in J m^{-2}; power in W m^{-2}; temperature in °C; wind velocity in m s^{-1}; rainfall in mm; and time in s.

Solar radiation

Solar radiation consists of global sun and sky radiation at the location, Silicon photodiode with appropriate filter is extensively used in pyranometers along with cosine corrected diffuser to receive solar radiation between 0.4 and 1.1 µm band. This band approximately contributes to about 98% of global radiation from the sun. The silicon photodiode is preferred over copper-constantan thermopile because of its fast response. The silicon photodiode generates current proportional to the solar radiation impinging on it and is converted to voltage by passing through a standard resistor. 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 leveled through the use of a mounting and leveling fixture. The vertical edge of the sensor should be kept clean to maintain appropriate cosine correction. Stability, response time, and sensitivity are $< \pm 2$% change over a year, 10 ms, and 0.2 kWm^{-2} mv^{-1} respectively. At night the pyranometer may read slightly negative incoming solar radiation. This negative signal is caused by radio frequency (RF) noise. Negative values may be set to zero in the data logger program.

Wind speed

Wind speed is measured by an instrument called the anemometer. The anemometer cup assembly consists of three aluminum cups mounted on a cup assembly hub.. A stainless steel shaft, which rotates on precision-sealed ball bearings, connects the cup assembly to a magnet assembly. When the shaft is rotated, the turning magnet assembly causes a reed switch to close. There are two contacts (reed switch closures) per revolution. The frequency of closures is linear from threshold to 45 m s^{-1}. It has a threshold (stopping speed) of 0.45 m s^{-1} (1.5 kmph), calibrated range of 0-45 m s^{-1} (0-160 kmph), gust survival of 0-53 m s^{-1} (0-190 kmph), and accuracy of 1.5% or 0.11 m s^{-1} (0.4 kmph) in the temperature range of -50°C to 70°C. The anemometer follows this equation:

$$V = 0.447 + f/1.250$$

where V = wind speed (m s^{-1}); f = output frequency (hz); and 0.447 is threshold speed (m s^{-1}).

Wind direction

The wind direction is sensed by a vane. The vane drives a 10 kilo ohm potentiometer designed with shorting at crossover. Campbell Scientific has provided a fixed 10 kilo ohm resistor on the excitation line. This resistor prevents erroneous measurements when the potentiometer shorts to ground as the wind direction crosses over the west side of north to the east side of north. AC half bridge instruction with appropriate excitation is used and voltage between the wiper and analog ground. The resistance

between the wiper and analog ground varies with wind direction. Orientation of the wind direction sensor is done after the data logger has been programmed, and the location of True North has been determined. True North is usually found by reading a magnetic compass and applying the correction for magnetic declination, where magnetic declination is the number of degrees between True North and Magnetic North. Magnetic declination for a specific site can be obtained from a standard map at the local airport. Declination angles east of True North are considered negative, and are subtracted from 0 (360) degrees to get True North. Declination angles west of True North are considered positive, and are added to 0 degrees to get True North. Orientation is most easily done with two persons, one to aim and adjust the sensor, while the other observes the wind direction displayed by the data logger.

Rainfall

Rainwater is collected through the collecting funnel of tipping bucket raingauge having a standard diameter mounted at least 30 cm above ground and away from objects. The tipping bucket mechanism embedded with a small magnet activates a sealed reed switch that produces a contact closure for each 0.254 mm or 0.1 mm of rainfall. The volume of rainwater required to cause a tip depends on diameter (6", 8", or 9.6") of the funnel and capacity of the buckets. Switch closure duration is approximately 135 milliseconds and these events are recorded by the data logger using pulse counting program instruction with switch closure configuration. The accuracy of tipping bucket raingauges up to 10 mm h^{-1}, 10-20 mm h^{-1}, 20-30 mm h^{-1} intensity are ± 1 %, -2.5%, and -3.5% respectively. There is a provision to adjust the capacity of buckets using two screws in the raingauge. Rotation of screw clockwise increases the number of tips and counter clockwise rotation decreases the number of tips per unit amount of water. One half turn of both screws causes a 2% to 3% change. Depending on the intensity of rain for a location, appropriate raingauge has to be selected to achieve maximum accuracy. For high rainfall intensity locations, raingauge having higher bucket capacity has to be used.

Relative humidity

Relative humidity and air temperature can be monitored by using electronic relative humidity probe or aspirated psychrometer having wet and dry bulb thermometers.

Electronic relative humidity probe (Vaisala probe)

Relative humidity probe contains a platinum resistance temperature detector (PRT) and a Vaisala Humicap capacitive relative humidity sensor. Change in temperature leads to change in resistance of PRT and is recorded by the data logger in half bridge configuration. Composition of air effects the dielectric constant of the capacitor, changing the frequency generated in the oscillator circuit. Frequency and pulse width of the oscillator is related to the relative humidity prevailing at the point of measurement. Humidity is recorded using single ended voltage measurement with excitation instruction in the data logger. Temperature measurements are in the range of -40°C to 60°C, outputting 0.008 to 1.0 V with maximum accuracy of ±0.2°C at 20°C. Humidity accuracy at 20°C is ±2% and response time with membrane filter is about 15 s.

Aspirated psychrometer

The aspirated psychrometer consists of two sensors, wet temperature sensor covered with a wick, wetted by distilled water and dry temperature sensor. These temperature sensors are thermistors having negative temperature coefficient. They are basically temperature sensors having a characteristic of resistance change with change in temperature. Air at the velocity of >4.0 m s^{-1} is drawn using a DC fan mounted in line with the temperature sensors in a radiation covered PVC tubing and powered by car battery. Pre-calibrated thermistors are mounted into the PVC tubing and their calibration constants are incorporated in fifth order polynomial functions of data logger program in getting the measured temperatures in °C. Using the station atmospheric pressure, relative humidity is calculated.

Soil temperatures

Soil temperatures at the depth of 5 cm, 10 cm, and 20 cm are monitored using copper-constantan thermocouple wire sensors of 24 gauge mounted on a wooden peg. When two wires composed of dissimilar metals (thermocouple) are joined at both ends and one of the ends is heated, there is a continuous current, which flows in the thermoelectric circuit—Thomas Seebeck effect. The net open circuit voltage (Seebeck voltage) is a function of the junction temperature and the composition of the two metals and is recorded by the data logger. All dissimilar metals exhibit this effect, laws assume wires are homogeneous, that is, free of defects and impurities. The most common combinations of two metals are: copper-constantan (T-type), iron-constantan (J-Type), chromel-constantan (E-Type), and chromel-alumel (K-Type) having average sensitivity of 40.5, 52.6, 67.9, and 38.8 mv/°C respectively. In agrometeorological data collection, T-type thermocouple is preferred for its easy assembly and operable temperature range (-200°C to 350°C).

Sample outputs of the automatic weather station (AWS)

Kothapalli AWS, 1999 - Rainfall hourly events.

Julian day	Date & month	Time (h)	Rainfall (mm)	Total rainfall (mm)
161	10 6	1800	0.254	0.254
164	13 6	2300	0.254	0.508
166	15 6	1100	0.254	0.762
166	15 6	2100	1.270	2.032

Kothapalli AWS, 1999 - Hourly data.

Date & month	Time	Year	SR (Wm^{-2})	AvgAT (ºC)	AvgRH (%)	WV ($m\ s^{-1}$)	WD (deg)	ST5 (ºC)	ST10 (ºC)	ST20 (ºC)	RF (mm)
28 7	600	1999	0	22.0	89.6	5.2	230	22.9	23.6	25.9	0
28 7	700	1999	27.7	22.2	89.2	5.6	219	22.8	23.5	25.8	0
28 7	800	1999	109.6	22.4	89.1	5.8	226	23.1	23.5	25.8	0
28 7	900	1999	177.9	22.9	87.6	5.8	226	23.5	23.8	25.7	0

Note: SR = solar radiation; AvgAT = average atmospheric temperature; AvgRH = average relative humidity; WV = wind velocity; WD = wind direction; ST = soil temperature at depths of 5 cm (ST5), 10 cm (ST10), and 20 cm (ST20); and RF = rainfall.

Kothapalli AWS, 1999 - Daily data (for the past 24 hours) as per IMD (India Meteorological Department) standard.

Date& Month	Year	SR (MJ m^{-2})	MaxAT (ºC)	MinAT (ºC)	MaxRH (%)	MinRH (%)	WV (ms^{-1})	WD (deg)	ST5 (ºC)	ST10 (ºC)	ST20 (ºC)	TRF (mm)
11 6	1999	14.9	32.34	23.52	84.7	47.7	4.5	233	31.5	32.3	33.8	0.254
12 6	1999	17.3	31.69	23.45	82.2	48.2	4.1	216	31.8	32.1	32.9	0
13 6	1999	15.5	30.85	23.20	86.0	51.4	3.9	211	31.9	32.3	33.1	0.254
14 6	1999	17.9	31.67	23.21	85.1	46.5	4.0	240	32.2	32.5	33.0	0

Note: SR = solar radiation; AT = atmospheric temperature; RH = relative humidity; WV = wind velocity; WD = wind direction; ST = soil temperature at depths of 5 cm (ST5), 10 cm (ST10), and 20 cm (ST20); and TRF = total rainfall.

Runoff and Soil Loss Measurement

P Pathak

Various methods are available for measuring runoff and soil loss depending upon the specific needs of the location. Each method has its own characteristics that favor its adoption under certain conditions of measurements and limit its use under other sets of conditions. Any method selected should measure runoff and soil loss accurately for low, medium, and high rates of discharge. This section provides information on some commonly used runoff and soil loss measuring devices, their constructional details, installation, and limitations.

Runoff Measurement

Precalibrated devices for measuring runoff are most commonly used at research stations because of their high accuracy. The two most commonly used devices are H-type flumes and weirs.

H-type flumes

Presently, three types of flumes—HS, H, and HL—are available for small-, medium-, and high-discharge rates, respectively. They have different specifications to suit various ranges of water flow. The shape of flume provides the following distinct advantages that favor its use under a variety of flow conditions (USDA 1979):

1 The increase of throat opening with the rise of stage facilitates accurate measurement of both low and high flow of water.

2 The converging section of flume makes it self-cleaning because of increased velocity. Consequently, the flume is suitable for measuring flows having sediment in suspension and low bed-loads.

3 It is simple to construct, rigid and stable in operation, and requires minimal maintenance for retaining its rating.

4 Its installation is simple and is generally not affected by the steepness of the channel gradient.

Flumes are basically designed for free-flow conditions and are therefore not recommended for submerged-flow conditions. Free-flow occurs when flow downstream of the measuring structure does not affect flow conditions within and in the upstream sections of the structure, i.e., there is sufficient fall near the outlet of the structure. On the other hand, submerged flow occurs when downstream flow strongly influences that within and at the upstream section of the measuring structure. Flumes are also not recommended for flows carrying excessive amounts of coarse bed-loads.

HS-flume

HS-flumes are designed to measure small flow rates ranging from 0.0014 to 0.0227 $m^3 s^{-1}$ (0.05 to 0.8 $ft^3 s^{-1}$) with a high accuracy. Details of dimensions, capacities, and construction tolerances of the flume are shown in Figure 1. Construction details are as given for H-flumes below.

H-flumes

H-flumes are used where the maximum runoff ranges from 0.009 to 0.85 $m^3 s^{-1}$ (0.3 to 30 $ft^3 s^{-1}$). The dimensions and flow capacities are shown in Figure 2. Table 1 gives the ratings for H-flumes of various sizes.

Construction specifications are as follows (USDA 1979; Pathak et al. 1981):

1 Prepare drawings, using the proportional dimensions shown in Figure 2. (For HS-flumes use Figure 1.)

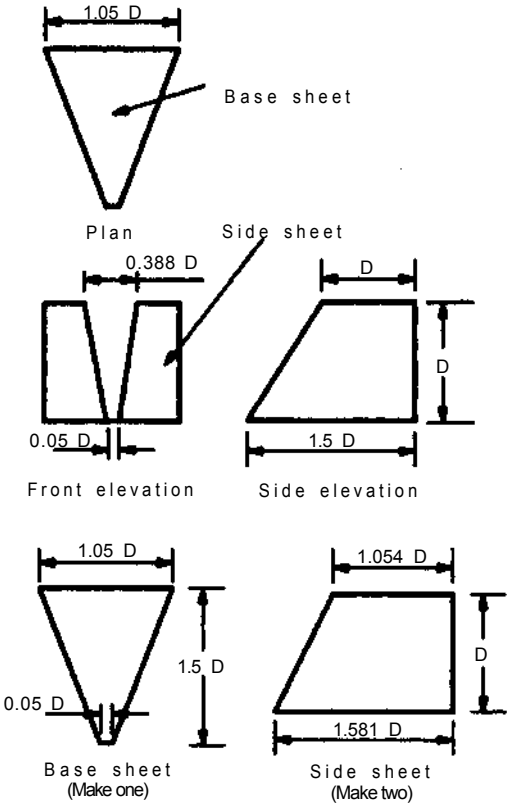
2 If possible use only good-quality materials in constructing the flumes.

3 Use mild steel sheets (3.25 mm or 1/8 inch thick) without any distortion. Make all joints watertight and strong.

4 Make the vertical sides of the flume from one sheet. The bottom plate must not contain more than one joint and no portion of this joint should lie near the outlet opening. Any necessary joint in the bottom plate must be transverse to the longitudinal axis of the flume and must be made in such a way that the joint is substantially flush. Make all dimensions for which tolerances are not indicated on the drawings within 0.65 cm or 1/4 inch of those given on the drawings.

5 Cut all plate edges straight and sharp. Do not warp the plates or distort them by cutting.

6 Clamp the plates rigidly in position and get the proper dimensions and slopes before making the final connections. Make the side plates perpendicular to the bottom of the flume. All cross-sections of the flume must be symmetrical about the longitudinal axis. No projections should occur on the inside of the flume.



Proportions of the type HS-flume

Approximate capacities	
Depth-D (ft)	Capacity (ft^3s^{-1})
0.4	0.085
0.6	0.230
0.8	0.470
1.0	0.820

Figure 1. Dimensions, capacities, and construction tolerances of the HS-flume.

Installation of HS- and H-flumes

When flumes are installed, the approach boxes should, whenever possible, be depressed below the natural ground surface (see Figure 3). Where the watershed or plot slope is small and the flow dispersed, gutters may be provided to collect the runoff at the bottom of the slope and channel it into the approach box.

Metal flumes should be fixed to the concrete approach (Figs. 4 and 5). The concrete cut-off wall should extend below the concrete approach at the upstream face of the flume to provide substantial support and to prevent seepage below the flume. The flume floor must be level. If silting is a problem, a 1 in 8 sloping false floor can be set to concentrate low flows and thereby reduce silting. The difference in calibration for a flume with a flat floor and that with a sloping false floor is less than 1%.

Table 1. Rating tables for H-flume: discharge in ft^3 s^{-1} (U5DA 1979).

0.5-ft flume

Head (ft)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	0	Trace	0.0004	0.0009	0.0016	0.0024	0.0035	0.0047	0.0063	0.0080
0.1	0.0101	0.0122	0.0146	0.0173	0.0202	0.0233	0.0267	0.0304	0.0343	0.0385
0.2	0.0431	0.0479	0.0530	0.0585	0.0643	0.0704	0.0767	0.0834	0.0905	0.0979
0.3	0.1057	0.1139	0.1224	0.1314	0.1407	0.1505	0.1607	0.1713	0.1823	0.1938
0.4	0.205	0.217	0.230	0.244	0.257	0.271	0.285	0.300	0.315	0.331

1.0-ft flume

Head (ft)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	0	Trace	0.0007	0.0017	0.0027	0.0040	0.0056	0.0075	0.0097	0.0122
0.1	0.0150	0.0179	0.0211	0.0246	0.0284	0.0324	0.0367	0.0413	0.0462	0.0515
0.2	0.0571	0.0630	0.0692	0.0758	0.0827	0.0900	0.0976	0.1055	0.1138	0.1226
0.3	0.132	0.141	0.151	0.161	0.172	0.183	0.194	0.206	0.218	0.231
0.4	0.244	0.257	0.271	0.285	0.300	0.315	0.331	0.347	0.364	0.381
0.5	0.398	0.416	0.434	0.453	0.472	0.492	0.512	0.533	0.554	0.576
0.6	0.598	0.621	0.644	0.668	0.692	0.717	0.743	0.769	0.796	0.823
0.7	0.851	0.880	0.909	0.939	0.969	1.000	1.031	1.063	1.096	1.129
0.8	1.16	1.20	1.23	1.27	1.30	1.34	1.38	1.41	1.45	1.49
0.9	1.53	1:57	1.61	1.66	1.70	1.74	1.78	1.83	1.87	1.92

1.5-ft flume

Head (ft)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0	Trace	0.0011	0.0023	0.0039	0.0057	0.0078	0.0103	0.0131	0.0164
0.1	0.0200	0.0237	0.0276	0.0319	0.0365	0.0414	0.0467	0.0523	0.0582	0.0645
0.2	0.0711	0.0780	0.0854	0.0931	0.1011	0.1095	0.1183	0.1275	0.1371	0.1470
0.3	0.157	0.168	0.179	0.191	0.203	0.215	0.228	0.241	0.255	0.269
0.4	0.283	0.298	0.314	0.330	0.346	0.363	0.380	0.398	0.416	0.435
0.5	0.454	0.473	0.493	0.514	0.535	0.557	0.579	0.601	0.624	0.648
0.6	0.672	0.697	0.722	0.747	0.773	0.800	0.827	0.855	0.883	0.912
0.7	0.942	0.972	1.002	1.033	1.065	1.097	1.130	1.163	1.197	1.231
0.8	1.27	1.30	1.34	1.38	1.41	1.45	1.49	1.53	1.57	1.61
0.9	1.65	1.69	1.73	1.78	1.82	1.86	1.91	1.95	2.00	2.05
1.0	2.09	2.14	2.19	2.24	2.30	2.35	2.40	2.45	2.50	2.56
1.1	2.61	2.67	2.73	2.78	2.84	2.90	2.96	3.02	3.08	3.14
1.2	3.20	3.27	3.33	3.39	3.46	3.52	3.59	3.66	3.73	3.80
1.3	3.87	3.94	4.01	4.08	4.15	4.22	4.30	4.37	4.45	4.52
1.4	4.60	4.08	4.76	4.84	4.92	5.00	5.08	5.16	5.24	5.33

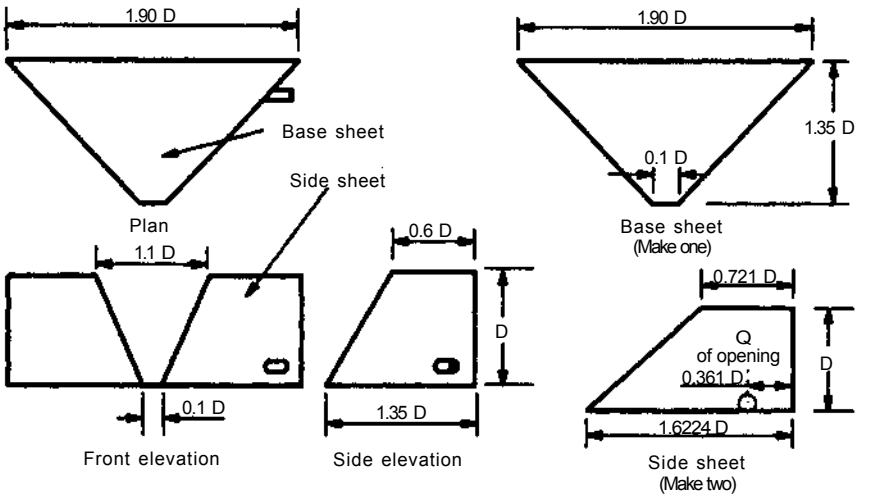
2.0-ft flume

Head (ft)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	0	Trace	0.0014	0.0031	0.0050	0.0073	0.0100	0.0130	0.0166	0.0205
0.1	0.0248	0.0293	0.0341	0.0392	0.0447	0.0505	0.0567	0.0632	0.0701	0.0774
0.2	0.0850	0.0930	0.1015	0.1103	0.1195	0.1290	0.1390	0.1494	0.1602	0.1714
0.3	0.183	0.195	0.207	0.220	0.234	0.248	0.262	0.276	0.291	0.307
0.4	0.323	0.339	0.356	0.374	0.392	0.410	0.429	0.448	0.468	0.488
0.5	0.509	0.530	0.552	0.574	0.597	0.620	0.644	0.668	0.693	0.719
0.6	0.745	0.771	0.798	0.826	0.854	0.882	0.911	0.941	0.971	1.002

Continued

Table 7. continued

0.7	1.03	1.07	1.10	1.13	1.16	1.20	1.23	1.27	1.30	1.34
0.8	1.38	1.42	1.46	1.49	1.53	1.57	1.62	1.66	1.70	1.74
0.9	1.78	1.83	1.87	1.92	1.96	2.01	2.06	2.10	2.15	2.20
1.0	2.25	2.30	2.35	2.40	2.45	2.51	2.56	2.62	2.67	2.73
1.1	2.78	2.84	2.90	2.96	3.02	3.08	3.14	3.20	3.26	3.32
1.2	3.38	3.45	3.51	3.58	3.65	3.71	3.78	3.85	3.92	3.99
1.3	4.06	4.13	4.20	4.28	4.35	4.43	4.50	4.58	4.66	4.74
1.4	4.82	4.90	4.98	5.06	5.14	5.23	5.31	5.40	5.48	5.57
1.5	5.65	5.74	5.83	5.92	6.01	6.11	6.20	6.29	6.38	6.48
1.6	6.58	6.67	6.77	6.87	6.97	7.07	7.17	7.27	7.37	7.47
1.7	7.58	7.68	7.79	7.90	8.00	8.11	8.22	8.33	8.44	8.56
1.8	8.67	8.78	8.90	9.01	9.13	9.24	9.36	9.48	9.60	9.72
1.9	9.85	9.97	10.09	10.21	10.34	10.47	10.60	10.72	10.85	10.98



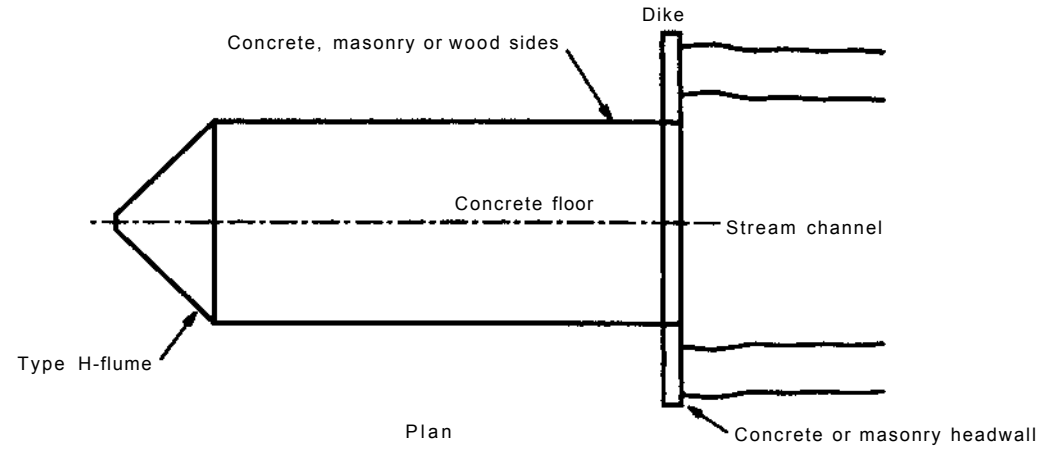
Proportions of the type H-flume

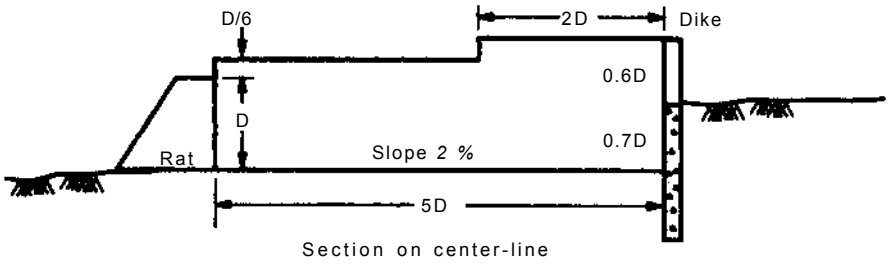
Approximate capacities	
Depth - D (ft)	Capacity ($ft^3 s^{-1}$)
0.50	0.3
0.75	1-
1.00	2
1.50	5+
2.00	11
2.50	19
3.00	30+

Flume Depth - D (ft)	Outlet opening dimension Tolerances		
	Bottom width (in)	Top width (in)	Depth (in)
0.50	0.02	0.1	0.05
0.75	0.02	0.1	0.05
1.00	0.02	0.1	0.05
1.50	0.03	0.1	0.05
2.00	0.03	0.1	0.05
2.50	0.03	0.1	0.05
3.00	0.03	0.1	0.05
4.00	0.05	0.1	0.10

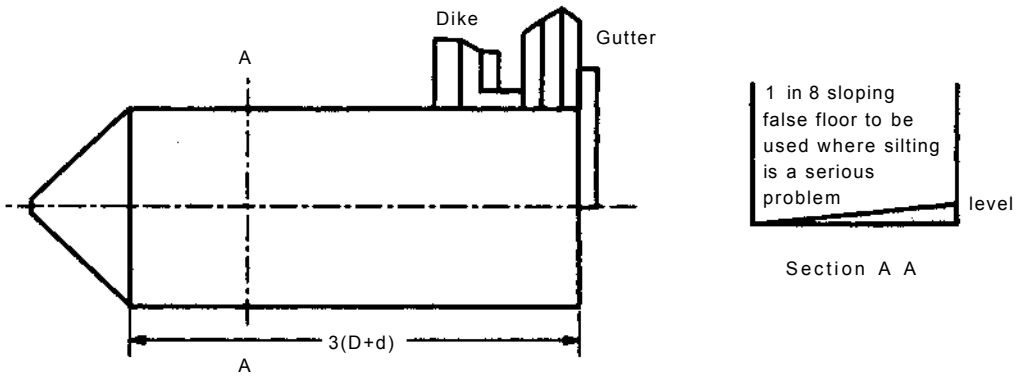
Note: For flumes lss than 1 ft deep, the length of flume is made greater than 1.35 D so that the float may be attached.

Figure 2. Dimensions, capacities, and construction tolerances of the H-flume.





Straight headwall installation
(for use when flume is to be installed in a well-defined natural channel)



Drop box installation
(for use when the runoff must be concentrated by gutters or dikes)

Figure 3. Plans showing straight headwall and drop-box installations of HS- or H-flumes (*USDA 1979*).

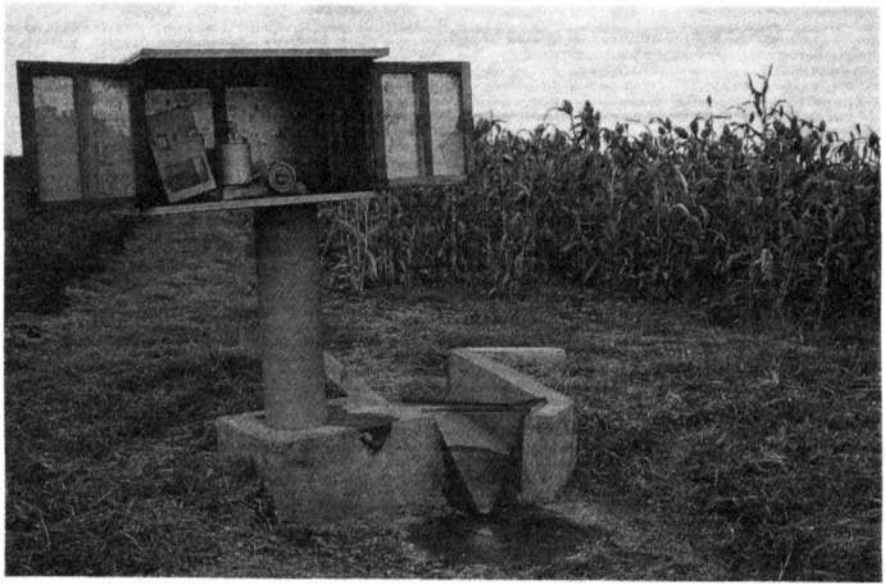


Figure 4. H-flume attached to a stilling well and connected to a drum-type recorder for measuring runoff.

Figure 5. A V-notch attached to a stilling well and connected to a drum-type recorder for measuring runoff.

Submergence effect on H-flumes

Flumes should be installed with free outfall or no submergence wherever possible. If submergence occurs, the free discharge head (H) can be computed by using the following equation, presented in non-metric units to be consistent with those given in USDA (1979):

$$H = d_1/\{1 + 0.00175[\exp (d_2/d_1)^{5.44}]\}$$

where H is the free flow head (in ft), d_1 is the actual head with submergence (in ft), d_2 is the tail water depth (in ft) above flume zero head, and $0.15 < d_2/d_1 < 0.90$.

Weirs

Weirs are the simplest and reliable structures that can be used in many situations to measure runoff. They can be used most effectively where there is a fall of about 18 cm (or 0.6 ft) or more in the waterway, and also where submergence on the upstream section is not undesirable. They are generally classified on the basis of width of the crest and shape of the weir opening. In this section, we describe one of the most commonly used weirs.

Sharp-crested triangular weir or V-notch weirs

V-notch weirs are often used for measuring runoff from small plots (Fig. 5). They have been accurately rated in the laboratory regarding crest characteristics, their placement in the channel or waterway, the approach waterway, flow conditions, and the relation expressed in the form of discharge formulae. Generally, a weir crest consists of a metal blade with a sharp edge. The distinct advantage of the triangular weir is its suitability for measuring high as well as low flows with a high degree of accuracy. The most commonly used triangular weirs have 90° and 120° V-notches.

Details of a 37.5-cm (or 1.25 ft) 90° V-notch are shown in Figure 6, and Table 2 gives the related ratings. The weir blades are normally constructed of angle iron 89 x 89 x 13 mm, or non-corrodible metal plate 6 mm (0.25 in) thick. The installation and construction of the approach channel should strictly follow the instructions given below.

Setting V-notch weirs

The following conditions are necessary for accurate measurement of flow with sharp-crested V-notch weirs (USDA 1979; Pathak et al. 1981):

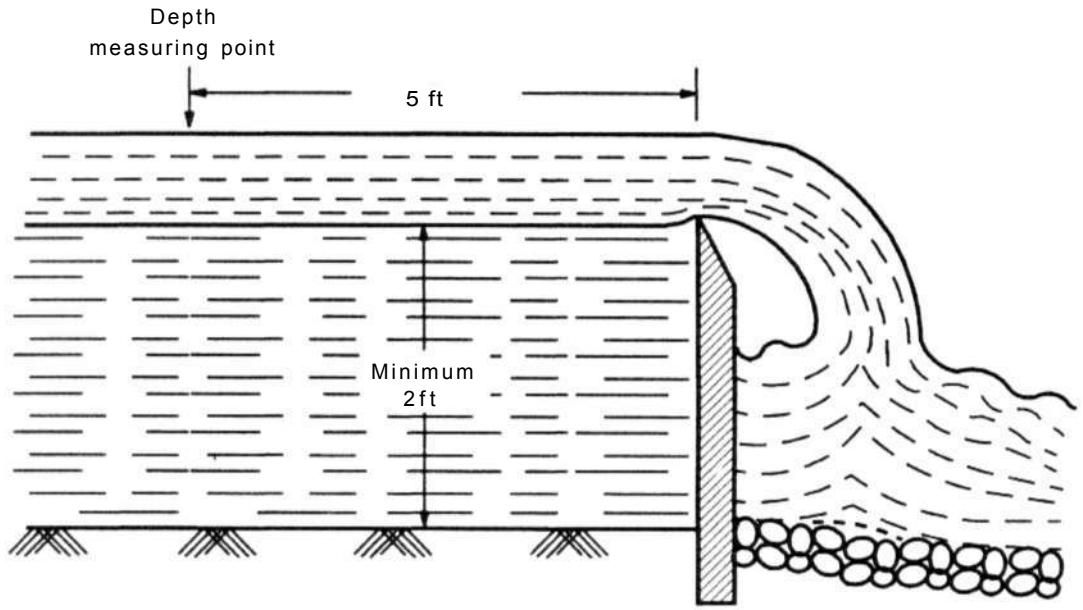
1 The thickness of the weir blade should not be more than 6 mm.

2 The upstream corners of the notch must be sharp. They should be machined or filed perpendicular to the upstream face, free of scratches and not smoothed off with abrasive cloth or paper. Knife edges should be avoided because they are difficult to maintain.

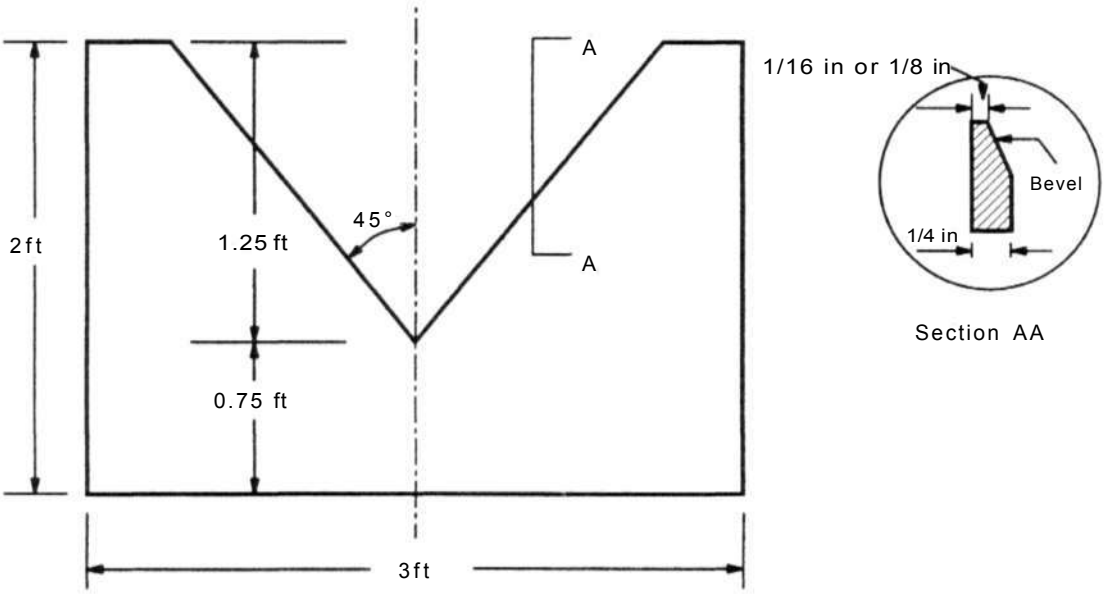
3 The downstream edges of the notch should be relieved by chamfering if the plate is thicker than the prescribed crest width (1-2 mm). The chamfer should be at an angle of 45° or more to the surface of the crest.

Table 2. Rating table for a 90° sharp-crested V-notch: discharge in ft^3 s^{-1} (USDA 1979).

Head (ft)	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	0	0.0005	0.001	0.0015	0.002	0.003	0.004	0.005	0.006	0.007
0.1	0.008	0.010	0.012	0.015	0.018	0.022	0.026	0.030	0.035	0.040
0.2	0.046	0.052	0.058	0.065	0.072	0.080	0.088	0.096	0.106	0.115
0.3	0.125	0.136	0.147	0.159	0.171	0.184	0.197	0.211	0.226	0.240
0.4	0.256	0.272	0.289	0.306	0.324	0.343	0.362	0.383	0.403	0.424
0.5	0.445	0.468	0.491	0.515	0.539	0.564	0.590	0.617	0.644	0.672
0.6	0.700	0.730	0.760	0.790	0.822	0.854	0.887	0.921	0.955	0.991
0.7	1.03	1.06	1.10	1.14	1.18	1.22	1.26	1.30	1.34	1.39
0.8	1.43	1.48	1.52	1.57	1.61	1.66	1.71	1.76	1.81	1.86
0.9	1.92	1.97	2.02	2.08	2.13	2.19	2.25	2.31	2.37	2.43
1.0	2.49	2.55	2.61	2.68	2.74	2.81	2.87	2.94	3.01	3.08
1.1	3.15	3.22	3.30	3.37	3.44	3.52	3.59	3.67	3.75	3.83
1.2	3.91	3.99	4.07	4.16	4.24	4.33				



Some installation conditions for 1.25-ft 90 ° V-notch weir



Metal plate dimensions

Figure 6. Detail plan and dimensions for a 1.25-ft 90° V-notch weir (USDA 1979).

4 The distance of the lowest crest point from the bottom of the approach channel (weir pool) should preferably not be less than twice the depth of water above the lowest crest point, and in no case less than 30 cm.

5 The distance from the sides of the weir to the sides of the approach channel should preferably be no less than twice the depth of water above the lowest crest point, and never less than 30 cm.

6 The overflow sheet (nappe) should touch only the upsstream edges of the crest.

7 Measurement of the head on the weir should be taken as the difference in elevation between the lowest crest point and water surface at a point upstream from the weir at a distance that is four times the maximum head on the crest.

8 The cross-sectional area of the approach channel should be at least 8 times that of the overflow sheet at the crest for a distance that is 15 times the depth of the flow and, if it is less, then the head should be corrected by using an appropriate method.

Water-level Recorders and their Installation

Accurate determination of runoff volume, peak runoff rate, and other related information from small and medium areas invariably requires the continuous recording of the water level. Stage-level recorders are commonly used for this purpose. A stage-level recorder produces a graphic record of the stage of flow over a control with respect to time, and it is accepted as very reliable.

Many types of stage-level recorders are commercially available. They can be broadly classified into two types: mechanical type stage-level recorder and digital automatic stage-level recorder.

Mechanical stage-level recorder (5-FW-1)

The mechanical stage-level recorder mechanically converts the vertical movement of a counter-weighted float resting on the surface of a liquid into a curvilinear, inked record of the height of the surface of the liquid relative to a datum plane with respect to time. The time element consists of a weekly winding spring-driven clock supported on a vertical shaft to which the chart drum is firmly secured vertically (Fig. 7). The gauge element consists of a float and counterweight-graduated float

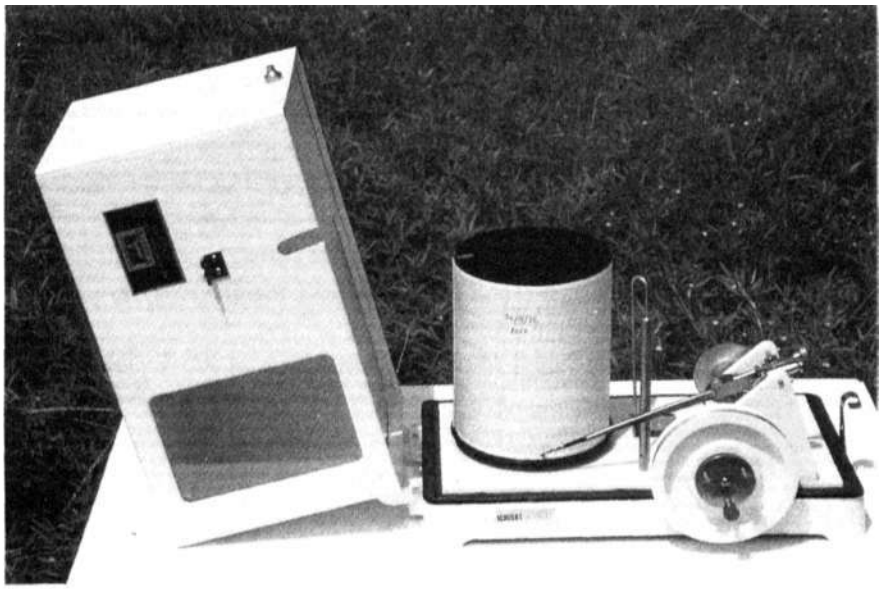


Figure 7. A drum-type recorder for the continuous recording of runoff.

pulley. The movement of the float is transmitted to a cam and, with the help of a set of gears, it moves the pen on the chart in a vertical direction. Some recorders have a reversing mechanism and can therefore record an unlimited range of flow depth. Detailed information about operation and maintenance is given in an instruction book that is normally supplied with the equipment.

Digital automatic stage-level recorder (Thalimedes)

Thalimedes is a float operated shaft encoder with digital data logger which can be used to continuously monitor the runoff from the watershed/field (Fig. 8). It is easy to handle and its cost-effective ratio makes it an appropriate device for modernization of existing mechanical chart-operated stage-level recorder monitoring stations.

The in situ data logging of the measured value results in the reduction of the expenditure of both cost and time as well as in elimination of errors that are brought in when data is readout or transferred manually. It eliminates all the problems associated with the mechanical chart type such as the problems associated with the movement of chart, and drying/clogging/blotting of pen in the chart paper. The continuous recording of water levels ensures an uninterrupted measurement in changes of water level over a long period which in turn yields a reliable database for competent decisions.

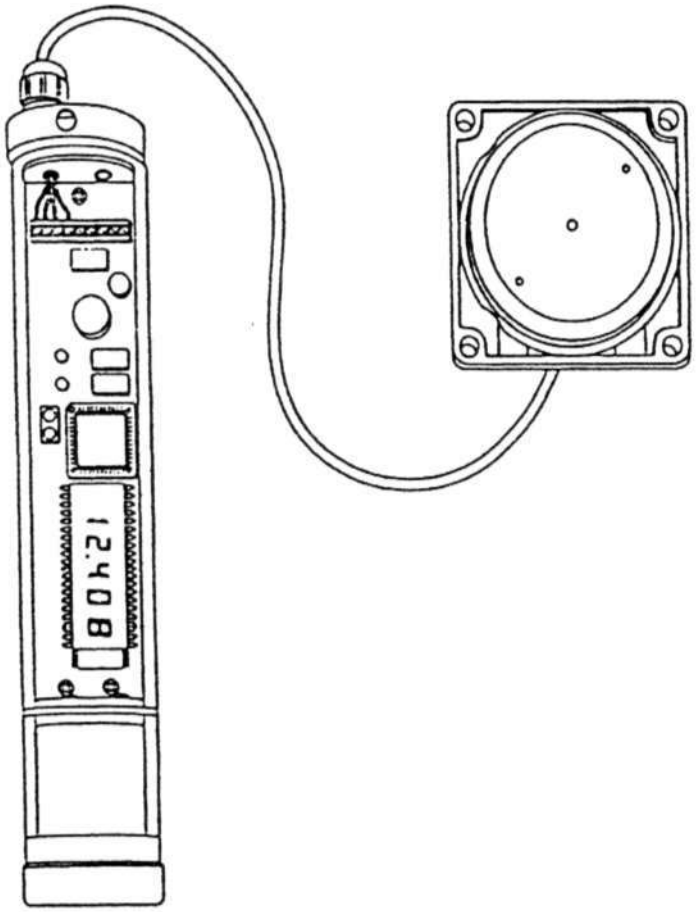


Figure 8. Data logger Thalimedes with shaft encoder.

Thalimedes utilizes state-of-the-art technology in communication with RS-232 and SDI 12 interface for connecting it with various data transmission options such as serial modem, radio, satellite, and dedicated line. The real time data recording is also possible.

It is clear and easy to read LCD (Liquid Crystal Display) which indicates the date, time, and battery status and the measured value (water level) facilitates the level monitoring function even in direct sunlight. The display is activated for water level monitoring through an integrated motion sensor. In Thalimedes, there are no switches because it has been observed that the mechanical switches start giving trouble after some years.

Thalimedes also incorporates contact free IrDA (infrared) interface which transfers the data without any (RS-232) communication cable. The IrDA interface (in RS-232 mode) has been utilized as a standard for communicating from device to a computer. The IrDA interface makes Thalimedes insensitive to humidity and dust, and it offers the possibility of high transfer rate (in just few seconds).

Thalimedes has a ring memory which enables the data storage up to 30000 measured values so that logging interval can be preset from 1 minute to 24 hours. In this memory, for example, we can store 205 days (6.8 months) data at the interval of every 10 minutes or 123 days (4 months) data at the interval of every 6 minutes. Thalimedes operates with 1.5 V power supply (one C-cell alkaline type) for battery system operation of up to 15 months at hourly measuring and storage interval. It is quite easy to change the battery. While changing the battery, the stored data (memory) is not affected.

The data in the Thalimedes can be communicated to the note book PC, Palmtop, and Vota. The measured values are stored as ASCII files and it can be utilized for graphical or tabular evaluation with Excel, Lotus, Quattro-pro, Hydras II (OTT's software for hydrometry evaluation).

The measurement principle using shaft encoder

Changes in the water level are transferred via a float cable and counterweight system to the float pulley on the shaft encoder unit. The rotation caused by this action is converted into an electronic signal which is transferred by the transducer cable to the data logger and then saved as a measured value.

The attachment kit is included facilitating easy installation of Thalimedes either as a stand alone unit or in combination with any other stage-level recorder. A well pipe assembly kit (optional accessory) permits installation of Thalimedes in pipe of 10-15 cm in diameter.

Salient features of digital automatic stage-level recorder (Thalimedes) compared to mechanical stage-level recorder

- Thalimedes is a microprocessor-based electronic data logger. Being float operated, the shaft encoder is an ideal stage-level recorder.

  Digitial LCD of measured water level (mm, m, or ft), date, time, and battery status (not possible with mechanical models).
- Thalimedes operates on a single 1.5 V DC C type battery which (lasts up to 15 months at hourly measurement) (not possible with mechanical models).
- Ring memory: EEProm stores upto thirty thousand (30000) measured values.
- Sampling and logging intervals can be set from 1 minute to 24 hours (flexibility not possible with mechanical models).
- Data transfer through non-contact IrDA interface (infrared technology) avoiding connectors and cable; 11000 measured values in 4 seconds for further processing.
- No moving parts; problem due to gear/clock and chart mechanism is avoided.
- No switches/connectors; so there are no contact problems.

- Compact, rugged, and light (only 0.32 kg); shaft encoder 0.14 kg.
- Digital automatic stage-level recorder (Thalimedes) with the above and many more unmatched features and facilities is superior to mechanical stage-level recorders.

Technical information

Data logger with an integrated RS-232 interface for direct connection of the Thalimedes to various data transmission systems such as:

- Serial modem
- GSM modem
- Satellite modem

IrDA interface (infrared technology) for cable free data transfer:

- PC standard
- Personal computers

SDI 12 interface:

- LCD
- Single-line

Ring memory (EEPOM):
Storage capacity of data over approximately 9 months at a storage interval of 1 hour. The sample and storage intervals can be set from 1 min ... 24 h.

Shaft encoder:
Sensor system with mounting bore holes and deflection pulley for float cable.

Resolution: 1 mm (cm, inch, foot, etc.) scalable

Measuring range: 0 ... 19.999 m (mm)
0... 199.99m (cm)

Float pulley:
For float cable with a diameter of 1 mm (default) other cable diameters can be scaled.

Battery:
1.5 V power supply (1 x 1.5 V C-type cell) for a system operation up to 15 months at hourly measuring/ storage interval.

Other technical information

Measurement range switch	± 19.999 m	± 199.99 m	± 199.99 ft
Resolution	0.001 m	0.01 m	0.01 ft
Maximum measuring error	± 0.002 m	± 0.002 m	± 0.0066 ft
Temperature range	-20 to +70°C		
Encoder unit float pulley circumference	200 mm		
Temperature range	-20 to + 70°C		
Transducer cable length	1 m		

Installation of stage-level recorders

The gauging site equipped with a stage-level recorder has three essential components: a stilling well, intakes, and recorder shelter (see Figures 4 and 5) (Pathak et al. 1981; USDA 1979).

Stilling well

The well over which the stage-level recorder is installed is essentially a stilling weli. Inside it the float and counterweight of the recorder rise and fall in response to fluctuations in the water level without being affected by surges or waves that might result in inaccurate measurements. Regardless of the method used, the well should be located to one side of the waterway (so that it does not interfere with the flow pattern over the spillway) and, if possible, near the measuring flow section of the precalibrated structure. The size of the well will depend upon the required stability, depth, type of material, and space required by the float and the counterweight.

Constructional details of a brick masonry well are shown in Figure 9. Instead of brick masonry, galvanized iron and concrete pipes can also be used in constructing the well (Pathak et al. 1981). They should be built on solid foundations with waterproof bases. In swelling clay soils, e.g., Vertisols, larger foundations are needed. The following should be taken into consideration when stilling wells are constructed:

1 The bottom of the well should be at least 20 cm lower than the lowest intake.

2 The portion of the stilling well underneath the lowest intake must be watertight.

3 The inside diameter of the well should not be less than the sum of the diameter of recorder pulley, half the diameter of the float, half the diameter of the counterweight, and 7.0 cm.

4 The inside surface of the well should be smoothened, either by plastering or by lining with a thin metal sheet.

5 The depth of the well should be about 20 cm more than double of the maximum expected head. This provides a full range of scale and avoids the danger of submerging the counterweight of the float.

6 The size of the well should not be too large because, if it is large, there may be a lag between the rise or fall of water level in the well.

Intakes

The connection between the stilling well and the precalibrated structure is accomplished by means of intake pipes. These intakes can be one or more galvanized pipes or several 2.5-cm diameter holes. A general guide to the size and number of intakes required is that their total cross-sectional area should be at least 1% of the cross-sectional area of the stilling well. In general, more than one intake should be provided at different elevations. This gives two distinct advantages. First, it safeguards against clogging of the intake by sediment and other materials, and secondly, it facilitates better connection with the water as it rises or falls.

Data analysis

Mechanical type stage-level recorder

The regular keeping of notes on instrument operation is vital to data tabulation, especially when appreciable lag occurs between obtaining the record and tabulating data. Notes on prevailing conditions are vital to data analysis and interpretation (USDA 1979).

Notes made on charts should include watershed-plot number, chart number, removal time, corrections on time, stage, notch base-level, and lowest intake level (see example in Figure 10). Charts

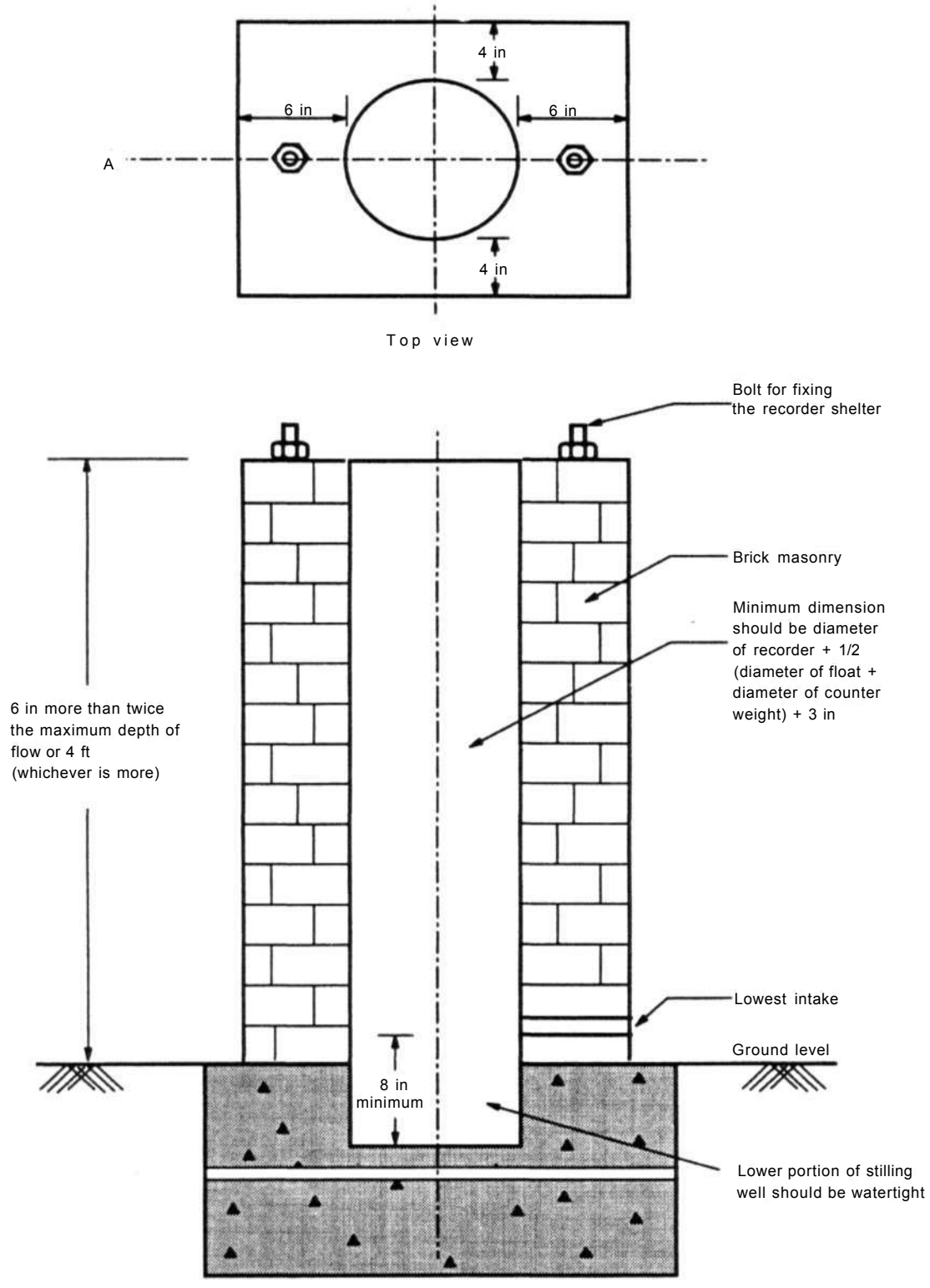
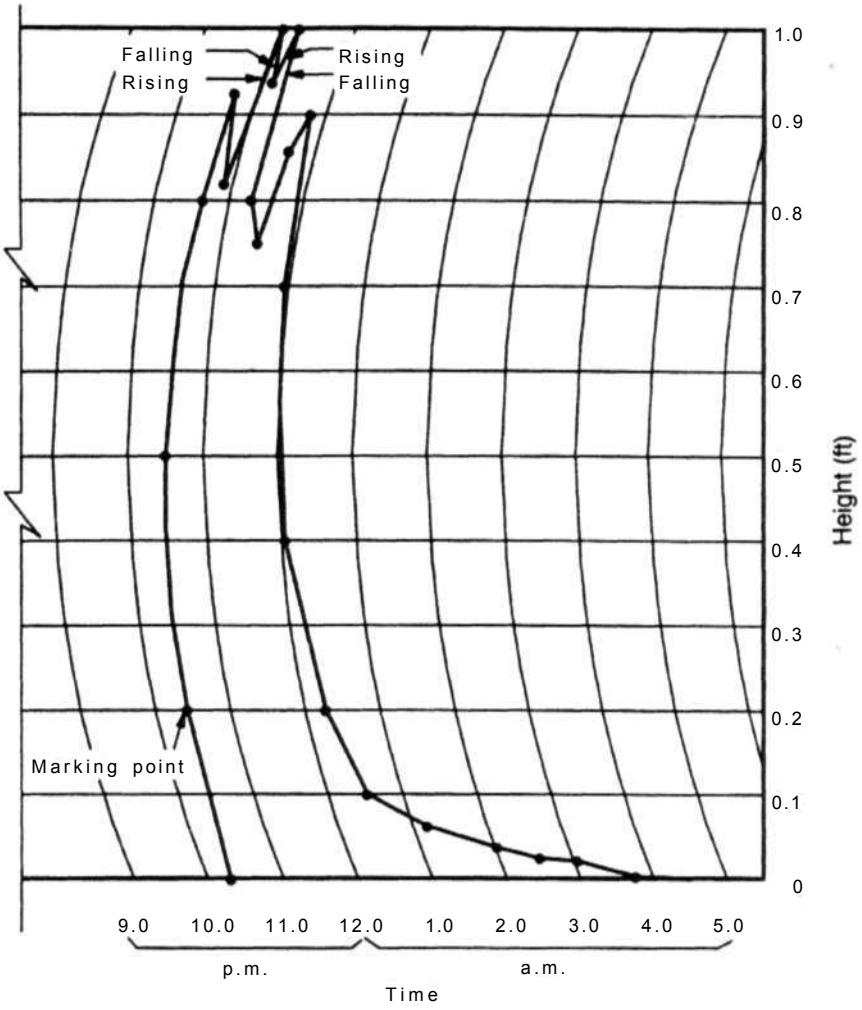


Figure 9. Details of stilling well (Pathak et al. 1981).



Station BW 1 Watershed (2-ft Parshal Flume).....

Beginning Date.....Time.....Staff gauge reading

Ending Date .24.8.79.....Time.....Staff gauge reading

Stage Height Ratio 5" of Chart =.....Water

Chart Changed By T. Somaiah.....Remarks.....

Figure 10. Example of a runoff hydro graph (BW1 Watershed, ICRISAT, Patancheru, 24/08/79).

should be numbered and dated to show that the record is continuous, although no runoff may have occurred during the period covered by some charts (Laryea et al. 1997).

For charts covering such no-runoff periods, record only the chart number and dates. No other notes are required because the charts' main purpose is to show continuity of records.

For charts covering periods during which runoff occurred, use a light pencil for writing all notes, and proceed as follows:

1 Write chart number and dates in the space provided.
2 Enter date, time of placement, and removal.
3 Note the level of spillway crest and lowest intake.

4 Check monthly to see how placement and removal marks agree with the watch time. If they do not agree within 10 min, apply a time correction. To determine this correction, assume a straight-line variation between placement or inspection and removal. For example, if at the time of removal of the chart the following observations were taken:

   a the time difference between the watch and the recorder time is 40 min or less;

   b the total period for which chart was kept on recorder is 30 h; or

   c the total period of runoff is 6 h;

   then the correction to be applied to the runoff period will be 40 x 6 / 30 = 8 min. Eight minutes should therefore be added to the original 6 h (i.e., total runoff period).

5 Check if there are any discrepancies between the chart line and the index pointer. Check also for failure of the pen to reverse at the edges of the printed portion of the chart. If the pen reverses below the limits of the printed chart at about the same extent at both the upper and lower reversals, apply a constant correction to each traverse. This correction for the traverse upward across the chart is positive, whereas that for the downward traverse is negative. Where the lower reversal is correct but the upper reversal falls short, a graduated correction is required. Since tabulations are to be made only to the nearest 0.3 cm, a graduated correction would not be feasible; thus a constant correction should be applied for a given range in stage. If the upper reversal falls short by 0.3 cm, the correction should be applied only to the upper half of the chart. If the upper reversal is 0.6 cm short, a correction of 0.01 should be applied from 0.25 to 0.75, and 0.02 applied from 0.75 to 1.25 (USDA 1979; Pathak et al. 1981).

Data reduction and processing

The runoff chart obtained from a stage-level recorder gives a continuous record of depth of flow with respect to a reference level, and as a function of time. This stage graph is subsequently processed to obtain the runoff rates and volumes that are later used for analysis. The runoff information used in agricultural hydrologic research experiments normally comprises: (a) number of runoff events; (b) runoff volume; (c) peak ninoff rates; and (d) flow durations and time to peak.

Chart annotation errors and corrections

Special attention should be given to c harts as soon as they are removed from the recorder (USDA 1979; Pathak et al. 1981). Check and note on the analog trace such abnormalities as faulty records due to clock stoppage, malfunction of the pen, debris lodged on the control, or clogging of intakes. By comparison with rainfall and runoff records from nearby stations, adjust the chart to represent the true record as closely as possible.

Marking and tabulation

Marking and tabulation consists of marking all the breaks of the hydrographs where the slope changes. The rate of change of flow between two adjacent marks is assumed to be uniform, and so that segment of the hydrograph is considered to be straight. The number of points will depend upon the fluctuations of stages, which will obviously be more when there have been flash flows. The tendency to take a minimum number of points to reduce labor in computation should not be allowed to impair the accuracy of the data and a uniform time interval is generally not suitable for small watersheds.

Marking and tabulating a chart are illustrated by the example given in Figure 10, based on the following data:

Watershed no.: BW 1

Area: 3.45 ha

Runoff measuring device: H-flume

H-flume size: 60 cm (2 ft)

Stage recorder: FW-1 type (Belfort Company)

Stage ratio used: 5:12

Time scale used: One revolution in 24 h.

The following steps should be taken to mark and tabulate runoff charts:

1 Complete the information on the top of a sheet as shown in Table 3.

2 Complete the chart annotation and record the necessary information.

3 Mark the recorded hydrographs wherever the slope changes as shown in Figure 10 and add some intermediate points. The total number of points made on this chart is 23.

4 Note the times at each of the points in column 1 (see Table 3).

5 Record the corresponding stage of flow in column 3 of Table 3 and repeat until all the points have been tabulated. In an FW-1 type recorder with 5:12 gauge scale ratio, each smallest division on the vertical scale represents 0.6 cm (or 0.02 ft). Therefore, the total number of small vertical divisions is counted and then multiplied by 0.6 cm (or 0.02 ft) to get the actual depth of flow at the various points.

Table 3. Sample computation of runoff from runoff hydrograph.

Time	Time interval (min)	Gauge height (ft)	Discharge from rating table (ft^3s^{-1})	Average discharge for time interval (ft^3s^{-1})	Runoff		
					For time interval (ft^3)	Accum-ulated (ft^3)	Accum-ulated (m^3)
7.52							
7.56	1	0.20	0.09	0.043	10.20	10.20	0.29
8.00	4	0.50	0.51	0.297	71.28	81.48	2.31
8.02	2	0.80	1.38	0.945	113.34	194.82	5.51
8.04	2	0.92	1.87	1.625	195.00	389.82	11.04
8.12	8	0.82	1.46	1.665	799.20	1189.02	33.65
8.18	6	1.00	2.25	1.855	667.80	1856.82	52.55
8.21	3	1.06	2.56	2.405	432.90	2289.72	64.80
8.24	3	1.00	2.25	2.405	432.90	2722.62	77.05
8.28	4	0.80	1.38	1.815	435.60	3158.22	89.3-8
8.38	10	0.75	1.20	1.290	774.00	3932.22	111.28
8.44	6	0.86	1.62	1.410	507.60	4439.82	125.65
8.48	4	0.90	1.78	1.700	408.00	4847.82	137.19
8.54	6	0.70	1.03	1.405	505.80	5353.62	151.51
9.02	8	0.40	0.32	0.677	324.96	5678.58	160.70
9.10	8	0.20	0.085	0.204	97.92	5776.50	163.48
9.20	10	0.10	0.025	0.055	32.94	5809.44	164.41
9.44	24	0.06	0.010	0.017	25.06	5834.50	165.12
10.20	36	0.04	0.005	0.008	16.20	5850.70	165.58
10.40	20	0.02	0.001	0.003	3.84	5854.54	165.68
11.00	20	0.02	0.001	0.001	1.68	5856.22	165.73
11.30	30	0.01	0.001	0.001	1.98	5858.20	165.79
12.00	30	0.00	0.000	0.00035	0.63	5858.83	165.81

Notes: Total runoff duration = 4 h 4 min
Peak runoff rate= 0 .02 $m^3 s^{-1} ha^{-1}$
Total runoff = 4 .81 mm

Computation

The marking and tabulation information is then computed to obtain total runoff volume data, as follows:

1 The time interval in column 2 (Table 3) is obtained by the difference in the successive values of the timings in column 1. For example, the interval between the first and second point is 4 min. Time intervals can be similarly obtained for the other segments.

2 Gauge heights in column 3 are converted into discharge rates in $ft^3\ s^{-1}$ with the help of appropriate rating tables, and recorded in column 4. For this example, the rating table for a 2-ft (or 60 cm) H-flume (Table 1) was used.

3 The average discharge rates in $ft^3\ s^{-1}$ for time intervals obtained by averaging successive discharge rates are recorded in column 5. For example, for the first time interval of 4 min the average discharge is 0 + 0.085 / 2 = 0.0425 $ft^3\ s^{-1}$. Similarly, the average discharge for the other time intervals may be calculated.

4 The runoff volumes in ft^3 for the time intervals are obtained using the relation: column 5 x column 2 x 60, and recorded in column 6. For example, the runoff volume during the first time interval is 0.0425 x 4 x 60 = 10.20 ft^3.

5 Columns 7 and 8 give the cumulative values of runoff in ft^3 and m^3 respectively. Column 7 is obtained by adding the values in column 6. The last value gives total runoff. Column 8 is obtained by multiplying column 7 by a conversion factor (2.83×10^{-2}).

6 Remarks may be added as footnotes to record total ninoff duration in hours and minutes, peak runoff rate in $m^3\ s^{-1}\ ha^{-1}$, and total runoff volume in mm. The peak runoff rate is obtained first in $ft^3\ S^{-1}$ by dividing the maximum value in column 4, by the area of the watershed. It is then converted into $m^3\ s^{-1}\ ha^{-1}$ by multiplying by 0.0283. For the particular example given in Table 1 the peak rate is 0.02 $m^3\ s^{-1}\ ha^{-1}$. To get the total runoff in mm, take the last value of column 8, which is the total runoff in m^3, divide it by the area (m^2), and then multiply the result by 10^3.

Compilation

The storm runoff thus obtained is compiled separately to give values of daily, monthly, and annual runoff. One column may be added to these compilations for recording corresponding rainfall values. The proforma shown in Table 4 will be found useful for runoff data entry. Sample data recorded is presented in Table 5 and Figure 11.

Table 4. Proforma for the compilation of runoff data.

Watershed no. : Year
Area : Treatment :

Serial number	Date	Daily rainfall (mm)	Rainfall WMI[1] (mm h^{-1})	Runoff (mm)	Runoff (% of seasonal rainfall)	Peak rate ($m^3\ s^{-1}\ ha^{-1}$)

1. WMI = weight mean intensity.

Table 5. Data sheet from the digital automatic stage-level recorder at ICRISAT, Patancheru, India.

Date		10-7-1999 to 30-10-1999
Equipment Name	:	Thalimedes (Electronic Stage-Level Recorder)
Project Name	:	Watershed Project
Field	:	ICRISAT Research Station (BW 7)
Time Interval	:	Every 2 min
Readings Unit	:	cm

Date: 10-07-1999

00:02:00	0	0	0	0	0	0
00:14:00	0	0	0	0	0	0
00:26:00	1	7	15	23	29	31
00:38:00	30	29	28	26	24	23
00:50:00	21	20	18	17	16	16
01:02:00	15	13	13	12	11	10
01:14:00	9	9	8	8	7	6
01:26:00	6	5	5	4	3	2
01:38:00	2	1	1	1	1	0
01:50:00	0	0	0	0	0	0
02:02:00	0	o	0	0	0	0
02:14:00	0	0	0	0	0	0

The above data is shown in Figure 11 as runoff hydrograph.

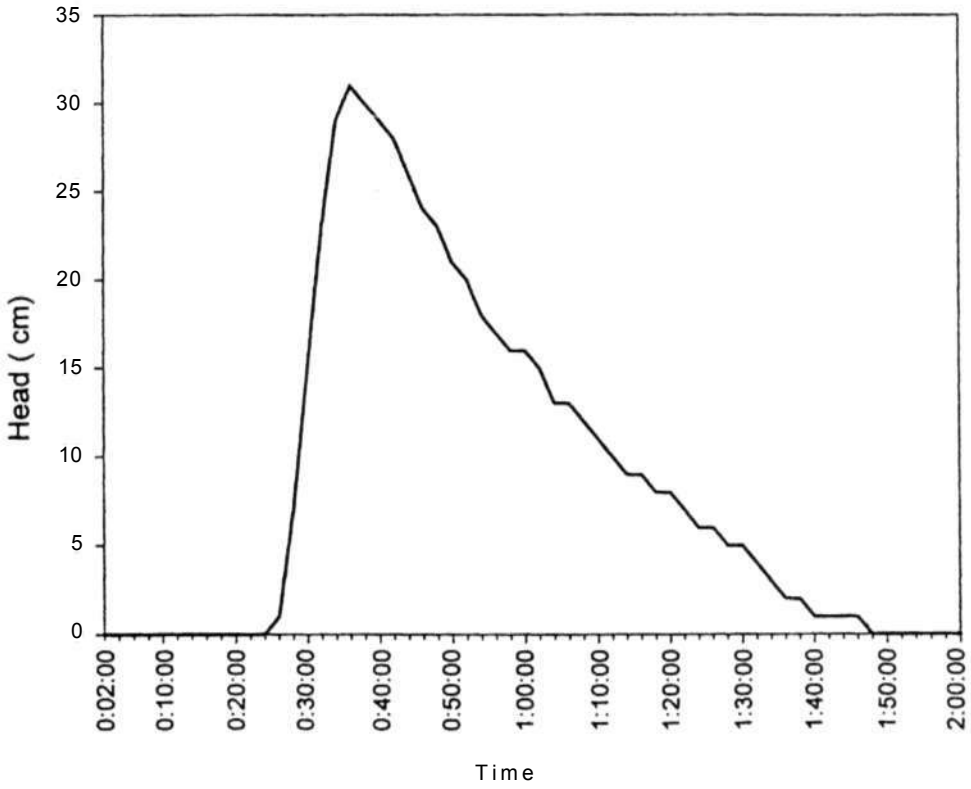


Figure 11. Runoff hydrograph (10 July 1999, BW 7, ICRISAT. Patancheru. India).

Maintenance of flumes and stilling well

The structure and upstream pond area must be kept free of weeds and trash. Sediment must be removed as it accumulates. The level of the crest should be checked at least yearly to ensure that the gauge is on zero. The crest should be examined for nicks or dents that might reduce accuracy of measurement.

If constructed properly, stilling wells will require little servicing. The well and intake pipes should be free of silt. When the well is cleaned, or debris is removed from the intake pipe, the recorder pens should be raised from the chart because a surge in the well may cause excess ink on the chart to soften the paper, thus causing the pen to tear it. After every major flow event, intakes should be checked and, if necessary, the silted soil removed.

Multi-slot divisor

Multi-slot divisors (Fig. 12) are generally used as standard devices for measuring runoff volume and soil loss from small areas. The details for this method can be obtained from Ullah et al. (1972). The divisor consists of a number of slots of equal dimensions fitted at the end of a divisor box. The device is based on the principle that a uniform horizontal velocity of approach will be maintained in the divisor box throughout the entire head variations, to obtain equal division of flow and sediments. Any variation in the velocity distribution is likely to result in unequal division of flow, which in turn will introduce varying degrees of error in measurement. Water passing out from one of the slots is led into a collecting drum and measured. Water from the remaining slots is allowed to drain away.

The device is generally useful for low discharge rates and has some advantages: it is simple in design and operation; there is no risk of mechanical failure; data processing is relatively simple; and it can measure both runoff and soil loss. But its use is limited to the determination of total runoff volume and soil loss only, so it is little used in research where detailed information is required on variations with time in runoff and soil loss (e.g., peak runoff rate, runoff duration, and sediment concentration).

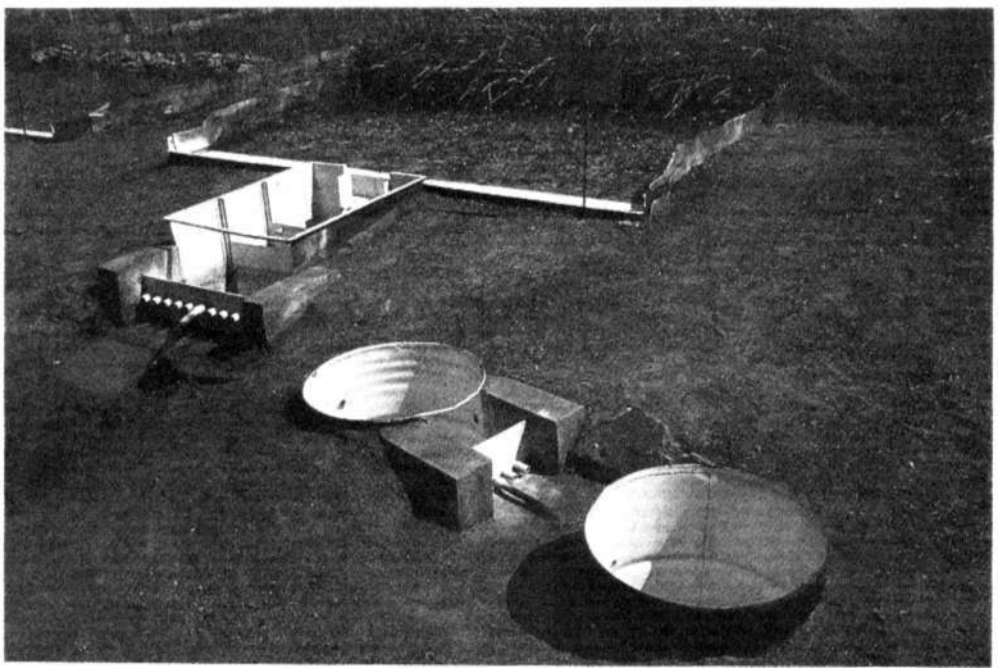


Figure 12. Multi-slot divisors connected to tank and drums for collecting runoff from erosion plots.

Design criteria and specifications

Criteria for the design of a multi-slot divisor are based on the following information (Ullah et al. 1972):

1 Maximum runoff volume expected in 24 h.

2 Peak rate of ninoff expected from the plot for the design frequency.

3 Maximum soil loss expected from the heaviest storm.

In general, the components for a multi-slot divisor installation are: boundary wall; runoff collector to catch and concentrate the flow from the plot; stilling tank; multi-slot divisor; and collecting tank.

Selection of divisor

The selection of a suitable size of divisor depends on the expected rate of runoff and the proportion of the runoff to be stored in the collecting tank. The divisor size is determined by the number of slots and dimensions of the slots, which, in turn, decide the capacity of the divisor. Aliquot size is also called the divisor ratio. For example, a 5-slot divisor has a divisor ratio of 1:5. The choice of the divisor is based on the capacity, number of slots, width, and length of the slots.

The number and size of slots

The number of slots (N) required to handle the expected maximum flow is calculated by using the relation:

$$N = 10 APF/C$$

where F is the expected maximum ninoff percentage in decimal fraction, A is the area (ha), C is the capacity of the storage tank (m^3), and P is precipitation (mm).

If the number of slots exceeds 15, it is desirable to use two divisors in series to obtain the required divisor ratio.

Once the number of slots has been decided, the size of the slots, based on the expected peak flow, is determined. It has been observed in practice that the percentage accuracy is likely to diminish considerably when large divisors with low flow depths are used. It is therefore advisable to select a divisor that has a capacity equal to the expected runoff rate. If the divisor ratio and the amount of expected runoff from the plot are known, the size of the collecting tank can be estimated.

Calibration of multi-slot divisors

After installation of the entire unit, it is essential to check the accuracy of the divisor to ensure that reliable data are obtained. To do that, the following steps should be taken.

1 Fill the stilling tank with water up to the level of the precision plate crest.

2 Stop adding water when it is about to flow over the crest.

3 Add a known amount of water into the stilling tank at a uniform rate, and collect the aliquot.

4 Multiply the aliquot by the number of slots to obtain the total amount of water.

5 Compare the amount thus obtained with the actual amount of water, to determine the percentage error.

6 Repeat this at various depths of flows. The water is generally transferred from the storage tank containing a known amount of water to the stilling tank through rubber or plastic pipes.

Maintenance

A few important precautions listed below are essential for getting accurate results:

1 Calibration should be checked every year before the rainy season.

2 Yearly painting is necessary to prevent corrosion and rust formation. The slot and the crest plate should be painted with good-quality paint.

3 During the rainy season, the slot should be cleaned after every runoff event.

4 The trash collected should be removed and the tank cleaned properly.

5 Observations should be made during the rains to see that the divisors are actually functioning correctly and that there is no leakage or extraneous water entering the collecting tanks.

6 All lids should be tightly closed after measurements are made.

7 The outlet of the collecting tanks should be checked for leakage.

Soil Loss Measurement with a Sediment Sampler

Depth integrating sediment sampler

Design criteria

Sediment samplers have been used extensively for monitoring sediments lost from experimental plots. Among the best known and most widely used are the Coshocton wheel runoff sampler and the multi-slot divisor. However, the use of these samplers has usually been restricted to watersheds that are less than 1 ha, primarily because of their limited capacity. This section describes a simple sediment sampler developed to monitor sediments from watersheds up to 400 ha (Pathak 1991), based on the following design criteria:

1 The time variation in sediment load is relatively more important than the horizontal and vertical variation.

2 The sampler must be able to monitor the sediment quantity efficiently during that segment of the hydrograph at or near the peak rate (since this segment accounts for the major portion of soil loss).

Working principle and operation

To simplify the design of the runoff sampler, momentary or instantaneous fluctuations in sediment concentration across a flow section are avoided. This is done by selecting the sampling site near the high-turbulence downstream point where the sediment variation across the flow section is minimized. The rapidly fluctuating nature of runoff flow from small watersheds, and its relation with time, is used in the sampler to account for the time variation in sediment loads (Pathak 1991). This is achieved by taking representative samples for different hydrograph segments and by collecting samples at different flow depths. The samples are taken through small-diameter pipes which are set at specified heights from the bed of the channel (Fig. 13), and are connected to separate containers by plastic pipes.

The working principle of the sampler is explained in Figure 14 in the form of a single-peak runoff hydrograph. The lowest pipe samples the sediment throughout the total runoff period, while the upper pipes, depending upon their relative positions, sample for shorter periods. The sample volume and sediment concentration for each container are determined individually and hydrograph data are recorded at each sampling point. The actual sediment concentrations for the different hydrograph segments and total soil loss are calculated by using the following equation:

$$S_t = V_0 (Vs_0 Cs_0 - Vs_1 Cs_1) / (Vs_0 - Vs_1) + V_1 (Vs_1 Cs_1 - Vs_2 Cs_2) / (Vs_1 - Vs_2) + \ldots$$

$$+ V_{n-1}(Vs_{n-1}, Cs_{n-1} - Vs_n Cs_n) / (Vs_{n-1} - Vs_n) + V_n Cs_n$$

where $Vs_0, Vs_1, Vs_2, \ldots, Vs_n$ and $Cs_0, Cs_1, Cs_2, \ldots, Cs_n$ are the volumes and sediment concentrations of the runoff samples collected in the containers $M_0, M_1, M_2, \ldots, M_n$, respectively.

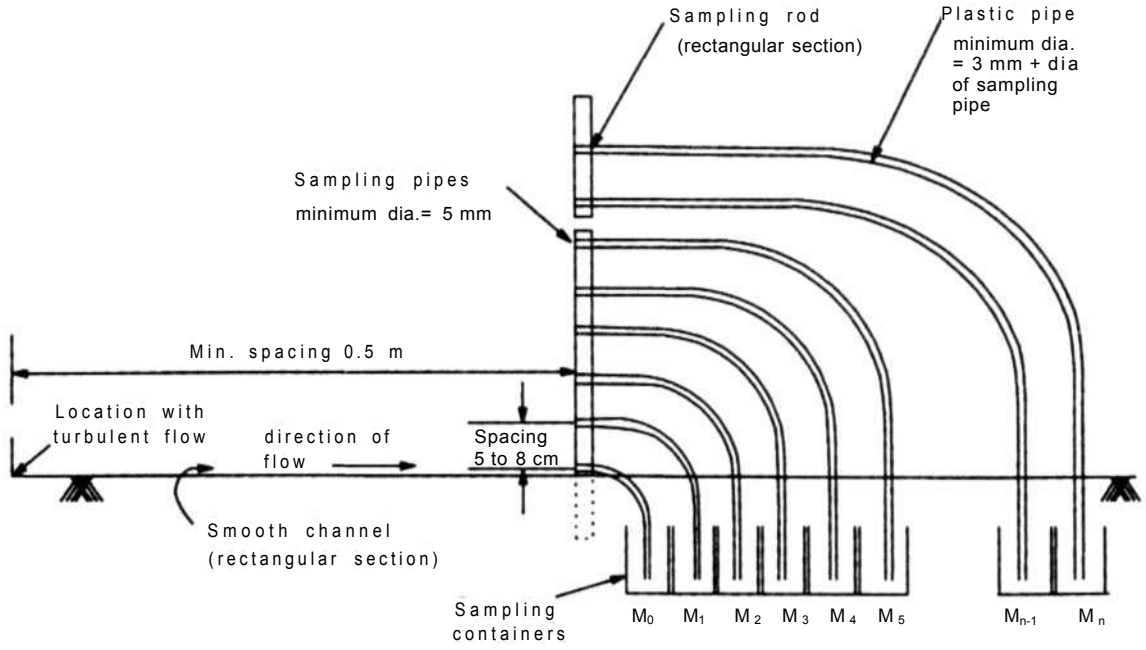


Figure 13. Schematic diagram of the sediment sampler.

The $V_0, V_1, V_2, \ldots, V_{n-1}, V_n$ are the runoff flow volumes for the hydrograph segments, $OO'_1O_1 + P_1P_1P_0$, $O_1O'_1O'_2O_2 + P_2P'_2P'_1P_1$, $O_2O'_2O'_3O_3 + P_3P'_3P'_2P_2$, ..., $O_{n-1}O'_{n-1}O_{n-1}O'_nO_n + P_nP'_nP'_{n-1}P_{n-1}$, $O_nO'_nP'_nP_n$ (see Figure 14).

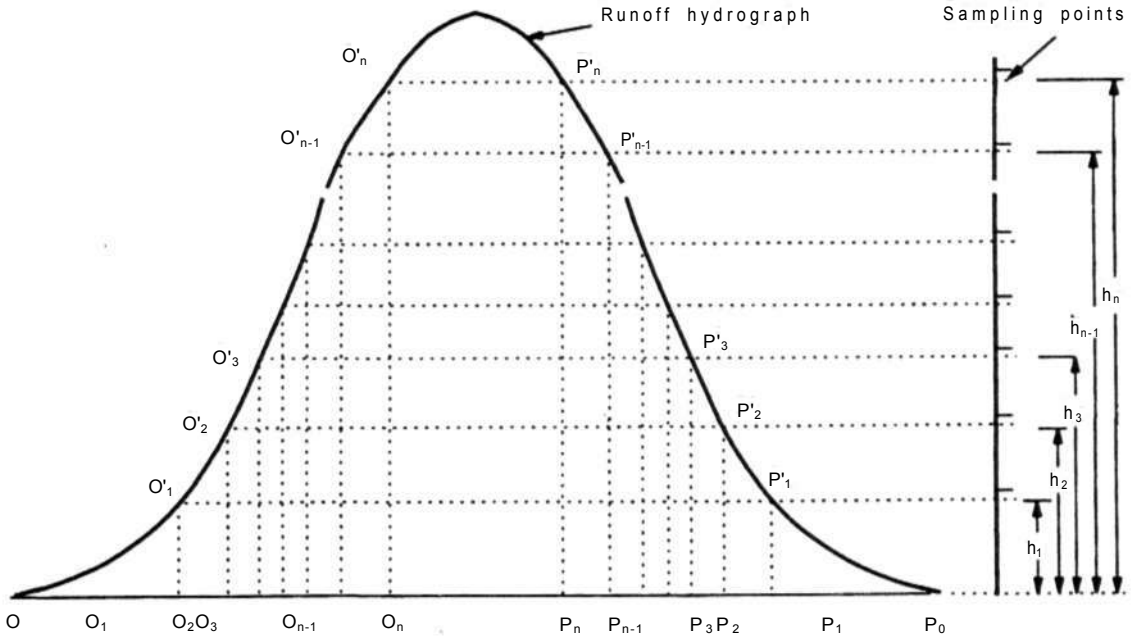


Figure 14. Working principle of the sediment sampler.

The values of V_0, V_1, V_2,..., V_n can be calculated from the runoff hydrograph, while the values of Vs_0, Vs_1,..., Vs_n and Cs_0, Cs_1,..., Cs_n can be determined from the samples collected in containers M_0, M_1,..., M_n.

Construction and installation

The fabrication of the sediment sampler, based on the following guidelines, is quite simple and can be done with readily available materials (for further details see Pathak 1991):

1 The materials and cross-section of the rod should be chosen to meet the requirement of low vibration in the rod during flow. Minimum vibration is important for accurate sampling.

2 The intake approach conditions for all the sampling pipes should be similar because a minor difference may result in considerable modification in sampling rates.

3 Plastic pipes of slightly larger diameter than the sampling pipes should be used to avoid additional resistance to the sampled flow.

4 The number of sampling pipes and their spacing are determined on the basis of the desired accuracy and sediment flow conditions. A wider spacing between the sampling pipes on the lower portion and relatively closer spacing on the upper part of the sampling rod is recommended.

5 Containers of different sizes should be used, as the sample volumes to be collected vary in each container.

6 The metal rod holding the sampling pipes should be firmly fixed in the concrete channel bed.

7 The distance between the sampling point and turbulence location is critical and selection should be made on the basis of the expected degree of turbulence.

Limitations

The sediment sampler, however, has the following limitations:

1 It is not efficient where the eroded sediments contain a very high proportion of medium and coarse sands.

2 For storms having multiple peaks (more than two) its accuracy to estimate soil loss is low.

3 This sampler is useful only for small watersheds (less than 400 ha).

Pumping sediment samplers

Automatic pumping sediment samplers monitor the temporal changes in the suspended sediment concentration during the runoff event. This sampler consists of mechanical circular structure fitted with windscreen wiper motor (DC shunt motors) and pump motor with about 50 bottles and controllable by an electronic module specially designed for this purpose (Rama et al. 1988). The other details about this pumping sediment sampler are described in the following paragraph.

Operation of sediment sampler

- The microcontroller control unit, which when initialized by the water level sensors, operates the system, first by purging the pipe to clean off the old sample water, positions the nozzle on sample hole and then pumping the sample water into a bottle and positions the nozzle on to the next purge hole. The pump is kept at the center of the channel, completely immersed in the flowing water.
- About 750 ml of runoff water is pumped into each bottle. A total of 50 bottles per runoff event can be collected. The system stops automatically with the help of a micro-switch after pumping 50 bottles.

The control unit

The sediment sampler microcontroller system controls the pump and motor of the sediment sampler automatically after sensing the input from the water level sensors which is energized when the runoff water reaches to a certain level in the channel. After getting the signal from the water level sensors, the pump is switched ON automatically for purging which is indicated by the GREEN LED for a time span of 12 sec. Then the pump is switched OFF and then the motor is switched ON to move to the next sample which is indicated by the YELLOW LED. As soon as it reaches the next position the motor is switched OFF and the pump is switched ON to fill the sample which is again indicated by the GREEN LED. After this, once again the motor is switched ON to move to the next position and it stops there for the set time.

After the set time (i.e., 5 min to 20 min) the cycle starts in the same sequence if the water level sensor is ON or else it waits further until the water level sensor is ON.

Theory of operation

Under idle conditions the entire system draws a minimum current of about 60 mA. The uninterrupt program enabled it to keep scanning for the runoff water in the channel. Once the water level signal comes, the pump is turned ON and it purges the pipe clean of the previous sample, then the pump stops and the index motor moves and positions the shaft on to the next hole which opens into a sampling bottle. Then the pump is turned ON again and it pours sample sediment water into the bottle for a predetermined time. A volume of about 750 to 800 ml is poured into the bottle and the pump stops. The motor is ON and moves the shaft on to the next purging hole. At the designed time interval, this sequence repeats. This way, one sample bottle is filled for every 5, 10, 15, or 20 min intervals. After a total of 50 sample bottles, the system becomes non-operational for that particular runoff event. To start the system again the controller unit has to be reset.

Problems faced

The volume of water pumped into the bottles is not the same as in the samplers during the same and different runoff events. The variation is considerable even with the same controller unit and on the same watershed. Sometimes, there is an overflow of volume in the bottles. At other times, the volume reaches the brim of the bottles (i.e., 1 litre) or the water is filled only less than $\frac{3}{4}^{th}$ of the bottle. This problem could be due to the fact that all the time the pump is not working at the same efficiency level. The pump resistance showed variation, when checked, ranging from 2.5 ohms to 30 ohms, as the mud and other particles (the last runoff event) sticking to the pump motor can vary its resistance. One solution could have been to run the pump continuously throughout the runoff event; this keeps stirring the liquid mass. But as the field is not supplied by any AC power lines, car batteries are being used as power supply. Continuous running of the Bilge Pumps (12 V, 3.5 amps) will lead to fast draining of the battery. Hence this solution is not adopted in the field.

To overcome this problem, run the pump motor in fresh, clean water immediately after an event, to clean it properly. Also, care has to be taken to see that the pumps are not resting on the base of the troughs, to avoid the pump from touching the bed-load.

The pumps had to be wrapped in a mesh covering to avoid grass or other large particles from being sucked into the pump along with sediment water. This is because grass and other materials used to sometimes get wound to the pump motor and stop it from rotating.

The box terminal strip of the control unit sometimes do not make proper contact with the motors and the sensor. This could be due to poor quality of the connector terminal. Permanent soldering had to be done at some points.

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Soil Moisture Measurement

Piara Singh

Agricultural scientists, farmers, and other producers are often interested in the nutrient and water status of soil in order to increase and sustain food and feed production. The questions often asked on soil water are: How dry or wet is the soil? How much moisture can a soil hold and supply to plants to support normal growth and maintain or improve yields?

Moisture content is the basic measurement required to answer these questions, and there are several direct and indirect methods for measuring it. In this chapter we present the gravimetric and neutron probe methods. The gravimetric (direct) method is the most important because it is also employed to calibrate instruments used in the indirect methods, e.g., neutron probe.

Gravimetric Method

Equipment

An auger or a sampling tube, hammer for driving the soil tube (if required), a knife, a board or hard wood, soil containers with tight-fitting lids, a wooden box for transporting samples, an oven with means for controlling the temperature at 100-110°C, a balance for weighing the samples.

Principle

Water content measurements by gravimetric method involves weighing the wet soil sample, removing the water from the soil by oven-drying, and re-weighing the sample to determine the amount of water removed. Water content then is obtained by dividing the difference between wet and dry masses by the mass of the dry sample, to obtain the ratio of the mass of water to the mass of dry soil. When multiplied by 100, this becomes the percentage of water in the sample on a dry-mass (or, as often expressed, on a dry-weight) basis (Klute 1986).

Procedure

The procedure given here is intended for use in routine work where moderate precision (say a precision of ±0.5% water content) is desired.

1 Select the site where the samples are to be taken.

2 Drive the sampling tube or the auger to the desired soil depth.

3 Pull out the soil sampling tube or auger and remove the soil sample and transfer it to the labeled moisture can. Cover the can immediately with a lid and place it in the wooden box.

4 Repeat the above procedure for collecting more soil samples from various soil depths and sites.

5 Transport the samples to the laboratory.

6 Weigh the samples before and after oven-drying at 105°C for 24 h.

7 Record the weights of wet and oven-dried samples and the tare weight of cans.

Calculations

$$\theta_g = (w_w - w_d) / (w_d - w_c)$$

$$\theta_v = \theta_x \rho_b / \rho_w$$

where θ_g = gravimetric water content (g of water g^{-1} of soil), θ_v = volumetric water content (cm^3 cm^{-3}) W_w = mass of wet soil and container (g), W_d = mass of dry soil and container (g), W_c = mass of container (g), ρ_b = bulk density of the soil (g cm^{-3}), and ρ_w = density of water (g cm^{-3}).

Notes:

1. The gravimetric method is the basic one for moisture content determination. When other methods are employed, the results should be calibrated with the gravimetric method.
2. The time necessary to reach constant dry-weight will depend upon the type of oven used, the size and number of samples in the oven, and the nature of soil.
3. Avoid adding wet samples in the oven when the previous samples in the oven are at an advanced stage of drying.

Neutron Probe Method

Equipment/materials

Neutron moisture meter with scaler rate meter, aluminum access tubes, rubber stoppers, access tube cap, soil auger, film badges, leak test kits, license (if required).

Principle

The property of the hydrogen nuclei to scatter and slow down neutrons from radioactive substances is the basic principle in this technique. When neutrons from a radioactive substance in the probe come in contact with hydrogen nuclei of water molecules, the fast neutrons are slowed down. These low energy neutrons (thermalized) are detected and counted by a meter. The number of neutrons counted is proportional to the hydrogen nuclei and, hence, the volumetric water content in the soil system. The device for counting the thermalized neutrons is the scaler rate meter. This method is referred to as the neutron probe technique or the neutron moisture meter (NMM) technique (Klute 1986), in which two procedures are involved.

Procedure A: Installation of access tubes and probe calibration

1 A range of moisture contents is needed to calibrate the neutron probe for a given soil type. This can best be done in the dry season by wetting a few plots in a field to different levels of water content (for example, one plot wetted to field capacity, another with no wetting, and a third with intermediate wetting).

2 Push a soil tube (diameter depending upon the type of the probe used) slowly into the soil by hammering or using a hydraulic machine, without causing soil compaction, and take 10 cm long soil core samples starting at 5 cm soil depth to the maximum rooting depth.

3 Transfer these soil samples to polyethylene bags or soil cans and transport them to the laboratory for determining water content by the gravimetric method.

4 Plug one end of the aluminium access tube with a rubber stopper. With this closed end in the hole, push the access tube into the hole such that it fits snugly to the maximum depth. Cut off the extra tube so that only 25 cm of it projects out of the soil.

5 Place the probe unit over the access tube preparatory to lowering it into the hole.

6 Select an appropriate counting time and take four or five standard counts while the source is still in the shield.

7 Take actual probe counts by lowering the source to the middle of each layer sampled, i.e., at 10, 20, 30, 40, 50 cm soil depth, and so on.

8 Repeat this process of soil sampling, installation of access tubes, and probe readings for the wet and dry plots. Repeat this process several times so that there are sufficient data points (minimum of six moisture ranges with three replicated samples for each range) for developing a calibration curve.

9 Multiply the gravimetric moisture content by bulk density of each horizon to calculate the volumetric moisture content. Because of variability in soil texture and structure, different bulk densities may have to be used for different soil layers.

10 Calculate the count ratio (CR) by dividing actual counts from each soil depth by the mean standard count.

11 Develop a calibration equation for the soil by regressing volumetric moisture content (θ_v) on the count ratios as dependent variable. The calibration equation thus developed is used for estimating water content of the soil if count ratios are known.

Procedure B: Taking probe readings and soil moisture estimation

Procedure B is used for estimating soil moisture content in experimental plots.

1 Install neutron probe access tubes in plant rows of each experimental plot using the procedure described above for neutron probe calibration. The number of tubes per plot is determined by the size of the plot and soil variability.

2 Clean the access tube with a long brush or with a cloth wrapped on a stick to remove dust or moisture sticking inside the tube. Check the tubes with a dummy probe so that it moves freely in the hole.

3 Place the neutron probe over the tube and take 4-5 standard counts while the probe is still in the shield.

4 Lower the source into the tube and take readings at every 10-cm depth intervals starting at soil depth of 10 cm.

5 Calculate CR by dividing the actual counts by the mean standard count.

6 Calculate volumetric moisture content by substituting the value of CR in the calibration equation. For example, the calibration equation developed for a Vertisol at ICRISAT Center, Patancheru, India using the Didcot probe is:

$$\theta_v = -0.122 + 0.539\ CR$$

Sample calculations

Given the standard count as 500 and actual counts as 250, 400, and 450 for the 30, 45, and 60-cm soil depths, respectively, the moisture content can be calculated using the above calibration equation as shown in Table 1.

Table 7. Sample calculations for soil moisture content

Soil depth (cm)	Actual count	Count ratio	Volumetric water content ($cm^3\ cm^{-3}$)
30	250	0.5	0.147
45	400	8.8	0.309
60	450	0.9	0.363

Notes:

1 For the 0-5 cm soil layer, determine moisture content by the gravimetric method, and multiply by the bulk density of the horizon to obtain the volumetric water content.

2 Separate calibration curves may be needed for different soil layers of the same soil profile if they markedly differ in soil properties.

3 With reasonable attention to safety rules supplied by the manufacturer, the health hazard involved in using the equipment is small. The following are the important precautions:

   a Keep the probe in the shield at all times except when it is lowered into the soil for measurements.

   b Personnel who operate the probe should reduce exposure to the small radiation escaping from the shield by maintaining a distance of a few meters between them and the probe, except when changing its position.

   c Transport the probe in the back of a truck, or in car trunk.

   d Have operators wear a film badge at waist level.

   e When the probe is not in use, lock it in a storage room away from people.

   f Have a semi-annual leak test performed on the source by a competent safety officer.

   g Probe maintenance should be performed by personnel trained in the use of radioactive equipment.

Water-holding Capacity

The capacity of soils to absorb and retain water provides a reservoir from which water is withdrawn by plants during periods between rainfalls and/or irrigation. Available water capacity (AWC) of the soil is defined as the water retained in the rooting zone of the soil at field capacity (FC) [drained upper limit (DUL) minus the permanent wilting point (PWP)]. However, plant available water is the amount of water retained in the rooting zone between FC and the lower limit (LL) of water extraction by roots (APSRU 1995). Field capacity is defined as the amount of water held in the soil after excess water has drained away and after the rate of downward movement of water has perceptibly decreased (Taylor and Ashcroft 1972). Field capacity in sandy soils may be established in 1-2 days after drainage, while that of clayey soils (e.g., Vertisols) may take a week or more after saturation of the profile. The LL of water extraction is defined as the amount of water left in the soil profile when a well-fertilized crop in its full vegetative stage and in an environment of low evaporative demand wilts permanently due to drought stress.

Estimation of field capacity (FC) or drained upper limit (DUL)

Equipment

Spade or shovel, water tank and a pipe line, polyethylene plastic, soil auger, moisture cans, balance, oven, a tensiometer, and a bulk density sampler.

Principle

Water is added to soil in situ to re-wet the soil profile to a desired depth. After the water has moved into the drier underlying soil, and drainage from the initially wetted zone becomes negligible, the water content of the soil profile at that time is regarded as being at FC (APSRU 1995).

Procedure

1 Select an appropriate field site and construct an earthen dike about 30 cm high around an area approximately 3 m x 3 m.

2 Install a tensiometer in the middle of the pond. The tensiometer cup should be located at the depth of maximum rooting. Seal the soil surface-tensiometer tube interface with wet clay to minimize preferential water flow down the outside of the tube.

3 Line the bank with plastic sheeting to limit lateral water movement.

4 Pond the bordered area to a depth of 15 cm and continue to do so, on a weekly basis, until the tensiometer readings indicate that the profile is saturated (i.e., matric potential is zero). This may be very quick or may take several weeks, depending on soil type.

5 When the tensiometer readings indicate saturation, cover the site with an evaporation barrier, e.g., grass, followed by polyethylene sheeting.

6 Continue to monitor the tensiometer until it shows that the water has ceased draining through the profile.

7 At this point, gravimetric soil water meas" ements are taken and water content determined. Make at least five separate borings and take samples at successive increments to the depth of wetting or maximum rooting. Bulk density measurements should also be made using cores.

Calculations

The in situ soil water content at FC is calculated by

$$FC_w = M_w / M_s$$

or

$$FC_v - FC_w \ \rho_b/\rho_w$$

$$DUL = FC_v$$

where FC_w = gravimetric FC (g water g^{-1} soil), FC_v = volumetric FC (cm^3 water cm^{-3} soil), M_w = mass of water (g), M_s = oven-dried mass of soil (g), ρ_b = bulk density of soil (g soil cm^{-3} soil), and ρ_w = density of water (g water cm^{-3} water).

Notes:

1 Where greater precision is required or soil variability is known to be large, the number of sampling sites should be increased.

2 Bulk density of the soil (as described under soil moisture characteristics) should be determined concurrently with the FC to convert the gravimetric to volumetric water content.

Pressure outflow method for estimating permanent wilting point (PWP)

Principle

By statistical correlation procedures it has been observed that PWP, measured by the sunflower method (not discussed here), is equivalent to the soil water content of a disturbed soil sample placed on a permeable membrane or porous plate and equilibrated with an applied pressure of 1.5 MPa (Klute 1986).

Equipment

Mortar and pestle or soil grinder, sieve having 2 mm diameter holes, pressure plate or pressure membrane apparatus, rubber or brass sample rings to retain soil samples, trays, regulated air pressure system, moisture cans, spatula, balance, and drying oven (Klute 1986).

Procedure

1 Air dry the soil, crush it in a mortar (with a pestle) or soil grinder, and pass through a 2 mm sieve. Discard the material retained by the 2 mm sieve. If the soil is stony, the percentage by weight of coarse fragments must be determined on a subsample for use in the PWP computations.

2 Place the soil sample rings onto the plates and fill these rings with soil. Make sure that soil has good contact with the plate.

3 Place the plates along with the soil samples in the trays. Wet the plate and the soil samples from below slowly with a water bottle until the samples are wet and there is thin layer of standing water on the plate.

4 Leave the samples to wet fully overnight.

5 The next day, transfer the plates to the pressure chamber and place the lid on it and bolt it tightly with a wrench.

6 Apply a positive pressure of 1.5 MPa to the pressure chamber.

7 When the extraction is complete, remove the soil samples.

8 Weigh the samples before and after oven-drying for 24 h at 105°C and calculate the moisture content by the gravimetric method.

Calculations

The permanent wilting point approximation on a weight basis (PWP_w) and on a volume basis (PWP_v) are given as:

$$PWP_w = M_w/M_s$$

and

$$PWP_v = PWP_w \, \rho_b/\rho_w$$

For soils having >2% by weight coarse fragments

$$PWP_w = (M_w/M_s)/(1+M_{cf}/M_s)$$

$$PWP_v = PWP_w \quad \rho_b/\rho_w$$

where M_w = mass of water (g), M_s = oven-dried mass of soil (g), M_{cf} = mass of coarse fragments (g), ρ_b = bulk density of the soil including coarse fragments (g cm^{-3}), and ρ_w = density of water (g cm^{-3}).

Notes:

1 The 1.5 MPa pressure plate results correlate so well with the PWP measured by the sunflower method for non-saline soils that it is usually used in place of the time-consuming sunflower method.

2 For fine-textured soils, undisturbed soil cores taken from the field can also be used to determine PWP instead of the disturbed soil samples.

Estimation of lower limit (LL) of water Extraction: Field Method

Procedure

The LL is obtained by allowing a crop at full vegetative stage to extract water until it wilts as a result of drought stress. This is achieved by covering a small plot within the crop with a temporary rain shelter (3 x 3 m) at or around anthesis in order to restrict water supply to the crop until it wilts. Soil water content is determined when the crop wilts, and that water content is considered to be the LL for that particular crop (APSRU 1995).

Calculations

Calculations are the same as for drained FC_v or upper limit.

Notes:

1 The crop should be well fertilized and should provide complete cover to the soil so that water extraction from the profile is maximal.

2 The plot selected should be away from trees so that it is unaffected by tree roots.

3 Repeated measurements over two or more seasons may be needed to obtain a good estimate of the LL.

Available water capacity (AWC)

The AWC is the amount of water in the soil that can be removed by plants. For field soils, the AWC is estimated by the difference in soil water content between FC and PWP:

$$AWC_w = FC_w - PWP_w$$

or

$$AWC_v - FC_v - PWP_v$$

where AWC_w and AWC_v are calculated in kg kg^{-1} and m^3 m^{-3}, respectively. Sometimes AWC_v is calculated on a volumetric basis per unit area or as mm m^{-1} (i.e., mm of water in a soil of 1 m depth).

Example:

Given the following data on AWC_w and bulk density of soil shown in Table 2, calculate the total amount of available water in mm m^{-1} of soil. Solution: Total available water content up to 100 cm soil depth = 19.61 cm = 196.1 mmm^{-1}.

Table 2. Sample data for the calculation of available water capacity.

Depth increment (cm) (1)	AWC_w ($g\ g^{-1}$) (2)	Bulk density ($g\ cm^{-3}$) (3)	AWC_v ($cm^3\ cm^{-3}$) (4) = 2 x 3	Layer thickness (cm) (5)	Depth of water (cm) (6) = 4 x 5
0-5	0.05	1.2	0.06	5	0.30
5-20	0.10	1.3	0.13	15	1.95
20-80	0.15	1.4	0.21	60	12.60
80-100	0.17	1.4	0.24	20	4.76
Total					19.61

Plant available water capacity

The plant available water capacity (PAWC) is the maximum amount of soil water available to the plant. The PAWC is determined from DUL or FC of the soil and the LL of a particular crop grown in that soil. It is estimated as the difference between DUL and LL:

$$PAWC = (DUL - LL) * (\text{increment depth})$$

where DUL and LL are expressed as volumetric water content, and increment depth in mm.

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Data Needs for Soil Water Balance Simulation

Piara Singh

There are several kinds of water balance models differing in complexity, operation, and purpose. These can be classified as:

1 Agroclimatic models: The models are usually single layer models used for characterization of environments for soil water availability.

2 Management models: The soil profile is divided into two or three layers and the information generated by these models is used for soil and crop management.

3 Physical process models: The soil profile is divided into many layers for studying the flow processes in the soil more precisely.

All these models differ in the use of theoretical or empirical descriptions of processes and, therefore, differ in the accuracy to predict various water balance components. Data required for input also varies with the type of model being used. Generally the agroclimatic models need the minimum input data and the process models need the maximum data, especially on soil properties. It is often not possible to get all the climatic or soil characteristics data required by the model. Various methods are available to estimate the data if the primary data on climatic elements and soil properties for location are available (Ritchie et al. 1983, 1987). The data needs of the Keig and McAlpine (1974), Ritchie's single layer model (1972), and Ritchie's multiple layer model (1985) are discussed.

Keig and McAlpine Model

Water balance model of Keig and McAlpine (1974) estimates soil water balance on weekly basis. It needs the following data inputs:

1 Weekly potential evapotranspiration.

2 Weekly rainfall.

3 Initial available soil water content.

4 Available water-holding capacity.

The outputs of the model are weekly soil water changes, water surplus, water deficits, actual evapotranspiration, and ratio of actual evapotranspiration to potential evapotranspiration.

Ritchie's Single Layer Model

Ritchie's single layer model (1972) needs the following data for its execution:

1 Daily rainfall, maximum and minimum temperatures, and solar radiation.

2 Initial water content, maximum available water-holding capacity, and lower limit of water extraction.

3 Leaf area index and light extinction coefficient.

4 Dates and amount of irrigation, if any.

5 Stage-I and Stage-II evaporation coefficients.

6 Crop emergence date.

The model calculates daily and cumulative water balance components, viz., soil evaporation, plant evaporation, evapotranspiration, excess water, and total water changes in the soil profile as function of time.

Ritchie's Multiple Layer Model

Weather data

Weather data in the model is primarily used for the estimation of potential evapotranspiration. Minimum data required are daily values of:

1 Solar radiation.

2 Maximum and minimum temperature.

3 Rainfall.

If Penman method is used, additional data needs are daily average wind speed and morning and afternoon relative humidity.

Ideally, the weather data should be recorded at a site near the location where the model is to be used. The temperature and radiation data will probably not vary a great deal if the weather recordings are some distance from the site. However, rainfall is sufficiently variable spatially that it must be measured at the site of interest for model testing or use of the model for prediction at a specific site.

Soil data

The soil factors considered to influence water balance can be categorized as:

1 Water entry and retention:
  USDA curve number (CN2) for runoff
  Drainage coefficient (SWCON) for drainage

2 Loss of water by evaporation:
  Soil albedo (SALB)
  Upper limit of Stage-I evaporation (U)

3 Extractable soil water limits:
  Drained upper limit (DUL)
  Lower limit of water extraction (LL)

4 Saturated soil water content

5 Initial conditions of soil water content

6 Environment for root growth:
  Root weighting factor (WR)

USDA curve number (CN2)

Runoff is calculated using the USDA Soil Conservation Service (SCS) procedure known as the "curve number technique" (Soil Conservation Service 1972). The procedure uses total precipitation in a calendar day to estimate runoff. Runoff curves are specified by numbers which vary from 0 (no runoff) to 100 (all runoff). The SCS handbook provides a list of runoff curve numbers for various hydrological soil groups and soil-cover complexes. To determine the runoff curve number for cropland soils, it is necessary to decide which of four hydrologic soil groups best describes the soil. Description of the groups is given in Table 1. The curve number (CN2) is determined from the soil texture and slope of the site using information in Tables 1 and 2. The curve number is further modified for the degree of conservation practices followed as indicated in Table 2.

Table 1. The soil hydrology groups needed for selection of a runoff curve number for croplands.

Hydrologic group	Description
A. Lower Runoff Potential	Includes deep sands with very little silt and clay, also deep, rapidly permeable loess.
B. Moderately Low Runoff Potential	Mostly sandy soils less deep than A, and loess less deep or less aggregated than A, but the group as a whole has above-average infiltration after thorough wetting.
C. Moderately High Runoff Potential	Comprises shallow soils and soils containing considerable clay and colloids, though less than that of group D. The group has below-average infiltration after thorough wetting.
D. Highest Runoff Potential	Includes mostly clays of high swelling percentage, but the group also includes some shallow soils with nearly impermeable sub-horizons near the surface.

Table 2. Runoff curve numbers (CN2) for various hydrological 'conditions, slopes, and conservation practices.

		Hydrologic conditions		
Slope (%)	A	B	C	D
0-2	61	73	81	84
2-5	64	70	84	87
5-10	68	80	88	91
>10	71	83	91	94

Note: Modification for conservation practices.
Good: CN2 * 1.0; Fair: CN2 * 1.04; Poor: CN2 * 1.08.

Drainage coefficient (SWCON)

Because water can be taken up by plants while drainage is occurring, the drained upper limit soil water content is not always the appropriate upper limit of soil water availability. Drainage rates among soils vary greatly. Many productive agriculture soils drain quite slowly, and may thus provide an appreciable quantity of water to plants before drainage stops.

The coefficient SWCON varies between 0 and 1 and represents the fraction of water between the actual water content and the DUL that drains in one day. Thus for a coefficient of 0.5 with the soil water at saturated soil water content, the water content would decrease to half of the difference between the two limits in one day. On the second day, half of the remaining water between the limits would drain, and so on. Further details of this procedure are available in Ritchie (1985).

When field values of SWCON are not available, the values are approximated from soil descriptions based on the permeability classification as given in Table 3.

Table 3. Permeability classification.

Permeability class	Drainage coefficient (SWCON)
Very rapid	0.85
Rapid	0.75
Moderately rapid	0.60
Moderate	0.40
Moderately slow	0.25
Slow	0.05
Very slow	0.01

Soil albedo (SALB)

Soil albedo (SALB) is the reflectance of solar radiation from the soil surface. It is input to the model because of its variability between soils. Under most circumstances, precise albedo values are not very important nor very sensitive in influencing the water balance. The soil albedo varies with surface roughness and wetness, usually being lower for wet and rough conditions. For the models, the soil albedo is used to calculate potential evaporation from the soil surface. Therefore, the approximations that are made are based on wet surface conditions. The color of the upper horizon is used to approximate the albedo as shown in Table 4.

Table 4. Color modifiers.

Color	Albedo[1]
Brown	0.13
Red	0.14
Black	0.09
Gray	0.13
Yellow	0.17

1. Add 001 for lighter modifiers and subtract 0.01 for darker modifiers. If the additional modifier "very" is present, add or subtract 0.02.

Upper limit of Stage-I evaporation (U)

The upper limit constant (U) (mm) can have an important influence on the amount of soil evaporation during periods when the soil surface is frequently wetted by rainfall. The equations for U are as follows:

U = 8 + 0.08 * CLAY	SAND <80, CLAY <50
U = 5 + 0.15 * (100-SAND)	SAND >80
U = 5 + 0.06 *(100 - CLAY)	CLAY >50

where CLAY has a particle size less than 0.002 mm, SILT is between 0.002 and 0.05, and SAND is between 0.05 mm and 2 mm, as defined by the US Soil Classification System. For poorly drained soils, the above value for U is increased by a multiplier equal to (3 - 13 * SWCON), when the SWCON value is less than 0.23.

Extractable soil water limits

The soil water limits needed as inputs are defined as: (1) drained upper limit (DUL), the highest field measured water content of a soil after it has been thoroughly wetted and allowed to drain until drainage becomes practically negligible; (2) lower limit of water extraction (LL); and (3) potential extractable soil water (PLEXW), the difference in water content between DUL and LL. Procedures for determining the field measured limits are presented in Ritchie (1981).

Saturated soil water

For this calculation we assume that for most cases the saturated soil water content (SAT) is equal to 0.85 of the total porosity. Thus the value is calculated from the equation:

$$SAT = (1 - D_f/2.65) * 85$$

where D_f is the measured bulk density of soil at 0.03 MPa.

Initial conditions of soil water content

If the initial soil water content at various depths is not known, they can often be reliably estimated if the model is run beginning at a time when the initial conditions are at the LL or DUL. In regions where the soil water supply is almost always depleted at the end of a season, the model can be run from the time until the sowing date by assuming that the entire profile is at the input LL values. The initial condition at the sowing date then becomes the values approximated from the off-season water balance, assuming a bare soil condition. In regions where the precipitation is almost always sufficient to provide soil water conditions at the DUL, just before sowing, then the input values can be assumed to be DUL at or just before sowing.

Root weighting factor

The root weighting factor (WR) is needed for determining the root distribution for new growth each day. By definition, the depth of soil used as model input is to contain the full grown root zone of the crop. The WR value is the weighting that each depth of soil will receive relative to the total WR values for depths where root growth is occurring, assuming good aeration and sufficient soil water content. Because root growth is always more dominant near the surface under optimum water contents, a value of WR between 0 (zero) and 1 is calculated for each depth increment (i) from:

$$WR_i = 1 * e^{(-0.02 * Zi)}$$

where Z is the depth of the center of layer i.

The value of WR_i is modified by a constant factor based on the qualitative descriptions for the presence of roots in the soil. The modifiers are given below with the multiplier constant for WR shown in parentheses:

No roots seen (0.1)
Roots between peds (0.4)
Roots between horizontal planes (0.4)

Management and other data

Sowing or emergence date (Julian)
Harvest date (Julian)
Dates (Julian) and amounts of irrigation [volume of water (mm)]
Leaf area index or percent light interception
Extinction coefficient
Light use efficiency (g MJ^{-1})

Sowing or emergence and harvest dates are needed for the start and end of simulation. Data on irrigations, if any, are needed to influence soil water recharge and its use by the crop. Leaf area index (LAI) or light interception (LI) data are needed to estimate actual evapotranspiration and its partitioning between soil evaporation and transpiration. Extinction coefficient is needed in combination with LAI to estimate light interception by the crop canopy if direct measurement of LI are not available. Light use efficiency for a crop is needed to estimate total dry matter production during the season in order to calculate root weight and root length density in the soil profile needed for soil water extraction estimations. LAI, LI, extinction coefficient, and light use efficiency data are needed for the "stand alone" Ritchie's (1985) model; however, these variables are estimated if Ritchie's model is a submodel of the larger crop growth model.

References

Keig, B., and McAlpine, J.R. 1974. WATBAL: A computer program for the estimation and analysis of soil moisture from simple climatic data (second edition). Technical Memo 74/4. Queensland, Australia: Division of Land Research, Commonwealth Scientific and Industrial Research Organization.

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Soil Conservation Service. 1972. National engineering handbook section 4: Hydrology. Washington, D.C., USA: United States Department of Agriculture.

Biological and Chemical Properties of Soil

S P Wani and T J Rego

Chemical Analysis

Soil sampling for analysis of soil chemical, biological, and physical parameters is a very important part of the whole process. If the soil sample does not represent the field or plot, the analysis done on such samples has no relevance. Similarly, improper sampling or processing of soil before the analysis also leads to erroneous results and interpretation. For general soil fertility evaluation, usually soil samples are taken up to 15 cm depth and sometimes up to 30 cm depth. The general rule is that the depth of soil sampling should have relevance to root depth of crop while in specific studies soil sampling is done to deeper depths. The number of spots from which soil has to be collected to a desired depth depends upon the variability of the field/plot. Usually the composite soil sample is reduced to about 750 to 1000 g for most of the chemical analysis. Generally the sample is air dried in shade and powdered with a wooden pestle and sieved through appropriate size mesh sieve as per the requirements of chemical analysis. Only in case of mineral nitrogen (N) estimation, fresh soil sample is used.

Time of sampling: Initial soil sampling before sowing, and at predetermined crop growth stages.

Size of core: Soil sampling is done using 5 cm diameter steel (MS) tubes.

No. of cores: About 10 to 12 cores for each plot of 50 m^2.

Lubricant oils should not be used while sampling for organic carbon estimation. While sampling for estimation of other elements, lubricant oils can be used.

Processing of soil: Soil samples are air dried under shade after breaking the clumps. Dried samples are hand pound and passed through 2 mm screen.

Mineral N: For mineral N estimation, fresh soil samples (without air drying) are tested. The clumps are broken and the sample is extracted with 2M potassium chloride (KCI) immediately. Otherwise, samples are stored in the deep freezer until extraction. Moisture content of each sample should be estimated.

Organic carbon: Samples already prepared for laboratory with 2 mm screen should be further subsampled and ground to pass through 0.15 mm (100 mesh) screen.

Total N - Macro Kjeldahl method: Samples already prepared for laboratory with 2 mm screen should be further subsampled and prepared based on N content of the soil.

- Soils containing <0.5% N should be ground to pass through a 32 mesh (0.5 mm) screen.
- Soils containing 0.5% to 1% N should be ground to pass through 60 mesh (0.1 mm) screen.
- Soils containing > 1% N should be ground to pass through a 100 mesh (0.15 mm) screen.

Soil samples prepared and passed through 2 mm screen should be used for other estimations.

Soil pH

Weigh 20 g of soil and put in a 100 ml beaker. Add 40 ml of distilled water (1:2) and stir frequently for 30 min. Measure the pH of the soil suspension immediately after stirring using a pH meter.

Electrical conductivity

Allow the above soil suspension to settle and estimate the electrical conductivity (EC) in the clear supernatant liquid with a conductance meter.

Total nitrogen

Thiosulphate modification of Kjeldahl method to include nitrate and nitrite.

Apparatus: Aluminium Block Digestor, 250 ml digestion tubes, 800 ml Kjeldahl flasks, and 250 ml conical flasks.

Reagents

Kjel tabs: Thompson & Capper Company (UK)

K_2SO_4		100 parts	5 g
$Cu(II)SO_4.$	$5H_2O$	6 parts	
Se		1 part	

Alternatively, powder the reagents separately, before mixing in a mortar. A cake forms during mixing.

Sulfuric acid (H_2SO_4): Concentrated

Sodium hydroxide (NaOH) solution: Approx. 10N

Take 5 kg of reagent grade NaOH in a thick-walled, 15 litre Pyrex glass bottle marked to indicate a volume of 12.5 litres. Add around 8 litres of CO_2-free water and mix. Allow it to cool and make up the volume to 12.5 litres. Make an arrangement that permits the alkali to be stored and dispensed with protection from the atmosphere.

Mixed indicator: Methyl red + bromocresol green

0.5 g of bromocresol green and 0.1 g of methyl red are dissolved in 100 ml of 95% methanol and the pH adjusted to 4.5 with dilute NaOH or dilute hydrochloric acid (HCl) (= 0.1N).

Boric acid: Approx. 4%

Weigh 200 g of boric acid (H_3BO_3) into 4,500 ml of water. Stir with a magnetic stirrer until dissolved. Add 25 ml of (methyl red + bromocresol green) indicator solution and stir. Adjust the volume to 5 litres (5 ml indicator $litre^1$).

Sodium thiosulphate ($Na_2S_2O_3.\ 5H_2O$) solution: 20%

Dissolve 200 g of $Na_2S_2O_3.\ 5H_2O$ in 800 ml of water and make up to 1000 ml.

Procedure

Weigh about 10 g soil, ground to pass through 60 mesh sieve, in a 250 ml digestion tube. Add 15 ml of 20% $Na_2S_2O_3$. Soak for at least 30 minutes. Add 2 Kjel tabs (10 g) and 35 ml of conc. H_2SO_4 under fume hood. Keep it on the Al block digestors pre-heated to 125°C. When frothing has ceased (approx. 1 h) increase the heat to 365°C. Wait till the digest clears and continue the digestion for one more hour (total time approx. 2½ h).

After completion of digestion, allow the flasks to cool. Add around 50-60 ml water. Break the lumps of digest with a teflon or glass rod and mix thoroughly. Transfer the soluble contents into a Kjeldahl flask. Continue more washings to ensure complete transfer of soluble matter leaving behind insoluble silicate. Add 130 ml of 40% NaOH and distil the contents. Collect the distillate in the conical

flask containing 25 ml of boric acid. The flask should be marked to indicate volume of 150 ml. Titrate the distillate against 0.025N H_2SO_4.

Calculation

1 ml of 0.025N H_2SO_4 consumed is equal to 350 μg N; or

$$N(\%) = \frac{[\text{Volume (ml) of acid consumed - Blank}]\ (14.01)\ (100)\ (A)}{[\text{Weight of the soil (g)}]\ (1000)}$$

where A = Normality of H_2SO_4.

Reference

Dalal, R.C., Sahrawat, K.L., and Myers, R.J.K. 1984. Inclusion of nitrate in the Kjeldahl nitrogen determination of soils and plant materials using sodium thiosulphate. Communications Soil Science Plant Analysis 15:1453-1461.

Determination of inorganic nitrogen in soils

Reagents

Potassium chloride (KC1) solution, approx. 2M: Dissolve 1,500 g of reagent-grade KCl in 8 liters of water, and dilute the solution to 10 liters.

Magnesium oxide (MgO): Heat heavy MgO in an electric muffle furnace at 600 to 700°C for 2 h. Cool the product in a desiccator containing potassium hydroxide (KOH) pellets, and store it in a tightly stoppered bottle.

Boric acid-indicator solution: Dissolve 20 g of pure boric acid (H_3BO_3) in about 700 ml of hot water, and transfer the cooled solution to a 1 liter volumetric flask containing 200 ml of ethanol and 20 ml of mixed indicator solution prepared by dissolving 0.300 g of bromocresol green and 0.165 g of methyl red in 500 ml of ethanol. After mixing the contents of the flask, add approximately 0.05N sodium hydroxide (NaOH) cautiously until a color change from pink to pale green is just detectable when 1 ml of the solution is treated with 1 ml of water. Then dilute the solution to volume with water, and mix it thoroughly.

Devarda's alloy: Prepare this reagent by ball-milling a good-quality alloy (Fisher Scientific Co., Pittsburgh, or J.T. Baker Chemical Co., Phillipsburg, New Jersey, USA) until the product passes through a 100-mesh screen and at least 75% of it passes through a 300-mesh screen. Store the finely divided alloy in a tightly stoppered bottle.

Sulfamic acid (NH_2SO_3H): Dissolve 2 g of sulfamic acid (certified; Sargent-Welch Scientific Co., Skokie, III) in 100 ml of water. Store the solution in a refrigerator.

Sulfuric acid (H_2SO_4): 0.005N standard.

Standard ($NH_4^+ + NO_3^-$)-N solution: Dissolve 0.236 g of ammonium sulfate [$(NH_4)_2SO_4$] and 0.361 g of potassium nitrate (KNO_3) in water. Dilute the solution to a volume of 1,000 ml in a volumetric flask, and mix the solution thoroughly. If pure, dry reagents are used, this solution contains 50 µg of NH_4^+-N and 50 μg of NO_3^--N ml^{-1}. Store the solution in a refrigerator.

Standard ($NH_4^+ + NO_3^- + NO_2^-$)-N solution: Dissolve 0.236 g of ammonium sulfate [$(NH_4)_2SO_4$],

0.123 g of sodium nitrite ($NaNO_2$), and 0.361 g of potassium nitrate (KNO_3) in water. Dilute the solution to a volume of 1000 ml in a volumetric flask, and mix the solution thoroughly. If pure, dry reagents are used, this solution contains 50 µg of $NH4^+$-N, 25 µg of NO_2-N, and 50 µg of NO_3^--N ml^{-1}. Store the solution in a refrigerator.

Procedure

Place 20 g of soil in a 250 ml, wide-mouthed bottle, and add 100 ml of *2M* KC1. Stopper the bottle, and shake it on a mechanical shaker for 1 h. Allow the soil-KCl suspension to settle until the supernatant liquid is clear (usually about 30 min), and perform the analyses described on aliquots of this liquid. If the KCl extract cannot be analyzed soon after its preparation (within 24 h), filter the soil-KCl suspension (Whatman no. 1 filter paper), and store the filtrate in a refrigerator until analyses can be performed.

Steam distillation procedures in presence of nitrite

Ammonium-nitrogen (NH_4^+-N): Take 5 ml of H_3BO_3-indicator solution to a 50 ml Erlenmeyer flask that is marked to indicate a volume of 30 ml, and place the flask under the condenser of the steam distillation apparatus so that the end of the condenser is about 4 cm above the surface of the H_3BO_3. Pipette an aliquot (usually 10-20 ml) of the soil extract into a distillation flask, and add 0.2 g of MgO through a dry powder funnel having a long stem that reaches down into the bulb of the flask. Attach the flask to the steam distillation apparatus and immediately commence steam distillation by closing the stopcock on the steam bypass tube of the distillation apparatus. When the distillate reaches the 30-ml mark on the receiver flask, stop the distillation by opening the stopcock on the steam bypass tube, rinse the end of the condenser, and determine NH_4^+-N in the distillate by titration with 0.005N H_2SO_4 from a microburette (1 ml of 0.005N H_2SO_4 equals 70 µg of NH_4^+-N). The color change at the endpoint is from green to a permanent, faint pink.

(Nitrate + nitrite)-nitrogen [(NO_3^- +NO_2^-)-N]: After removal of NH_4^+-N from the sample as described earlier (NH_4*-N), remove the stopper from the side arm of the flask. Add 0.2 g of Devarda's alloy rapidly through a dry powder funnel that reaches down into the flask about 1 cm below the base of the ground joint on the side arm, and immediately replace the stopper in the neck of the side arm. Then determine the amount of NH_4^+-N liberated by steam distillation as described earlier (NH_4^+-N).

(Ammonium + nitrate + nitrite)-nitrogen [(NH_4^+ + NO_3^- + NO_2^-)-N]: Proceed as described earlier (NH_4^+-N), but add 0.2 g of Devarda's alloy to the distillation flask immediately after the addition of MgO and before connection of the flask to the distillation apparatus.

(Ammonium + nitrate)-nitrogen [(NH_4^+ + NO_3^-)-N]: Proceed as described earlier [(NH_4^+ + NO_3 + NO_2^-)-N], but treat the sample in the distillation flask with 1 ml of sulfamic acid solution, and swirl the flask for a few seconds to destroy NO_2^- before the addition of MgO and Devarda's alloy.

Nitrate-nitrogen (NO_3^--N): Follow the procedure described for determination of (NO_3^- + NO_2^-)-N, but perform the analysis on a sample that has been treated with sulfamic acid to destroy NO_2^-.

Calculations

$$N(ppm) = \frac{[\text{Volume (ml) of acid consumed - Blank}]\ (14.01)\ (100)\ (A)\ (R)\ (10^4)}{[\text{Weight of the soil (g)}]\ (1000)}$$

where A = Normality of H_2SO_4; and R = Dilution factor.

Reference

Keeney, D.R., and Nelson, D.W. 1982. Nitrogen inorganic forms. Pages 643-698 *in* Methods of soil analysis. Part II (Page, A.L., Miller, R.H., and Keeney, D.R., eds.). 2nd edition. Madison, Wisconsin, USA: American Society of Agronomy and Soil Science Society of America.

Available P (Olsen's P)

Reagents

Sodium bicarbonate ($NaHCO_3$) solution, 0.5M: Adjust the pH of this solution to 8.5 with 1M sodium hydroxide (NaOH). Add mineral oil to avoid exposure of the solution to the atmosphere. Prepare a fresh solution before use if it has been standing over 1 month in a glass container. Store the solution in a polyethylene container for periods of >1 month, but check the pH of the solution each month.

Sulfuric acid (H_2SO_4), 5N: Add 141 ml of cone. H_2SO_4 to 800 ml of distilled water. Cool the solution and dilute to 1000 ml with distilled water.

Standard phosphate solution: Place 0.4393 g of potassium dihydrogen phosphate (KH_2PO_4) in a 1 liter volumetric flask. Add 500 ml of distilled water, and shake the contents until the salt dissolves. Dilute the solution to 1 liter with distilled water. Add 5 drops of toluene to diminish microbial activity. This solution contains 0.1 mg of phosphorus (P) ml^{-1}.

Dilute phosphate solution: Dilute 20 ml of the standard phosphate solution to 1 liter with distilled water. This solution contains 2 µg of P ml^{-1}.

Ammonium paramolybdate [$(NH_4)_6Mo_7O_{24}.4H_2O$]: Dissolve 12 g of ammonium paramolybdate in 250 ml of distilled water. Dissolve 0.2908 g of potassium antimony tartarate ($KSbO.C_4H_4O_6$) in 100 ml of distilled water. Add these dissolved reagents to 1 liter of 5N H_2SO_4 (141 ml of conc. H_2SO_4 diluted to 1 liter), mix thoroughly, and dilute with distilled water to 2 liters. Store in a Pyrex glass bottle in a dark and cool compartment (Reagent A).

Ascorbic acid: Dissolve 1.056 g of ascorbic acid in 200 ml of reagent A and mix. This ascorbic acid (Reagent B) should be prepared as required because it cannot be kept for more than 24 h.

Procedure

Take 5 g of soil in a 250 ml Erlenmeyer flask and add 100 ml of the sodium bicarbonate solution. Shake the flask for 30 min with a suitable shaker. Filter the suspension through Whatman no. 40 filter paper. Add activated charcoal (P free) to obtain a clear filtrate, but this step is not necessary in most soils when the ascorbic acid method is used. Shake the flask immediately before pouring the suspension into the funnel.

Place 5 ml aliquot of the extract in a 25 ml volumetric flask, and acidify with 5N H_2SO_4 to pH 5. This can be done by taking 5 ml of 0.5M extracting solution and determining the amount of acid required to bring the solution to pH 5 using p-nitrophenol indicator. Then add the required acid to all the unknowns. Add 20 ml of distilled water, and then add 4 ml of reagent B. The color will be stable for 24 h, and maximum intensity is obtained in 10 min. The absorption maximum of the blue color formed in the presence of antimony is at 882 nm. Calibrate the method using a standard P solution. Prepare a blank with distilled water and 4 ml of reagent B.

Reference

Olsen S.R., and Sommers, L.E. 1982. Phosphorus. Pages 403-430 *in* Methods of Soil Analysis. Part II (Page, A.L., Miller, R.H., and Keeney, D.R., eds.). 2nd edition. Madison, Wisconsin, USA: American Society of Agronomy and Soil Science Society of America.

Total P in soils

One gram of sample (60 mesh screened) is digested with 15 ml of 72% $HClO_4$ in 30 ml micro Kjeldahl flasks on an electric micro-digestion unit for 60 min. After cooling, about 15 ml of water is added into each flask. The contents are swirled and then filtered through Whatman no. 42 filter paper into 100 ml volumetric flasks. The flasks and residues on the filters are repeatedly washed with a total volume of 60 to 65 ml of water, after which they are made up to volume. Perchloric acid blanks also are digested and treated in the same manner, and used to adjust the spectrophotometer scale for 0 absorbance. Transfer 5 ml of the filtrate from the $HClO_4$ soil digest to test tubes. Add 5 ml of the mixture vanadate-molybdate reagent, mix, and measure the color at 440 nm after 30 min.

For calibration purposes prepare standards.

Reference

Tandon, H.L.S., Cescas, M.P., and Tyner, E.H. 1962. An acid free vanadate-molybdate reagent for the determination of total phosphorus in soils. Soil Science Society of America Proceedings (32):48—51.

Organic carbon

Reagents

Potassium dichromate ($K_2Cr_2O_7$), IN: Dissolve 49.04 g of reagent grade K_2Cr_2O7 (dried at 105°C) in distilled water, and dilute the solution to a volume of 1000 ml.

Sulfuric acid (H_2SO_4): Concentrated (not less than 96%). If Cl is present in soil, add silver sulfate (Ag_2SO_4) to the acid at the rate of 15 g liter[1],

Phosphoric acid (H_3PO_4): Concentrated.

1,10-Phenanthroline-ferrous complex, 0.025M: Dissolve 14.85 g of 1,10-phenanthroline monohydrate and 6.95 g of ferrous sulfate heptahydrate ($FeSO_4.7H_2O$) in water. Dilute the solution to a volume of 1000 ml. The 1,10-phenanthroline-ferrous complex is available under the name of Ferroin from G Frederick Smith Chemical Co. (Columbus, Ohio, USA).

Barium diphenylamine sulfonate: Prepare a 0.16% aqueous solution. This reagent is an optional substitute for 1,10-phenanthroline-ferrous complex.

Ferrous sulfate heptahydrate ($FeSO_4.7H_2O$) solution, 0.5N: Dissolve 140 g of reagent grade $FeSO_4.7H_2O$ in water. Add 15 ml of conc. H_2SO_4. Cool the solution and dilute it to a volume of 1000 ml. Standardize this reagent daily by titrating it against 10 ml of IN $K_2Cr_2O_7$ as described below.

Procedure

Grind the soil to pass through a 0.5-mm sieve. **Do not use Fe or steel mortars.** Transfer a weighed sample, containing about 10-25 mg of organic carbon (C), but not > 10 g of soil, into a 500 ml wide-mouthed Erlenmeyer flask. Add 10 ml of IN $K_2Cr_2O_7$ and swirl the flask gently to disperse the soil in the solution. Then rapidly add 20 ml of conc. H_2SO_4, directing the stream into the suspension. Immediately swirl the flask gently until soil and reagents are mixed; then more vigorously for 1 minute. Allow the flask to stand on a sheet of asbestos for about 30 min. Then add 200 ml of water to the flask, and filter the suspension. If experience shows that the endpoint of the titration cannot otherwise be clearly discerned, add 3 to 4 drops of 1,10-phenanthroline indicator, and titrate the solution with 0.5N $FeSO_4$. As the endpoint is approached, the solution takes on a greenish cast and then changes to dark green. At this point, add the ferrous sulfate heptahydrate drop by drop until the color changes sharply

from blue to red (maroon color in reflected light against a white background). Make a blank determination in the same manner, but without soil, to standardize the $K_2Cr_2O_7$. Repeat the determination with less soil if >75% of the dichromate is reduced.

Calculation

Calculate the results according to the following formula, using a correction factor *f* = 1.30 or a more suitable value found experimentally:

$$\text{Organic C (\%)} = \frac{(\text{meq } K_2Cr_2O_7) - (\text{meq } FeSO_4)\ (0.003)\ (100)}{\text{Weight of water-free soil (g)}}$$

Note: meq = milli equivalents = normality of the solution * volume (ml) of the solution used.

Reference

Nelson, D.W., and Sommers, L.E. 1982. Total carbon, organic carbon, and organic matter. Pages 539-579 *in* Methods of soil analysis. Part II (Page, A.L., Miller, R.H., and Keeney, D.R., eds.). 2nd edition. Madison, Wisconsin, USA: American Society of Agronomy and Soil Scienge Society of America.

Exchangeable cations

Place 5 g of <2 mm air-dried soil in a 50 ml centrifuge tube. Add 25 ml of IN ammonium acetate (NH_4OAC). Place a stopper and shake the tube for 30 min. Place the tube in a centrifuge, and spin at 2000 rpm for 10 min. Pour the supernant into a 50 ml volumetric flask. Repeat with an additional 25 ml, and finally bring up to a volume of 50 ml with IN NH_4OAC. Determine cations using an atomic absorption spectrophotometer.

Calculation

$$\text{Cation content (ppm)} = \frac{(50)\ (x)}{\text{Weight of the soil (g)}}$$

where x is the cation content (ppm) present in the diluted sample.

Reference

Thomas, G.W. 1982. Exchangeable cations. Pages 159-165 *in* Methods of soil analysis. Part II (Page, A.L., Miller, R.H., and Keeney, D.R., eds.). 2nd edition. Madison, Wisconsin, USA: American Society of Agronomy and Soil Science Society of America.

DTPA extractable Zn, Fe, Mn, and Cu

The DTPA extractant consists of 0.005M DTPA, 0.01M calcium chloride ($CaCl_2$) and 0.1M TEA (triethanol amine) buffered at pH 7.3. Shake 10 g of soil with 20 ml of extractant for 2 h and filter using Whatman no. 42 filter paper. The concentrations of zinc (Zn), iron (Fe), manganese (Mn), and copper (Cu) are determined directly in the extracts by using an atomic absorption spectrophotometer.

$$\text{Micronutrient content (ppm)} = \frac{(20)\ (x)}{\text{Weight of the soil (g)}}$$

where x is the micronutrient content (ppm) present in diluted extract.

Reference

Lindsay, W.L., and Norvell, W.A. 1978. Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil Science Society of America Journal 42:421-428.

Cation exchange capacity

Transfer 6 g soil to a centrifuge tube and add 33 ml of IN NaOAC solution (pH adjusted to 8.2). Shake the stoppered tube for 5 minutes in a reciprocating shaker. After centrifuging for 10 min, decant the clear supernatant liquid as completely as possible and discard it. Treat the sample with 3 additional 33 ml portions of IN NaOAC solution for a total of 4 treatments. Suspend the sample in 33 ml of 95% ethanol and shake it for 5 min; centrifuge and discard the clear supernatant liquid. Wash the sample with 2 additional 33 ml portions of ethanol.

The EC of the supernatant liquid from the 3rd washing should be less than 40 micro mhos cm^{-1}. The absorbed sodium is replaced from the sample with three 33 ml portions of IN NH_4OAC. The decantate is collected in a 100 ml volumetric flask. This solution is made to volume and mixed. Sodium is determined by using either an atomic absorption spectrophotometer or flame photometer.

Calculations

Cation exchange capacity (CEC) in meq $100g^{-1}$ soil = (7.25) (x) - 1 to 100 ml dilution; CEC in meq $100g^{-1}$ soil (1.81) (x) - 1 to 25 ml dilution
where x is the conentration of sodium in ppm from the graph.

Reference

Thomas, G.W. 1982. Exchangeable cations. Pages 159-165 *in* Methods of soil analysis. Part II (Page, A.L., Miller, R.H., and Keeney, D.R., eds.). 2nd edition. Madison, Wisconsin, USA: American Society of Agronomy and Soil Science Society of America.

Biological Properties

Soil sampling

For determining biological properties of soil, generally soil samples to a depth of 15 to 30 cm are collected unless specific depths need to be studied for various biological properties. Appropriate precautions while collecting soil samples from each plot/treatment must be taken as in sampling for chemical analysis. An important point to be remembered for biological analysis is that samples should be stored in shade and preferably at low temperatures (e.g., in ice box) during transportation. During collection, oil should not be used for applying to coring tube. The samples should not be dried. Samples in polythene bags must be stored at low temperature (4-5°C) in cold room or refrigerator till they are analyzed. Do not store samples in the freezer compartment.

Sample preparation

If samples are too wet then these can be air dried in the laboratory to reduce the moisture content so that samples can be processed easily. Sieve the samples through <2 mm sieve to separate gravel, roots, and other organic materials. If samples are dry then pre-incubate in bulk at 40% water-holding capacity

(WHC) at 22-25°C for seven days before assay (Brookes et al. 1985). This is essential to avoid the exaggerated values as generally there is a spurt of microbial activity in the soil after wetting of the dry soil. Homogenous subsamples should be used for biological assays.

Reference

Brookes, P.C., Kragt, J.F., Powlson, D.S., and Jenkinson, D.S. 1985. Chloroform fumigation and the release of soil nitrogen: the effects of fumigation time and temperature. Soil Biology and Biochemistry 17:831-835.

Soil respiration

Soil respiration is a process involving uptake of O_2 and/or release of CO_2 by living metabolizing entities in the soil (Anderson 1982). Microbial respiration is defined as the uptake of O_2 or release of CO_2 by bacterial, fungal, algal, and protozoan cells in the soil and includes the exchange of gases that result from both aerobic and anaerobic metabolism. Biomass (metabolically active cells) in the soil is the agent responsible for soil respiration.

Soil respiration can be measured in field or in the laboratory from the disturbed soil samples. The choice of the method depends on the objective of the experiment. Here we are interested to measure the soil respiration along with the biomass estimation to study the relationship between these parameters and the treatments under evaluation in the experiment. This means our choice for the method is restricted to laboratory methods and for convenience we would like to follow estimation of the CO_2 released from the disturbed soil samples collected from the field treatments. Laboratory method for estimating soil respiration by measuring the amounts of CO_2 released is described below.

Materials and reagents

Airtight, screw-capped glass jars of 1-2 litres capacity (the lids should be of good quality plastic), glass beakers, glass bottles to hold alkali solution, known strength NaoH solution, barium chloride ($BaCl_2$) 3N, phenolphthalein indicator (dissolve 1 g of phenolphthalein in 100 ml of 95% ethanol; do not use the indicator if autotitrator is used), known strength HCl acid, autotitrator or burette, and magnetic stirrer and magnet bar.

Procedure

Take 20 g (dry weight) moist soil in a glass beaker. Place the beaker in a glass jar with 5-10 ml distilled water to avoid desiccation of soil samples during incubation. Pipette fixed volume (10-15 ml) of standard NaOH solution in a glass bottle and place it in the same jar near the beaker containing soil. Close the lid of the glass jar and make it airtight. In case lids are not airtight put electrical steel grip tape around the lid and jar joint. Incubate the jars for 10 days at 22-25°C. This period should coincide with the samples for biomass estimation. If only respiration is to be estimated then any length of incubation period can be used. At the end of the incubation period remove the alkali bottles from the jars, label them, and close with parafilm to avoid CO_2 absorption from the atmosphere. Pipette out an aliquot of the alkali and add an excess amount of $BaCl_2$ to precipitate the carbonate as barium carbonate ($BaCO_3$). Add few drops of the phenolphthalein indicator and titrate the unneutralized alkali with standard HCl directly.

Calculation

$$C \text{ or } CO_2(mg) = (B-V)\ NE$$

where B = Volume (ml) of acid to titrate the blank alkali; V = Volume (ml) of acid to titrate the alkali in the CO_2 collectors from the treatment to the end point; N = Normality of acid; and E = Equivalent weight.

If the data are expressed in terms of C, then E = 6; if expressed as CO_2, then E = 22.

Reference

Anderson, J.P.E. 1982. Soil respiration. Pages 831-872 *in* Methods of soil analysis. Part II (Page, A.L., Miller, R.H., and Keeney, D.R., eds). 2nd edition. Madison, Wisconsin, USA: American Society of Agronomy and Soil Science Society of America.

Net N mineralization

A key feature of the internal cycle is the biological turnover of N through mineralization and immobilization. Biological turnover through mineralization-immobilization leads to interchange of inorganic forms of N with the organic N. A decrease in mineral N levels with time indicates net immobilization; an increase suggests net mineralization. The fact that levels of mineral N remain unchanged does not necessarily mean that an internal cycling is not operating but that mineralization-immobilization rates, even though vigorous, are equal.

Materials and reagents

2M KCl, MgO, Devarda's alloy, 0.005N H_2SO_4, wide-mouthed screw-capped bottles, boric acid indicator solution (for details refer procedure for determination of inorganic N in soil).

Procedure

Weigh 20 g (dry weight) moist soil and put it in 250 ml Erlenmeyer flask or plastic container. Add 100 ml 2M KCl to the container and shake it for one hour on shaker at room temperature. Allow the soil to settle down and filter the supernatant through Whatman no. 1 filter paper, collect the clear filtrate, and store it in plastic bottles in cold room/freezer till further analysis. Analyze an aliquot (5-10 ml) of the filtered extract for NH_4^+-N and NO_3^--N content by following Kjeldahl distillation process as outlined in mineral N content analysis section. Use the mineral N content of soil at time t_o for calculating net N mineralization.

At the same time (t_o) weigh 20 g (dry weight) moist soil and put it in a glass beaker. Adjust the moisture content of the soil sample to 55% WHC and incubate in a screw-capped jar containing water at the bottom to avoid desiccation of the soil sample. Incubate at 25°C for 10 days and then extract in 2M KCl as indicated earlier. Follow the same procedure for filtering and mineral N estimation by distilling the filtrate.

Note: If microbial biomass N is estimated by chloroform fumigation and incubation method (CFIM) then the non-fumigated set serves the purpose for estimating net N mineralization during 10 days incubation.

Calculation

Net N mineralization g^{-1} soil 10 $days^{-1}$ = mineral N content g^{-1} soil (t_{10}) - mineral N content g^{-1} soil (t_o).

Microbial biomass

Soil organisms are involved in various transformations of elements in soil. Soil microbial biomass (generally measured as undifferentiated whole) is defined as the living part of the soil organic matter, excluding plant roots and soil animals larger than about 5 x 10^3 μm^3 (Jenkinson and Ladd 1981). Microrganisms act as nutrient flow regulators (source and sink) through the process of retention (immobilization) and release (mineralization) of nutrients [C, N, P, and sulfur (S)]. Different methods for measurement of microbial biomass (C and N) in soil have been described (Jenkinson and Ladd 1981).

Chloroform fumigation and incubation method (CFIM)

If soil is fumigated, the respiration rate of that soil immediately after removal of the fumigant will be less than that of non-fumigated soil. Later on, the respiration rate of the fumigated soil will increase sharply to a value exceeding that of non-fumigated soil and will then subside, i.e., there is a temporary flush in CO_2 evolution in the previously fumigated soil (a flush of decomposition).

Reagents: Ethanol-free chloroform ($CHCl_3$, IN NaOH, 0.05 N HC1, 3N $BaCl_2$, phenolphthalein indicator, 2M KCI, MgO, boric acid, mixed indicator of bromocresol green and methyl red indicator, Devarda's alloy, 0.005N H_2SO_4, distillation set (for details refer procedure for soil respiration and determination of inorganic N in soil).

Procedure: Weigh 20 g (dry weight) of moist sieved soil in triplicate. Put weighed soil samples in glass beakers. Add water to bring the samples to 55% WHC. Fumigate one set with $CHCl_3$, and leave the other set non-fumigated. For fumigating soil samples, place the beakers with soil in a large vacuum desiccator that is lined with moist filter paper. A beaker containing 50 ml of alcohol-free $CHCl_3$, and anti-bumping granules also is placed in the desiccator. The desiccator is then evacuated with the help of vacuum pump till the $CHCl_3$ starts boiling. Allow the $CHCl_3$ to boil for 1-2 min and then seal the desiccator and incubate the samples under $CHCl_3$ vapour for 18 to 24 h at 25°C. Then break the vacuum in the desiccator slowly, open it, and remove the moist paper and $CHCl_3$ vapours by repeated evacuations. Non-fumigated control soil samples are also kept in a desiccator lined with moist paper for 18 to 24 h at 25°C.

Both the sets (fumigated and non-fumigated control) of soils are put in airtight glass jars containing water at the bottom. A container with 20 ml of IN NaOH is also put in the container and closed containers are incubated at 25°C for 10 days.

At the end of 10 days incubation, C released is estimated by titrating an aliquot of alkali with standard acid as mentioned earlier under measurement of soil respiration.

Calculation:

$$\text{Microbial biomass C} = \frac{\text{C mineralized from fumigated soil incubated for 10 days - C mineralized from non-fumigated control soil incubated for 10 days}}{0.411\ (K_c)}$$

(Source: Anderson and Domsoh 1978).

Microbial N: Fumigated and non-fumigated soil samples incubated for 10 days are extracted with 2M KCI(1:5W/V).

Determine mineral N content in soil samples as mentioned earlier for mineral N estimation by distilling the aliquot of KCl extract.

$$\text{Microbial biomass N} = \frac{\text{Mineral } (NH_4^+ + NO_3)\text{-N in fumigated soil incubated for 10 days - Mineral N in non-fumigated control soil incubated for 10 days}}{0.57\ (K_n)}$$

(Source: Jenkinson 1988)

Results are expressed g^{-1} oven-dried soil.

Precautions:

- Soils should not be air dried before biomass measurements are made.
- Pre-incubation of soil before biomass measurements are made will improve the data obtained.
- $CHCl_3$ must be alcohol-free and note that alcohol-free $CHCl_3$ is not stable for long periods.
- The CFIM is not applicable for soils which have received recent additions of organic matter.

Fumigation and extraction method for measuring soil microbial biomass

Chloroform has been used as fumigant for measuring biomass because it is an effective biocide, and does not solubilize non-microbial soil organic matter or render it decomposable. The increase in extractable organic C, N, P, and S following fumigation of soil has been used to estimate the amounts of C, N, P, and S held in the soil microbial biomass.

Reagents: Alcohol-free $CHCl_3$; and other reagents are same as those listed under organic C and total N estimation methods.

Procedure: Follow the same procedure up to fumigation of soil for 24 h as mentioned under CFIM. After fumigation, extract the soils with 0.5M K_2SO_4 (1:4 soihsolution ratio) for 1 h. Filter the extracts through Whatman no. 1 filter paper and store the extracts at 4-5°C till further assay.

Biomass C: An aliquot of the K_2SO_4 soil extract is used for measuring organic C by digestion with $K_2Cr_2O_7$ and back-titrating with 0.2M ferrous ammonium sulphate (19.625 g ferrous ammonium sulfate dissolved in 300 ml distilled water containing 20 ml conc. H_2SO_4 and dilute it to 10:100 ml).

$$\text{Microbial biomass C} = \frac{\text{C content in extracts of fumigated soil - C content in extracts of non-fumigated soil}}{0.411\ (K_c)}$$

Biomass N: Aliquot of K_2SO_4 soil extracts (fumigated and non-fumigated) are used for measuring total N content. Total N is measured by Kjeldahl digestion method as described earlier under total soil N estimation.

$$\text{Biomass N} = \frac{\text{N content in fumigated soil extract - N content in non-fumigated soil extract}}{0.57\ (K\ )}$$

References

Anderson, J.P.E., and Domsoh, K.H. 1978. Mineralization ofbacteria and fungi in chloroform-fumigated soils. Soil Biology and Biochemistry 10:207-213.

Jenkinson, D.S. 1988. Determination of microbial biomass carbon and nitrogen in soil. Pages 368-386 *in* Advances in nitrogen cycling in agricultural ecosystems (Wilsom, J.R., ed.). Wallingford, Oxon, UK: CAB International.

Jenkinson, D.S., and Ladd, J.N. 1981. Microbial biomass in soil measurements and turnover. Pages 415-471 *in* Soil biochemistry (Paul, E.A., and Ladd, J.N., eds.). New York, USA: Marcel Dekker.

Most probable number (MPN) method for estimating population of rhizobia in soil

There is no selective medium for isolating rhizobia from soils. Therefore, bacteriologically controlled plant infection tests are usually used. Basically, the method consists of inoculating test plants, grown aseptically, with aliquots from a dilution series of the sample being examined. The number of rhizobia in the sample can be calculated from the proportions of the test plants forming nodules at each dilution. A method for plants grown in test tubes is described below.

Considering asepsis, convenience of handling, and economy of space, it is preferable to grow the test plants within glass tubes closed with cotton wool plugs. The different media used in these tubes are either agar, or sand, or vermiculite.

Seedling agar

The constituents of agar medium are:

$CaHPO_4$	1.0g	
K_2HPO_4	0.2 g	
$MgSO_4 . 7H_2O$	0.2 g	
NaCl	0.2 g	
$FeCl_3$	0.1 g	
Water	1000 ml	
Agar	8-15 g	(according to use as deep or slope)
pH adjusted to 6.5-7.0		

The medium has undissolved constituents and therefore should be kept agitated when being dispensed.

Tubes

Tubes, 150 x 20 mm, are satisfactory for the small-seeded species (e.g., white clover); tubes, 200 x 30 mm, will permit a fair degree of differentiation in the large-seeded species (e.g., subterranean clover). The approximate volumes of agar appropriate to tube size are given below:

Tube size		Volume of agar (ml)	
Inches	mm	Deep	Slope
6 x ¼	150x20	8	12
6 x 1	150 x 25	12	18
6 x1¼	150x30	18	30
8 x1 ¼	200 x 30	25	40

The tubes should be closed with cotton wool plugs of uniform depth (20 mm) and moderate compactness. When tubes are sufficiently uniform, the medium can be dispensed to a constant depth. Many small-seeded legume species grow best in tubes and accordingly are sought after as test plants.

Procedure

Select clean seed for uniform size. Surface sterilize seeds by momentary immersion in 95% ethanol followed by 3-5 min in 0.1% mercuric chloride ($HgCl_2$) solution. For hard-seeded species such as siratro, immersion for 10-20 min in concentrated H_2SO_4 will simultaneously scarify and sterilize the seed surface. In both cases, wash thoroughly in at least ten changes of sterile distilled water. Allow the seeds to stand in the final change of water for 2-3 h until imbibed. Spread the seeds on to 1.5% water agar in petri dishes. Incubate at an appropriate temperature (usually 26°C) in an inverted position to provide uniform seedlings with straight roots. When the roots are 1-2 cm long, transfer the seedlings aseptically into the test tubes containing N-free agar medium, one per tube. In order to avoid dislodging the seedling from its position at the top of the slope an overnight period with the tubes slightly slanted will help the young root grow along the agar surface. If the seed is known to give good germination, sow directly after sterilization and washing without pre-germination.

Preparation of soil dilutions

Suspend 10 g of the soil sample in 90 ml of diluting solution in a beaker. Shake it for 10 minutes on a wrist action shaker. This is $1:10^1$ dilution. Pipette 1 ml of the above suspension into 9 ml diluting solution and shake the container for a further 5 min. This is $1:10^2$ dilution. Prepare serial dilutions up to $1:10^7$ using a fresh pipette each time. Take three 1 ml portions from each of six ten-fold serial dilutions to inoculate three test plants. That means, you require 18 test plants for each sample.

Incubate the inoculated tubes in an illuminated chamber for 4 weeks providing 16 h light and 8 h dark period at a temperature of 26°C. If necessary, water the tubes during incubation.

After 4 weeks score the tubes for nodulation [positive (+) or negative (-)].

From the proportion of plants forming nodules at each dilution level, calculate the most probable number of rhizobia in the sample by using a modified version of Fisher and Yates (1963).

Most probable number (MPN) scoring data sheet

Name:
Date sowing:
Sample details: Date scoring:

Replications	10^{-1}	10^{-2}	10^{-3} 10^{-4}	10^{-5} 10^{-6}
R1				
R2				
R3				
R4				
R5				

No. positive:

No. negative:

Total no. of replications:

MPN count from table:

Most probable number (MPN) of nodule bacteria calculated from the distribution of positive (nodulated) test plants in a plant-infection test based on a ten-fold dilution series is presented below. Initial dilution-soil: diluting solution = 10:90.

No. of positive (nodulated) test plants (of 3) resulting from inoculation with 1 ml aliquots in dilutions of original sample						MPN of nodule bacteria in original sample before any dilution	
$1:10^2$	$1:10^3$	$1:10^4$	$1:10^5$	$1:10^6$	$1:10^7$	Estimate	Confidence limits (95%)
1	0	0	0	0	0	0.4×10^2	$0.1\text{-}2.5 \times 10^2$
2	0	0	0	0	0	0.9×10^2	$0.2\text{-}3.7 \times 10^2$
2	1	0	0	0	0	1.5×10^2	$0.4\text{-}5.2 \times 10^2$
3	0	0	0	0	0	2.3×10^2	$0.7\text{-}8.0 \times 10^2$
3	1	0	0	0	0	4.2×10^2	$1.0\text{-}17.2 \times 10^2$
3	2	0	0	0	0	9.2×10^2	$2.3\text{-}36.7 \times 10^2$
3	2	1	0	0	0	14.7×10^2	$4.1\text{-}52.1 \times 10^2$
3	3	0	0	0	0	23.0×10^2	$6.6\text{-}80.3 \times 10^2$
3	3	1	0	0	0	42.4×10^2	$10.4\text{-}172.5 \times 10^2$
3	3	2	0	0	0	91.8×10^2	$22.9\text{-}367.2 \times 10^2$
3	3	2	1	0	0	14.7×10^3	$4.1\text{-}52.1 \times 10^3$
3	3	3	0	0	0	23.0×10^3	$6.6\text{-}80.4 \times 10^3$
3	3	3	1	0	0	42.4×10^3	$10.4\text{-}172.7 \times 10^3$
3	3	3	2	0	0	91.9×10^3	$23.0\text{-}367.7 \times 10^3$
3	3	3	3	1	0	14.7×10^4	$4.1\text{-}52.2 \times 10^4$
3	3	3	3	0	0	23.0×10^4	$6.6\text{-}80.8 \times 10^4$
3	3	3	3	1	0	42.7×10^4	$10.4\text{-}175.2 \times 10^4$
3	3	3	3	2	0	93.3×10^4	$23.2\text{-}375.1 \times 10^4$
3	3	3	3	2	1	14.9×10^5	$4.2\text{-}53.6 \times 10^5$
3	3	3	3	3	0	24.0×10^5	$6.7\text{-}85.7 \times 10^5$
3	3	3	3	3	1	46.2×10^5	$10.4\text{-}205.0 \times 10^5$
3	3	3	3	3	2	109.9×10^6	$25.7\text{-}470.5 \times 10^5$
3	3	3	3	3	3	$>240.0 \times 10^6$	

Reference

Fisher, R.A., and Yates, T. 1963. Statistical tables for biological, agricultural and medical research. Edinburgh, UK: Oliver & Boyd.

Measurement of biological nitrogen fixation

During the century since the discovery that nodulated legumes fix atmospheric N_2 into forms which can be used for synthesizing their own protein, legumes have become important features of many agricultural systems. Traditional agriculture has utilized N_2-fixing components for production of food and fiber, often without realizing the potential benefits of such systems. Current attempts to improve traditional methods or to realize the full potential of more advanced agricultural systems and to introduce innovations will ultimately be assessed in terms of improvements to production and to the quality of the products. Nevertheless, evaluation of developments on the way to achievement of these improvements will be aided by more accurate quantitative assessment of the levels of N_2 fixation actually achieved in the field.

Ecological considerations for conservation of landscapes demand an understanding of the relative importance of N_2-fixing components in the maintenance of N-balance. Development of farming systems requires the preservation of nutrient balance. Understanding the amount of N_2 fixed by legumes in various cropping sequences allows development of more efficient systems for maintaining N-balance. Measurement of N_2-fixation establishes whether a legume is achieving its potential, and thus becomes an added means of identifying constraints, such as nutrient limitations.

Residual effects on subsequent crops are frequently attributed to N_2 fixation. Other benefits such as improvements in soil structure or control of pests or diseases may have additional effects.

There are several techniques for measuring N_2-fixation associated with field crops. These can be broadly grouped as:

1 Direct
   a N-difference method
   b ^{15}N-based method
2 Indirect
   a Acetylene reduction assay
   b Analysis of N-solubles in plant

Each method has its advantages and limitations. The choice of the method depends on the purpose of the experiment and available facilities. Some of the methods commonly used are described in brief.

N-difference method

The simplest field estimates of N_2 fixation are obtained by measuring total amount of N in the legume crop. Kjeldahl analyses for N content of plant dry matter can be used to estimate total N yield of a field of legumes. This determination is, however, based on the assumption that all crop N comes from fixation; N derived from N_2 fixation and from soil as mineral or fertilizer N are not distinguished. To estimate fixation, it is therefore necessary to determine the quantity of plant N which is obtained from soil. This is achieved by measuring the N content of a non-fixing reference plant (non-nodulated legume or a non-legume). This quantity is subtracted from total legume N to determine N_2 fixed.

This technique is based on the assumption that the test legume and reference plant remove identical amounts of N from the soil. This, however, is largely dependent upon the success of the researcher in matching growth rates of fixing and non-fixing crops. Other factors known to affect plant growth, such as water availability, insects, and diseases, should be similar in both crops. Reference plants commonly used include cereals (usually wheat, barley, or ryegrass), non-nodulating isolines of legumes (available for chickpea, groundnut, soybean, and pigeonpea), and uninoculated or ineffectively nodulated legumes. Of these, the non-nodulating isolines probably give the best results, although differences in root morphology may cause considerable error. The potential for N assimilation by most non-legumes is not as high as for legumes, generally resulting in an overestimation of N_2 fixation. If levels of soil N are low and reference plants accumulate much less N than the fixing legume, error due to plant type will be minimal.

Advantages of this assay are simplicity and the fact that it is a direct measure of plant growth and N fixation/uptake. It is also a time-integrated measurement, giving a total fixation estimate for the whole season. Matching growth rates and N uptake in reference and fixing crops remains the major disadvantage of this technique. There are three possibilities: (1) approximately equal amounts of soil N will be assimilated by test and reference plants, resulting in an accurate estimate of N_2 fixation; (2) in a low N soil, the more vigorous nodulated plant will produce greater root mass and therefore explore a greater volume of soil. N_2 fixation will be overestimated because the N_2-fixing legume will take up more soil available N than the reference plant; and (3) the fixing legume with an active symbiosis will require and take up less soil N than the reference plant, and fixation will be underestimated.

Calculation: Several variations of the N-difference method exist. Generally the quantity of legume N

derived from N_2 fixation (Q) is calculated as:

$$Q = \text{N yield (legume)} - \text{N yield (reference)} \quad (1)$$

In the case where legume and reference are not well matched, measurement of postharvest soil mineral N can be determined in the fixing and non-fixing plots and added to the differences in total N yields of the two crops:

$$Q = \text{N yield (legume)} - \text{N yield (reference)} + [\text{N soil (legume)} - \text{N soil (reference)}] \quad (2)$$

The use of equation 2 assumes that mineralization, leaching, and denitrification are identical under each crop, which may not be generally true. More importantly, data may be confusing owing to the lack of precision in soil-N measurement techniques.

Acetylene reduction assay

The advent of the acetylene reduction technique for measuring nitrogenase activity, under development since 1968, has provided a powerful tool for work in the field of biological nitrogen fixation (BNF). The assay is based on the principle that nitrogenase, the enzyme responsible for reducing the N_2 to ammonia, also reduces acetylene (C_2H_2) to ethylene (C_2H_4). Ethylene and acetylene can be readily measured by flame ionization gas chromatography. Acetylene reduction assay (ARA) is a simple and an indirect method to test nitrogenase activity. It is about one thousand times more sensitive than ^{15}N techniques and 10^6 times more than the Kjeldahl technique for measuring nitrogenase activity.

The major difficulty, however, with the use of the ARA is in quantifying the amounts of N_2 fixed over time. The relationship between the rate of reduction of C_2H_2 and that of N_2 varies with the experimental system and is seldom experimentally determined.

Procedure: Plant roots should be dug carefully along with the nodules. In plants of crops such as pigeonpea the nodules are attached delicately to the roots which get separated during digging and the rooting is very deep which results in low recovery of nodules. The plant roots and nodules are put in airtight wide-mouthed glass bottles (jam bottles) and jars are closed with Suba seal and screw cap. Acetylene gas is injected (10% of free volume of the assay container) and incubated for 30 minutes in shade. Containers without roots serve as blanks. At the end of 30 minutes, gas samples are collected from each container through the Suba seal and stored in pre-evacuated 'Venoject' tubes. Gas sample vacuatainers should be brought to normal atmospheric pressure by puncturing with a syringe needle.

After thorough mixing, 0.5 ml gas sample is withdrawn with 1 ml syringe and injected on to a gas chromatograph (GC) fitted with a flame ionization detector and a column packed with a porapak N. Measurement of C_2H_2 and C_2H_4 concentration is used to calculate amount of ethylene produced in a given time. In its usual form each assay gives an estimate of the rate of nitrogenase activity at the time of assay. To determine total activity over a period of growth, many assays are needed.

^{15}N-based methods

The stable, heavy isotope of nitrogen (^{15}N) is used as a tracer in investigations on BNF with the following assumptions: (1) the behavior of ^{15}N in chemical, physical, and biological processes is identical to that of ^{14}N (plant roots confronted with two sources of a nutrient will therefore take up that nutrient in the proportions present); and (2) the application of ^{15}N does not affect the supply of nitrogen from the soil.

^{15}N dilution: In the ^{15}N dilution method, ^{15}N labeled fertilizer or organic materials are added to the growing medium, in amounts insufficient to significantly affect N_2 fixation, in an attempt to label the inorganic N pool from which the plants obtain their N. The method assumes that roots of the test crops or varieties utilize the same volume of soil for their N requirement.

One of the often stated advantages of ^{15}N dilution methods is that the calculated proportion (P) of plant N obtained from N_2 is independent of the variability which is always associated with

measurements of total N in field-grown plants. Further, as the values for *P* change with time the plants integrate these changing proportions up to the point at which plants are taken for analysis.

Both fixing and non-fixing reference plants are grown in the presence of a ^{15}N labeled source in as near-identical conditions as is practical. If both the plants contain identical concentrations of ^{15}N, no N_2 fixation has occurred. Any ^{14}N incorporated by the presumed "fixer" from the atmosphere will lead to a lower ^{15}N concentration, i.e., isotope dilution occurs. From comparisons of the ^{15}N contents of the two plants it is possible to calculate the amount of N_2 fixed.

Calculation:

$$\text{N fixed (\%)} = 1 - \frac{\text{Atom N (\%) excess (fixing plant)}}{\text{Atom N (\%) excess (non-fixing plant)}} \times 100$$

Actual N fixed = N (%) fixed x total N uptake by the plant.

Quantification of vesicular-arbuscular mycorrhiza in plant roots

Quantification of mycorrhizae is needed to determine the degree and intensity of root colonization of the plants. The primary purpose of any assay for vesicular-arbuscular mycorrhiza (VAM) is to establish whether roots are colonized and to determine the degree of development of mycorrhizae within the root system.

The Phillips and Hayman (1970) procedure for clearing and staining roots for rapid assay of mycorrhizal colonization represents a major breakthrough in VAM research. This procedure is less time consuming and quickly became the most commonly used clearing and staining procedure in mycorrhizal research. However, it had a serious drawback that it used hazardous phenols or saturated chloral hydrate in staining and destaining procedures. The modified procedure excluding phenol is currently widely used.

Root sample collection

The primary site for VAM to develop is in the cortical region of the terminal feeder roots which is the most active site for nutrient uptake. As roots mature, the cortex ruptures and is sloughed off and, thus, mycorrhizae are seldom observed in older roots. Fine terminal roots are left in the soil if considerable caution is not taken during the excavation of plant root systems. If root systems are improperly excavated, roots undergoing secondary growth will constitute the greatest proportion of the sample, resulting in a significant underestimation of the percentage of roots colonized by mycorrhizal fungi. The procedure for root sample collection is given below:

- Regardless of whether the host plant is annual, perennial, herbaceous, or woody, the fine terminal feeder roots are the primary site of VAM development.
- Carefully excavate the roots and collect subsamples of terminal feeder roots. Collect representative subsamples of the entire root system from four or five different portions.

  (Note: Precaution should be taken while excavating roots so that the cortex is not damaged.)
- Wash the root samples gently with tap water.
- Preserve subsamples in tubes or vials with formalin : acetone : alcohol (FAA) fixation solution.

  (Standard FAA is prepared with 50% alcohol with V/V/V ratio of 90:5:5).
- Samples collected and preserved in FAA are used primarily for assessing the fungal morphological characteristics in the roots. These samples are not useful in nutritional or biochemical analysis.

Clearing and staining procedure for roots

- Wash root specimens stored in FAA solution after decanting FAA solution.
- Cover root sample with 10% KOH solution.
- Place the specimens with 10% KOH solution in autoclave at 15 psi for 10 min (If autoclave is not available, alternatively, heat the specimens at 90°C for 1 h in a well-ventilated exhaust hood.) The KOH solution clears the host cytoplasm and nuclei and readily allows stain penetration.
- Pour off the KOH solution and wash the specimen with tap water at least three times or until no brown color appears in the rinse water.
- Cover root sample with alkaline hydrogen peroxide (H_2O_2) at room temperature for 10 to 20 min or until roots are bleached.

  (Alkaline H_2O_2 is prepared by adding 3 ml of ammonium hydroxide (NH_4OH) to 30 ml of 10% H_2O_2 and 567 ml of tap water. Three ml of regular household ammonia works well as the NH_4OH source. This solution should be made up as needed; it looses its effectiveness even if stored overnight.
- Wash the sample thoroughly using tap water at least three times.
- Cover specimens with 1% HCl and soak for 3 to 4 minutes and then pour off the solution. **DO NOT RINSE AFTER THIS STEP** as the specimens must be acidified for proper staining.
- Cover the specimens with 0.08-0.1% trypan blue in lactoglycerol solution (200 ml lactic acid, 400 ml glycerin, 400 ml tap water, and 0.8-1 g trypan blue stain) (Harinikumar and Bagyaraj 1988).
- Put the samples in the autoclave for 10 min at 16 psi.
- Pour off the staining solution and add destaining solution (lactoglycerol without trypan blue stain).
- Do not rinse specimens after staining.

References

Harinikumar, K.M., and Bagyaraj, D.J. 1988. Effect of crop rotation on native vesicular-arbuscular mycorrhizal propagules in soil. Plant and Soil 110:77-80.

Phillips, J.M., and Hayman, D.S. 1970. Improved procedures for clearing and staining parasitic and vesicular-arbuscular mycorrhizal fungi for rapid assessment of infection. Transactions of British Mycological Society 55:158-161.

Plant Observations

G Alagarswamy and S P Wani

Experimental Layout

Location of the experiment should be in an uniform piece of land. The replications should be compact and avoid odd shape replications. If the experimental site shows any visible land effects such as poor patch or shallow soil depth, it is essential to block the replicates within the variation.

Plot size

The plot size depends on the crop. If growth analysis is to be carried out frequently (3-4 times), it is necessary to have large plots. Generally, it requires about 8 m^2 for the growth analysis sampling alone. For bulk harvest at the end of the season 10-12 m^2 area is required. Besides this net area enough border areas for bulk harvest and border areas between growth samplings need to be ensured. It is essential to demarcate the areas for growth sampling and bulk harvest from the beginning of the experiment to avoid confusion during the course of the crop season.

Number of rows

The number of rows depends on the types of crops.

Non-destructive Plant Sampling (for Phenology)

It is essential to record the time of various plant developmental stages. They are: (1) seedling emergence; (2) flowering; and (3) physiological maturity.

Seedling emergence

Mark an area within several rows and count the emergence of seedlings over 5 days or until there is no emergence. Seedling counts need to be made on alternate days. A seedling is considered to have emerged if the plant part is visible at the soil surface. For measuring the emergence use a 2-m row length.

Flowering

The observation depends on the type of crop. For cereals such as sorghum, flowering is recorded when the anthers are seen in the head; for pearl millet, when the stigmas are visible fully; and for legumes, when the first flower appears. For maize, the emergence of silks from the ear is measured. For measurement, mark a specific length of a row and observe every alternate day. In cereals 50% flowering is reached when 50% of heads have either anthers, stigma, or silks depending on the crop; and in legumes, when 50% of plants in a marked area have the first flower open.

Physiological maturity

Physiological maturity is the stage when there is a black spot on the basal region of a single seed in the bottom portion of the head. The seed is very hard. Allow 10 days after the formation of black layer for harvesting.

Destructive Sampling

Destructive sampling is necessary to measure the total plant biomass and biomass in various plant parts. The number of harvests may usually be 4-5 times during the crop life cycle and each sampling may be done at 10-15 days interval from seedling emergence. This sampling can also coincide with some of the developmental stages of the crop such as 20 days after emergence, at flowering, 15 days after flowering, and one at physiological maturity.

During the sampling periods it is essential to determine the following:

- Plant and tiller numbers (if any).
- Total dry weight.
- Dry weight of plant parts [leaf, stem, and heads (cereals) or pods (grain legumes)].
- Weight of fallen leaves (important for pigeonpea).

Sampling quadrate

While laying out the experiment it is essential to make sure you demarcate specific areas (sampling quadrate) for growth analysis and destructive sampling. This avoids leaving a large empty area within the experimental plot causing large border effects. A common sampling area would be about 1.25 m^2 for cereals and for other crops such as pigeonpea a larger area may be marked. It is essential to reserve a specific sampling area to collect the fallen leaves at intervals. This is essential to avoid underestimation due to decomposition of leaves at bottom layers especially for pigeonpea since there will be a lot of fallen leaves.

Sampling method for dry weight

- Use the central two rows in a four-row plot and cut the plants from the ground level in the sampling quadrate. Count the plant numbers.
- Separate plant parts such as leaf, stem, and panicles if any, from the plants. Take a sub-sample of leaves from the total for leaf area estimation (about 10% of total leaves: procedure for leaf area is estimation given below).
- Cut the stems into smaller bits. Keep all the plant parts in a cloth bag and dry in an oven at 80°C for 72 h.
- After drying, cool the samples for some time and weigh the dry plant parts.
- Grind the dry plant part samples for nutrient analysis.

Leaf area measurement

The sub-samples taken from the total leaf sample can be measured using a leaf area meter. Alternatively use the following formula:

$$\text{Leaf area} = (\text{Leaf length} \times \text{Leaf breadth}) \times \text{Calibration factor}$$

The calibration factor for sorghum and maize is 0.75. For other crops it can be worked out. After measuring the leaf area from the sub-sample dry the leaves in an oven as explained earlier. Take the dry

weight of the sample and do not forget to add to the total leaf dry weight estimated. Leaf area index can be calculated using the leaf dry weight ratios.

Example:

Leaf area in sub-sample	= 1000 cm^2
Sub-sample leaf dry weight	= 5 g
Specific leaf area	= 1000/5 g = 200 $cm^2 g^{-1}$
Rest of leaf dry weight	= 20 g
(from dry weight estimation procedure)	
Total leaf dry weight	= 5 + 20 = 25 g
Total leaf area	= 200 x 25 = 5000 cm^2.

Bulk harvest

- Count the total number of plants in the bulk harvest area. Cut off the plants from above the ground level.
- For determining the dry weight of bulk samples use the sub-sampling technique. From the bulk harvest take a sub-sample of plants of 10 kg fresh weight or less. Estimate the fresh weight of both sub-sample and rest of the bulk sample at the same time. Dry the sub-sample in an oven and weigh it. Work out a ratio of fresh to dry weight in the sub-sample and use this ratio to derive the dry weight of the rest of sample from bulk harvest. Do not forget to add the sub-sample dry weight to the rest of the bulk sample to get total dry weight.
- Cut the panicles/heads from the bulk sample. Air dry them for 4-5 days in hot sun. Estimate the air dry weight of the panicle. This weight may be useful to derive threshing percentage. The grains are threshed from the dry panicles and weighed.

Socioeconomic Data-sets

P K Joshi and P Parthasarathy Rao

Sustainable development of rainfed agriculture is receiving high priority to accelerate the pace of development and improve the quality of life of millions of people dependent on agriculture. To develop feasible technologies and effective policies for sustainable development, it is necessary to: (1) identify existing and potential production and resource constraints; (2) test the techno-economic feasibility of improved technologies, and identify the most vulnerable areas for targeting the technologies; and (3) understand the response of ultimate client on improved technologies and its related policy issues. To achieve these objectives sufficient amount of data is required. The main purpose of this paper is to list the data needs for conducting socioeconomic studies to propose appropriate policy directions for enhancing productivity and sustainability in the tropical, intermediate rainfall zone. It also gives important sources of necessary data-sets.

Socioeconomic studies in Integrated Watershed Project can broadly be grouped into seven important areas. These are: (1) characterization of the production system for crop intensification; (2) nutrient management; (3) waterlogging and land degradation; (4) farmers' perception about improved technologies; (5) assessment of financial and economic feasibility of improved technologies; (6) constraints to adoption of improved technologies; and (7) modeling to extrapolate research information.

Essential Data-sets

A range of data-sets required to critically analyze and propose a set of recommendations and policies for sustainable development of rainfed agriculture is discussed.

Characterization of the production system

The main purpose to characterize different production systems is to identify existing and potential production constraints, and propose potential areas for targeting technology transfer for sustainable development. It requires huge data-set from a number of secondary sources, both published and unpublished. The following socioeconomic data-sets may be essential to complement other data needs for characterizing the production system(s).

Land use pattern

The land use pattern includes the following data: geographical area, forest area, non-agricultural use, barren and uncultivable land, permanent pasture and other grazing lands, land under miscellaneous trees and groves, culturable wasteland, permanent (other) fallow, current fallow, net area sown, area sown more than once, and gross cropped area (GCA).

Area, production, and yield of important crops

Time series data for the past 25-30 years on area, production, and yield of all major and minor crops grown in the production system(s) will be required to examine spatial and temporal changes in area under different crops and possible crop substitution. Important crops in the production system are:

- Cereals: Rice (season-wise), wheat, sorghum (season-wise), pearl millet, maize, finger millet, and other millets.

- Pulses: Chickpea, pigeonpea, and other pulses (season-wise).
- Oilseeds: Groundnut (season-wise), rapeseed and mustard, sesame, linseed, and other oilseeds.
- Cash crops: Sugarcane, cotton, jute, mesta, and tobacco.
- Fruits and vegetables: Onion, other vegetables, and fruits.

Input use

Data required: Crop-wise labor use, crop-wise fertilizer use, crop-wise area under high-yielding varieties (HYVs), crop-wise pesticide use, crop-wise irrigated area, number of tractors, number of bullocks, and crop-wise cost of cultivation.

Output and input prices

Farm harvest and retail prices of important crops and the prevailing input prices during the past 25-30 years will be required to examine the cost, profitability, and competitiveness of different crops in the region.

Farm harvest prices:

- Cereals: Rice (season-wise), wheat, sorghum (season-wise), pearl millet, maize, finger millet, and other millets.
- Pulses: Chickpea, pigeonpea, and other pulses (season-wise).
- Oilseeds: Groundnut (season-wise), rapeseed and mustard, sesame, linseed, and other oilseeds.
- Cash crops: Sugarcane, cotton, jute, mesta, and tobacco.

Input prices: Seed, fertilizers, pesticides, farm operations, sex-wise labor wages, crop-wise canal rates, and electricity charges for irrigation.

Irrigation

Information required: Gross irrigated area, net irrigated area, source-wise irrigated area, crop-wise irrigated area, number of private tube wells, number of public tube wells, number of pumpsets, and irrigation potential.

Economic variable

Data required: Total working force (sex-wise), dependence in agriculture, agricultural laborers, poverty indicators.

Demographic information

Information required: Total population, urban population, rural population, distribution by age and gender, literacy indicators, proportion of literate males and females.

Rural infrastructure

Information required: Intensity of roads in rural areas, number of regulated markets, number of rural banks (nationalized, cooperative, regional rural banks), number of electrified villages, number of sugar factories, number of other processing mills, number of research centers, number of technology transfer agencies, and number of staff engaged in technology transfer.

Degradation of natural resources

Data required: Extent of land degradation (e.g., soil erosion, soil salinity, waterlogging, deforestation, etc.), depth of watertable and its trend, extent of pest/disease damage and application of pesticide, and

extent of water runoff and downstream flooding.

Economic feasibility of improved technologies

Studies on economic feasibility of all improved management strategies and technologies are essential to know their costs and benefits under different scenario. The following data-set is required to assess the economic feasibility of improved technologies:

- Capital cost: Component-wise cost of any soil and water management technology which has a long life.
- Input cost: Item-wise cost of all inputs required for crop production with improved technology; item-wise cost of all inputs required for crop production with existing (local) technology.
- Output: Output produced and prices with improved technology; output produced and prices with existing (local) technology.

Accessing the database and interfacing with geographical information system (GIS)

The data are stored in Foxpro version 2. The files can be retrieved as Foxpro files or as QPRO (spread sheet), Excel, or Text files (ASCII). Using ARCVIEW software, the database is now conveniently interfaced with GIS. At ICRISAT, data for any variable can be plotted across all districts in 13 states of India. Indeed, any combination of agricultural, climatic, and socioeconomic data can be superimposed onto the district-level map for analysis or illustrative purposes: Maps have been digitized based on two time periods, 1966 and 1991.

Nutrient management

Nutrient management studies intend to: (1) assess the crop-wise fertilizer use pattern in production systems PS7 and PS8; (2) measure economic (in)efficiencies of different nutrients; and (3) to evaluate the constraints to adoption of recommended nutrient management strategies. Both macro- and micro-level data-sets are needed to accomplish these objectives.

Macro-level data-set

Data collected to characterize the production system(s) may be used to assess district-wise consumption of different fertilizers. The same data-set may be used to determine factors (e.g., price and non-price) affecting fertilizer consumption in the semi-arid tropics (SAT).

Micro-level data-set

- Fertilizer use pattern: Crop-wise, dry and wet areas, and different sources of irrigated areas.
- Cost of fertilizer: Prices of different fertilizers, labor used for fertilizer application, wages of labor for fertilizer application, and method of fertilizer application.
- Fertilizer benefits: prices of produce, and production at different levels of fertilizer application.
- Factors determining fertilizer use: Farm size, cropping pattern, irrigated area, area under HYVs, soil type, use of organic matter, area under green manuring, prices of complementary inputs, and rainfall and its distribution.

Land degradation

The important objectives under land degradation are to: (1) assess farmers' perception on land degradation, and quantify private and social cost of land degradation; (2) examine farmers' coping strategies to manage degraded lands; (3) assess socioeconomic factors to determine the adoption of indigenous and improved technologies; (4) assess economic feasibility of different strategies to manage land degradation; and (5) apply models to extrapolate research results to other locations. The following data-sets may be generated to undertake these studies.

Land degradation and waterlogging

Type of the problem (soil erosion, rills, gullies, waterlogging, soil salinity, runoff problem, etc.), extent of land degradation, soil type, soil depth, area affected by waterlogging, duration of waterlogging, location of fields affected by waterlogging or any kind of land degradation, yield loss due to land degradation.

Resource allocation to affected areas: Crops grown in affected areas, use of different inputs for crop production in affected areas, and yield and net returns under different levels of degradation and waterlogging.

Coping strategies: Land management, soil management, input management, nutrient management, crop management, engineering measures, leased-in and leased-out land, cost of each management strategy, benefits from each management strategy, income from livestock enterprises, focus towards off-farm work, and accumulation and disposal of assets.

Alternative use of degraded land

Area under forest, area under grasses, area kept for animal grazing, and any other use of degraded land.

Personal characteristics

Head of the household, sex of head of the household, age of the head of the household, educational level of the head of the household, sources of income, any position in village committees, and links with extension agencies.

Farmers' perception on land degradation

Farmers' knowledge about land degradation, stage of land degradation, farmers' response to land degradation, farmers' views on seriousness of the problem, land value of degraded land, investment strategies on degraded lands.

Land and ownership

Owned land (irrigated/unirrigated), leased-in land, leased-out land, operated area, fallow land (other fallow), quality of land, number of fragments, location of fragments, and season-wise cropping pattern.

Constraints to adoption of improved technologies

In the past, several technologies were developed and demonstrated to the farming community. A few were accepted by the farmers. Some were partially adopted or adopted after some modification. Many technologies were not adopted by the farmers. A large number of factors are responsible for adoption of specific technology. Studies under this section are proposed to identify factors which constrain and/or facilitate adoption of improved technologies. The following type of data-sets, supplemented by some of the data-sets listed above, will be needed.

Lack of information

Education level, contacts with extension agencies, contacts with research organizations, frequency of watching agricultural programs in television, frequency of listening agricultural programs in radio, attendance to any farmers' day, discussion of problems with fellow farmers, frequency of reading agricultural column in newspaper, consult any agricultural magazine, frequency of visits to any agricultural agency, number of extension programs in the villages, number of government and non-government organizations functioning in the village, and presence of T&V program in the village.

Agroclimatic and soil constraints

Month-wise rainfall, soil type, soil pH, and hydraulic conductivity of soil.

Resource constraints

Lack of capital, unavailability of credit, priority of obtaining credit for different purposes, interest paid on earlier credit, unavailability of subsidy, unavailability of improved cultivars, unavailability of water for irrigation, labor unavailability, and higher wages of labor.

Inadequate technology

Cost of the technology, yield gains due to technology, benefits of improved technology, difficulty in adoption, and unavailability of appropriate implements.

Modeling

By supplementing data from the experiment station the above-stated data-sets will be used for modeling to extrapolate research results to other locations.

Resource use

Nutrient-wise fertilizer, operation-wise labor, time and volume of irrigation, time and quantity of herbicide or pesticide, sowing time and seed rate, method of sowing, and factor shares.

Output

Yield of main crop and intercrop (if any) under different treatments, and yield of by-product under different treatments.

Prices of input and output

Prices of all inputs used for crop production, prices of main crop and intercrop, and prices of by-product.

Resource availability

Land for specific crop or activity, season-wise labor availability, source-wise irrigation water available, season-wise water availability, information on extent of land degradation.

Data Sources and Analysis

Characterization of production system

Data source

District and block-wise information is collected to characterize the production system(s). A time-series of each listed variable should be developed for a period of 25-30 years. Important sources of data in India are:

Agricultural Statistics (state-wise); Area and Production of Principal Crops (Vol. I & II); Different issues of Agricultural Situation in India; Fertilizer Statistics; Different issues of Agricultural Census; Season and Crop Reports of different States; Population Census of different States; Food Statistics; and Livestock Census (Vol. I & II).

For other countries, the statistical bulletin of the respective country can be consulted. It can be supplemented by the FAO Production Year Book.

Analysis

The analysis should be undertaken to characterize the potential regions for crop intensification. The analysis will include: (1) identification of socioeconomic constraints in the production system(s); (2) examination of spatial and temporal changes in acreage under different crops, land use pattern, resource availability; and (3) potential target areas for introducing improved technologies. These can be analyzed as follows:

- Simple (linear) and compound (log-linear) growth rates are computed for each variable listed under the characterization of production system.
- Production function analysis is done using crop intensification as dependent variable. Several technical, socioeconomic, agroclimatic, and institutional factors are identified to determine factors constraining or facilitating crop intensification.
- Economic efficiencies are worked out to assess whether double cropping is profitable or there is enough scope (or potential) to increase yields and profitability of single crop by improving technical and allocative efficiencies.

Economic feasibility of improved technologies

Data source

Regular observations from on-station and on-farm trials will be essential to collect data on quantity of various inputs used for crop production and yield under different treatments. Information from the on-station trial should also be collected on item-wise material and labor used for making some soil and water conservation measures. These data-sets are to be supplemented by the data on input and output data from input and output market.

Analysis

- Enterprise or partial budgets are developed to measure marginal rate of returns due to improved technology.
- Benefit-cost analysis are carried out for technologies which are related to prevent or reclaim degraded natural resources.

Nutrient management

Data source

The main source of district-wise fertilizer consumption in India is the 'Fertilizer Statistics'. Another source is the "Statistical Abstract" published by the Economic and Statistical Unit of the State departments. Country-wise data on fertilizer consumption may be available from FAO Production Year Book. For primary data, on-farm survey will be required to collect detailed information from farmers. A questionnaire may be designed for this purpose to collect desired information.

Analysis

Fertilizer-related information is analyzed to address the issues focusing fertilizer-use efficiency. Fertilizer use pattern in different crops grown under different environments (e.g., irrigated and unirrigated, different cropping sequence, etc.) can be assessed. Using appropriate technique, marginal rate of return of fertilizer application under different environments is computed to make suitable fertilizer recommendations.

The analysis can be extended to estimate production or profit functions of different forms to derive demand for fertilizer, and measure technical and allocative efficiencies. Discriminate or tobit analysis can also be done to determine factors affecting fertilizer use in SAT.

Waterlogging and land degradation

Data source

Information on waterlogging and land degradation is not readily available from published sources. Some state-wise estimates are available and documented in "Indian Agriculture in Brief". District-wise statistics on waterlogging and land degradation is rarely available. The following sources may have this kind of information:

National Bureau of Soil Survey and Land Use Planning; National Remote Sensing Agency; Central Soil and Water Conservation Research & Training Institute; Ministry of Environment; Ministry of Irrigation; and Soil Conservation Department in different States.

One has to rely more on survey data at benchmark sites. The survey may be undertaken to measure the extent of waterlogging and land degradation.

Analysis

Waterlogging and land degradation are important production constraints in rainfed agriculture. The analysis under this theme includes estimation of losses due to land degradation, farmers' perception about land degradation, and strategies adopted by the farmers to cope with the land degradation. The financial and economic feasibility of alternative technological or management options may be assessed to propose cost-effective options to manage degraded lands.

Constraints to adoption of improved technologies

Data source

Literature review may provide good idea about constraints to adoption of improved technologies. For specific technology, a reconnaissance survey should be undertaken to identify important constraints.

Analysis

One of the most important objectives of such studies is to identify factors responsible for adoption of the improved and indigenous technologies to alleviate production and/or resource constraints. The objective of collating information in this section is to identify important constraints in adoption of improved technologies. The study will identify both types of factors which constrain and/or facilitate adoption of improved or indigenous technologies. The results of these studies will help in designing appropriate technologies and policies to improve the sustainability of the production system. A number of factors will be identified and their role in adoption process will be evaluated by estimating appropriate production or profit function.

Modeling

Data sources

Important data sources for modeling are from experimental results, on-farm testing results, and farmers' interviews. Observations are decided depending upon the data need of the model.

Analysis

The model is simulated and optimized under different resource availability and policy scenario.

Data Collection

Biases in survey estimates are obviously introduced through data collection method, time of survey questionnaire design, and skill of enumerator. Proper care should be taken to avoid the error caused by following wrong approach. The following steps should be adopted to collect reliable information. A sample survey questionnaire for watershed baseline data collection is described in Appendix IV.

Sampling scheme

In this section, a general sampling scheme is proposed for most of the surveys. Sampling scheme will vary with the objectives of the study. Care should be taken while finalizing the sampling scheme. Here it is a guideline to select final sampling unit.

A three stage sampling will be most appropriate for the type of studies proposed under watershed project.

Stage I

Divide the whole study area (country or state or production system or district) into three strata. Stratification is done on the basis of the intensity of the specific activity which one intends to study. For example, if one plans to study farmers' perception on land degradation, the three strata are: (1) highly degraded area; (2) moderately degraded area; and (3) low level of degraded area. If it is nutrient management, stratification is done on the basis of fertilizer (nutrient) consumption: (1) high nutrient consuming region; (2) moderate fertilizer consuming region; and (3) low fertilizer consuming region. Similarly, if one intends to identify constraints to adoption of specific technology, stratification is done as per the area under the crop which is relevant to the technology. In this case, one should be careful in delineating the study area. Select one district randomly (or agroclimatic zone) from each strata.

Stage II

Follow same procedure as in Stage I to divide the district (or agroclimatic zone) into three strata depending upon the intensity of the driving variable. Select one block (or other unit) from each district

(or agroclimatic zone). In case of limited budget, each district may be divided into two strata instead of three, and select one block from each strata.

Stage III

Prepare list of villages and rank them according to the criteria used for stratifying the district in Stage I. Select three villages from each of the strata. One additional village may also be selected as a control village, making a total of ten villages in one stratum. Ten farmers (3 large, 3 medium, 3 small, and one control) from each village may be selected. The criteria of categorizing, farmers are:

- Small farmer - land holding ≤ 1.99 ha.
- Medium farmer - land holding between 2.00 and 3.99 ha.
- Large farmer - land holding ≥ 4.00 ha.

Selection of farmers is made randomly from each size class. In case of low budget for survey, a cluster of villages is formed, and farmers are selected from the cluster to reduce the sample size.

Method of data collection

Several approaches are adopted to generate desired information from the respondents. These include: (1) community group interview; (2) formal interview with individual households; (3) frequent visits to the study area and regular discussions with the respondents; (4) direct observations; and (5) rapid rural appraisal method. Either of the approaches may be selected depending upon the objectives of the study, availability of budget for the survey, and the affordable error in the estimates.

Community group interview may be better while characterizing the production system; formal interviews with individual households may be good for studies related to nutrient management and constraint analysis; while rapid rural approach may be appropriate for studies on land degradation and waterlogging. One should also go for direct observation to measure extent of land degradation and associated externalities with it.

Timing of survey

Survey timing is very important to obtain reliable information. It should be done when farmers are relatively free to give sufficient time to enumerators for discussion. Data collection immediately after the harvest of the crop will give more reliable information about production and input use. Information on land degradation and waterlogging may be collected when these problems exist on the farm.

Selection of investigator and training

Selection of investigators and their training is the most important step in collection of appropriate data. It has been observed that field conditions for investigators are arduous, and the work is tedious. Interviewing the farmers requires special skill and great patience. The investigator should have commitment for data collection. He/she should clearly understand the objectives of the study and questions listed in the survey schedule. Investigators are required to be familiar with the farming system and to have knowledge of improved technologies. They should have knowledge of farmers' language and should understand the local terms. It is necessary for better communication between the investigator and the farmer. A training program should be conducted to provide the method of data collection so that they understand each question to get the correct information from the farmers.

Instructions to investigators

- Be familiar with local terminology used by the farmers in the village for measurement. Convert them into standard measurement and enter the information such as area in acres or hectares, weight in kg, quintals, and tons and liquids in liters.

- Have a clear understanding about the objectives of the study, modules, instructions required for data gathering, and codes.
- Visit all respondent houses and important places in the village and indicate them in a map with different colors (farm size, school, gram panchayat, bank, meeting place, temple, seed and fertilizer, shop, etc.)
- Visit few fields in the village to understand the cropping pattern, varieties used, proportion of inter/ mixed crops, pests and diseases.
- If respondent does not understand the questions due to his ignorance, try to explain with patience by giving few examples.
- Treat and respect all respondents equally irrespective of their caste, political influence, social and economical status.
- Do not show/discuss the collected information of one respondent to other farmers and village officials. Keep every thing in confidence.
- Schedules/worksheet should be filled clearly and neatly. Try to provide detailed information in the space provided in the worksheet if you feel something is useful and interesting to researchers.
- Consult your supervisor or researcher if they come across any problem related to work and personal aspects.

A Rainfed Agriculture Typology for Development Planning

Diversity of agriculture and development planning: need for a typology of agriculture

Agricultural development planning is often complicated by extremely diverse agro-ecological and socioeconomic conditions underlying currently observed agricultural practices. A country as large and diverse as India is a prime example for such challenges to development initiatives. This study addresses the crucial question of how to create a useful number of spatial sub-divisions, i.e., a typology, to aid development planning bodies [such as the Indian Council of Agricultural Research (ICAR)] whose geographic mandate spans the full range of diversity in Indian agriculture (Scholz 1987).

By focusing attention on a limited number of agricultural scenarios that offer similar opportunities for response to development initiatives, a set of well-defined regions is a useful aid in developing research programs, policy initiatives, and infrastnicture development projects. Delineation of homogeneous regions also provides a clear focus for measuring achievement and impact that facilitates resource allocation decisions across alternative uses. In research, the identification of similar geographical units to which successful development initiatives can be extended helps utilize economies of scale (Bidinger et al. 1994). Analysis of the spatial units thus created will provide information about the predominant causes of differences in agriculture, and the rate of adoption of development initiatives across rural India.

In the past, the primary goal of agricultural development planning was largely to increase agricultural production. Development strategies were sought to achieve three objectives: (1) to promote the production of crops that are agro-ecologically "best-suited" to an area; (2) to realize natural potential; and (3) to improve production technologies. In this context, it was necessary to delineate regions that were characterized by similar opportunities and constraints to increasing production. Thus it was natural to ascribe primary importance to features that defined the agricultural production technology and determined the productivity potential: physiography, climate, and soils. Agricultural research and extension, policy, and infrastructure development-related decisions could then be made for agro-ecologically homogeneous regions as a whole.

However, given an expanded vision of agricultural development that accords importance to increasing production while emphasizing more efficient use of resources and increasing profitability for farmers, such a delineation of regions is too narrow. What is needed is a typology of agriculture that incorporates not only the factors that define production technology and output, but also the socioeconomic factors that determine the nature of constraints which limit the ability of farmers to produce more efficiently and sustainably. **Agriculture typology refers to a system of types of agricultural production that have certain characteristics in common that would also allow individual production units to be considered representative examples of their group.**

Agricultural activities dominate almost all rural economies. Development strategies and policy instruments must be related to specific features of agricultural activities to induce economic development of rural areas. Therefore, information on the dominant agricultural activities must be an integral part of any attempt to classify districts in India with a view to designing agricultural research programs, making infrastructure investments, or designing poverty alleviation programs for rural areas.

Constructing an improved typology

Identification of key variables

The earlier discussion has two important implications for the construction of a typology. Firstly, that socioeconomic variables must be incorporated in an effective manner along with due consideration of agro-ecological characteristics, and secondly, that attention has to be paid to the existing situation while evaluating alternate plans for effecting change.

Incorporating all conceivably relevant natural and socioeconomic factors that differentiate agricultural systems from each other is neither possible nor practical. Neither is it possible to perfectly model the underlying mechanisms that determine agricultural systems because they are immensely complex. Hence, a set of key socioeconomic and agro-ecological variables must be identified. Subsequent to the identification of key variables, data have to be examined to determine if such variables are available and accessible. Data collection at the district-level was designed to serve this purpose.

Important requirements of a typology

In order to design strategies and choose instruments to be used in both the short and long terms in areas that will likely benefit from the same development strategies, it is important to construct a typology which identifies regions:

- That have similar constraints to the development of the agricultural economy.
- In which development initiatives can be directed to identifiable economic activities.
- That are homogeneous in terms of expected outcomes in response to external changes.

Approaches to the problem

In constructing a rainfed agriculture typology for India, two approaches were considered. Firstly, a structural approach focusing on the underlying determinants of agricultural production. Secondly, an agricultural activities-based approach, focusing on the results of the interactions of the underlying variables themselves and following what is analogous to a reduced form approach in regression analysis.

Structural approach: The structural approach identifies regions by classifying districts into groups that have similar patterns of underlying structural variables (agro-ecological and socioeconomic characteristics). That this approach is potentially capable of satisfying the requirements outlined above is motivated by the following argument: the regions will be structurally similar by definition, and hence responses to external changes would be similar (provided all the relevant stnictural characteristics have

been identified). Moreover, one would expect similar agricultural systems to emerge from similar structural characteristics. Thus, the resulting regions would also be identifiable in terms of types of agricultural systems or production systems.

Key structural variables: The following key structural variables can be identified on the basis of the known technology and economics of agricultural production.

- Agro-ecological variables

  Physical environment:

  - terrain/topology
  - climate
  - soils
  - water resources

  Biotic environment:

  - pests
  - diseases
  - weeds

- Socioeconomic variables
  - output/input market-related
  - labor market-related
  - capital market-related
  - information-related
  - road density
  - presence of processing plants
  - food availability
  - poverty-related (rural wage rate, poverty measures)
  - literacy
  - social attributes: property rights, size of land holdings
  - policy/legal restrictions

Limitations of the structural approach: The success of the structural approach hinges upon the list of variables being comprehensive. A comprehensive identification of variables is usually not possible. Also, it is not possible to perfectly model the interaction between underlying variables. This gives rise to difficulties in answering such questions as: What is the appropriate weight for a characteristic? What are the relevant threshold levels for the variables? Moreover, success depends upon the same underlying variables having equal importance across the various agricultural production systems in a country. Furthermore, there is no guarantee that one would be able to relate each zone to a dominant determinant variable or set of variables, or be able to link zones to specific production systems.

Agricultural activities-based approach: Features of existing agricultural production can be observed that are in themselves a manifestation of the various factors that influence or determine farmer decisions. This approach does not require an exact model of the interactions between the underlying structural features. One or more integrator variable(s) would reduce the onus on the researcher for comprehensive identification of determining factors and their appropriate weights. However, in constructing a typology based upon one or more integrator variables, one should not lose sight of the need to relate development strategies and policy instruments to specific features of the agricultural activities. The final typology should be such that each region can be identified on the basis of similar specific agricultural activities and their relative importance rather than being simply a nondescript

agglomeration of areas formed on the basis of a combination of weighted "key" variables.

One possible integrator variable is the set of agricultural activities undertaken by farmers. Since agricultural activities undertaken by farmers are an articulation of the multiple objectives of the farm within the underlying agro-ecological and socioeconomic constraints of the environment (Collinson 1996), agricultural activities are likely to fulfill the required role of an integrator of key structural variables. Regions identified on the basis of agricultural activities can then be expected to exhibit similar patterns in both the underlying socioeconomic and bio-physical characteristics that have been identified (and perhaps some that were not identified).

As basic descriptors of agricultural activities, agricultural enterprises and their combinations (in area or value terms) can be used to construct a typology. Similar descriptors are common in the agricultural geography literature (Kostrowicki 1981). If necessary, it is possible to further differentiate the agricultural regions on the basis of attributes of agriculture [operational: input intensity (land, labor, fertilizer, machinery/ animal power) and production: degree of commercialization/specialization]. The dis-aggregation would be applications-oriented, i.e., with a view to the particular purpose in mind.

Methodology for constructing and validating the agricultural activity-based typology

Constructing the typology

The data of 1991-93 (triennium average) were used from all rainfed districts in the 13 states of Andhra Pradesh, Bihar, Gujarat, Haryana, Karnataka, Maharashtra, Madhya Pradesh, Rajasthan, Tamil Nadu, Orissa, Punjab, Uttar Pradesh, and West Bengal. A rainfed district was defined as any district where less than 40% of the GCA is under irrigation. Other criteria were also tried, e.g., using less than 35% and less than 30% of the GCA, but these reduced the number of rainfed districts considerably and did not necessarily reduce the importance of irrigated crop based systems in those typologies. The final sample thus consisted of 201 districts (out of a total of 340 in the 13 states). These districts were subsequently clustered into groups (agricultural systems) based on similar shares of the total value of production (TVP) contributed by specific crop and livestock activities.

Key integrator variables: Of the 24 potential crop activities for which data were available from the database, attention was restricted only to the major crops in the region, i.e., those crops that accounted for more than 10% of the TVP in at least 5% of the 201 districts. This was deemed necessary in order to restrict the outcome to major rainfed agricultural systems and to avoid the creation of a very small number of districts in a particular cluster. Because the number of rainfed systems was limited, it was critical to allow maximum discrimination on the basis of differences between major systems. Effectively, the restriction eliminated such crop activities as maize, barley, finger millet, pigeonpea, sunflower, safflower, castor, linseed, and sesame. As a result, the following 15 crop-based activities were included in the analysis: irrigated rice, rainfed rice, irrigated wheat, rainfed wheat, rainy season sorghum, postrainy season sorghum, pearl millet, chickpea, minor pulses, groundnut, soybean, rape seed and mustard, cotton, sugarcane, and total fruit and vegetables.

Livestock activity is represented by two variables: gross value of production from dairy enterprises based on numbers of female bovines (cows and buffaloes) and average milk production and, gross value of production from goat and sheep meat based on numbers and average production, again expressed as a percentage of the sum total of TVP for the district. These data were derived from the latest available livestock census for each state.

To capture the economic importance of various agricultural activities, the values of production data for the crop- and livestock-based activities were used as the integrator variables in clustering districts into systems. Specifically, these values were:

- Gross value of production for 15 major crop activities, expressed relative to the TVP for all crop and livestock activities in a particular district.

- Gross value of production for two major livestock activities: dairy and sheep and goats, expressed relative to the TVP for all crop and livestock activities in a particular district.

Clustering: For the clustering procedure itself, a two-stage hierarchical/non-hierarchical technique was considered most appropriate. Non-hierarchical methods compared to hierarchical ones, generally result in clusters having lower pooled within-cluster sums of squared deviations. A clustering algorithm based upon the Euclidean distance measure of dissimilarity was used. The disadvantage in using non-hierarchical methods, however, is the lack of practical dynamic programing algorithms that converge to a global optimum. To overcome this, it is necessary to initially specify the number and composition of base clusters (i.e., initial centroids) upon which the non-hierarchical clustering is to be built. Specification of the initial centroids affect the final clustering. In other words, with a pre-specified number of clusters it is necessary to find a method of determining the global optimum. Therefore, hierarchical methods were used in the first stage to identify the base clusters. The number of base clusters are pre-determined within specific ranges by the programer. In this case, several runs were made specifying various numbers of clusters within a range of 10 to 35.

In the first stage, 17 binary variables (0, 1) were constructed to represent the presence or absence of a particular crop or livestock activity in the district based on its contribution to the TVP (1 if it exceeded 10% of the TVP, 0 if it did not). Hierarchical complete linkage using the Jacard dissimilarity measure was used to form the base clusters (Kaufman and Rousseeuw 1990).

The 15 crop-based and 2 livestock-based activity variables were also used in the second stage; only the time specific relative shares of the TVP (when over 10%) were used instead of the binary variables. Thus, in the second and final stage, interval-scaled variables were used in a non-hierarchical algorithm to minimize within-cluster variance to arrive at a final set of district groupings or clusters.

Several different typologies were generated by varying the levels of "similarity" between districts, thus resulting in different numbers of clusters. None of the standard statistics for determining the appropriate number of clusters is satisfactory in the present case. This is generally true when a relatively small number of clusters capture the majority of variation in the underlying data. Usual criteria are especially inadequate for detecting less than eight clusters (Nerlove et al. 1996). In this case, a target of 15 to 30 was given as a recommended number of rainfed systems for the typology, with a preference for less if possible (Deepak Ahluwalia, World Bank, personal communication).

Validating the typology

The objective is to validate the methodology for generating a useful agricultural system typology, one which is able to integrate both agro-ecological and socioeconomic factors. Validation will help in identifying the key integrator variables and in predicting the classification of new districts whose membership is presently unknown.

The discriminant analytical model is a useful tool for assessing the discriminating power of a given set of predictor variables (see below). Conceptually, a linear discriminant function of the set of predictor variables is formed in an optimal way to minimize the within-typology variance so that more homogeneity within the typology is retained while forming the zones or systems of the typologies. The discriminant functions thus generated are used to estimate the discriminant scores for each district based on the probability of that district being classified into every possible system of the typology. Based on the highest probability observed, each district is 'assigned' to a system, which is then compared with the actual classification of the district. Such comparisons are then aggregated to evaluate the discriminating power of the predictor variables under different sets of grouping variables based on the rates of correct classification.

There are two predictor variable sets covering socioeconomic and agro-ecological factors. The socioeconomic predictor variable set includes eight variables:

1 Rural literacy (percentage of rural population literate)

2 Wage rate (agricultural wage in Rs day $^{-1}$)

3 Market density (number of regulated markets ha^{-1} of GCA)

4 Population density (rural population ha^{-1} of GCA)

5 Road density (km ha^{-1} of GCA)

6 Irrigation (percentage of GCA)

7 Fertilizer use (kg nutrients ha^{-1} of GCA)

8 Credit (institutional credit ha^{-1} of GCA)

Data from triennium averages (1991-93) were used in all cases. The agro-ecological predictor variable set includes:

- Normal rainfall
- Soil type
- Length of growing period (LGP)

Several iterations were carried out to determine the final predictor variable set for the validation exercise. Among the socioeconomic variable sets, it was found that inclusion of credit resulted in distortions affecting stability in the discriminating power of the predictor variable set. This and other problems associated with the credit data meant that in order to retain all 201 districts for the final analysis, it was necessary to restrict the socioeconomic variables to seven by excluding the credit variable from the stability analysis. For the agro-ecological variables, several iterations with rainfall, soil type, and LGP data were conducted. Based on these interactions it was concluded that the soil type variable does not contribute to the discriminating power of the predictor variable set. It was therefore decided to use normal rainfall and LGP both individually and in combination to capture agro-ecological characteristics.

The "grouping variables" consisted of the 16 agricultural activity-based zones (AAZ) and, for comparison with the structural approach, 16 agro-ecological zones (AEZs). In the final analysis these groupings were considered independently for evaluating and testing the classification of 201 districts from 13 states.

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Managing Databases: Storage and Retrieval

H Mohanty

Data Models

The underlying structure of a database is the data model, i.e., collection of conceptual tools for describing data, data relationships, data semantics, and consistency constraints. The various data models that have been proposed fall into three groups.

Object-based logical data models

The object-based logical data models are used in describing data at logical and view levels. They provide fairly flexible structuring capabilities and allow data constraints to be specified explicitly; e.g., Entity-Relationship model; Object-oriented model; Semantic data model; and Functional data model.

Record-based logical data models

The record-based logical data models are used in describing data at logical and view levels. In contrast to object-based data models, they are used both to specify the overall logical structure of database and to provide a higher level description of implementation; e.g., Relational model; Network model; and Hierarchical model.

Physical data models

The physical data models are used to describe data at the lowest level. In contrast to logical data models, these give implementation details; e.g., Unifying model; and Frame-Memory model.

Entity-Relationship Model

The Entity-Relationship (E-R) data model is based on a perception of a real world that consists of a set of basic objects called entities, and of relationships among these entities. The E-R data model is one of several semantic data models; the semantic aspect of the model lies in the attempt to represent the meaning of the data. The E-R model is extremely useful in mapping the meaning and interactions of real world enterprises onto a conceptual schema. Because of this utility, many database design tools draw on concepts from the E-R model. Some basic notions that the E-R model employs are discussed.

Entity

An entity is a thing or object in the real world that is distinguishable from all other objects. It has a set of properties, and the values for some set of properties may uniquely identify an entity. An entity is represented by a set of attributes. Attributes are descriptive properties possessed by each member of an entity set.

An entity set is a set of entities of the same type that share the same properties or attributes. Entity sets need not be disjointed. The designation of an attribute for an entity set expresses that the database stores similar information concerning each entity in the entity set; however, each entity may have its own value for each attribute.

Formally, an attribute of an entity set is a function that maps from the entity set into a domain. Since an entity set may have several attributes, each entity can be described by set of (attribute, data value) pairs, one pair for each attribute of entity set (Table 1).

Table 1. Student table: an example of an entity set

Name	Roll no.	Residence	Address
Janakirama Raju	98MCMT09	R.No. E-109, NRS Hostel	HCU, Hyd-46
Praveen Kumar	98MCMT16	R.No. E-103, NRS Hostel	HCU, Hyd-46
Upendra Ram	98MCMT29	R.No. E-104, NRS Hostel	HCU, Hyd-46
Biswajit Das	98MCMT31	R.No. L-103, NRS Hostel	HCU, Hyd-46
Nagavally	98MCMT08	R.No. 210, LH-3	HCU, Hyd-46

Notes:

Entity set:	Student
Attributes:	Name, Roll No., Residence, Address
Composite Attributes:	Name (first name, middle name, last name)
	Address (street, city, state, zipcode)
	Street (street no., street name)

Relationship

A relationship is an association among several entities. A relationship set is a set of relationships of the same type. Formally it is a mathematical relation on n to 1 (possibly non-distinct) entity sets.

If E1, E2, ..., En are entity sets, then relationship set R is a subset of {(e1, e2, e3, ..., en) / e1 ϵ E1, e2 ϵ E2, ..., ene En} where (e1, e2, e3, ..., en) is a relationship.

The association between entity sets is referred to as participation, that is the entity sets participate in relationship-set. A relationship instance is an E-R schema which represents that an association exists between the named entities in the real world enterprise that is being modeled.

The function that an entity plays in a relationship is called that entity's role. Since entity sets participating in a relationship set are generally distinct, roles are implicit and are not usually specified. But they have importance in recursive relationship set. So explicit role names are necessary to specify how an entity participates in a relationship instance (Fig. 1).

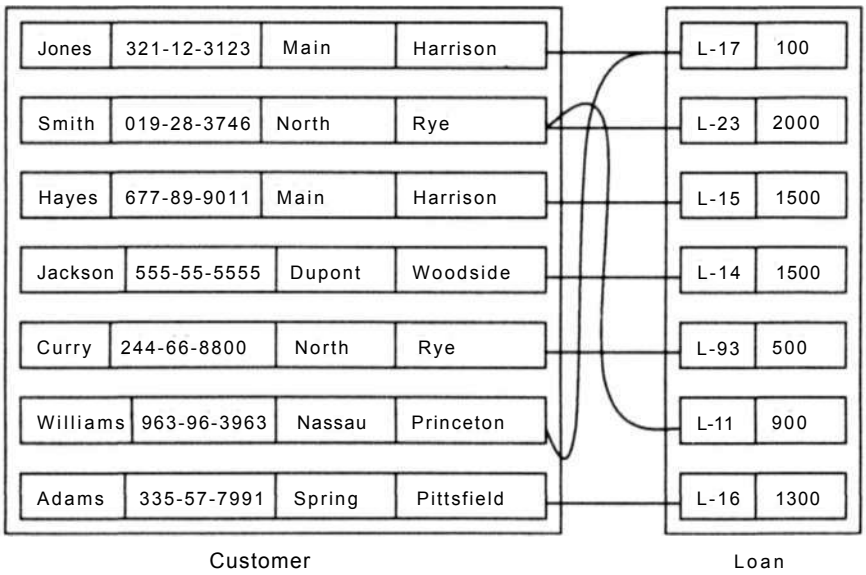


Figure 1. Customer-loan relationship.

Aggregation

The limitation in E-R model is that it is not possible to express relationships among relationships. The best way to model that situation is to use aggregation. Aggregation is an abstraction through which relationships are treated as higher level entities.

For example, let us consider a database describing information about customers and their loans (Fig. 2). Suppose that each customer-loan pair has a bank employee who is the loan officer for that particular pair. It appears that the relationship sets borrower and loan officer can be combined into one single relationship set. Nevertheless, we should not combine them, because doing so would obscure the logical structure of this schema.

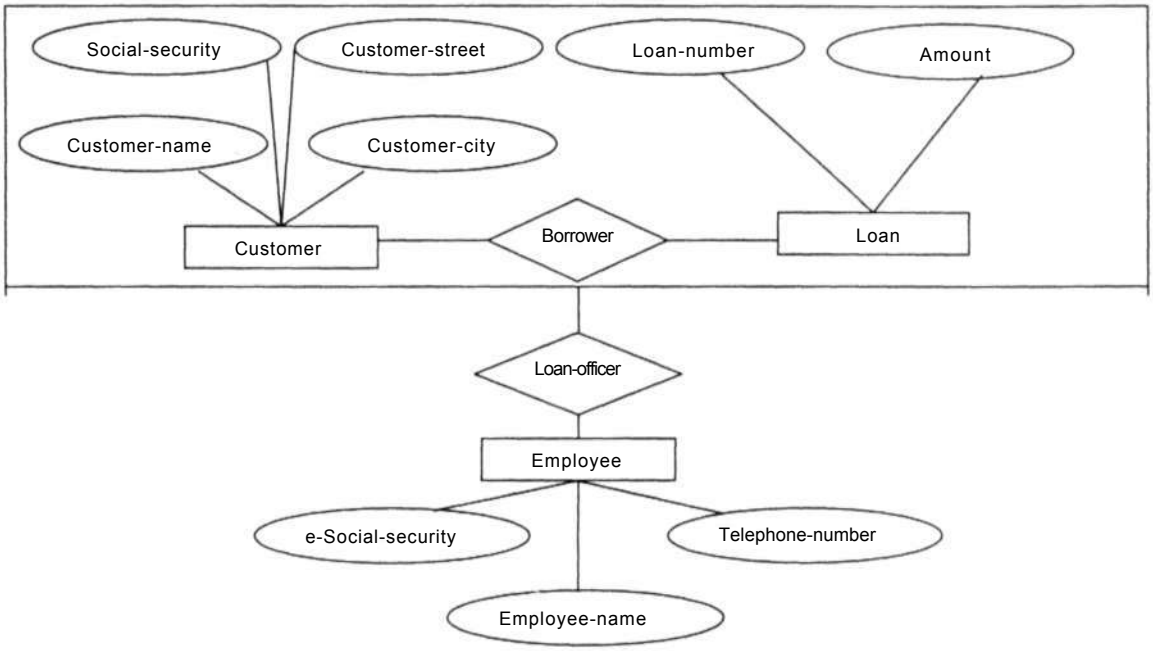


Figure 2. An Entity-Relationship model using aggregation.

Using aggregation for this example, we regard the relationship set borrower and the entity sets customer and loan as a higher-level entity set called borrower. Such an entity set is treated in the same manner, as is any other entity set.

Generalization

The refinement from an initial entity set into successive levels of entity sub-groupings represents a top-down design process in which distinctions are made explicit. The design process may also proceed in a bottom-up manner in which multiple entity sets are synthesized into a higher-level entity set based on common features.

For all practical purposes, generalization is a simple inversion of specialization. We will apply both processes, in combination, in the course of designing the E-R schema for an enterprise.

Generalization proceeds from the recognition that a number of entity sets share some common features (namely, they are described by the same attributes and participate in the same relationship

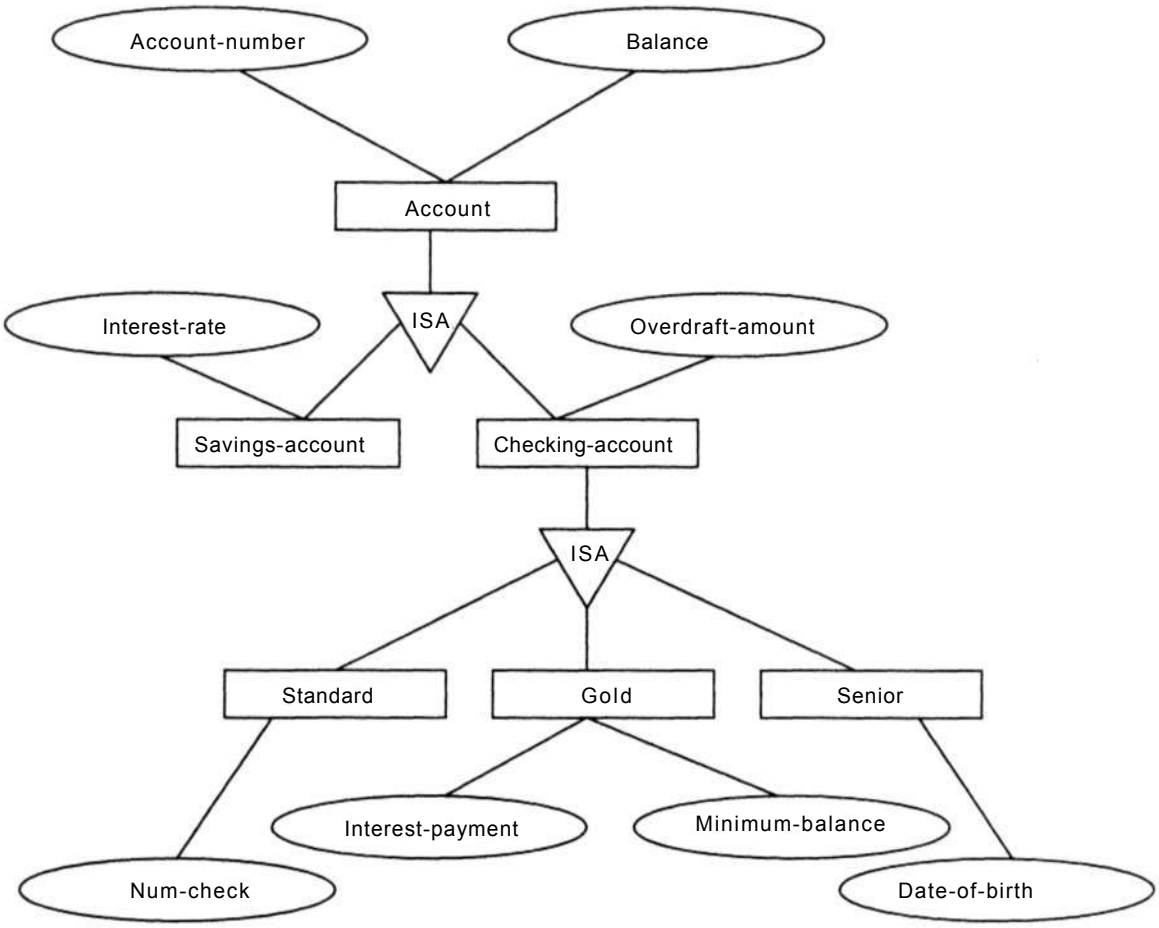


Figure 3. Entity-Relationship diagram with generalization.

sets). Based on their commonalties, generalization synthesizes these entity sets into a single, higher-level entity set (Fig. 3). Generalization is used to emphasize the similarities among lower-level entity sets and to hide the differences; it also permits an economy of representation in that shared attributes are not repeated.

Entity-Relationship diagram

The overall logical structure of a database can be expressed graphically by an E-R diagram (Fig. 4). The relative simplicity and pictorial clarity of this diagramming technique described below may well account largely for the widespread use of the E-R model.

- Rectangle represents entity sets.
- Ellipse represents attributes.
- Diamond represents relationship sets.
- line represents link attributes to entity sets and entity sets to relationship sets.
- Double ellipse represents multi-valued attributes.
- Dashed ellipse represents derived attributes.
- Double lines indicate total participation of an entity in a relationship set.

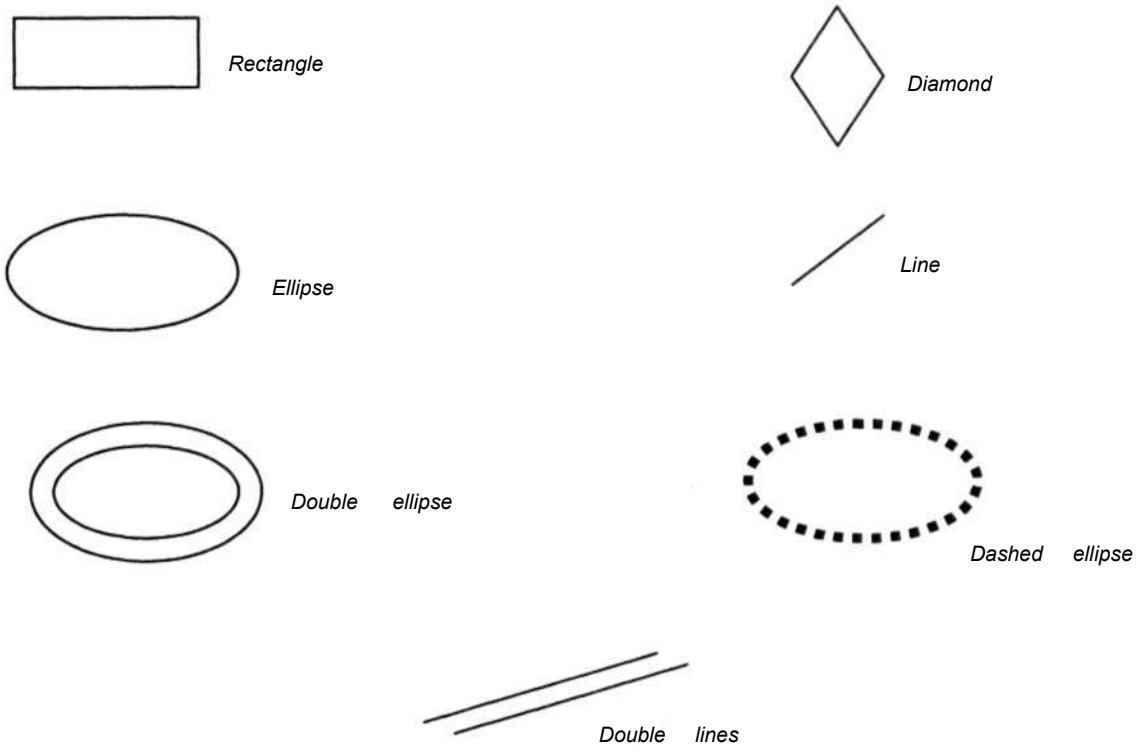


Figure 4. Entity-Relationship diagram primitives.

To indicate different cardinalities of relationships, directed or undirected, line is used between the relationship set and entity set. Roles in E-R diagrams are indicated by labeling the lines that connect diamonds to rectangles.

E-R diagram to database generation algorithm

A database that conforms to an E-R database schema can be represented by a collection of tables. For each entity set and for each relationship set in the database, there is a unique table that is assigned the name of the corresponding entity set or relationship set. Each table has multiple columns, each of which has a unique name.

Both the E-R model and the relational-database model are abstract, logical representations of real world enterprises. Because the two models employ similar design principles, an E-R design can be converted into a relational design. A database representation from an E-R diagram can be converted to a table format basis for deriving a relational-database design from an E-R diagram. Although important differences exist between a relation and a table, informally, a relation can be considered to be a table of values.

Step 1: Tabular representation of strong entity sets

Let E be a strong entity set with descriptive attributes a1, a2, ..., an. Represent this entity by a table called E with n distinct columns, each of which corresponds to one of the attributes of E. Each row in this table corresponds to one entity of the entity set E.

Step 2: Tabular representation of weak entity sets

Let A be a weak entity set with attributes a1, a2, ..., am. Let B be the strong entity set on which A is dependent. Let the primary key of B consist of attributes b1, b2,..., bn. Represent the entity set A by a table called A with one column for each attribute of the set:

{ a1, a2, ..., am } U { b1. b2, ..., bn }

Step 3: Tabular representation of relationship sets

Let R be a relationship set, let a1, a2,..., am be the set of attributes formed by the union of the primary keys of each of the entity sets participating in R, and let the descriptive attributes (if any) of R be b1, b2, ..., bn. Represent this relationship set by a table called R with one column for each attribute of the set.

{ a1, a2, ..., am } U { b1, b2, ..., bn }

Step 4: Tabular representation of multi-valued attributes

For a multi-valued attribute M, create table T with a column C that corresponds to M and columns corresponding to the primary key of the entity set or relationship set of which M is an attribute.

Step 5: Tabular representation of generalization

There are two different methods:

1 Create a table for the higher-level entity set. For each lower-level entity set, create a table that includes a column for each of the attributes of that entity set plus a column for each attribute of the primary key of the higher-level entity set.

2 If the generalization is disjointed and complete, i.e., if no entity is a member of two lower-level entity sets directly below a higher-level entity set, and if every entity in the higher level entity set is also a member of one of the lower-level entity sets, then an alternative representation is possible. Here, create no table for the higher-level entity set. Instead, for each lower-level entity set, create a table that includes a column for each of the attributes of that entity set plus a column for each attribute of higher-level entity set.

Step 6: Tabular representation of aggregation

Here transformation is straight forward, in the sense that a separate table is created for the relationship set with the primary keys of other sets which are treated as entities with the abstraction provided by aggregation.

Relational algebra

The relational algebra is a procedural query language. It consists of a set of operations that take one or two relations as input and produce a new relation as their result. The fundamental operations in the relational algebra are given below:

1 Select operation:

The select operation selects tuples that satisfy a given predicate.

Denoting symbol: σ

The predicate appears as a subscript to a. The argument relation is given in parenthesis following the σ.

Example: $\sigma_{\text{branch-name} = \text{"perryridge"}}(\text{loan})$

2 Project operation:

The project operation is a unary operation that returns its argument relation, with certain attributes left out. Since a relation is set, any duplicate rows are eliminated.

Denoting symbol: $\prod$

Those attributes that appear in the result as a subscript to $\prod$ are listed.

Example: $\prod_{loannumber.amount}(loan)$

3 Composition of relational operations:

Composing relational algebra operations into relational algebra expressions is just like composing arithmetic operations (such as +,*, -) into arithmetic expressions.

Example: $\prod_{customer\text{-}name}(\sigma_{customer\text{-}city="Harrison"}(Customer))$

4 Union operation:

The result of the operation is similar to that of union operation on sets.

Denoting symbol: $\cup$

For a union operation $r \cup s$ to be valid, it is required that two conditions hold:

a The relations r and s must be of the same parity, i.e., they must have the same num attributes.

b The domains of the i^{th} attribute of r and the i^{th} attribute of s must be the same for all i.

5 Set difference operation:

It allows us to find tuples that are in one relation but are not in another.

Denoting symbol: -

The expression r-s results in a relation containing those tuples in r but not in s.

Example: $\prod_{customer\text{-}name}(loan) - \prod_{customer\text{-}name}(borrower)$

6 Cartesian product operation:

The Cartesian product operation, denoted by a cross (X), allows us to combine information from any two relations. The Cartesian product of relations r1 and r2 is written as (r1 X r2).

Denoting symbol: X

Example: r = borrower X loan

7 Renaming operation:

Unlike relations in the database, the results of relational algebra expressions do not have a name that can be used to refer them. It is useful to be able to give them names; the rename operator, denoted by the lower-case Greek letter rho(p), lets us perform this task. Given a relational algebra expression E, the expression

$$\rho_x(E)$$

returns the result of expression E under the name x.

A relation r by itself is considered to be a (trivial) relational algebra expression. Thus, we can also apply the rename operation to a relation r to get the same relation under a new name.

8 Set intersection operation:

The result of the operation is similar to that of intersection operation on sets.

Denoting symbol: $\cap$

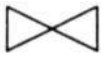
$r \cap s = r - (r - s)$

The set intersection is not a fundamental operation and does not add any power to the relational algebra. It is simply more convenient to write $r \cap s$ than to write r - (r - s).

9 Natural join operation:

The natural join is a binary operation that allows to combine certain selections and a Cartesian product into one operation. It is denoted by the "join" symbol.

The natural join operation forms a Cartesian product of its two arguments, performs a selection forcing equality on those attributes that appear in both relation schemata, and finally removes duplicate attributes. The natural join is central to much of relational database theory in practice.

Denoting symbol: 

10 Division operation:

The division operation, denoted by ÷ is suited to queries that include the phrase "for all".

A tuple t is in r ÷ r s if and only if both of two conditions hold:

a t is in $\prod_{R-s}(r)$

b For every tuple t_s in s, there is a tuple t_r in r satisfying both of the following:

i $t_r[S] = t_s[S]$

ii $t_r[R-S] = t$

11 Assignment operation:

It is convenient at times to write a relational algebra expression in parts using assignment to a temporary relation variable. The assignment operation denoted by ← works in a manner similar to the assignment in a programing language.

The evaluation of an assignment operation does not result in any relation being displayed to the user. Rather, the result of the expression to the right of the ← is assigned to the relation variable on the left of the ←. This relation variable may be used in subsequent expressions.

Structured Query Language (SQL)

The formal languages provide a concise notation for representing queries, but commercial database systems require a query language that is more user-friendly. SQL is the most influential commercially marketed product language. It uses a combination of relational algebra and relational calculus constructs. Although SQL is most popular as a query language, it contains many other capabilities besides querying a database. It includes features for defining the structure of the data, for modifying data in the database, and for specifying security constraints.

The SQL's fundamental constructs and concepts are briefly discussed. Individual implementations of SQL may differ in details, or may support only a subset of the full language.

Basic structure

A relational database consists of a collection of relations, each of which is assigned a unique name. The basic structure of an SQL expression consists of three clauses: select, from, and where.

- The select clause corresponds to the projection operation of the relational algebra. It is used to list the attributes desired in the result of a query.
- The from clause corresponds to the Cartesian product operation of the relational algebra. It lists the relations to be scanned in the evaluation of the expression.
- The where clause corresponds to the selection predicate of the relational algebra. It consists of a predicate involving attributes of the relations that appear in the from clause.

Examples:

```
select A1, A2,..., An
from r1, r2; ..., rm
where P
```

A_i represents attribute, and each r_i is a relation. P is a predicate.

Example 1: Find all customers for loans made at Perryridge branch with loan amounts greater than 1200.

```
select loan-number
from loan
where branch-name = "Perryridge" and amount > 1200
```

Example 2: For all customers who have a loan from the bank, find their names and loan numbers.

```
select distinct customer-name, borrower.loan-number
from borrower, loan
where borrower.loan-number = loan.loan-number and brach-name = "Perryridge"
```

Rename operation

SQL provides a mechanism for renaming both relations and attributes. It uses the as clause, taking the form:

old-name as new-name

Example:

```
select distinct customer-name, borrower.loan-number as loan-id
from borrower, loan
where borrower.loan-number = loan.loan-number and branch-name = "Perryridge"
```

Tuple variables

The as clause is particularly useful in defining the notion of tuple variables, as is done in the tuple relational calculus. A tuple variable in SQL must be associated with a particular relation. Tuple variables are defined in the from clause via the use of the as clause.

Example: For all customers who have a loan from the bank, find their names and loan numbers.

```
select distinct customer-name, T.loan-number
from borrower as T, loan as S
where T.loan-number = S.loan-number
```

String operations

The most commonly used operation on strings is pattern matching using the operator like. Patterns are described using two special characters:

- Percent (%): The % character matches any sub-string.
- Underscore (_): The _ character matches any character.

Example:

```
where customer-street like "%Main_ Road%"
```

Ordering the display of tuples

SQL offers the user some control over the order in which tuples in a relation are displayed. The order by clause causes the tuples in the result of a query to appear in sorted order.

Example: To list in alphabetic order all customers who have a loan at the Perryridge branch.

```
select distinct customer-name
from borrower, loan
where borrower.loan-number = loan.loan-number and branch-name = "Perryridge"
order by customer-name
```

Set operations

Union operation

Union operation automatically eliminates duplicates, unlike select clause. To allow duplicates we must write union all in place of union.

Example:

```
(select clause) union (select clause)
```

Intersect operation

The intersect operation automatically eliminates duplicates. We can retain duplicates using intersect all in place of intersect.

Example:

```
(select clause) intersect all (select clause)
```

Except operation

The except operation automatically eliminates duplicates. To retain them use except all.

Example: To find all customers who have an account but no loan at the bank.

```
(select distinct customer-name from depositor)
except
(select customer-name from borrower)
```

Aggregate functions

Aggregate functions are functions that take a collection (a set or multi-set) of values as input and return a single value. SQL offers five built-in aggregate functions:

1 Average: avg
2 Minimum: min
3 Maximum: max
4 Total: sum
5 Count: count

Example 1: Find the number of depositors for each branch.

```
select branch-name, count (distinct customer-name)
from depositor, account
where depositor.account-number = account.account-number
group by branch-name
```

Example 2: Find average balance for all accounts.

```
select avg (balance)
from account
```

Views

A view in SQL is defined using the create view command. To define a view, we must give the view a name, and must state the query that computes the view. View names may appear in any place that a relation name may appear. The form of the create view command is

```
create view v as <query expression>
```

Example:

View consisting of branch names and the names of customers who have either an account or a loan at that branch and it is to be allied as all-customer.

```
create view all-customer as
(select branch-name, customer-name
from depositor,account
where depositor.account-number = account.account-number)
union
(select branch-name, customer-name
from borrower, loan
where borrower.loan-number = account.account-number)
```

Modification of database

Deletion

A delete request is expressed in much the same way as query. Only whole tuples can be deleted; values on only particular attributes cannot be deleted. To delete tuples from several relations, use one delete command for each relation. The predicate in the where clause may be as complex as a select command's where clause.

In SQL, a deletion is expressed by

```
delete from r
where P
```

Example: Delete all loans with loan amounts between Rs.1300 and Rs.1500.

```
delete from loan
where amount between 1300 and 1500
```

Insertion

To insert data into a relation, either specify a tuple to be inserted or write a query whose result is a set of tuples to be inserted. Obviously, the attribute values for inserted tuples must be members of the attribute's domain. Similarly, tuples inserted must be of the correct parity.

Example 1: To insert that there is an account A-9732 at Perryridge branch and that it has a balance of 1200.

```
insert into account
values ("Perryridge", "A-9732", 1200)
```

Example 2: One also can insert a set of tuples at a time into a table. For example, a bank decided to provide Rs. 200/- to all the customers who have taken loan from the bank "Hyderabad". So we need to create account for all the loan members with an initial deposit of Rs. 200/-. This is achieved by:

```
insert into account
select branch-name, loan-number, 200
from loan
where branch-name = "Hyderabad"
```

Updates

In certain situations, a value in a tuple may be changed without changing all values in the tuple. For this purpose, the update statement can be used. As could for insert and delete, choose the tuples to be updated using a query.

Example: Pay 5% interest on accounts whose balance is greater than average.

```
update account
set balance = balance * 1.05
where balance > select avg (balance)
from account
```

Case Study

In Relational Database Management Systems the data gathered from different applications are in the form of tables. The data is collected manually and it will be entered into the different tables of database. The basic details of creating a database are presented in this section with the help of a case study.

Before creating a database, decisions need to be made about what information should be remembered and what to be ignored. This activity is called data modeling and the product is a data model. A data model defines the kinds of questions that can be answered by the database and thus determines its potential and limitations. There are several kinds of data models and the most popular one is the E-R model.

The E-R data model is based on a perception of a real world that consists of a set of basic objects called entities, and of relationships among these objects. An entity is represented by a set of attributes. Attributes are descriptive properties possessed by each member of an entity set. The E-R model is extremely useful in mapping the meanings and interactions of real world enterprises on to a conceptual schema. In E-R model, an entity is represented as a rectangle, relationship as diamond, and attributes as ellipses connected to entity rectangle.

Consider a real world case related to ICRISAT. The data collected for a particular application is as follows.

General:	Institute name
	Names and address of the people
	Country
	Telephone, Email address
	Experiment title
	Location
Site details:	Site name
	Latitude (deg, min)
	Longitude (deg, min)
	Elevation
	Natural vegetation
	Soil series name
	Soil classification

	Weather station name
	Time of weather observations
Experimental details:	Experiment name
	Design of experiment
	Replications
	Layout or map
Measurements (date-wise):	
Weather -	Daily rainfall, maximum and minimum temperatures, and solar radiation
Soil water -	Pre-plant soil water contents:
	Depth-wise volumetric water contents
	In-season soil water contents:
	Depth-wise volumetric water contents
Soil fertility -	Pre-plant fertility measurements:
	Depth-wise NO_3-N, NH_4^+-N, P, K, and pH
	In-season fertility measurements:
	Depth-wise NO_3 -N, NH_4^+-N, P, K, and pH
Crop phenoogy - (crop-specific)	Vegetative stages
Growth analysis - (crop-specific)	Periodic dry matter production, leaf area index
Crop damages - (crop-specific)	Type of damage, tissue damaged, leaf loss (%), plant loss (%)

From the above collected data we have to form tables. Before forming tables we have to identify entities and relationships among data. An entity is a "thing" or "object" in the real world that is distinguishable from all other objects.

Let us consider the data pertained to General. It contains Institute name and other details belonging to that institute such as the country to which it belongs and details about people, etc. Here we can separate these general details into two entities. One is Institute and the other is Person, because both are distinguishable from each other. The attributes of institute are Institute name, Country, Experiment title, and Location. The attributes of Person are Person name, Person ID, Address, Telephone, Email address.

We have to identify an attribute or set of attributes with which we can distinguish all tuples of a table. This attribute or set of attributes is called primary key of the table. We shall use the term primary key as the principal means of identifying entities within an entity set. From Institute entity we can take Institute name as primary key and from Person entity, Person ID as primary key. Now we have to form relationship between these two things if any exists. Here a person belongs to a particular institute. There may be many number of persons but each person belongs to a particular institute. The relationship between person and institute say Person-Institute has to be formed. Now it contains primary keys of both institute and person, i.e., Person ID and Institute name. Sometimes the relationship may contain additional attributes. In the example represented in Figure 5, joining date is taken as an additional attribute for Person-Institute relationship.

After drawing the E-R diagram, form tables for each entity and relationship of the E-R diagram with attributes as field names of the table. So, for the E-R diagram shown in Figure 5 three tables, viz., Person, Person-Institute, and Institute have to be created. Similarly, tables for other data collected can be formed. The details of all tables that can be defined for the above data is discussed. The E-R diagram for all these tables is shown in Figure 6.

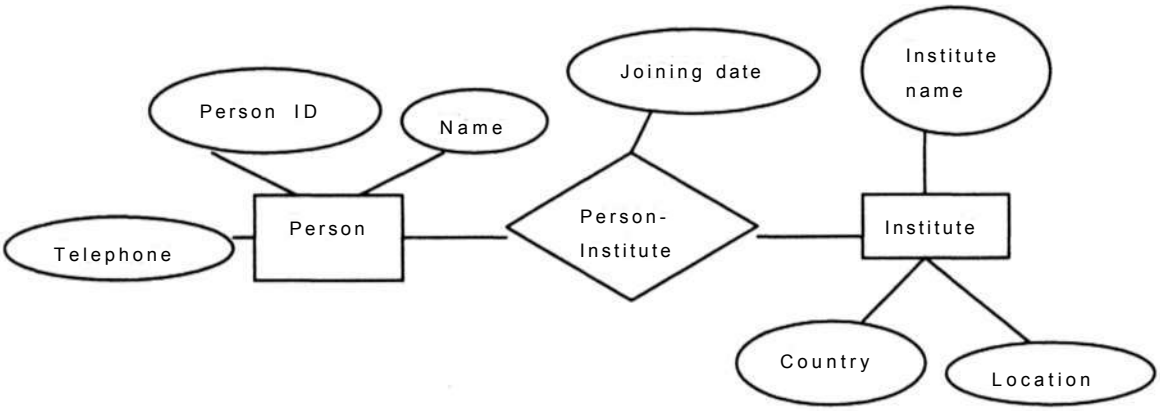


Figure 5. The Entity-Relationship diagram for Person, Institute entities.

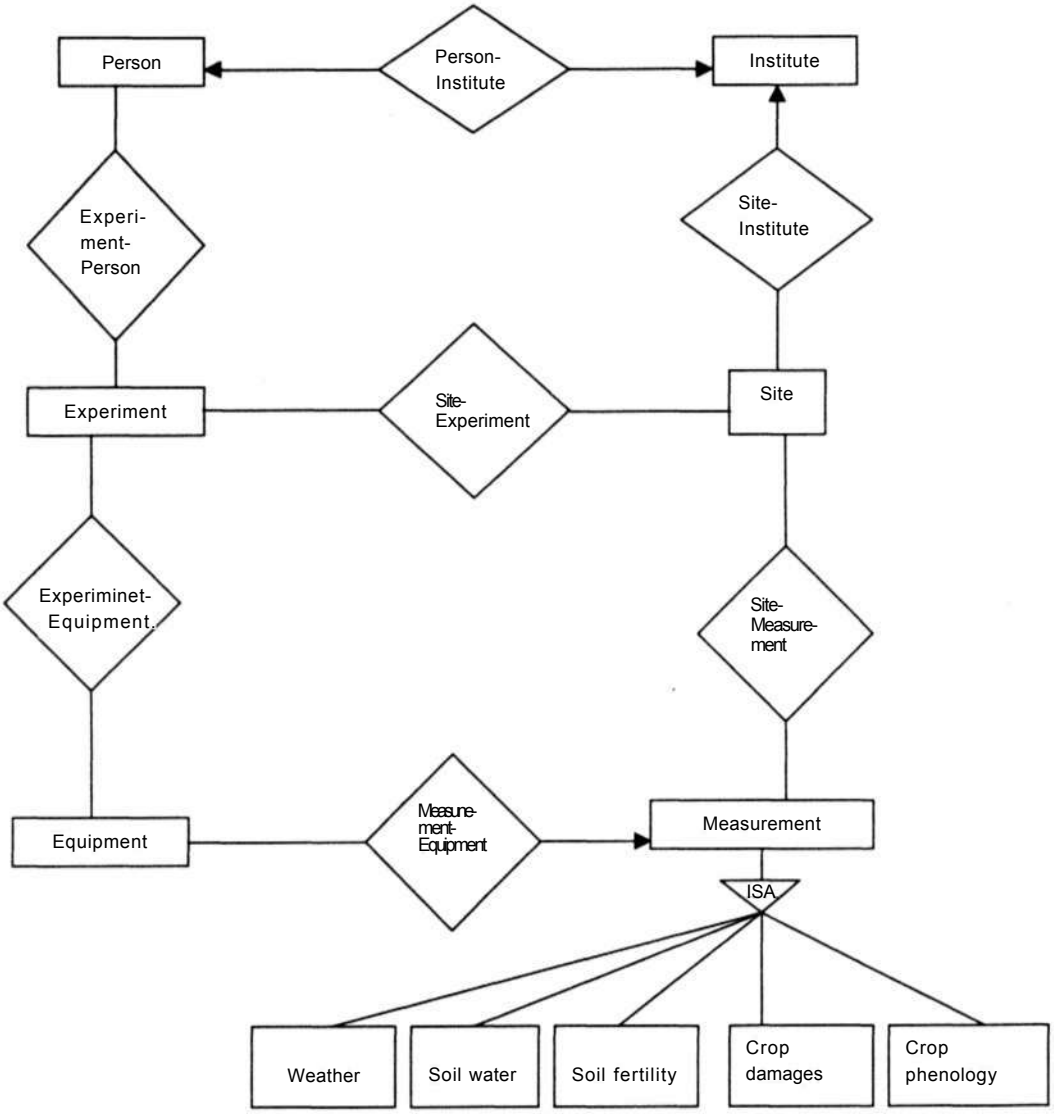


Figure 6. The Entity-Relationship diagram for all tables created.

Database tables and their schemata

1	Person (Entity)	(Person ID. Person name, Telephone).
2	Person-Institute (Relationship)	(Person ID, Joining Date, Institute name).
3	Institute (Entity)	(Institute name, Country, Location).
4	Site (Entity)	(Site name. Latitude, Longitude, Elevation, Natural vegetation, Soil series name, Soil classification, Weather station name)
5	Site-Institute (Relationship)	(Site name, Institute name).
6	Experiment (Entity)	(Experiment name, Design, Layout)
7	Site-Experiment (Relationship)	(Site name, Experiment name)
8	Person-Experiment (Relationship)	(Person ID. Experiment name)
9	Equipment (Entity)	(Equipment name. Type)
10	Equipment-Experiment (Relationship)	Equipment name. Experiment name)
11	Measurement (Entity)	(Date, Team name, Type of measurements)
12	Weather measurements (Entity)	(Date. Type of measurements. Daily rainfall, Maximum temperature, Minimum temperature, Solar radiation)
13	Soil water measurements (Entity)	(Date. Type of measurements. Water content)
14	Soil fertility measurements (Entity)	(Date. Type of measurements. NO_3 -N, NH_4^+-N, P, K, pH)
15	Crop phenology measurements (Entity)	(Date. Type of measurements. Crop name)
16	Crop damages measurements (Entity)	(Date. Type of measurements. Crop name, Type of damage, Leaf loss (%), Plant loss (%)
17	Measurements-Equipment (Relationship)	(Date, Type of measurements, Equipment name)
18	Measurements-Site (Relationship)	(Date. Type of measurements. Site name)

SQL

Create tables for all the database tables and then enter the data collected in them. SQL can be used to do manipulations on this data. SQL uses a combination of relational algebra and relational-calculus constructs. SQL includes features for defining the structure of the data, for modifying the data in the database, and for specifying security constraints.

The basic structure of SQL consists of three clauses: select, from, and where. The select clause is used to list the attributes desired in the result of a query. The from clause lists the relations to be scanned in the elevation of expression. The where clause consists of predicate involving attributes of the relations that appear in the from clause.

A typical SQL query has the form:

select A1, A2, ..., An
from r1, r2, ..., rm
where condition

The SQL language has several parts.

Data Definition Language

The Data Definition Language (DDL) provides commands for defining relation schemata, deleting relations, creating indices, and for modifying relation schemata.
For the case study under discussion we can create all the tables mentioned above using SQL DDL.

Example: **create table** Person

(Person ID **integer not null**
Person name **char(30)**
Telephone **integer**
Primary key (Person ID)

Using this SQL statement we created a table for Person. The primary key for this table is Person ID. One can remove a table from a database using **drop** statement.

Example: **drop table** Person
The above statement removes person table from database.

Data Manipulation Language

The SQL Data Manipulation Language (DML) includes a query language based on both the relational algebra and the tuple relational calculus. It includes commands to insert tuples into, delete tuples from, and to modify tuples in the database.
Example: **delete** from Person

Where Person ID - 16

This query deletes from Person table all the tuples having Person ID equal to 23. So depending upon the predicate mentioned in where clause it deletes the corresponding tuples. Similarly, one can insert data into a table using insert statement.

Example: insert into Person (Person ID, Person name, Telephone)

Values (16, "Praveen", 12121)

This statement inserts the given data into table Person.

View definition

The SQL DDL includes commands for defining views. A view is a relation that is not part of the logical model but is made visible to the user as a virtual relation. The syntax is create view v as <query expression >.

Example: **create view** praveen as

(**select** *
from Person
where Person name = "Praveen")

This statement creates a table named praveen with all attributes of table named Person and with data equal to data in Person table where Person name equal to Praveen.

In addition to the above-mentioned operations, SQL contains several other clauses that can be used to do simple arithmetic operations, and manipulations on data contained in different tables.

Principles of Scientific Sampling in Watershed Studies

S Chandra

Data in a watershed database emanate from (research and development) investigations conducted on research farms/laboratories and farmers' fields. The value and quality of these databases, and decisions made using them are critically dependent on the quality and reliability of investigations generating these data. The quality and reliability of these investigations depends largely also on the extent to which they have been designed using statistically sound mechanisms. Depending on the purpose, these investigations either involve sampling a watershed or a part thereof to assess certain natural/biological characteristic(s) of the watershed, or employ an experimental design to compare two or more farm technologies at a certain level of the watershed in order to generate data on variables of interest. This presentation will focus on use of efficient sampling designs, as data generation mechanisms, to improve the quality and reliability of data from watershed investigations.

It is worth noting at the outset that the basic role of statistics, either through the use of a statistically sound sampling scheme or an experimental design, is to act as a filter to separate the unwanted variation (noise) from the variation of interest (signal), and to provide a valid and accurate measure of the level of noise to quantify the strength of signal.

The purpose of sampling is to know about the population parameter(s) of interest from information contained in a sample selected from that population. Resorting to sampling, rather than studying the entire population, saves money, allows the work to be completed speedily and timely, and assures quality and accuracy of data. Also, if taking observations requires destruction of experimental material, for example uprooting a plant from a plot, sampling appears to be the only feasible way to learn about the population characteristics. To properly grasp the ideas of scientific sampling, it is desirable to know the terminology used in sampling theory.

- A**n element** is the basic unit of measurement or observation.
- **The (target) population** is the totality of elements for which information is sought.
- **A sampling unit** is a subset of elements acting as a single unit for inclusion in the sample.
- **The sampling frame** is the list of distinct sampling units comprising the entire population of interest.
- **A sampling design** is the mechanism used in selecting a sample from the population.

For example, sampling is often resorted to in order to learn about the average amount of a plant nutrient in a certain variety of soybean grown on a large plot containing say 1000 plants. Each plant in the plot defines an element. The 1000 plants together define the target population. If observations are to be made on an individual plant basis, a single plant defines the sampling unit, there being 1000 sampling units in total that make up the sampling frame. On the other hand, if a single observation is to be made from say 5 contiguous plants in a row, there will be 1000/5 = 200 sampling units in the plot, the plot being divided into 200 subsets of plants, each subset containing 5 plants/element and acting as a single sampling unit. The sampling frame now consists of 200 distinct sampling units.

Samples selected from a population may be broadly of two types depending on the mechanism adopted in the selection of sampling units included in the sample. A sample is called a **probability sample** if (1) each sampling unit in the population has a known, non-zero, not necessarily equal, probability of being included in the sample; (2) the sample is drawn by some method of random selection consistent with these probabilities; and (3) these probabilities are accounted in making the estimates from the sample. In a **non-probability sample,** each sampling unit in the population has either a probability of 0 or 1 for inclusion in the sample.

A probability sample is preferable to a non-probability sample as the former is based on a more objective basis backed by a sound statistical theory than a non-probability sample. With a probability

sample, it is possible to use probability theory to study the biases and the standard errors of the estimates from different sampling plans. This information greatly helps in selecting a suitable plan for a particular sampling investigation.

The Concepts of Precision and Accuracy

The concepts of precision and accuracy play a key role in determining the quality of data. To understand these concepts, assume that we wish to learn about some population characteristic M (termed as parameter), say average amount of some plant nutrient in a soybean variety grown on a plot, having a total of say N = 100 plants. Under the given set of conditions (for example an imposed treatment}, the soybean variety will have an "inherent" true value M of the plant nutrient. Suppose we take a probability sample of n = 10 plants from the plot using some suitable sampling design. We compute the sample mean, say m, based on the 10 plants in the sample. The sample thus provides us with an estimate m for the inherent true population value M.

It is clear that the value of m will rarely, if ever, exactly match the value of M. One obvious reason for this difference is the fact that the sample contains only a small subset of the total population. Other factors that contribute to this difference could be measurement and recording errors.

We could take $^{100}C_{10}$ number of samples, each of size n = 10, from a population of N = 100 individuals. Each of the $^{N}C_{n}$ possible samples will have the same chance of being the sample that we may be actually using. Each such sample will generally give rise to a different sample mean m. If the average of these $^{N}C_{n}$ values of m, denoted as E(m) and read as expected value of m, equals the population value M, we say that the sample mean is an unbiased estimate of the population mean M.

The three quantities M, m, and E(m) provide a basis to define the concepts of precision and accuracy of any sample statistic m as an estimate of the population parameter M. **Bias,** B(m), of an estimate m is defined as:

$$B(m) = E(m) - M \tag{1}$$

The **sampling error,** S(m), in an estimate m is:

$$S(m) = m - E(m) \tag{2}$$

The **estimation error,** ES(m), of an estimate m is defined as:

$$ES(m) = m - M = [\{m - E(m)\} + \{E(m) - M\}] \tag{3}$$

The **mean square error** (MSE) of an estimate m is defined as:

$$MSE(m) = E[\{m - M\}^2] = E[\{m - E(m)\}^2] + \{E(m) - M\}^2 \tag{4}$$

(covariance term is zero due to independence) $= var(m) + [B(m)]^2$

$=$ sampling variance $+ (Bias)^2$

The first term in equation 4 is the expected/average value of the square of sampling errors. This represents the **sampling variance** of the estimate m. The second term in equation 4 is the square of the bias in the estimate m. Therefore, the total variability [total amount of uncertainty] in the estimate m, measured by MSE(m), arises from two broad sources of errors, one due to the sampling errors and the other due to the bias (see equation 3). The **total error,** TE(m), in an estimate m is then equal to

$$TE(m) = [MSE(m)]^{1/2} = \{var(m) + [B(m)]^2\}^{1/2} \tag{5}$$

Clearly, for an unbiased estimate, the $TE(m) = [var(m)]^{1/2}$ since bias is absent.

The **precision** of the estimate m is defined as [1/var(m)]. The **accuracy** of the estimate m is a function of the bias in the estimate. Less is the bias, more accurate is the estimate.

One can increase both precision and accuracy of an estimate by increasing the sample size. That, however, is a costly way to obtain quality data. Attempts should always be made to get higher precision

and accuracy through the use of efficient sampling designs, optimal sample sizes, and efficient and accurate measuring devices.

Selecting a Sampling Design

Each sampling unit in a population contains information about the (unknown) quantity M. Information costs money, manpower, and resources. The critical question, therefore, is how much information to buy. Too small a sample size gives too little information that may raise doubts about the reliability or quality of the resulting estimate. Too large a sample size may give information more than what may be sufficient, hence leads to a waste of costly resources.

The amount of information in a sample depends on (1) sample size used; and (2) variation among sampling units. While a large sample size does increase the amount of information, this increase, however, is not proportionate to the increase in the sample size beyond a certain limit. More effort to increase the amount of information rather should be made by selecting an appropriate sampling design to effectively control the variation among sampling units.

There are various methods to determine an optimal sample size for a given problem. One of these methods is to choose a sample size by (1) specifying a bound on the estimation error, say, $|m-M| < A$; and (2) specifying a certain probability $(1-\sigma)$ that $|m-M| < A$, i.e., $Prob[|m-M| < A] = 1-\alpha$, where a is the probability of type I error. This implies that we are looking for a sample size that will be expected to provide us with an estimate m that will differ from the population value M by a (small) amount not exceeding the value A with a probability of $(1-\alpha)$.

Simple Random Sampling

Simple random sampling (SRS) is suitable for situations where the N sampling units are more or less homogeneous. It is intuitively fair and free from distortion since every sampling unit has the same chance to be included in the sample. It provides unbiased estimate of population mean.

The drawback of SRS is that it does not use any relevant information or judgement that we may have about the nature of the population. For example, farmers in a certain region A of a country may be more likely to spray insecticides than those in some other region B.

Sample size

The sample size in SRS is computed from $n = 4S^2/A^2$ where A is the allowable error in the sample mean and S is the population SD. This assures that the sample mean will be estimated with an allowable error of A with a probability of 0.95 ($\alpha = 0.05$ = risk) under the assumption of a normal distribution. A good guess of S can be made from results of previous samplings of this or similar populations. For example, from a previous similar sampling study to estimate the yield of wheat, we have $s^2 = 90.3$ kg^2 based on a sample of 222 fields in a region. How many fields should we sample to estimate the true yield within ±1 kg, with a (α=) 5% risk that the error will exceed 1 kg? This gives us:

$$n = 4s^2/A^2 = 4 \times 90.3 / 1^2 = 361 \text{ fields}$$

Stratified Random Sampling

In stratified random sampling (STRS), the N sampling, units in the population are divided, using our knowledge of the nature of population, into, say k, sub-populations or strata that are internally more homogeneous, such that $N_1 + N_2 + \ldots + N_k = N$ where N_i is the number of sampling units in stratum i (i = 1, ..., k). A random sample of size a, using SRS, is then separately drawn from stratum i (i = 1, ..., k), with $n, + n_2 + \ldots + n_k = n$ being the total sample size. A sample selected in this manner is expected

to be more representative of the population. By randomly selecting the same proportion of the sampling units from each stratum (proportional allocation), the sample is guaranteed to have the correct population proportion of good and bad sampling units instead of leaving this entirely to chance as in SRS. The STRS provides unbiased estimate of population mean, which is more precise than that in SRS.

Sample size

For a total sample size n, the value of n_i, the number of sampling units to be randomly selected from stratum i, can be determined, for example, using proportional allocation rule as indicated above, i.e., we sample the same fraction $p = n_i/N_i$ (i = 1, ..., k) from every stratum. A more practical approach, however, is to select:

$$n_1 = N_1 S_1 / \sqrt{c} \qquad (6)$$

where S_i is the SD of sampling units in i-th stratum, and c_i is the cost of sampling per sampling unit in i-th stratum. This method, called optimum allocation, provides the smallest SE of estimated mean for a given total cost of taking the sample. Equation 6 indicates that a larger sample should be taken, than with proportional allocation, in a stratum that is highly variable (large S_i) and a smaller sample in a stratum where sampling is expensive (large c_i). This appears to be consistent with common sense. Equation 6 reduces to proportional allocation if the SD and the cost per sampling unit is the same in each stratum.

Systematic Sampling

In this sampling scheme, in order to draw, for example a 10% sample from a list of 730 sampling units, we select a random number between 1 and 10, say 3, and pick up every 10-th sampling unit thereafter, i.e., sampling units 3, 13, 23, ..., ending with, the sampling unit 723. Such a sample is known as a systematic sample, since the choice of the first sampling unit at random determines the composition of the whole sample.

A systematic sample is easier to draw since only one random number is needed. It distributes the sample more evenly over the listed population. It has a kind of built-in stratification, e.g., in the above example, sampling units 1-10, 11-20, ... in effect form strata. It, however, differs from the STRS in that the sampling unit from the stratum is not drawn at random.

Systematic sampling often gives more accurate estimates than SRS. It, however, has one disadvantage and one potential disadvantage. There is no reliable method to estimate the standard error (SE) of the estimates. The potential disadvantage is that if the variation in the population mimics some periodic pattern, and if the interval in successive sampling units in the sample happens to equal the wavelength or a multiple thereof, the sample may be badly biased.

A detailed agriculturally-oriented account of the ideas presented above on scientific sampling is given by Yates (1960).

Reference

Yates, E 1960. Sampling methods for censuses and surveys. 3rd edition. London, UK: Griffin.

Appendix I

Data Needs for Strategic Research

General	Institute name Names and addresses of the collaborators Country Telephone, email addresses Experiment title Location/site
Site details	Site name Latitude (deg. mm.) Longitude (deg. min.) Elevation (m) Natural vegetation Soil series name Soil classification (family level of soil taxonomy) Soil profile characterization (layer-wise physical, biological, and chemical properties) Weather station name Location of weather station with respect to the experimental site (km) Time of weather observations
Experimental details	Treatments - Experimental factors and levels and their description Design of experiment Replications Layout or map
Management data	Tillage - Date, type (implement used) and depth of tillage, and residue incorporation Cultivars - Names of cultivars grown and their approximate duration Planting details - Planting date, plant population, row spacing, and seeding depth Fertilizers, inoculants, and amendments - Dates of application, material applied, method of application, depth of application, amount of N, P, K, and any other nutrient applied Biocides - Material applied, amount of active ingredient applied (kg a.i ha^{-1}), target Irrigation - Dates of irrigation, amount of irrigation (mm), method of irrigation, treatments/plots irrigated

Measurements

Weather - Daily rainfall, maximum and minimum temperatures, and solar radiation

Soil water - Pre-plant soil water contents: Depth-wise volumetric water contents

In-season soil water contents: Depth-wise volumetric water contents

Soil fertility - Pre-plant fertility measurements: Depth-wise organic C, total N and P, available N (NO_3^--N, NH_4^+-N) P, K, and pH; soil respiration, microbial biomass C and N, and number of mycorrhizal spores

In-season fertility measurements: Depth-wise organic C, available N (NO_3^--N, NH_4^+-N) and P, soil respiration, microbial biomass C and N

Crop phenology (crop-specific) - Vegetative stages

Reproductive stages - Dates of sowing, emergence, 50% flowering, beginning pod, beginning seed, physiological maturity, harvest maturity

Growth analysis (crop-specific) - Periodic dry matter production and partitioning different plant parts, leaf area index

Nodulation (at flowering) - number and mass of nodules, nitrogenase activity of legumes

Mycorrhizal colonization (at flowering) - root colonization by mycorrhizae

Harvest data - Date of harvesting, area harvested, total biomass, pod and seed yields

Nutrient uptake - Plant nutrient concentrations (N, P, K)

Hydrology and erosion - Daily runoff and erosion

Crop damage - Type of damage, tissue damaged, leaf loss (%), plant loss (%)

Appendix II

Data Needs for On-farm Research

General	Institute name Names and addresses of the collaborators Country Telephone, email addresses Experiment title Location/site
Site details	Site name Latitude (deg. min.) Longitude (deg. min.) Elevation (m) Natural vegetation Soil series name Soil classification (family level of soil taxonomy) Weather station name Location of weather station with respect to the experimental site (km) Time of weather observations
Experimental details	Treatments - Experimental factors and levels and their description Design of experiment Replications Layout or map
Management data	Tillage - Date, type (implement used) and depth of tillage, and residue incorporation Cultivars - Names of cultivars grown and their approximate duration Planting details - Planting date, plant population, row spacing, and seeding depth Fertilizers, inoculants, and amendments - Dates of application, material, method of application, depth of application of N, P, K, and any other nutrient applied Biocides - Material applied, amount active ingredient applied (kg a.i ha^{-1}), target Irrigation - Dates of irrigation, amount of irrigation (mm), method of irrigation, treatments/plots irrigated
Measurements	Weather - Daily rainfall, maximum and minimum temperatures, and solar radiation Soil fertility - Pre-plant fertility measurements: Depth-wise NO_3^--N, NH_4^+-N,P,K,and pH Crop phenology (crop-specific) - Sowing, emergence, 50% flowering, harvest maturity

Nodulation (at flowering) - Nodule number and mass for legumes
Mycorrhizal colonization (at flowering) - Root colonization by mycorrhizae
Harvest data - Date of harvesting, area harvested, total biomass, pod and seed yields
Nutrient uptake - Plant nutrient concentrations (N, P, K)
Hydrology and erosion - Daily runoff and erosion
Crop damage - Type of damage

Appendix III

Data Sheets

Table 1. Soils information for crop simulation models and resource characterization.

Provide the following information for your field where you conducted your crop modeling experiment or for a nearby field as described by your soil survey staff.

1. Institute/University : _____
2. Responsible researcher : _____
3. Location of the experiment : _____
4. Crop and experiment : _____
5. Field number : _____
6. Pedon number : _____
7. Soil description/soil series : _____
8. Soil classification : _____
9. Number of layers in soil profile : _____
10. Slope of land (%) : _____

11. Soil color (check one) : Brown, red, black, gray, yellow-red, or any other

12. Soil permeability (check one) : Very slow, slow, moderately slow, moderate, moderately rapid, rapid, very rapid, not permeable, unknown

13. Soil drainage (check one) : Very poor, poor, somewhat poor, moderately well, well, somewhat excessive, excessive, unknown

14. Water table present? : _____ At what depth? _____

15. Mean monthly air temperature (°C) :

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Max.												
Min.												

Table 1 (contd.)

Enter the information layer- or horizon-wise in the following table.

Soil horizon		Depth (cm)		Clay (%)[1] <0.002 mm	Silt (%)[1] 0.002–0.05 mm	Sand (%)[1] 0.05–2 mm	Coarse fragments[2] >2 mm (%)	Organic carbon (%)	pH 1:1 (H_2O)	Bulk density at 1/3 bar (g cm^{-3})	Soil water content (volume %)			Al saturation (%)	Quantity of roots[3]
No.	Designation	Upper	Lower								At –1/3 bar	At –15 bar	Saturated		
1															
2															
3															
4															
5															
6															
7															
8															
9															
10															
11															
12															

Notes: 1. Sum of percent sand, silt, and clay should be 100.
2. Express coarse fraction (>2 mm) as percentage of whole soil.
3. For quantity of roots, select one of the following for each layer:
none, very few, very few to few, few, few to common, common, common to many, many, matted, missing.

Table 2. Weather data sheet.

Location : _____ Hours of observations:

Latitude : _____ °N

Longitude : _____ °E Height above mean sea level: _____ m IST: _____ (hrs) IST: _____ (hrs)

Date	Rainfall (mm)	Cum. rainfall (mm)	Dry bulb (°C) (AM)	Wet bulb (°C) (AM)	Dry bulb (°C) (PM)	Wet bulb (°C) (PM)	Max temp (°C)	Min temp (°C)	Wind velocity (kmph)	Evaporation (open-pan) (mm)	Bright sunshine (hours)	Solar radiation (MJm^{-2} day^{-1})	PAR ($E\ m^{-2}\ s^{-1}$)

Note: PAR = Photosynthetically active radiation.

Table 3. Micrometeorological data.

Location : _____
Date : _____
Time : _____

DAE : _____
Observer : _____
Crop : _____

TRT	Rep	Plot no.	Light interception		Transmission (%)	Interception (%)	Dry bulb temp (°C)	Wet Bulb temp (°C)	RH (%)	Canopy temperature (°C)				Remarks
			Transmitted	Incoming						1	2	3	Mean	

Notes: DAE = Days after emergence.
TRT = Treatment.
RH = Relative humidity.

Table 4. Soil moisture data (Neutron Probe Method).

Factors

Experiment title : _____
Date of observation : _____
Location : _____
Crop : _____
Soil type : _____
Probe used : _____
Standard count : _____

	Levels				
	L1	L2	L3	L4	L5
F1 (Treatment)	_____	_____	_____	_____	_____
F2 (Replication)	_____	_____	_____	_____	_____
F3 (Tube number)	_____	_____	_____	_____	_____

Levels/Factors			Gravimetric samples from two soil layers (cm)						Probe counts at depths (cm)										
F1	F2	F3	FWT 0–10	DWT 0–10	CWT 0–10	FWT 10–22.5	DWT 10–22.5	CWT 10–22.5	30	45	60	75	90	105	120	135	150	165	180

Notes: FWT = Fresh (wet) weight of soil plus can.
DWT = Dry weight of soil plus can.
CWT = Can weight.

Table 5. Soil moisture data (Gravimetric Method).

Experiment title : _____
Date of sampling : _____
Location : _____
Soil type : _____
Crop : _____

Plot no.	Treatment no.	Rep no.	Depth (cm)	Wet soil + can wt. (g)	Dry soil + can wt. (g)	Can wt. (g)	Water loss (g)	Net dry wt. (g)	Moisture (%) (DWB)
			0–15						
			15–30						
			30–45						
			45–60						
			60–75						
			75–90						
			90–105						
			105–120						
			120–135						
			135–150						
			150–165						
			165–180						
			180–195						
			195–210						

Notes: DWB = Dry weight basis.

Techno-economic Survey for Production Practices and Constraint Analysis in Watershed Areas

Name of Watershed_____

1. General Information:

1. State	:	_____
2. District	:	_____
3. Taluka	:	_____
4. Village	:	_____
5. Household no.	:	_____
6. Name ofhousehold	;	_____
7. Sex	:	Male / Female
8. Educational qualification	:	
9. Main source ofincome	:	_____
10. Secondary source ofincome	:	
11. Farmer was earlier watershed program participant		Yes/No
12. Bank loan	:	Availed Rs._____year
		Outstanding Rs._____year
13. Contact with extension agents		Regular/Monthly/Yearly/ Occasionally/Never
14. Distance to market	:	_____(km)
15. Name ofthe investigator	:	_____
16. Date ofinterview	:	_____

II. Resource Availability:

1. Land holding information (in acres):

Class	Owned cultivated	Leased in	Share cropped in	Leased out	Share cropped out	Fallow land	
						Current	Permanent
Wetland							
Dryland							
Total land							

Total operated area (acres): in *kharif*_____in *rabi* _____

in summer _____

Rent (or share) in case of leased-in/leased-out (or share-in/share-out)

2. Characteristics of soil:

a) Soil texture : Sandy / loam / clayey / other (specify)
b) Soil type : Alluvial / red / black / other (specify)
c) Topography : Upland / mid-land / lowland
d) Depth of soil (m) :_____

3. Source of irrigation: Canal / Dugwell / Tubewell / Tank / River / Others

4. Family members and other resources engaged in agriculture:

	Always	**Peak periods**
Male	_____	_____
Female	_____	_____
Child	_____	_____
Regular farm servant	_____	_____
Bullocks	_____	_____
Tractors	_____	_____

5. Household composition:

Name	Sex	Age	Year schooling	Labor force participation (Check)			
				Daily farm wages	Off-farm work	Seasonal migrant	Work on own farm or business

6. Farm equipment*

Item	Number	Value
Iron plow		
Wooden plow		
Blade harrow		
Jumbo		
Gorru		
Electric motor		
Oil engine		
Mhote		
Persian wheel		
Bullock cart		
Crowbar		
Spade		
Khurpi		
Sickle		
Axe		
Bicycle		
Others		
(Specify.....)		
(Specify.....)		
(Specify.....)		

7. Livestock:

Species and type	Number	Value
Bullocks (improved breed)		
Bullocks (local)		
Milch cows (crossbreed)		
Youngstock (cattle)		
He-buffaloes		
She-buffaloes		
Youngstock (buffaloes)		
Goats		
Sheep		
Pigs		
Poultry		
Others		
(Specify.....)		
(Specify.....)		

III. Cropping Pattern: **Year:** _____

Plot sl. no./ Name	Sub-plot	Ownership status[1]	Crop/ Intercrop	Proportion[2]	Cropped area	Season[3]	Land quality	Irrigated area	Variety	Location of the plot[4]

1. Owned / leased-in / share cropped-in / leased-out / share cropped-out.
2. Always main crop is first.
3. K = *Kharif*; R = *Rabi*; S = Summer; P = Perennial.
4. Specify; upland, lowland, and normal.

Intercropping systems:

1. Do you practice intercropping: Yes/No
   If yes, what are the intercropping systems preferred.

   Intercrop (i)_____(ii)_____(iii)_____

   Area (i)_____(ii)_____(iii)_____

   Irrigated area (i)_____(ii)_____(iii)_____

Reasons for taking intercrop:

1.

2.

3.

Sequential cropping:

1. Do you practice sequential cropping: Yes/No
   If yes:

Sl. no.	Sequential crop		Area	Irrigated area
	Kharif	*Rabi*		

Reason for practicing sequential cropping:

Which system has potential for double cropping:

Name of the crop : _____

Reasons : _____

_____

_____

Sole crop:

Do you plant only one crop a year in one or more plots: Yes/No
If yes:

Sl.no.	Crop	Area	Irrigated area

IV. Crop Disposition:

Year:_____

Production/ Disposition/Market price	Name of crop and season					
	Crop					
	Season					
Total production						
• Grain or main product in . . . . . unit						
• Fodder or byproduct in . . . . . unit						
Disposition						
• Marketed						
• In kind payments to labor						
• Loan repayment						
• Still held in storage						
• Consumed						
• Other						
Sale price, if marketed						

V. Fertilizer and Pesticide Adoption:

(a)	Have you ever used inorganic fertilizers?
(b)	If yes, in what year did you first start to use inorganic fertilizer?
(c)	Do you apply fertilizer every year?
(d)	Do you apply farmyard manure every year?
	If not, how often?
(e)	Have you ever used pesticide?
(0	If yes, in what year did you first apply?
(g)	Do you own your own sprayer?
(h)	If not, are sprayers readily available?
0)	Is fertilizer readily available throughout the year?
0)	Are pesticides readily available throughout the year?

VI. Adoption of Soil Conservation Practices:

Practice	Adoption			Reasons for non/partial adoption					
	Not adopted	Adoption on at least one field	Adoption on all fields	Lack of knowledge	Not technically suitable to their specific location	Too costly	Not convenient	Neighboring farmers do not cooperate	Other risks
Keyline cultivation									
Leveling and smoothening									
Waterways									
Dugout ponds for water reuse									
Water waste weirs									
Deep plowing									
Deep furrows									
Keyline cultivation									
Dead furrow									

VII. Credit and Financial Liabilities:

Source of credit	Amount		Rate of interest	Security offered	Purpose of loan
	Borrowed	Outstanding			
Banks (specify)					
1.					
2.					
3.					
Government agencies					
1.					
2.					
3.					
Cooperative societies					
1.					
2.					
Moneylenders					
Farmers					
Friends and relatives					

VIII. Input-output Information:

Crop: _____ Plot no.: _____ Area: _____ Row arrangement: _____ (or proportion)

Variety: _____ Sub-plot: _____

Operations	Labor use[1]			Input/output			
	Source	Unit	Quantity	Wages	Quantity	Unit price	Remarks
1A. Land preparation (Plowing Primary and secondary tillage	M[a]	d[b]					
	F	d					
	B	d					
	T	h					
1B. Seedbed preparation (BBF/NBF/FLAT)	M	d					
	F	d					
	B	d					
	T	h					
2. FYM/Compost/Sheep penning/ Tank silt application	M	d					
	F	d					
	B	d					
	T	h					
FYM/Compost		q					
Animal penning		n					
Date of sowing							
3. Planting/Sowing	M	d					
	F	d					
	B	d					
4A. Seed: Crop 1		kg					
Crop 2		kg					
Crop 3		kg					
4B. Seed treatment	M	d					
	F	d					
		E					
		g					

Operations	Labor use[1]			Input/output			
	Source	Unit	Quantity	Wages	Quantity	Unit price	Remarks
5A. Fertilizer application	M	d					
	F	d					
		kg					
		kg					
		kg					
		kg					
		kg					
5B. Micronutrient application	M	d					
	F	d					
		kg					
		kg					
		kg					
6. Interculture	M	d					
	F	d					
	B	d					
7. Weeding/Weedicide application	M	d					
	F	d					
	SP	h					
		1					
		1					
8. Plant protection/Spraying/ Dusting/Shaking plants/ Hand picking pests	M	d					
	F	d					
	B	d					
	SP	h					
	D U	h					

Operations		Labor use[1]			Input/output			Remarks
		Source	Unit	Quantity	Wages	Quantity	Unit price	
9. Irrigation		M	d					
		F	d					
			h					
Source of rrigation								
10. Watching (birds, pigs, etc.)		M	d					
		F	d					
11. Harvesting[2]:	Crop 1	M	d					
		F	d					
Date of harvesting	Crop 2	M	d					
		F	d					
	Crop 3	M	d					
		F	d					
12. Threshing:	Crop 1	M	d					
		F	d					
		B	d					
		TH	h					
	Crop 2	M	d					
		F	d					
		B	d					
		TH	h					
	Crop 3	M	d					
		F	d					
		B	d					
		TH	h					
13. Marketing (including transport, storage, and labor charges)		M	d					
		F	d					
		B	d					
		T	h					
14. Fixed cost: Land rent: Cash			Rs					
Kind			kg					
Land tax:								

Operations		Labor use[1]			Input/output			Remarks
		Source	Unit	Quantity	Wages	Quantity	Unit price	
15. Grain yield:	Crop 1		kg					
	Crop 2		kg					
	Crop 3		kg					
			kg					
			kg					
16. Fodder yield:	Crop 1		q					
	Crop 2		q					
	Crop 3		q					
			q					
			q					
17. Stalk.....			q					
.....			q					

1. Labor input includes total labor days of family and hired labor for each operation. Specify male and female labor as well as bullock labor separately wherever necessary.
2. Estimate the labor requirement if you had given to contractor for harvesting.

Notes:
M = Male labor, F = Female labor, B = Bullock labor, T = Tractor/Truck, TH = Thresher, SP = Sprayer, DU = Duster, d = days, h = hours, n = numbers, 1 = litre, F Y M = farmyard manure.

- Specify clearly the units (eg., 5 kg, 2 tons, etc.).
- In irrigation operation use codes from code book.
- Cost of hiring tractors/bullocks includes cost of operator.
- Ask/calculate land rent for particular crop only.

IX. Sources of Information:

- State Agricultural Departments
- Research institutions (Specify)
- NGOs (Specify)
- Private agencies (Specify)
- Relatives/Friends
- Other farmers
- Through Magazines/Newspapers
- Radio
- Private seed dealers

X. Constraints in Production Practices:

1. Pertaining to technology YES/NO

(a) Seed and seed treatment

i. Low germination
ii. Low purity
iii. Uneven germination due to uncontrolled depth
iv. Late sowing due to unavailability of seed in time
v. Complete immunity not ensured by seed treatment
vi. Lack of local supply of improved seed
vii. Lack of knowledge about method of sowing
viii. Unavailability of suitable variety as recommended

(b) Water management

i. Lack of irrigation
ii. Undulated land
iii. Lack of knowledge about irrigation method and time
iv. Alternative irrigation is not possible
v. Defective land shaping
vi. Water is not supplied when required
vii. Stagnation of water in the field due to inadequate drainage system
viii. Declining water table

(c) Fertilizer and manurial management

i. Judicious balancing with recommended phosphatic and potassic fertilizer is not necessary in soil.
ii. High doses of fertilizers spoils the soils.
iii. Induction of more diseases and pests through application of fertilizer
iv. Fertilizer application is more expensive
v. Loss of fertilizer through leaching and runoff
vi. Due to poor soil conditions
Vii. Lack of timely supply
viii. Non-availability of F Y M
ix. Poor quality of F Y M
x. Lack of timely supply of F Y M
xi. Lack of fertilizer supply
xii. F Y M is not necessary
xiii. F Y M application

(d) Weed control

i. Chemical application not effective as hand weeding
ii. Difficulty in weeding in irrigated field
iii. Weedicides cause toxicity to crop
iv. Hand weeding time and labor consuming, thus expensive
v. High cost of weedicides
vi. Inadequate or nil knowledge of weedicide use

(e) Disease and pest control

i. Spraying is not effective
ii. Most of the diseases/pests are not under control
iii. Lack of supply of plant protection material
iv. Capital insufficient
v. Lack of knowledge about plant protection
vi. Lack of local supply
vii. Chemicals are more toxic to animals and humans
viii. No problem of diseases and pests in the field

(f) Harvesting and threshing

i. Difficulty in harvesting due to stagnation of water in the fields
ii. Appropriate time cannot be judged
iii. Lack of fruit picker

2. Pertaining to labor management

(a) Shortage of labor at the time of _____
(b) High wages of labor at the time of _____
(c) High labor mobilization at the time of _____
(d) Skilled/labor shortage for the purpose of _____

3. Pertaining to institutional infrastructure

(a) Credit

i. Not available from one agency and in time
ii. Rate of interest is not only high but varies from agency to agency
iii. Complicated loaning procedure
iv. Recovery procedure is stringent
v. The various fees, charges, and cost involved in running credit agencies are often very high

(b) Marketing

i. Monopoly and forced marketing in grain market/vegetable market
ii. Late and inadequate returns in the market
iii. Market located at a distant place
iv. More transportation charges
v. Unauthorized charge

(c) Extension

i. Farmer training conducted at distant places
ii. Improved production techniques are not demonstrated in the field
iii. Intensive contact of subject matter specialists from university and agricultural department with farmers is very low
iv. Key information and important technical information are not provided to village youth

Techno-economic Survey for Production Practices and Constraint Analysis in Watershed Areas

Name of Watershed _____

Guide questionnaire for Rapid Rural Appraisal:

Village information :

Name of the village : _____

Name of the tahsil _____

Name of the district : _____

Total population of village : _____

Total cultivating households : _____

Total labor households : _____

Total cultivated area in village : _____

Total fallow land in the village _____

Total irrigated area in the village : _____

Source of irrigation : _____

Average land holding : _____

Soil types in the village : _____

Major cropping patterns : _____

_____

Government schemes operating : _____

No. of sprayers in village : _____

Distance of fertilizer and pesticide shops from village _____

The semi-arid tropics (SAT) encompasses parts of 48 developing countries including most of India, parts of southeast Asia, a swathe across sub-Saharan Africa, much of southern and eastern Africa, and parts of Latin America. Many of these countries are among the poorest in the world. Approximately one-sixth of the world's population lives in the SAT, which is typified by unpredictable weather, limited and erratic rainfall, and nutrient-poor soils.

ICRISAT's mandate crops are sorghum, pearl millet, finger millet, chickpea, pigeonpea, and groundnut; these six crops are vital to life for the ever-increasing populations of the SAT. ICRISAT's mission is to conduct research which can lead to enhanced sustainable production of these crops and to improved management of the limited natural resources of the SAT. ICRISAT communicates information on technologies as they are developed through workshops, networks, training, library services, and publishing.

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