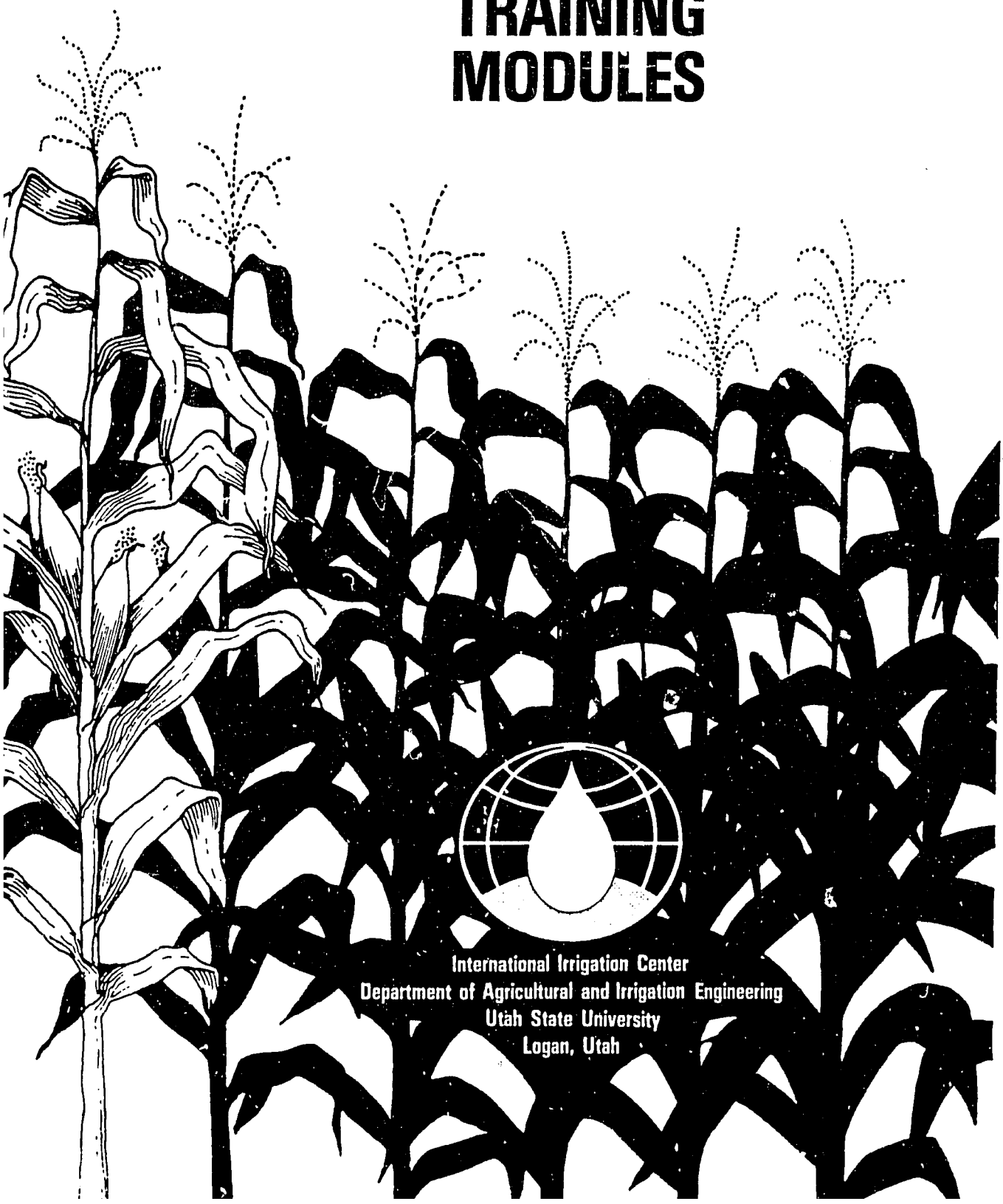
PN-ABG-581

ISN: 69048

IRRIGATION TRAINING MODULES



International Irrigation Center
Department of Agricultural and Irrigation Engineering
Utah State University
Logan, Utah

IRRIGATION TRAINING MODULES

INTERNATIONAL IRRIGATION CENTER
Department of Agricultural and Irrigation Engineering
Utah State University
Logan, Utah

1985

INDEX TO IRRIGATION TRAINING MODULES

This index provides a written and visual overview of the irrigation training modules, emphasizing the most important concepts contained in each. Appropriate modules for a given situation can easily be identified and selected for use. The series of video training modules is designed to introduce basic irrigation concepts to agricultural technicians who provide assistance to farmers. The modules are not intended to function as a complete training package, but rather to serve as a training aid to assist in the dissemination of more specific irrigation information. The primary funding to develop these modules was provided through USAID/Ecuador; therefore, the modules present many Ecuador-specific examples, although the concepts demonstrated can be universally applied. The 40 video modules are available in English and/or Spanish, in 1/2" VHS or Beta formats, and can be delivered in the television standard (NTSC, PAL, etc.) utilized in an individual country.

Produced by
INTERNATIONAL
IRRIGATION
CENTER
DEPARTMENT OF
AGRICULTURAL &
IRRIGATION ENGINEERING
UTAH STATE UNIVERSITY

Video Production by
INSTRUCTIONAL TELEVISION

Computer Graphics by
GRAPHIC SERVICES

Funded by
UTAH STATE UNIVERSITY

U.S. AGENCY FOR
INTERNATIONAL
DEVELOPMENT, WATER
MANAGEMENT
SYNTHESIS II PROJECT

USAID/ECUADOR

SEDRI & INERHI

For further
information write:
INTERNATIONAL
IRRIGATION CENTER
UMC 83
UTAH STATE UNIVERSITY
LOGAN, UTAH 84322

CONTENTS

MODULE	TITLE	PROGRAM LENGTH (min:sec) ENGLISH	SPANISH
CHAPTER 1	SOIL-WATER-WEATHER-PLANT-FERTILITY-RELATIONSHIPS		
1	Introduction to Hydro-Agriculture	5:10	5:46
2	Soil Water Storage and Availability	7:57	8:46
3	Quantitative Determination of Soil Moisture	6:58	6:45
4	The Use of Water by Plants	7:22	8:11
5	General Procedures and Estimation of Reference Crop Potential Evapotranspiration	7:53	9:15
6	Evapotranspiration - Selection of the Crop Coefficient	10:27	12:09
7	Crop Water Requirements for Ecuador	8:27	10:30
8	Critical Water Requirement Period of Crops	6:52	8:25
9	Determining When and How Much to Irrigate	14:20	17:29
10	Methods for Measuring Soil Water	9:47	11:14
11	Feeling the Soil to Determine When to Irrigate	9:31	11:58
12	Corn Production at Various Levels of Irrigation and Fertilizer Application	10:37	12:49
13	Crop Selection and Time of Planting as a Function of Rainfall and Irrigation Water Availability	12:14	15:39
14	Subsoil Conditions Which Affect Root Development, Water Penetration and Aeration	7:01	8:54
15	The Effects of High Water Tables on Crop Production and the Need for Drainage	6:52	8:52
16	Soil Salinity: Causes, Effects on Crop Production, Problem Solutions	9:36	11:56
17	Leaching Requirements for Adequate Salt Balance in the Soil	12:16	14:42

MODULE	TITLE	PROGRAM LENGTH (min:sec) ENGLISH	SPANISH
18	Irrigation Uniformity	8:19	10:51
19	Soil Erosion and Its Control	8:19	11:24
20	Water Infiltration Into Soils	9:12	11:35
CHAPTER 2	IRRIGATION TECHNIQUES		
21	Controlling and Conveying Water from the Source to the Field	11:22	14:30
22	Irrigation Methods: An Overview	6:42	8:12
23	Furrow and Corrugation Irrigation	8:53	12:06
24	Basin and Border Irrigation	10:44	14:11
25	Sprinkle Irrigation	10:15	13:58
26	Trickle or Micro Irrigation	10:24	13:46
27	Other Irrigation Methods	10:25	13:05
28	Surge Flow Irrigation	7:52	7:41
CHAPTER 3	EVALUATING THE ECONOMY OF WATER USE		
29	Basic Concepts for Irrigation System Evaluation	10:37	12:53
30	Types, Purpose and Terminology for System Evaluation	7:32	10:20
31	Water Conveyance Losses	8:02	10:37
32	Water Measurement	13:19	18:06
33	Furrow Irrigation Evaluation and Improvement	9:36	13:03
34	Border and Basin Irrigation Evaluation and Improvement	12:00	16:53
35	Sprinkle Irrigation Evaluation and Improvement	12:02	18:00
36	Trickle Irrigation Evaluation and Improvement	6:43	8:41

MODULE	TITLE	PROGRAM LENGTH (min:sec) ENGLISH	SPANISH
CHAPTER 4	MANAGEMENT TO IMPROVE AGRICULTURAL PERFORMANCE		
37	Improving Efficiencies Through Use of Reservoirs, Reuse Systems and Automation	7:58	10:56
38	Determining Water Delivery Requirements	8:56	11:33
39	Field Water Delivery Schedules	9:27	12:15
40	Irrigation Management Program and Managing Systems with Water Shortages or Excesses	12:13	15:41

Chapter One

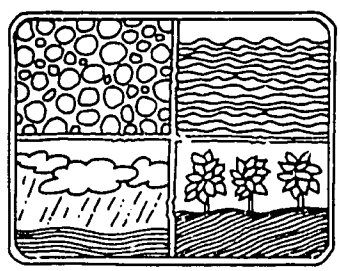
Soil, Water, Weather, Plant, Fertility Relationships

MODULE 1
INTRODUCTION TO HYDRO-AGRICULTURE

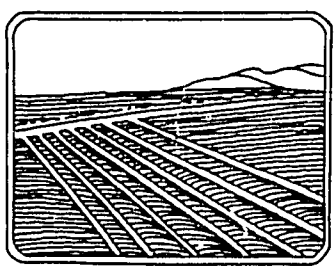
CONCEPTS:

SOIL, WATER, PLANT, WEATHER RELATIONSHIPS
IRRIGATION TECHNIQUES
MANAGEMENT TO IMPROVE PERFORMANCE
VITAL ELEMENTS FOR SUCCESSFUL AGRICULTURE

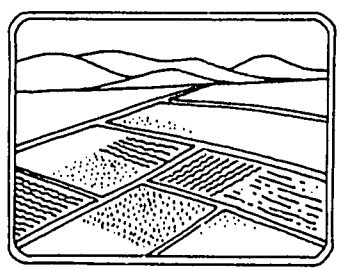
Module 1 serves as an introduction to the 39 subsequent modules. Basic concepts are presented which explain the role of water in crop production and how proper management can improve irrigation and crop yields. The four major topics which will be discussed in the modules are: (1) soil, water, weather, plant and fertility relationships; (2) irrigation techniques; (3) evaluating irrigation techniques; and (4) management to improve performance. The vital elements for successful agriculture are presented as: (1) soil; (2) water; (3) seeds; (4) nutrients; (5) sunlight; (6) air; (7) temperature; (8) pest, insect and weed control; (9) pruning; (10) plant protection; and (11) plant spacing.



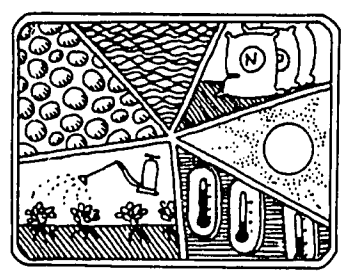
Soil, Water, Plant, Weather Relationships



Irrigation Techniques



Management to Improve Performance



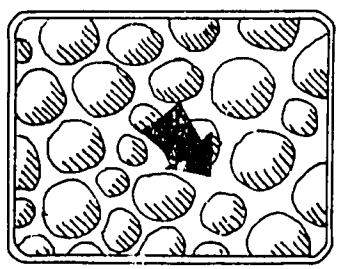
Vital Elements for
Successful Agriculture

MODULE 2
SOIL WATER STORAGE AND AVAILABILITY

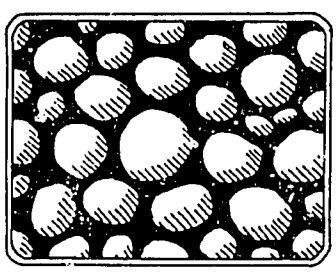
CONCEPTS:

SOIL WATER STORAGE
SATURATION
FIELD CAPACITY
PERMANENT WILTING POINT
WATER HOLDING CAPACITY
ROOT ZONE/WATER AVAILABILITY
SOIL TEXTURE/WATER STORAGE RELATIONSHIPS

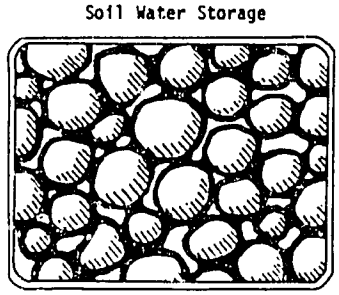
This module describes how the soil stores water, how much water the soil can hold and how much water is available to the plant. Water is stored in the spaces between soil particles (pores). When all the spaces are full of water, the soil is saturated. When the largest pores have drained, but water remains in the smaller pores, the soil is at field capacity. The permanent wilting point occurs when the amount of water is depleted enough that plants cannot recover even if they are irrigated. The amount of water the soil holds between field capacity and the permanent wilting point is the available water holding capacity. This depends on the size of the soil particles and the proportion of large, medium and fine particles (texture). Only the water present in the root zone of the plant is actually available to the plant.



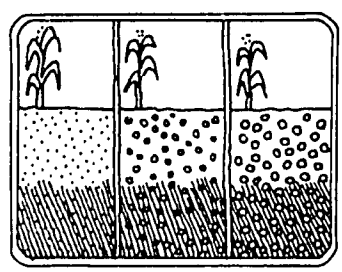
Soil Water Storage



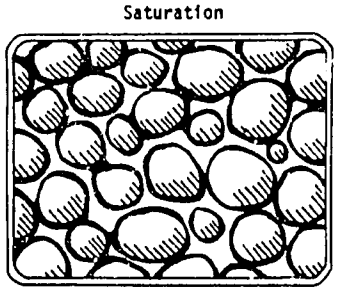
Saturation



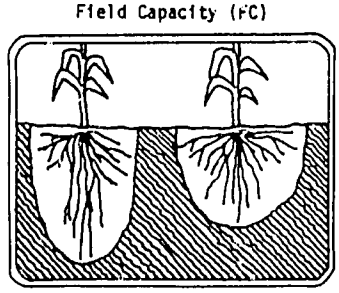
Field Capacity (FC)



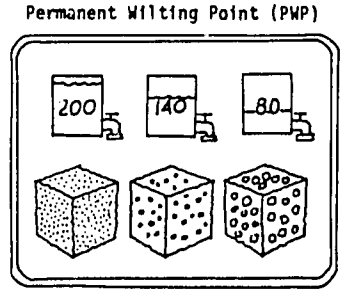
Permanent Wilting Point (PWP)



Water Holding Capacity (WHC)



Root Zone/Water Availability



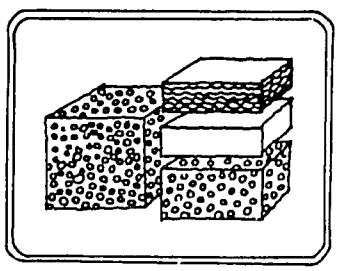
Soil Texture/Water Storage

MODULE 3
QUANTITATIVE DETERMINATION OF SOIL MOISTURE

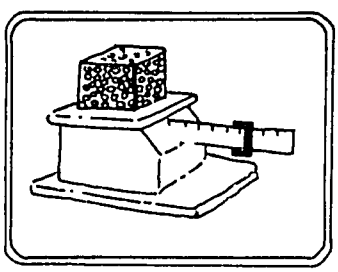
CONCEPTS:

BULK VOLUME/COMPONENTS
MEASURING SOIL WATER CONTENT BY WEIGHT
CONVERTING WEIGHT TO VOLUME
SOIL BULK DENSITY
EXPRESSING VOLUME AS EQUIVALENT DEPTH
ESTIMATING SOIL WATER CONTENT BY SOIL TEXTURE

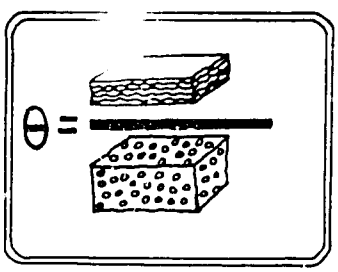
Module 3 presents quantitative parameters for measuring the actual soil moisture content. This determines when and how much to irrigate. The bulk volume of a specified amount of soil includes soil particles, water and air. Soil water content is most easily measured by weight, which is then converted to a volumetric basis utilizing the soil bulk density. For actually applying irrigation water to a field, the volumetric water content is expressed as an equivalent depth. The feel and appearance of the soil can be used as a guide for estimating soil water content when a quick determination of available water is necessary.



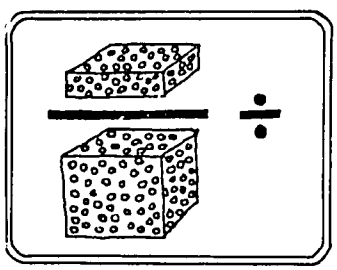
Bulk Volume/Components



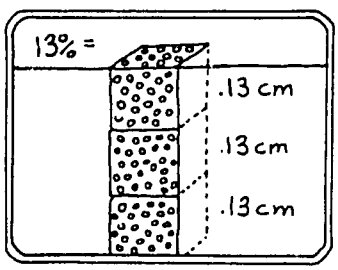
Measuring Soil Water Content by Weight



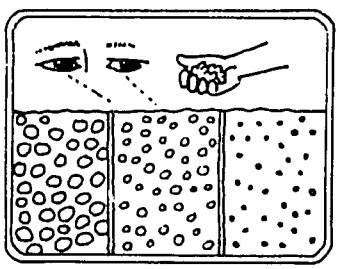
Converting Weight to Volume



Soil Bulk Density



Expressing Volume as Equivalent Depth



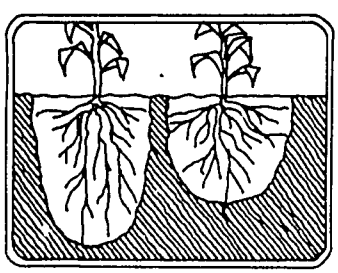
Estimating Soil Water Content by Soil Texture

MODULE 4
THE USE OF WATER BY PLANTS

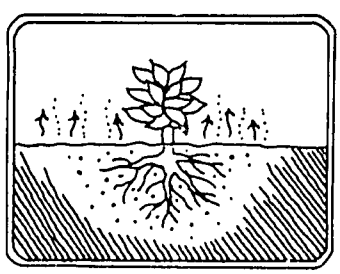
CONCEPTS:

SOIL MOISTURE RESERVOIR
EVAPORATION/TRANSPIRATION/EVAPOTRANSPIRATION
RATE OF WATER USE
MOISTURE WITHDRAWAL PATTERNS

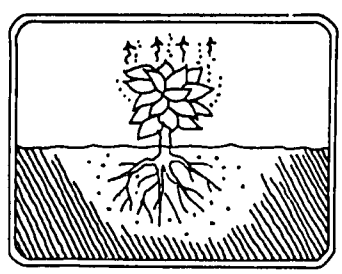
This module discusses the role that water plays in plant development. Water delivers nutrients, provides a medium for chemical reactions and cools the plant. The water a plant uses comes from the soil moisture reservoir, whose size is determined by the rooting depth of the plant. Plants extract water from different parts of their root zones depending on root depth, frequency of irrigation, soil uniformity and the withdrawal pattern of the crop. The rate of water use for a crop depends on weather conditions, crop type, stage of crop growth and water availability in the soil reservoir.



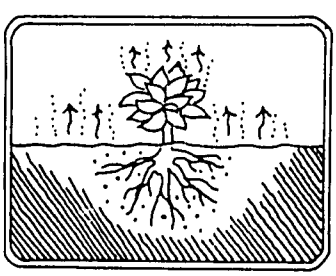
Soil Moisture Reservoir



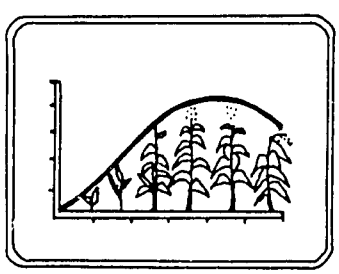
Evaporation



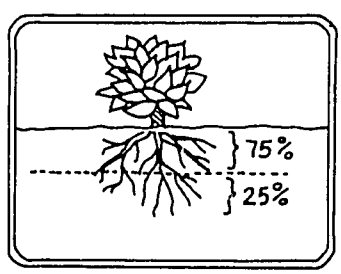
Transpiration



Evapotranspiration



Rate of Water Use



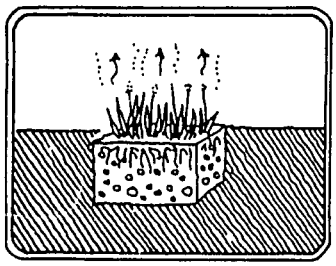
Moisture Withdrawal Patterns

MODULE 5
GENERAL PROCEDURES AND ESTIMATION OF REFERENCE CROP
POTENTIAL EVAPOTRANSPIRATION

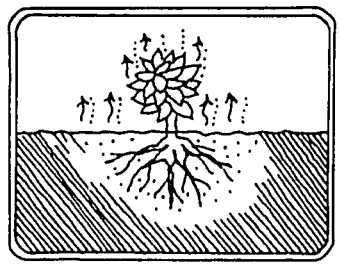
CONCEPTS:

POTENTIAL EVAPOTRANSPIRATION (ET_p)
EVAPOTRANSPIRATION (ET)
LYSIMETER MEASUREMENTS
REFERENCE CROP
ESTIMATING CROP WATER USE

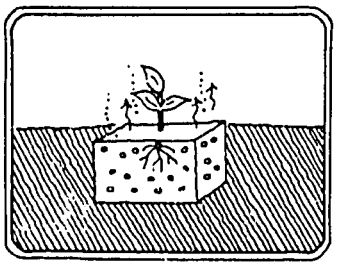
Evapotranspiration (ET) is a combination of evaporation and transpiration. Knowing the ET of a crop helps determine what crop to plant, when to irrigate and how much water to apply during an irrigation. Evapotranspiration can be measured by using lysimeters, which are large sealed tanks containing soils and crops. Specific measurements include the amount of water applied, the amount of water draining to the bottom and changes in soil water storage. When climate and crop data are available, a simple and accurate method can be used for estimating crop water use by: (1) determining the potential evapotranspiration (ET_p) of a reference crop; (2) determining the crop coefficient (K_c); and (3) multiplying ET_p by K_c to obtain the crop water use.



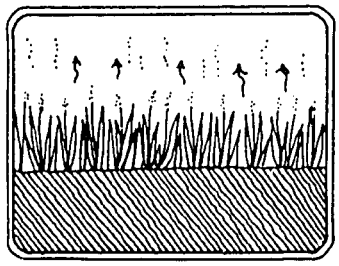
Potential Evapotranspiration (ET_p)



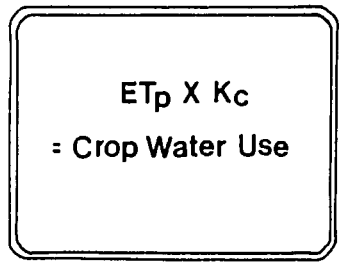
Evapotranspiration (ET)



Lysimeter Measurements



Reference Crops



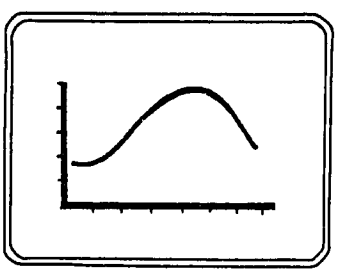
Estimating Crop Water Use

MODULE 6
EVAPOTRANSPIRATION-SELECTION OF THE CROP COEFFICIENT

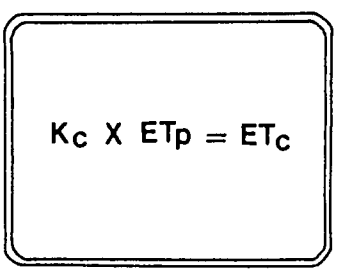
CONCEPTS:

CROP COEFFICIENT (K_c)
CALCULATING EVAPOTRANSPIRATION
FACTORS AFFECTING K_c
STAGES OF THE CROP GROWING SEASON

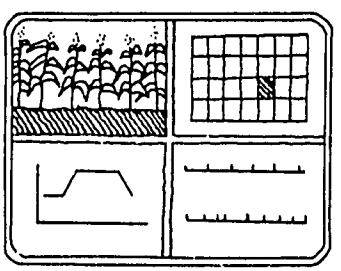
Evapotranspiration for a specific crop is determined by multiplying the potential evapotranspiration (ET_p) of the reference crop by the crop coefficient (K_c) of the crop under consideration. The major factors affecting K_c are: (1) the kind of crop; (2) planting date; (3) crop growth stage; and (4) the length of the growing season. The crop growing season is divided into four stages: (1) the initial stage; (2) the crop development stage; (3) the mid-season stage; and (4) the late-season stage. Six steps for establishing K_c through the growing season are: (1) establish the planting dates; (2) determine the length of the crop development stages; (3) establish K_c during the initial stage; (4) determine K_c at mid-season; (5) determine K_c during stage 2; and (6) determine K_c at the end of the season. This information can then be used to calculate the crop water use at any time.



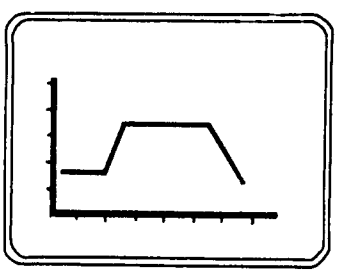
Crop Coefficient (K_c)



Calculating Evapotranspiration



Factors Affecting K_c



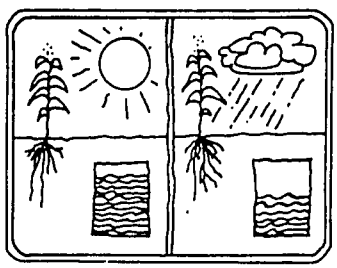
Stages of the Crop Growing Season

MODULE 7
CROP WATER REQUIREMENTS FOR ECUADOR

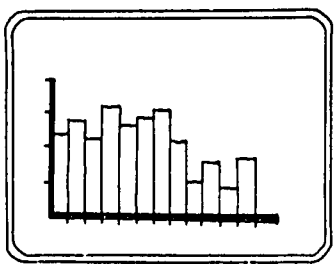
CONCEPTS:

CLIMATE AND CROP WATER REQUIREMENTS
RAINFALL AREAS/GEOGRAPHIC LOCATIONS IN ECUADOR
INFLUENCES ON CLIMATE
IRRIGATION NEEDS

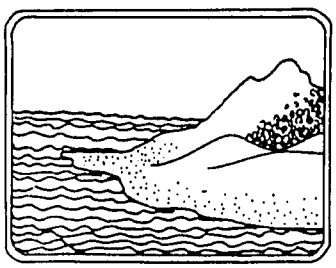
Module 7 discusses the relationship between crop water requirements and climate in Ecuador. Five different rainfall areas and geographic locations are emphasized: Salinas and San Lorenzo, two coastal areas; Quito and Riobamba, two inner Andean areas; and Mendez on the Amazon side of the Andes. The climate in Ecuador is influenced by ocean currents, elevation and topography. Because of the variation in rainfall in these locations, water use supplied by precipitation may vary from 0-100% of the crop water requirements. The differences between crop water use and effective precipitation determine the amount of irrigation necessary.



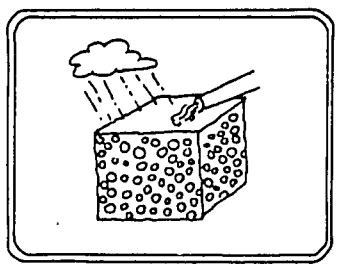
Climate and Crop Water Requirements



Rainfall Areas/Geographic Locations in Ecuador



Influences on Climate



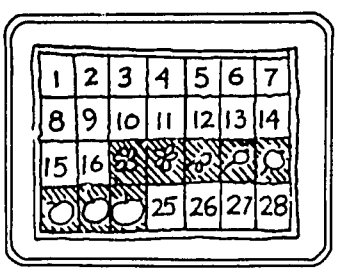
Irrigation Needs

MODULE 8
CRITICAL WATER REQUIREMENT PERIOD OF CROPS

CONCEPTS:

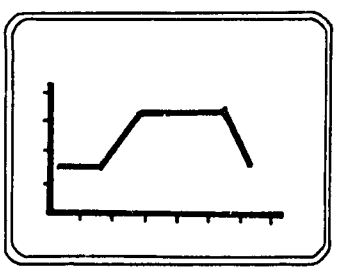
CRITICAL WATER USE PERIOD
SELECTING CROPS TO MATCH WATER AVAILABILITY
WATER REQUIREMENTS OF CORN

This module considers the critical water use periods of different crops. Adequate water supplies are necessary during these periods to insure good crop quality and yields. Generally, the most critical periods are during flowering and yield formation. Crops should be selected to suit water availability so that water shortages will not occur when the crop is most sensitive to moisture stress. The water requirement periods of corn are discussed in some detail, while the most sensitive stages of other crops are mentioned. Some of the effects of inadequate water supplies are also presented.



Critical Water Use Period

Selecting Crops
to Match Water Availability

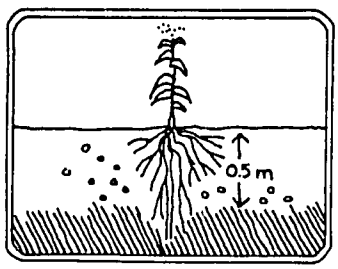

Water Requirements of Corn

MODULE 9
DETERMINING WHEN AND HOW MUCH TO IRRIGATE

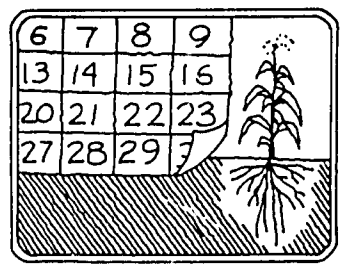
CONCEPTS:

ALLOWABLE WATER DEPLETION
IRRIGATION FREQUENCY
NET WATER APPLICATION REQUIREMENTS
GROSS WATER APPLICATION REQUIREMENTS
WATER HOLDING CAPACITY
DURATION AND STREAM SIZE REQUIRED

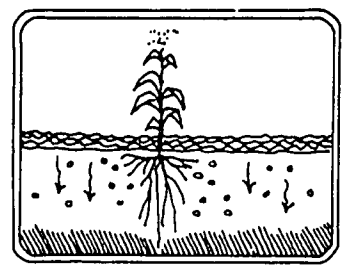
Irrigations must be correctly conducted in order to make the best use of the water supply. This module discusses the use of plant, soil, water and weather relationships to determine when and how much to irrigate. The allowable water depletion is the amount of water that can be withdrawn from the root zone before plant growth is affected. Irrigation frequency is based on allowable depletion, crop water use and other practical considerations. The amount of water necessary to eliminate the water deficit is the net depth of irrigation water to be applied. However, since irrigations are never uniform, a greater amount of water needs to be applied to the crop to compensate for the inefficiencies. Equations and examples are presented to quantify the variables for conducting irrigations at the correct times and in the correct amounts.



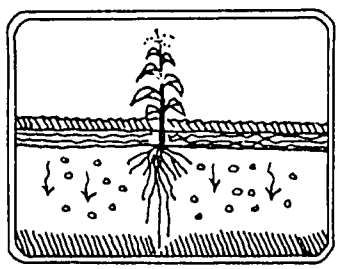
Allowable Water Depletion



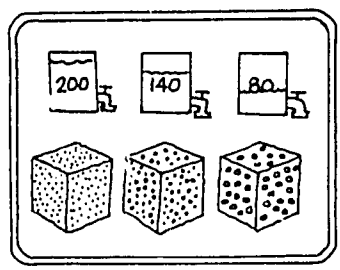
Irrigation Frequency



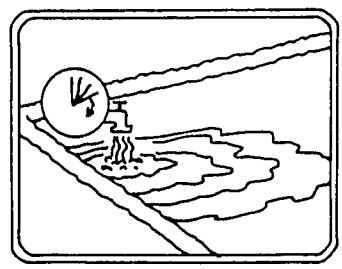
Net Water Application Requirements



Gross Water Application Requirements



Water Holding Capacity



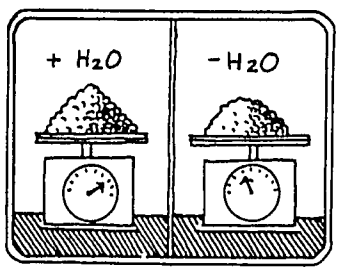
Duration and Stream Size Required

MODULE 10
METHODS FOR MEASURING SOIL WATER

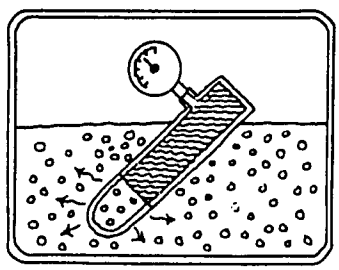
CONCEPTS:

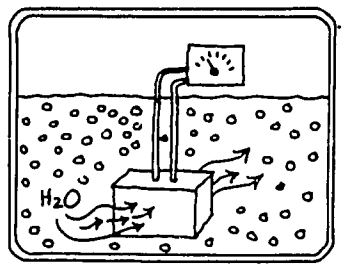
GRAVIMETRIC METHOD
TENSIOMETERS
ELECTRICAL RESISTANCE BLOCKS
NEUTRON PROBE
VISUAL AND FEEL METHOD
FACTORS AFFECTING CHOICE OF METHOD
SAMPLING DEPTH

Module 10 presents five of the more common methods of measuring soil water for better management of the soil water reservoir. These are: (1) the gravimetric method; (2) the use of tensiometers; (3) the use of electrical resistance blocks; (4) the use of neutron probes; and (5) the visual and feel method. There are advantages and disadvantages for each method. The means chosen depends on equipment availability, required accuracy, soil type and condition and the moisture sensitivity of the crop. Depth of sampling depends on the rooting depth of the crop and soil layering. Sampling locations should be in areas representative of plant density and growth and where soil texture or water penetration may vary.

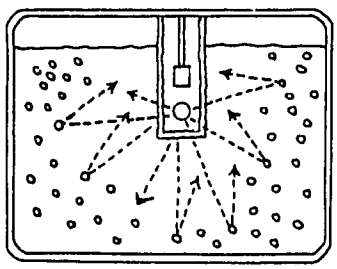


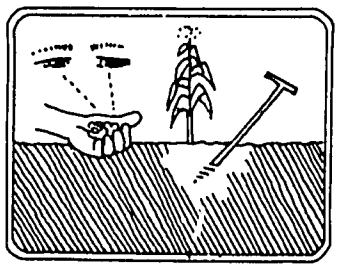
Gravimetric Method

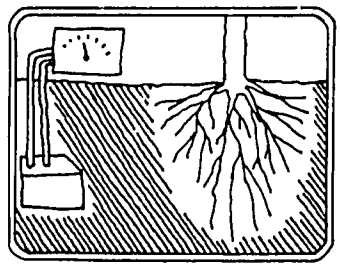

Tensiometers



Electrical Resistance Blocks


Neutron Probe


Visual and Feel Method

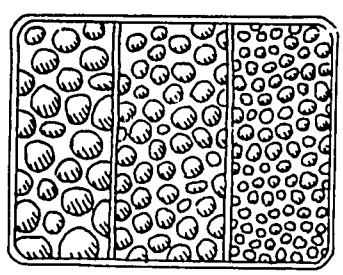

Sampling Depth

MODULE 11
FEELING THE SOIL TO DETERMINE WHEN TO IRRIGATE

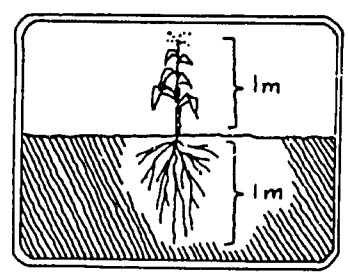
CONCEPTS:

SOIL TYPE
ROOT DEPTH
ALLOWABLE WATER DEPLETION
SOIL WATER CONTENT
FEEL METHOD

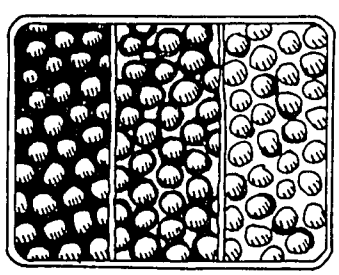
The feel method is one of the easier ways to estimate irrigation need. To determine when to irrigate it is necessary to know: (1) the soil type; (2) how deep the roots extend into the soil; (3) the allowable water depletion; and (4) the existing soil water content. Soils are classified as coarse, medium or fine-textured. Root depth is usually equal to plant height for estimating purposes, although this should occasionally be verified. An allowed depletion of one-half of the available water holding capacity is generally satisfactory, although it can vary for different crops. The soil water content can be approximately determined by means of the feel method. This involves taking and interpreting soil samples from representative locations in the field. This information can assist the farmer in determining the approximate frequency and duration of irrigations necessary for good crop production.



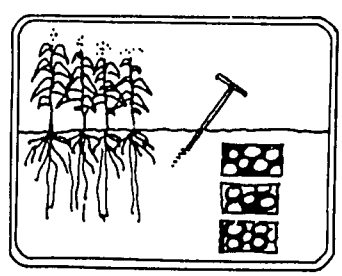
Soil Type



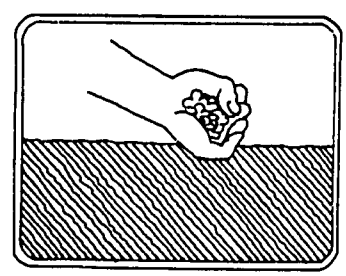
Root Depth



Allowable Water Depletion



Soil Water Content



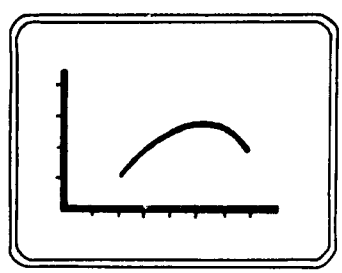
Feel Method

MODULE 12
CORN PRODUCTION AT VARIOUS LEVELS OF IRRIGATION
AND FERTILIZER APPLICATION

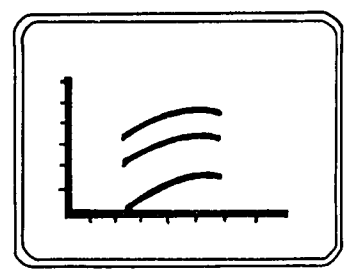
CONCEPTS:

CORN YIELDS/CONSTANT FERTILITY LEVELS
CORN YIELDS/VARIED FERTILITY LEVELS
CORN YIELDS/CONSTANT WATER LEVELS
CORN YIELDS/VARIED WATER LEVELS
FERTILIZER AND WATER APPLIED OVER LARGER AREAS
FOR GREATER PRODUCTION

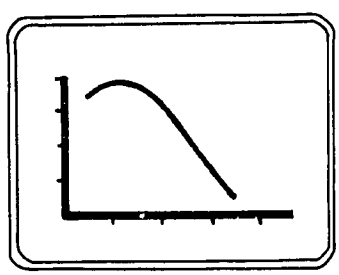
The timing and amount of irrigation water and fertilizer applications greatly influence crop production and yield, especially on low fertility soils. This module discusses how crop yields vary as irrigation and fertility levels are changed. Corn is used as the sample crop. Minimum fertility and soil moisture levels must be met to achieve any significant production. Generally it is more profitable to spread both irrigation water and fertilizer over a larger area than to apply concentrated amounts to a smaller area. Beyond a certain point, additional applications of water or fertilizer will not improve crop yields and may actually reduce yields.



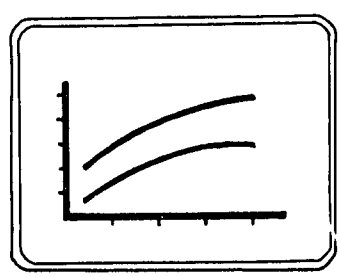
Corn Yields/Constant Fertility Levels



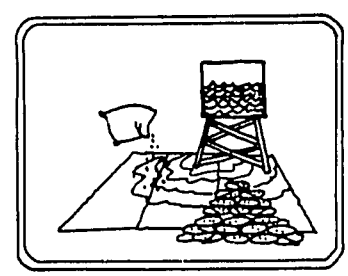
Corn Yields/Varied Fertility Levels



Corn Yields/Constant Water Levels



Corn Yields/Varied Water Levels



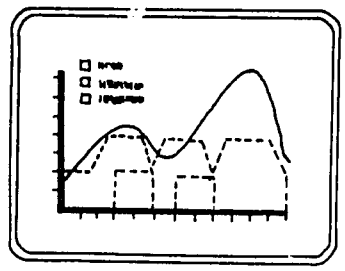
Fertilizer and Water Applied Over
Larger Areas for Greater Production

MODULE 13
CROP SELECTION AND TIME OF PLANTING AS A FUNCTION OF RAINFALL AND IRRIGATION WATER AVAILABILITY

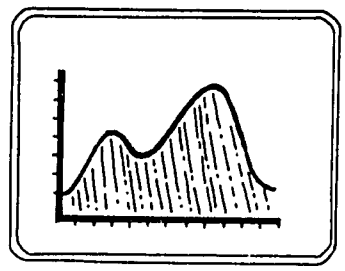
CONCEPTS:

WATER AVAILABILITY/CROP SELECTION AND PLANTING
MEAN RAINFALL
DEPENDABLE RAINFALL
EFFECTIVE RAINFALL
CROP WATER REQUIREMENTS

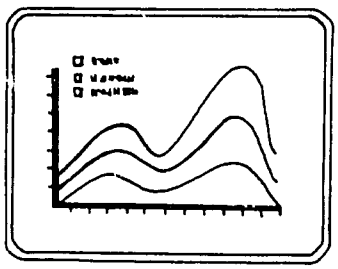
Water availability during the growing season and crop water requirements influence crop selection and planting dates. Careful selection minimizes the risk of crop failure while maximizing the use of water resources. Three concepts necessary for evaluating the amount of rainfall available for plant growth are: (1) mean rainfall; (2) dependable rainfall; and (3) effective rainfall. Mean rainfall is the average amount of precipitation that has been recorded for a certain period over several years. Dependable rainfall is the amount of precipitation which can be expected with a given degree of probability. Effective rainfall is that part of the rain which remains in the soil reservoir available for plant use. Procedures for determining dependable and effective rainfall are discussed. This knowledge, along with crop water requirements, can be used to determine irrigation needs.



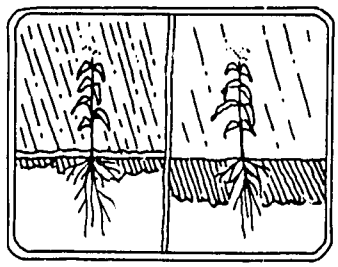
Water Availability/Crop Selection and Planting



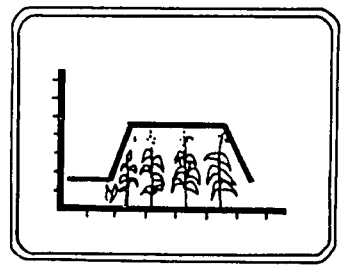
Mean Rainfall



Dependable Rainfall



Effective Rainfall



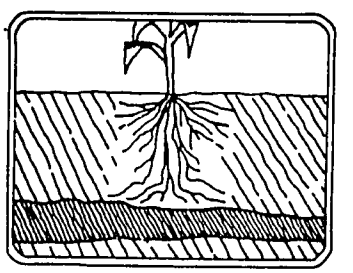
Crop Water Requirements

MODULE 14
SUBSOIL CONDITIONS WHICH AFFECT ROOT DEVELOPMENT,
WATER PENETRATION AND AERATION

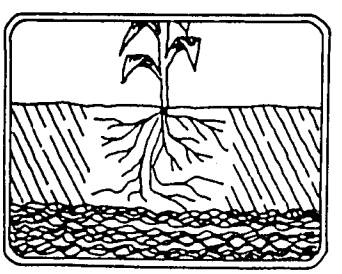
CONCEPTS:

HARD PANS/COMPACTED SOIL LAYERS
HIGH WATER TABLES
AERATION
IRRIGATION MANAGEMENT

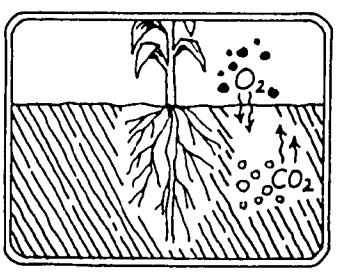
Certain subsoil continuous inhibit root development, restrict water penetration and air circulation and generally result in lower yields. These conditions are: (1) hard pans or compacted layers of soil; (2) high water tables; and (3) improper management of the soil water reservoir. Roots cannot easily penetrate compacted soil layers and will grow no closer than 30 centimeters to the free water table. High water content and tight, heavy soils also restrict air circulation in the soil. Deep plowing, incorporation of organic matter into the soil, proper tillage and preventing high water tables may alleviate these problems. Good irrigation management requires enough water to fill the root zone so that no dry layers remain, but not so much that the upper part of the root zone stays wet.



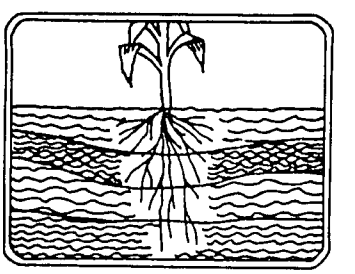
Hard Pans/Compacted Soil Layers



High Water Tables



Aeration



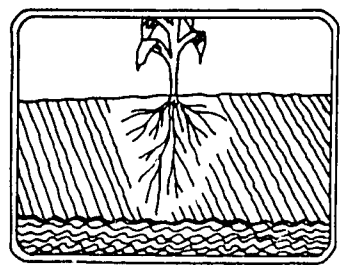
Irrigation Management

MODULE 15
THE EFFECTS OF HIGH WATER TABLES ON CROP PRODUCTION
AND THE NEED FOR DRAINAGE

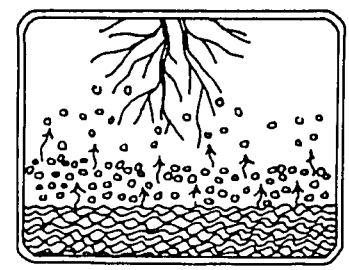
CONCEPTS:

WATER TABLE
CAPILLARY ACTION
CAPILLARY FRINGE
ROOT DEVELOPMENT
DRAINAGE

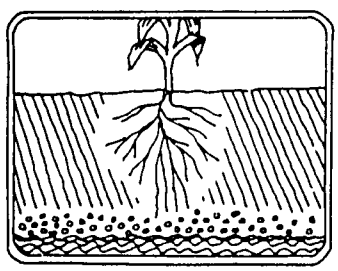
Groundwater levels too close to the soil surface often result in the deterioration of the soil structure and poor crops. The soil below the water table is saturated with water, while the soil just above is partially saturated because of capillary action. This capillary fringe can range from a few centimeters to half a meter, depending on soil type. Water from the water table moves up into the root zone through capillary action as the roots extract water and dry the soil. Roots will not develop below the water table or in the capillary fringe. Other problems associated with high water tables are insufficient aeration and the movement of salts into the root zone. Drainage systems may be required to control the height of the water table so that economical crop production is possible.



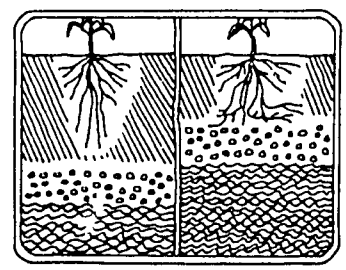
Water Table



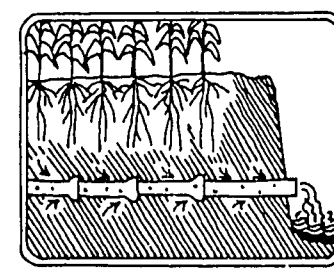
Capillary Action



Capillary Fringe



Root Development



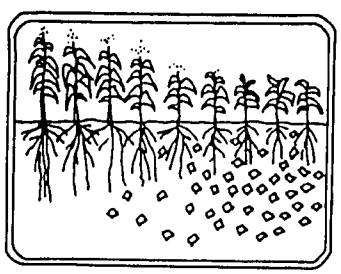
Drainage

MODULE 16
SOIL SALINITY: CAUSES, EFFECTS ON CROP PRODUCTION, PROBLEM SOLUTIONS

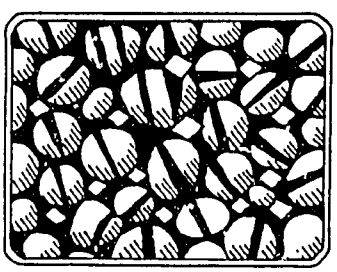
CONCEPTS:

- SALINITY PROBLEMS
  - DECREASE PLANT GROWTH
  - DETERIORATE SOIL STRUCTURE
  - RESTRICT WATER AVAILABILITY
- LEACHING
- CROP TOLERANCE TO SALTS

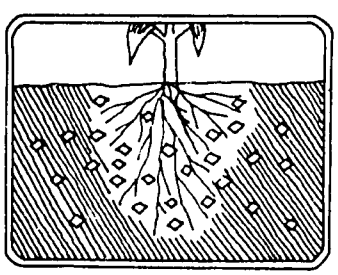
High salt levels in the soil reduce crop yields by restricting water availability, changing the soil structure and having toxic effects on the plants. Salinity problems occur when salts enter the soil profile by means of irrigation water or capillary action from high water tables. As the soil dries, the salt concentration increases in the root zone and restricts the uptake of water by the plants. To prevent damage to the crop, salts must be periodically washed out of the root zone by applying extra irrigation water. This process is called leaching and requires adequate drainage to remove the salty water. Crops differ in their salt tolerances, so proper crop selection is important in areas with salinity problems. Soils suspected of having salinity problems should be checked by chemical analysis so corrective measures can be applied before serious damage occurs.



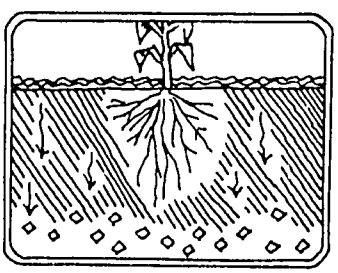
Decrease Plant Growth



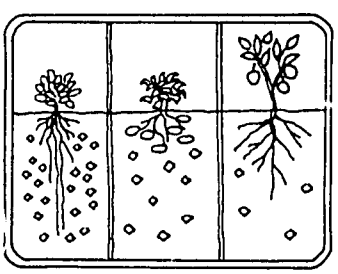
Deteriorate Soil Structure



Restrict Water Availability



Leaching



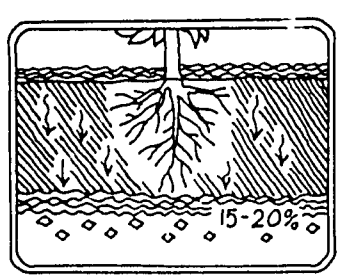
Crop Tolerance to Salts

MODULE 17
LEACHING REQUIREMENTS FOR ADEQUATE
SALT BALANCE IN THE SOIL

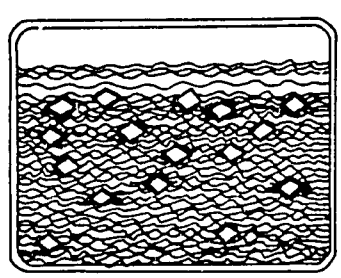
CONCEPTS:

LEACHING REQUIREMENT (LR)
IRRIGATION WATER QUALITY
CROP TOLERANCE TO SALTS

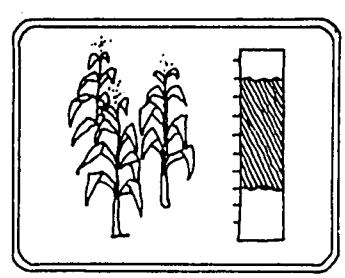
Maintaining an acceptable salt balance is important in maintaining the productivity of irrigated soils. In irrigated agriculture, soil salinity levels will increase unless extra water is applied in addition to that required for crop use. The amount of extra water is called the leaching requirement (LR) and depends on the quality of the water, crop tolerance to salts, soil salinity and the physical/chemical properties of the soil. This module presents several methods for determining the leaching requirement. Because salt accumulation during the growing season does not normally exceed the crop salt tolerance, leaching outside of the growing season can conserve irrigation water and avoid the leaching of fertilizers. However, leaching can be done at any time, depending on the available water supply.



Leaching Requirement (LR)



Irrigation Water Quality



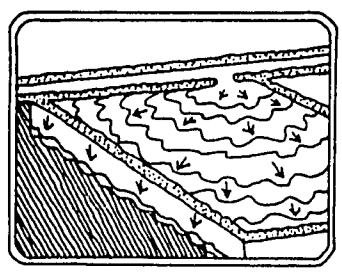
Crop Tolerance to Salts

MODULE 18
IRRIGATION UNIFORMITY

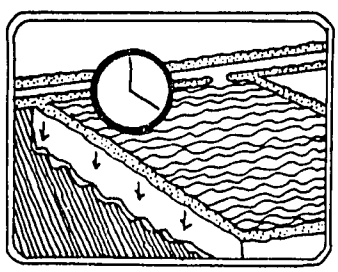
CONCEPTS:

IRRIGATION UNIFORMITY
INTAKE OPPORTUNITY TIME
WATER DISTRIBUTION IN THE SOIL PROFILE
INFILTRATION RATE

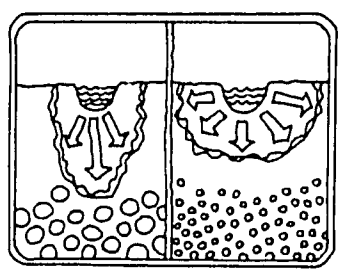
The uniformity of irrigation is a measure of how evenly water spreads over and penetrates the soil during an irrigation. Uniformity depends on factors such as intake opportunity time, infiltration rate, evenness of application, water distribution in the soil profile and on the irrigation method being used. Intake opportunity time is the amount of time that water is in contact with the soil. Non-uniform irrigation problems result from over- or under-irrigation. Uniformity problems can often be detected by observing simple visual indicators such as unevenness of growth and yellowing or wilting of crops. Proper irrigation system design and management will help minimize non-uniformities and improve crop yields.



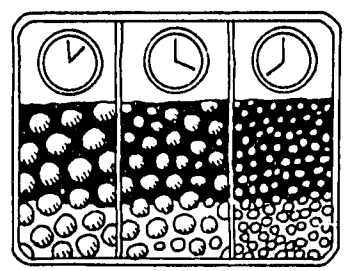
Irrigation Uniformity



Intake Opportunity Time



Water Distribution in the Soil Profile



Infiltration Rate

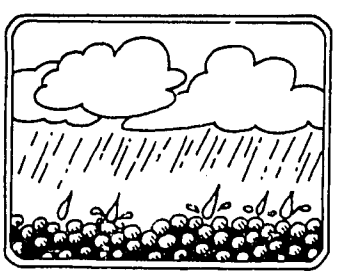
MODULE 19
SOIL EROSION AND ITS CONTROL

CONCEPTS:

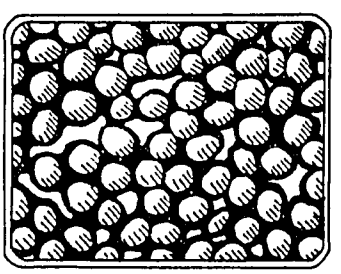
FACTORS AFFECTING EROSION
- CLIMATE
- SOIL
- VEGETATION
- TOPOGRAPHY

EROSION CONTROL MEASURES

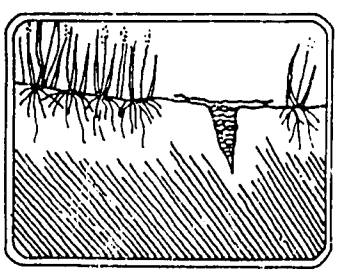
The major factors which affect soil erosion by water are climate, soil, vegetation, topography and control of the irrigation water. Precipitation amount and intensity are the primary climatic factors. Soil factors include soil structure, texture, organic matter content, moisture content and degree of compaction. Vegetation characteristics such as amount of foliage, type of root system and plant and stem density also influence the rate of soil loss. Topographic factors are the slope, length of slope and size and shape of the watersheds. Some of these factors can be controlled or modified to improve soil retention. Practices which cushion the impact of water droplets on the surface, slow the velocity of runoff or hold the soil in place will be effective in controlling erosion caused by rainfall. Soil conservation measures such as contour farming, buffer strip cropping, mulching and minimum tillage will preserve the soil structure and decrease erosion. Good irrigation management practices will also reduce erosion at the farm level.



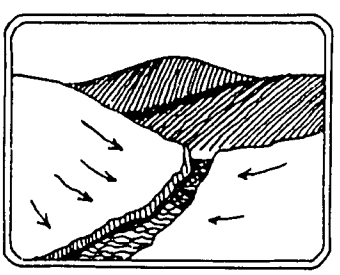
Climate



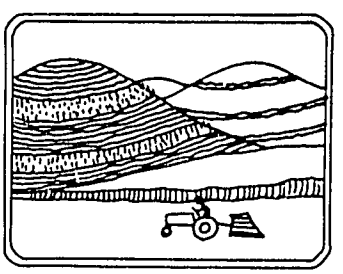
Soil



Vegetation



Topography



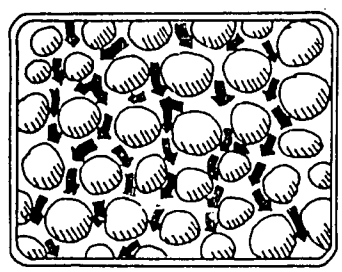
Erosion Control Measures

MODULE 20
WATER INFILTRATION INTO SOILS

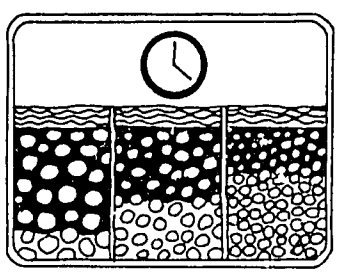
CONCEPTS:

- INFILTRATION
- INFILTRATION RATE
- FACTORS AFFECTING INFILTRATION RATES
  - SOIL TEXTURE
  - SOIL STRUCTURE
  - SURFACE SEALING/CRUSTING
  - SOIL LAYERING
  - AIR ENTRAPMENT

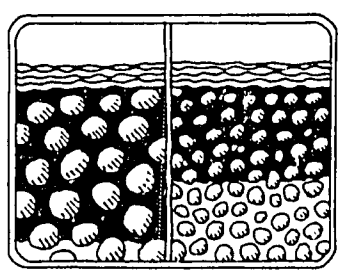
Infiltration is the entry of water into the soil through the surface. Irrigation systems are designed and managed so that the proper amount of water infiltrates into the soil during an irrigation. The infiltration rate is a measure of how fast water is entering the soil. The infiltration rate depends on: (1) soil texture; (2) soil structure; (3) soil water content; (4) water application rates; (5) surface sealing and crusting; (6) soil layering; and (7) air entrapment. Adding organic matter to the soil generally helps increase the infiltration rate. Mulching and tillage methods may also be effective in improving or maintaining intake rates.



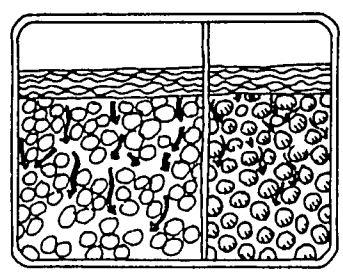
Infiltration



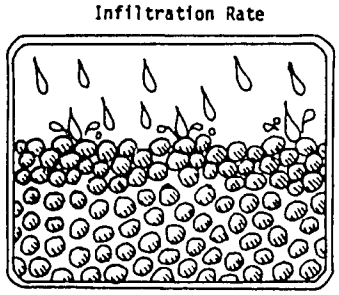
Infiltration Rate



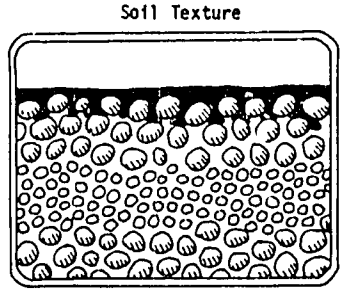
Soil Texture



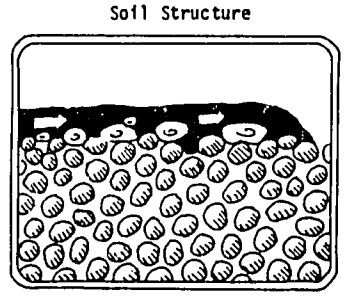
Soil Structure



Surface Sealing/Crusting



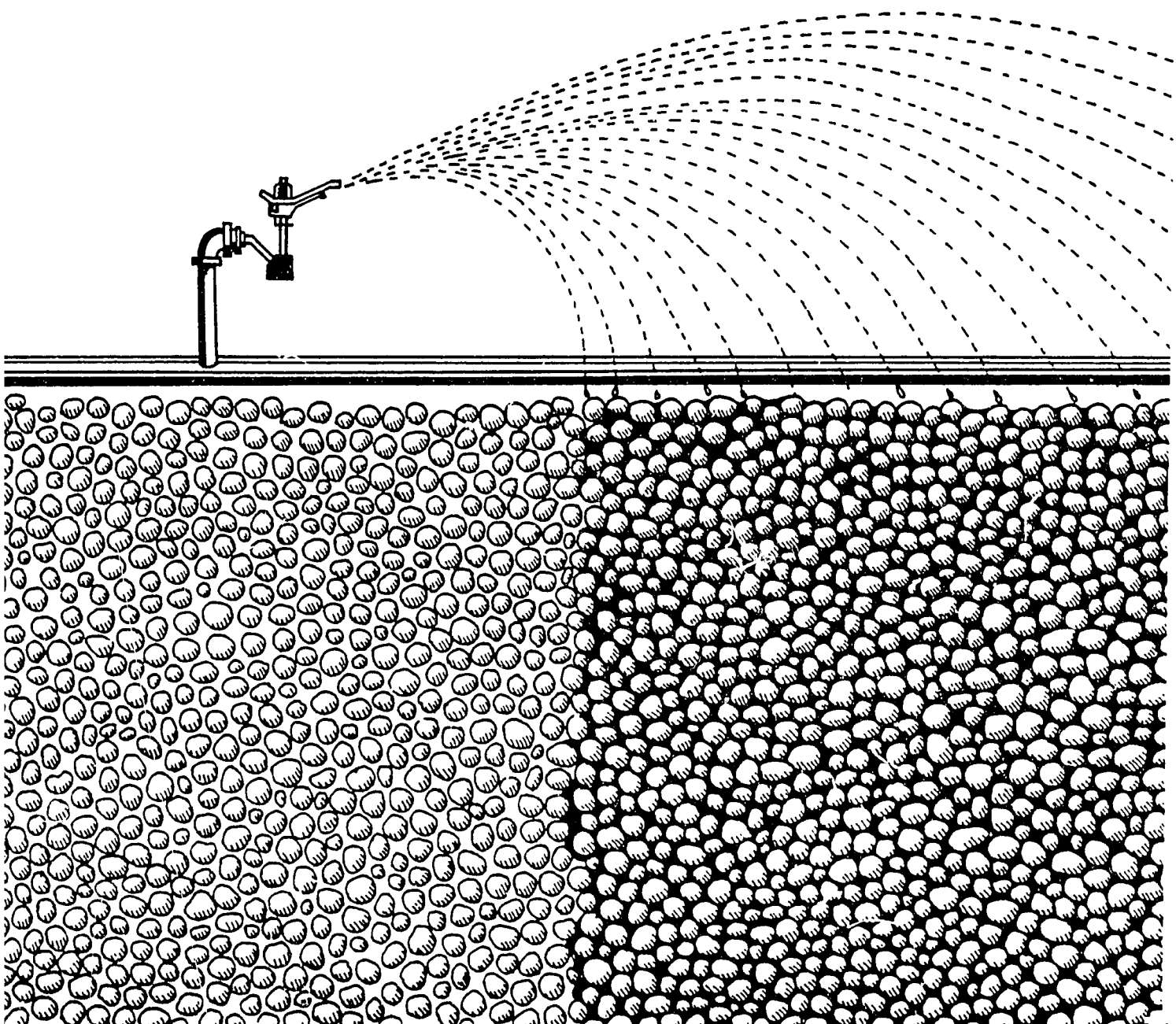
Soil Layering



Air Entrapment

Chapter Two

Irrigation Techniques

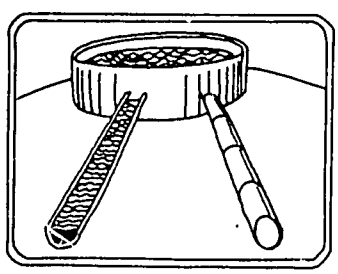


MODULE 21
CONTROLLING AND CONVEYING WATER FROM THE SOURCE TO THE FIELD

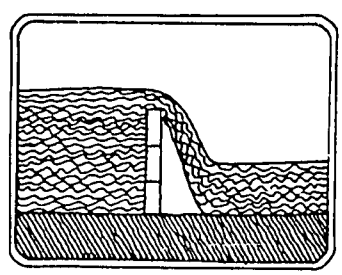
CONCEPTS:

CONVEYANCE SYSTEMS: OPEN AND CLOSED
CONTROL STRUCTURES
DISCHARGE CONTROL DEVICES
TRASH REMOVAL
COMMUNAL WATER DISTRIBUTION SYSTEMS

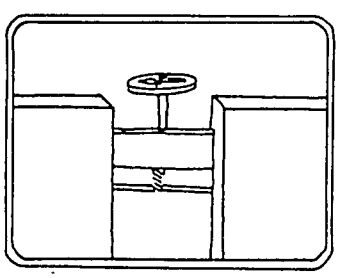
Water must be delivered from the supply source to the field so it will be available for irrigation at the correct time and in the right amounts. The best combination of conveyance and control structures for an irrigation system depends on: (1) the cost and availability of system components; (2) the water source capacity; (3) crop water requirements; and (4) physical and socioeconomic limitations. Open systems, such as lined and unlined ditches/canals, convey water in channels open to the atmosphere, while closed systems convey water through pipelines. Control structures are used to control the water level, flow rate and the diversion of water at the appropriate time and location. Discharge control devices release water from the farm ditch or pipeline into other farm canals or fields. Special structures remove a variety of trash and debris from the conveyance system. Plastic pipe, with its relatively low cost and ease of installation, makes multipurpose water distribution systems feasible at the community level.



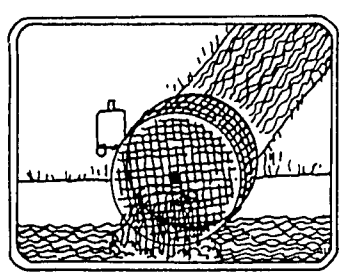
Conveyance Systems: Open and Closed



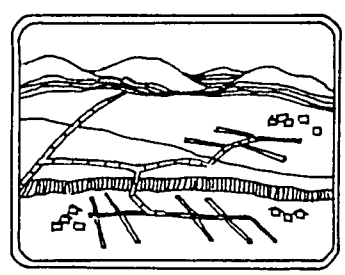
Control Structures



Discharge Control Devices



Trash Removal



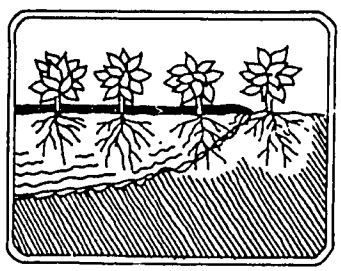
Communal Water Distribution Systems

MODULE 22
IRRIGATION METHODS: AN OVERVIEW

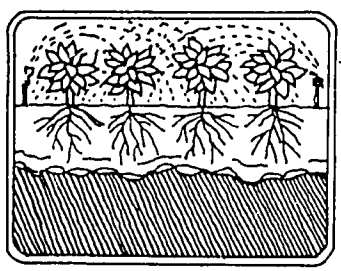
CONCEPTS:

SURFACE IRRIGATION
SPRINKLE IRRIGATION
TRICKLE IRRIGATION
SUBSURFACE IRRIGATION

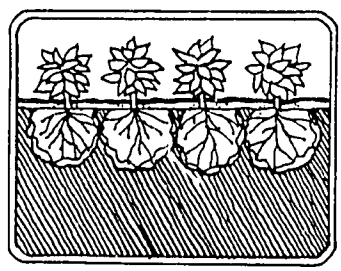
This module introduces the major irrigation methods and presents the principal factors that should be considered in the selection and design of an irrigation system. The primary methods of applying irrigation water on the farm are: (1) surface irrigation methods, where water flows over the surface of the field and infiltrates; (2) sprinkle irrigation, where water is sprinkled onto the soil surface as artificial rain; (3) trickle or micro irrigation, where water is applied to specific points on or below the soil surface; and (4) subsurface irrigation, where water tables are controlled below the root zone to make water available to the plants by capillary rise. Each system has advantages and disadvantages. Some of the factors that affect selection of an irrigation system are: (1) the flow rate and delivery schedule of the farm water supply; (2) water quality; (3) topography; (4) the size and shape of the fields; (5) soil and crop characteristics; (6) climatic conditions; and (7) economic feasibilty. The following modules will detail the components of the major irrigation methods and the criteria for their selection and design.



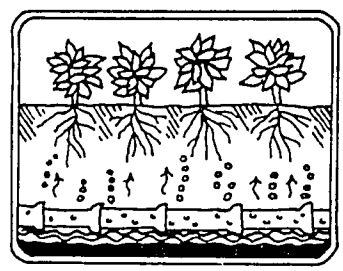
Surface Irrigation



Sprinkle Irrigation



Trickle Irrigation



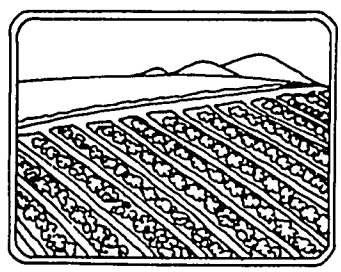
Subsurface Irrigation

MODULE 23
FURROW AND CORRUGATION IRRIGATION

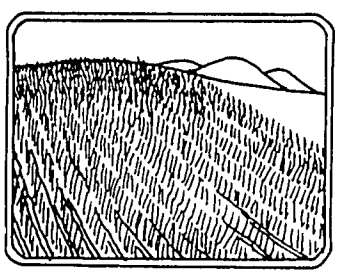
CONCEPTS:

- FURROW IRRIGATION
- CORRUGATION IRRIGATION
- DESIGN AND SELECTION FACTORS
  - SIZE AND SHAPE
  - CROP SUITABILITY
  - SOIL TEXTURE/WATER DISTRIBUTION
  - ADVANCE TIME/APPLICATION TIME
  - SLOPE DEGREE AND DIRECTION

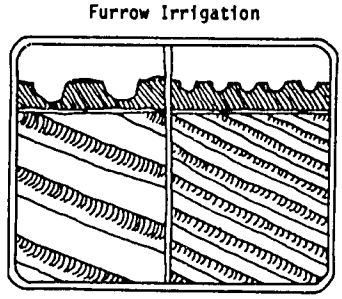
Furrow and corrugation irrigation are surface irrigation methods which use small, parallel channels to distribute water across a field. Corrugations are generally smaller and closer together than furrows. They are used to irrigate close-growing, non-cultivated crops such as small grains and pasture. Furrows are primarily used with row crops where water flows between rows of plants without coming in contact with the plants. Medium to moderately fine-textured soils are well suited to these irrigation methods because they have good horizontal and vertical permeability. Additional selection factors and the applicability of both systems under various conditions are also presented in this module.



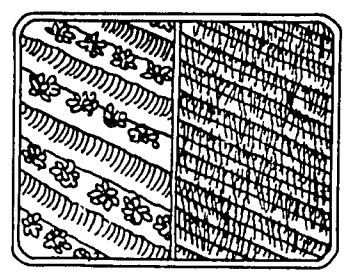
Furrow Irrigation



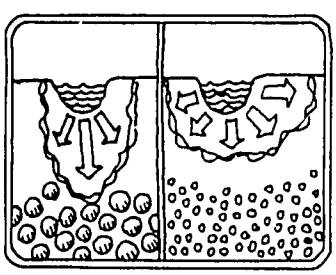
Corrugation Irrigation



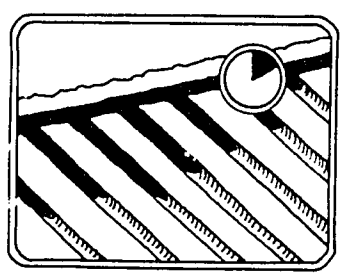
Size and Shape



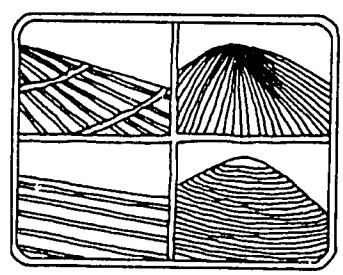
Crop Suitability



Soil Texture/Water Distribution



Advance Time/Application Time



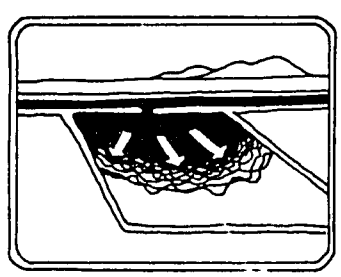
Slope Degree and Direction

MODULE 24
BASIN AND BORDER IRRIGATION

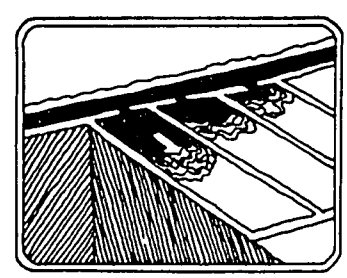
CONCEPTS:

BASIN IRRIGATION
BORDER IRRIGATION
LAND LEVELING
INFILTRATION RATE
STREAM SIZE

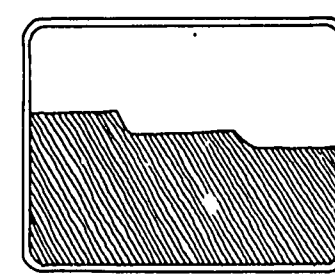
Basin and border irrigation are both surface irrigation methods in which water is flooded over a field enclosed by dikes. In basin irrigation, water enters a level area and remains ponded until it infiltrates the soil. Border irrigation refers to the flooding of a field in parallel strips; water infiltrates it travels downward along each strip. Both methods usually require careful land leveling for efficient irrigation. Proper design of a basin or border system involves careful consideration of soil characteristics, basin or border size, topography and crop suitability. Both methods are described in some detail, including their advantages, disadvantages and most important design considerations.



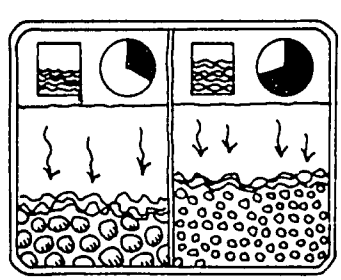
Basin Irrigation



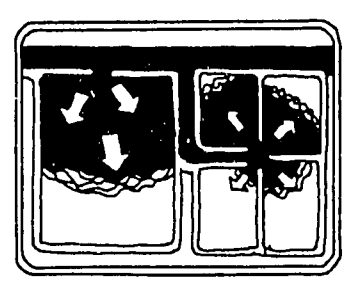
Border Irrigation



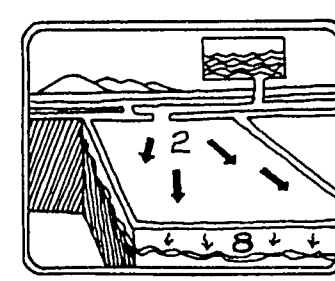
Land Leveling



Infiltration Rate



Stream Size



Flow and Infiltration Rates

A

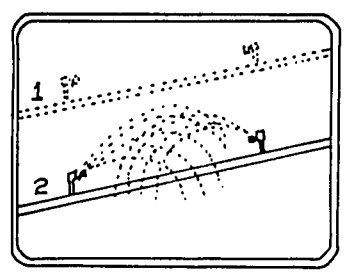
MODULE 25
SPRINKLE IRRIGATION

CONCEPTS:

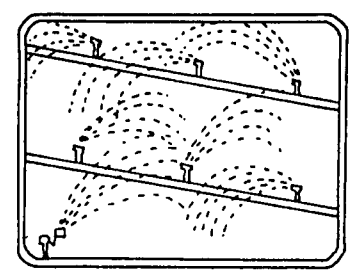
SPRINKLE SYSTEM CATEGORIES
- PERIODIC-MOVE
- FIXED
- CONTINUOUS-MOVE

CROP COOLING
DISTRIBUTION PATTERNS

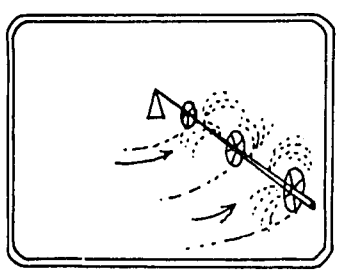
Sprinkle irrigation systems are designed to apply water uniformly in precise amounts, without erosion, on most crops, soil types and topographies. They are also used for applying fertilizers, soil amendments, pesticides and herbicides, and for crop cooling. Sprinkle systems are adaptable to a wide range of conditions and are categorized into three general types. Periodic-move systems stay in a fixed position while irrigating and are shut off to change positions. Fixed systems are stationary, while continuous-move systems move while irrigating. More detailed information is given about the systems included in each category. Application efficiencies above 75 percent are common for sprinkle systems, although wind can seriously reduce this percentage.



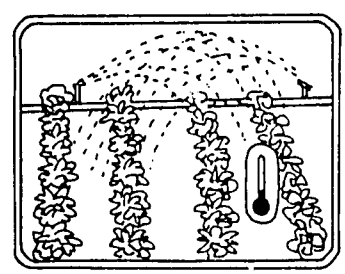
Periodic-Move



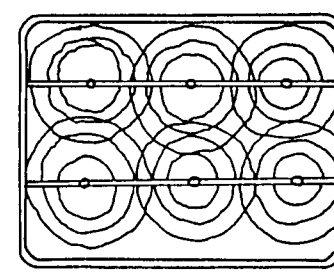
Fixed



Continuous-Move



Crop Cooling



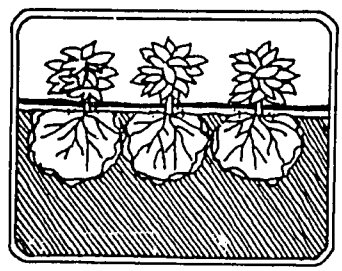
Distribution Patterns

MODULE 26
TRICKLE OR MICRO IRRIGATION

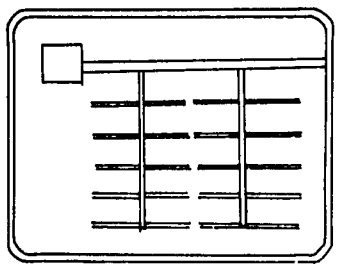
CONCEPTS:

TRICKLE IRRIGATION
TRICKLE SYSTEM COMPONENTS
WETTED ROOT VOLUME
EMITTER SPACING

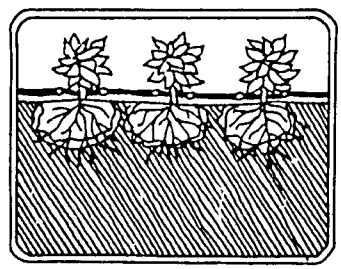
Micro irrigation applies water to specific points on the soil surface or in the soil profile rather than over a large, continuous area. The most widely used method is trickle irrigation. This method does not apply water to bare soil areas between plants, but concentrates its application at the plant roots using small, frequent amounts of water to supply the continuous needs of the crop. Typical system components are: (1) the water and pressure source; (2) accessories such as valves and pressure regulators; (3) mainlines; (4) submains; (5) laterals; and (6) emitters. At least 40 percent of the total root volume must be wetted during an irrigation. This depends on emitter flow rate and spacing, irrigation duration and soil type. The spacing of emitters is affected by the lateral spreading of the plant root system and on the wetting pattern within the soil. Careful maintenance is necessary for proper system operation. Micro irrigation is capable of very high water use efficiencies and crop yields may be higher than with other systems because it can supply water and nutrients as needed.



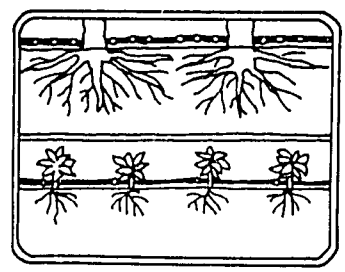
Trickle Irrigation



Trickle System Components



Wetted Root Volume



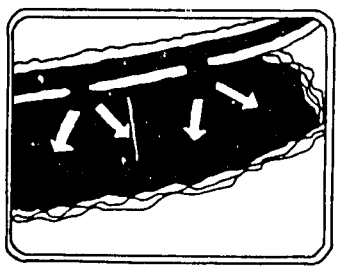
Emitter Spacing

MODULE 27
OTHER IRRIGATION METHODS

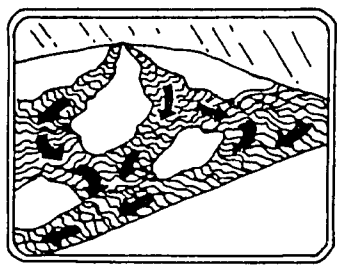
CONCEPTS:

UNCONTROLLED FLOODING
WATER SPREADING
CONTOUR DITCH IRRIGATION
SUBSURFACE IRRIGATION
CONTROLLED DRAINAGE

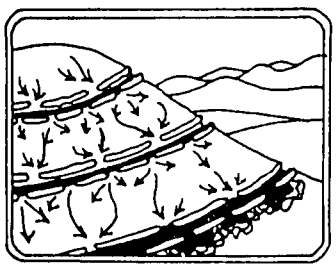
Several relatively inefficient, but commonly used methods of irrigation are uncontrolled flooding, water spreading, contour ditch irrigation and subsurface irrigation. Uncontrolled flooding consists of flooding extensive areas of land, usually from one main ditch. Water spreading is a form of surface irrigation in which flood waters from natural watercourses are spread out over relatively flat areas. This is not designed to meet crop needs, but to control rainfall runoff and apply it to low value range and pasture crops. Contour ditch irrigation uses a series of parallel ditches on the contour to help redistribute water as it flows downhill. In subsurface irrigation, water is applied below the soil surface to control the elevation of the water table. Capillary action then distributes the water throughout the root zone. Controlled drainage is a special application of subsurface irrigation used to insure adequate drainage through the rainy season and provide water to the crops during the dry season. These irrigation methods, while not generally recommended as good irrigation practices, offer a means of utilizing local conditions to provide crops with additional water with very little investment.



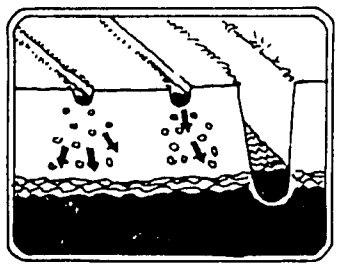
Uncontrolled Flooding



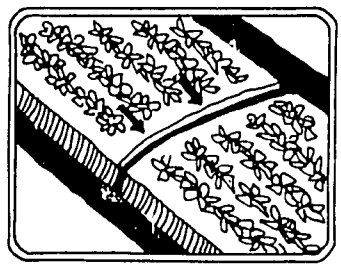
Water Spreading



Contour Ditch Irrigation



Subsurface Irrigation



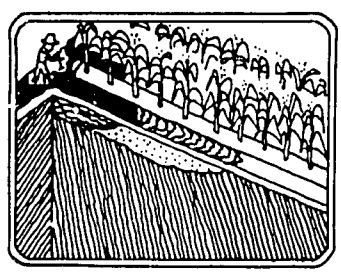
Controlled Drainage

MODULE 28
SURGE FLOW IRRIGATION

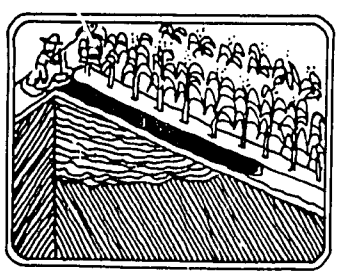
CONCEPTS:

SURGE FLOW IRRIGATION
CONTINUOUS FLOW IRRIGATION
SOIL SURFACE SEALING
APPLICATION UNIFORMITY

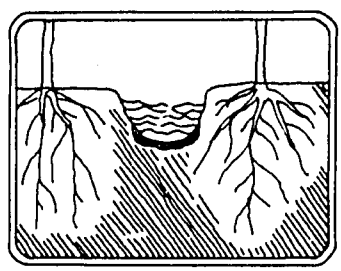
The surge flow technique involves the intermittent application of water to a field using furrows, borders or basins, as compared to conventional continuous flow irrigation which uses a constant inflow of water to a field until the irrigation is terminated. Surge flow switches a constant inflow rate between two furrows at regular intervals. Recession occurs in one furrow while water enters the second furrow. During the off-cycle period, suspended soil particles settle into a relatively dense layer on the surface. This decreases soil permeability and causes a faster advance over the previously wetted soil during the next surge. The result is a more uniform application of water, a reduction in deep percolation and a decrease in nutrient losses from excessive leaching. Longer field lengths can be irrigated with surge flow than with continuous flow, using the same inflow rates. This technique can be implemented with minimal capital and labor investments while increasing overall production.



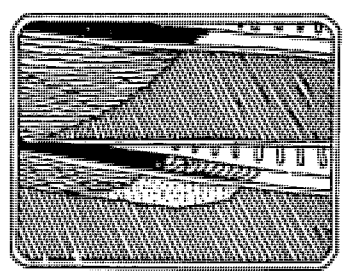
Surge Flow Irrigation



Continuous Flow Irrigation



Soil Surface Sealing



Application Uniformity

Chapter Three

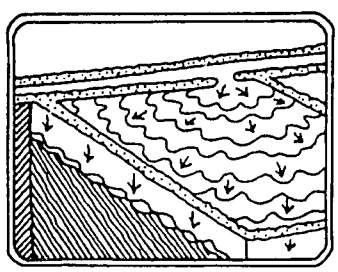
Evaluating the Economy of Water Use

MODULE 29
BASIC CONCEPTS FOR IRRIGATION SYSTEM EVALUATION

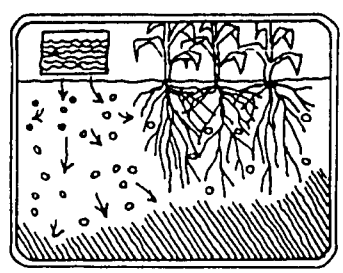
CONCEPTS:

WATER DISTRIBUTION
APPLICATION EFFICIENCY
WATER USE EFFICIENCY
STORAGE EFFICIENCY
DISTRIBUTION UNIFORMITY
CHRISTIANSEN UNIFORMITY COEFFICIENT

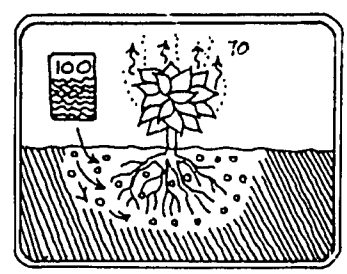
Good irrigation requires uniformity of water application, minimal runoff and deep percolation losses, and proper timing and depths of application based on crop requirements and soil characteristics. An evaluation of an irrigation system provides information that can be used to redesign an existing system or modify irrigation practices for better performance. This module presents concepts of water distribution and performance parameters which describe how well a system is operating. Water distribution for the major systems is discussed and parameters such as application efficiency, water use efficiency, distribution uniformity and storage efficiency are defined. The distribution uniformity (DU) and the Christiansen uniformity coefficient (UC) are the most common definitions for uniformity of water distribution.



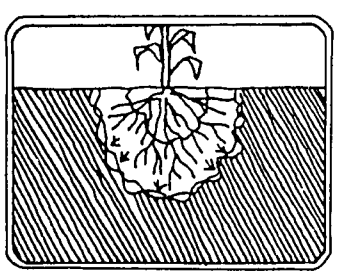
Water Distribution



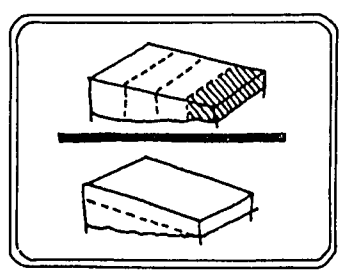
Application Efficiency



Water Use Efficiency



Storage Efficiency



Distribution Uniformity

$$UC = \left[1 - \frac{\Sigma|\bar{x} - x_i|}{n}\right] X100$$

Christiansen Uniformity Coefficient

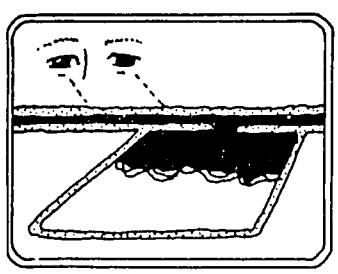
MODULE 30

TYPES, PURPOSE AND TERMINOLOGY FOR SYSTEM EVALUATION

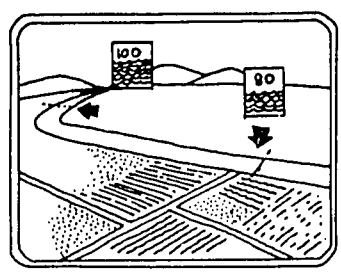
CONCEPTS:

- OBSERVED PERFORMANCE EVALUATION
- MEASURED PERFORMANCE EVALUATION
- SIMULATED PERFORMANCE EVALUATION
- SYSTEM VARIABLES
- EVALUATION TERMINOLOGY
- GRAPHICAL CURVES

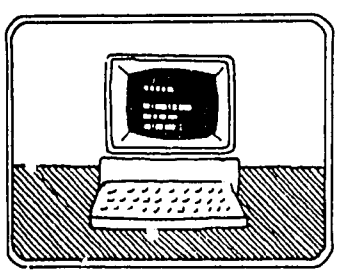
This module describes the methods used for evaluating irrigation systems, discusses variables that should be examined during evaluation and reviews terminology commonly used in system evaluation. Three ways to evaluate farm irrigation systems are: (1) observed performance evaluation; (2) measured performance evaluation; and (3) simulated performance evaluation. Factors under consideration during the evaluation process are the system design, timing of the irrigation, amount of water applied, the uniformity of irrigation, runoff and erosion. Application time, opportunity time, advance time, recession time and lag time are terms used in evaluation. Graphical curves are also useful in the evaluation process. The information derived from a properly conducted evaluation can be used to improve system performance and utilize available resources more efficiently.



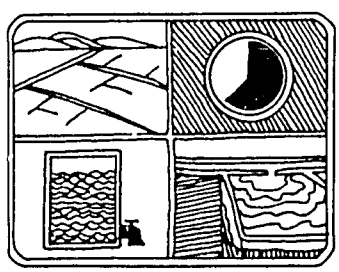
Observed Performance Evaluation



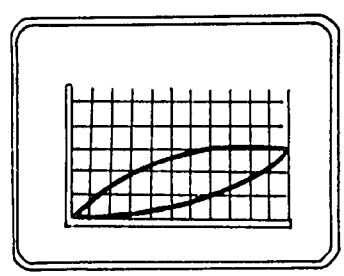
Measured Performance Evaluation



Simulated Performance Evaluation



System Variables



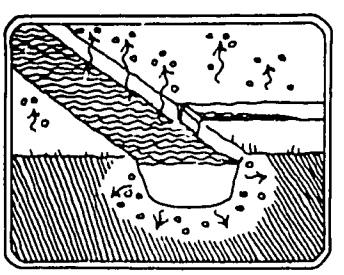
Graphical Curves

MODULE 31
WATER CONVEYANCE LOSSES

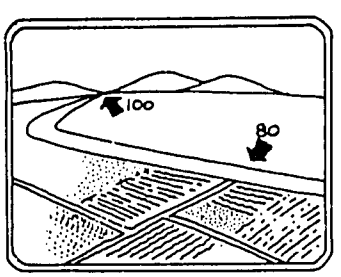
CONCEPTS:

CONVEYANCE LOSSES
WATER CONVEYANCE EFFICIENCY
MEASURING CONVEYANCE LOSSES
PONDING METHOD
INFLOW-OUTFLOW METHOD

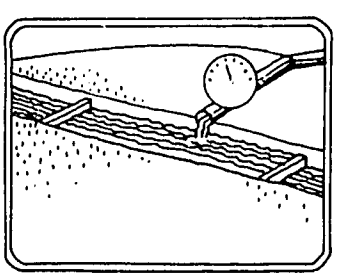
Water loss in a conveyance system occurs through seepage, leaky structures, evapotranspiration and poor maintenance and management of the supply system. This module describes factors that influence water loss in irrigation canals, methods for estimating conveyance losses and ways to reduce water losses in the system. Factors that influence conveyance losses are: (1) permeability of canal banks and bottoms; (2) leaky turnout structures, rodent holes and other animal damage; (3) the total wetted perimeter of the canal; (4) evaporation and evapotranspiration; (5) alternate filling and emptying of the canal; (6) water loss through wasteway structures; and (7) management of the entire system. Conveyance losses can be estimated by means of the ponding method or the inflow-outflow method. Water losses can be significantly reduced through proper construction, maintenance and management techniques. Water saved can then be utilized wherever needed.



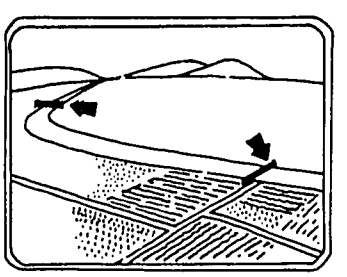
Conveyance Losses



Water Conveyance Efficiency



Ponding Method



Inflow-Outflow Method

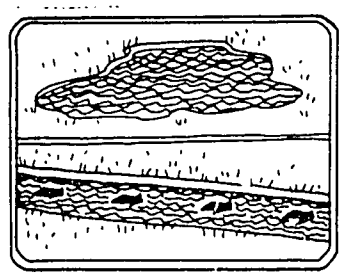
MODULE 32
WATER MANAGEMENT

CONCEPTS:

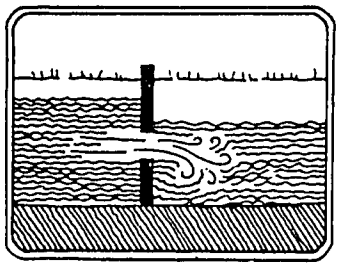
VOLUMETRIC OR FLOW RATE MEASUREMENT
WATER MEASUREMENT DEVICES

ORIFICES	MANOMETERS
WEIRS	PROPELLER METERS
FLUMES	VENTURI METERS
CURRENT METERS	

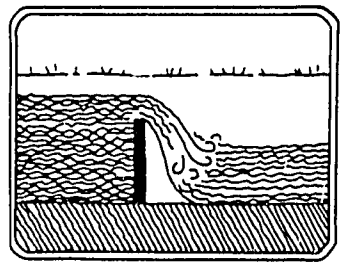
Accurate flow measurement is essential for determining the water available for irrigation planning and the management of water at the farm level. The selection of water measurement methods or devices depends on: (1) the need for volumetric or flow rate measurements; (2) the accuracy desired; (3) ease of construction; (4) ease of use; (5) cost; and (6) topographic conditions and channel configuration at the point where the flow will be measured. The devices most commonly used in open channels are orifices, weirs and flumes. Orifices, manometers, propeller and venturi meters are used in closed conduits. When standard flow measurement devices are unavailable, various farm delivery and control structures can be used to estimate flow rates.



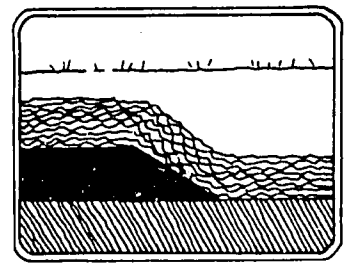
Volumetric or Flow Rate Measurement



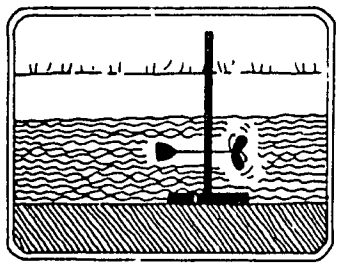
Orifice



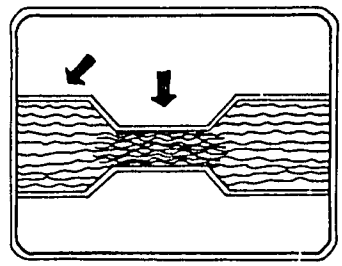
Weir



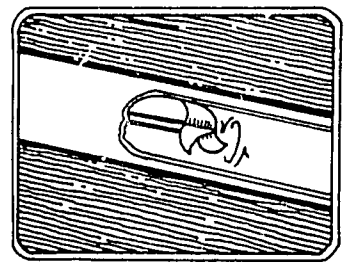
Flume



Current Meter



Venturi Meter



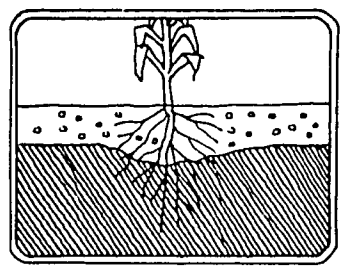
Propeller Meter

MODULE 33
FURROW IRRIGATION EVALUATION AND IMPROVEMENT

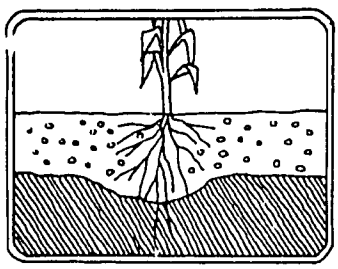
CONCEPTS:

MANAGEMENT ALLOWED DEFICIENCY (MAD)
SOIL MOISTURE DEFICIENCY (SMD)
FIELD OBSERVATIONS
FURROW CHARACTERISTICS

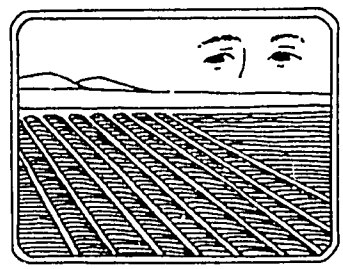
Evaluation of a furrow irrigation system provides information that can be used to improve the system and its operation. Simple evaluations of furrow systems are mainly based on field observations and consist of: (1) determining the management allowed deficiency (MAD); (2) checking the actual soil moisture deficiency (SMD); (3) checking the water in a furrow during irrigation for evidence of soil movement; (4) recording the total advance time and application time; (5) observing the time and rate of runoff; (6) observing the furrow shape for signs of erosion; (7) probing the soil along the furrow to determine penetration; and (8) observing crop height, color and vigor. More detailed evaluations require field measurements of furrow inflow, advance and recession with one or more inflow rates. Modifications to the furrow system may be made in the flow rate, frequency and depth of application, furrow characteristics and basic operation, based on evaluation results.



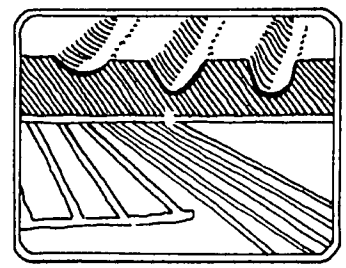
Management Allowed Deficiency (MAD)



Soil Moisture Deficiency (SMD)



Field Observations



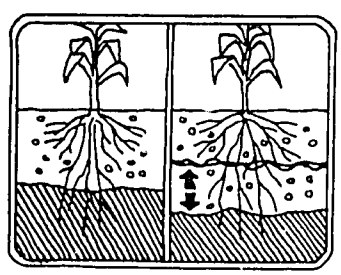
Furrow Characteristics

MODULE 34
BORDER AND BASIN IRRIGATION EVALUATION AND MANAGEMENT

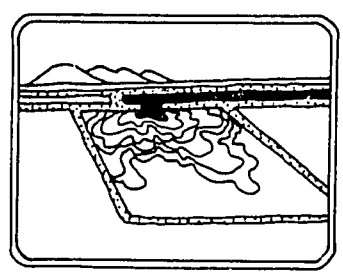
CONCEPTS:

COMPARISON OF MAD AND SMD
WATER DISTRIBUTION
WATER PENETRATION
ADVANCE AND RECESSION
DURATION OF IRRIGATION

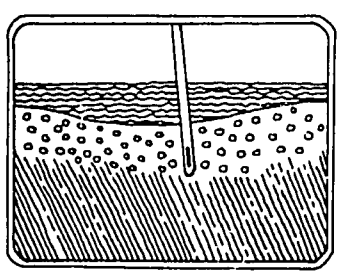
Evaluation of border and basin irrigation systems provides information for their improvement to insure uniform irrigation and efficient water management. A simple evaluation consists of four general steps: (1) verification of irrigation timing; (2) observation of erosion; (3) observation of water distribution; and (4) determination of water penetration. Detailed evaluations differ from simple evaluations in that the water dynamics are measured rather than observed. For border systems, the advance and recession of the water and the intake characteristics of the soil are measured. Similar detailed evaluations can be conducted for basin systems, but the analysis is simplified because there is no runoff. The comparison of MAD, SMD and infiltrated depth, along with uniformity and erosion observations, generally provide enough information to make improvements. Computer models can also be used to quickly evaluate alternatives. Flow rates and duration can be easily modified to insure good uniformity, but in poorly designed systems, major changes in design and construction may be necessary to facilitate efficient irrigation.



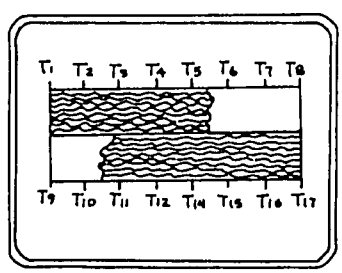
Comparison of MAD and SMD



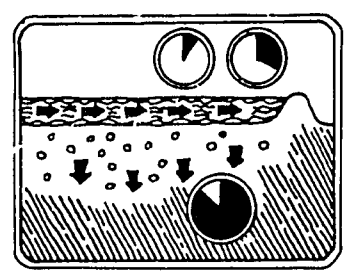
Water Distribution



Water Penetration



Advance and Recession



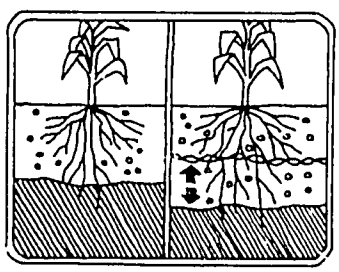
Duration of Irrigation

MODULE 35
SPRINKLE IRRIGATION EVALUATION AND IMPROVEMENT

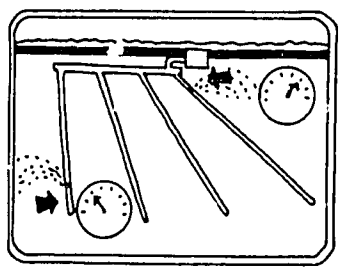
CONCEPTS:

SOIL MOISTURE DEFICIENCY (SMD)
MANAGEMENT ALLOWED DEFICIENCY (MAD)
MEASURING SYSTEM VARIABLES
- PRESSURES
- SPRINKLER DISCHARGES
- APPLICATION UNIFORMITY
- RUNOFF
- IRRIGATION DURATION

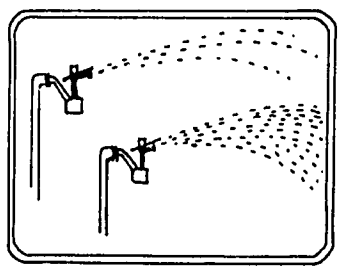
A well-designed and managed sprinkle system applies water in the right amount at correct intervals with high application uniformity, low evaporation losses and no significant runoff. A simple evaluation of a sprinkle system includes: (1) estimating the soil moisture deficiency (SMD) and the management allowed deficiency (MAD) to see if the irrigation was adequate and on time; (2) measuring pressures and pressure variations in the system; (3) measuring sprinkler discharges; (4) checking the uniformity of application; (5) observing runoff; and (6) evaluating application time or irrigation duration. This kind of evaluation can reveal problems in the system and be useful for adjusting the operation, but will not provide enough information for system redesign. A detailed evaluation will include additional measurements such as determining uniformity coefficients, application efficiency and other performance parameters. Changes may need to be made in sprinkler and lateral spacing by replacing worn component~~s~~ and adjusting pressures, irrigation frequencies and application depths to improve sprinkler system uniformities and efficiencies.



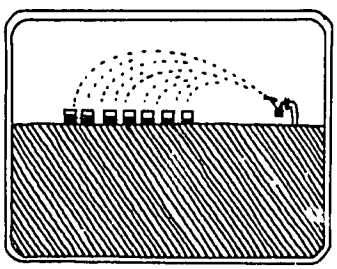
(MAD) (SMD)



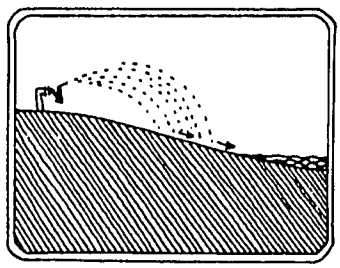
Pressures



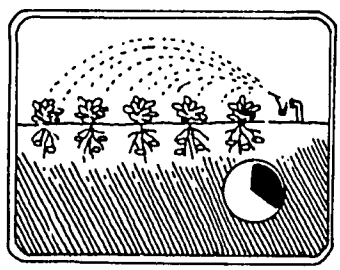
Sprinkler Discharges



Application Uniformity



Runoff



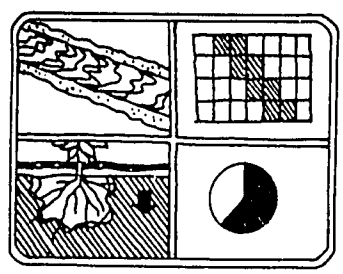
Irrigation Duration

MODULE 36
TRICKLE IRRIGATION EVALUATION AND IMPROVEMENT

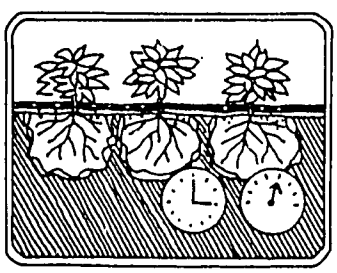
CONCEPTS:

FLOW RATE/FREQUENCY/DEPTH/DURATION
DISCHARGE RATES AND PRESSURES
PERCENTAGE OF SOIL WETTED
COMPARISON OF SMD AND MAD

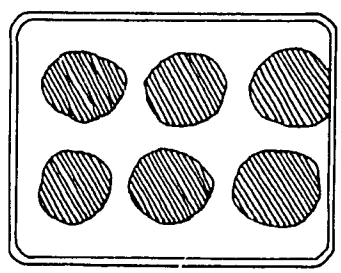
Trickle irrigation must apply approximately the same amount of water to each plant so that the wetted pattern in the soil profile covers enough volume of the root zone and the crop water requirements are met. The information necessary for system evaluation includes: (1) flow rates, duration and frequency of water application, or depth and interval of irrigation applications; (2) soil moisture deficiency and management allowed deficiency; (3) discharge rates and pressures along the line; (4) percentage of the wetted soil; and (5) observations of clogged emitters, plugged screens and filters and variations in pressures. The latter are indicators of possible uniformity problems. Other useful parameters for system evaluation are the average application depth, emission uniformity and actual and potential application efficiencies. Trickle systems can achieve very high efficiencies when uniformities are high, the wetted area is monitored and irrigation amounts are correct and properly timed.



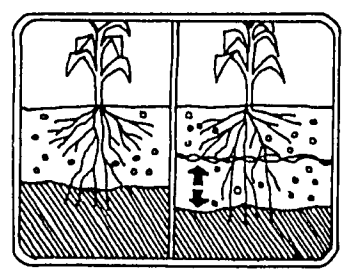
Flow Rate/Frequency/Depth/Duration



Discharge Rates and Pressures



Percentage of Soil Wetted



Comparison of MAD and SMD

Chapter Four

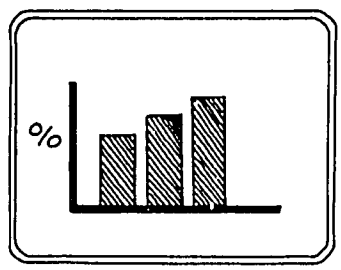
Management to Improve Agricultural Performance

MODULE 37
IMPROVING EFFICIENCIES THROUGH THE USE OF RESERVOIRS, REUSE SYSTEMS AND AUTOMATION

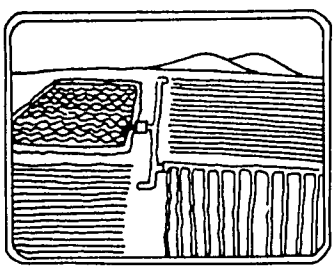
CONCEPTS

IRRIGATION SYSTEM EFFICIENCIES
RESERVOIRS
REUSE SYSTEMS
AUTOMATION

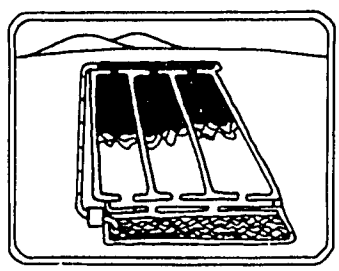
Design efficiencies of farm irrigation systems are determined from field evaluations. Surface irrigation methods generally have application efficiencies of 50 to 80 percent; sprinkle systems range from 60 to 80 percent; while trickle systems can achieve efficiencies of 90 percent or higher. Good design and management techniques can make application efficiencies above 80 percent possible for both surface and sprinkle irrigation methods. One of the keys to high efficiencies is precise and continuous control of the water in the supply system. When water deivery schedules are variable in time and quantity, small reservoirs may be necessary to maintain a stable supply of water. Tailwater reuse systems increase efficiencies by eliminating runoff losses in surface irrigation and by allowing the use of larger stream sizes for better uniformity. Automated irrigation systems reduce energy and labor requirements while providing precise control of flow rates and irrigation times. Cost and reliability are determining factors in implementing reservoirs, reuse systems and automation, but water and labor savings resulting from these improvements may justify the investment.



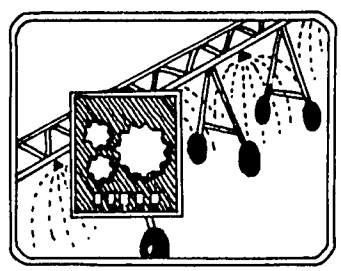
Irrigation System Efficiencies



Reservoirs



Reuse Systems



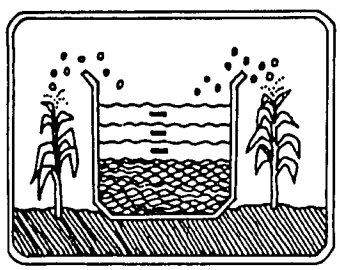
Automation

MODULE 38
DETERMINING WATER DELIVERY REQUIREMENTS

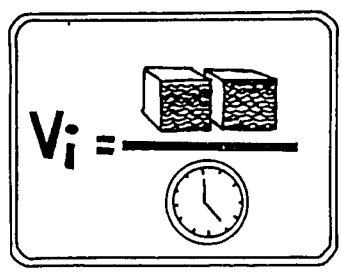
CONCEPTS:

NET IRRIGATION REQUIREMENT
CONTINUOUS FLOW DELIVERY REQUIREMENT
CONVEYANCE LOSS ALLOWANCE
FARM/PROJECT DELIVERY REQUIREMENT
ROTATIONAL UNIT DELIVERY REQUIREMENT

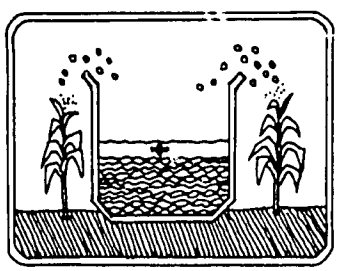
This module combines concepts presented in earlier modules such as crop water use, rainfall, leaching and irrigation efficiencies to determine seasonal and peak water supply requirements. These concepts allow the estimation of the total volume required over a given time period and the corresponding flow rates required for rotational deliveries. Formulas are presented for determining delivery requirements and examples using a farm/project and a rotational unit are given.



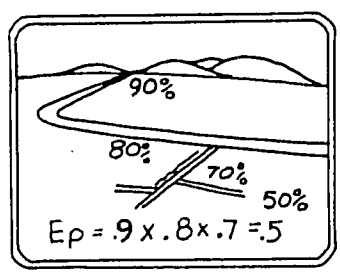
Net Irrigation Requirement



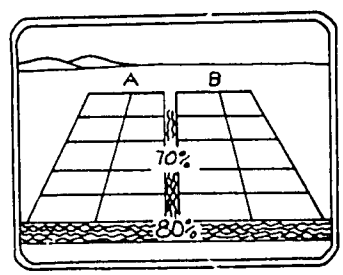
Continuous Flow Delivery Requirement



Conveyance Loss Allowance



Farm/Project Delivery Requirement



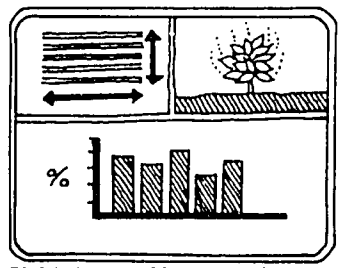
Rotational Unit Delivery Requirement

MODULE 39
FIELD WATER DELIVERY SCHEDULES

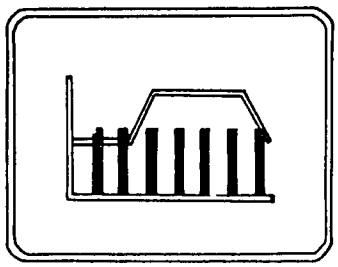
CONCEPTS:

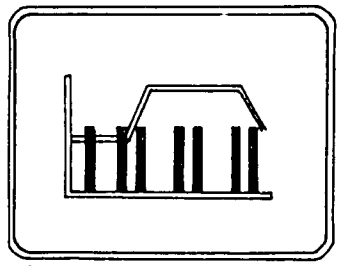
- FIELD WATER DELIVERY REQUIREMENT
- RIGID SCHEDULES
  - FIXED AMOUNT, FIXED FREQUENCY
  - FIXED AMOUNT, VARIABLE FREQUENCY
  - VARIED AMOUNT, FIXED FREQUENCY
- FLEXIBLE SCHEDULES
  - DEMAND
  - FREQUENCY DEMAND
  - LIMITED RATE DEMAND

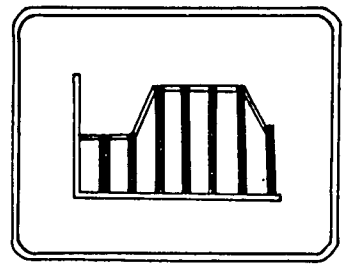
The field water delivery requirement depends on the size of the irrigated field, the evapotranspiration rate and the efficiency of the irrigation system. This module discusses the types of schedules used for water delivery and their advantages and disadvantages. Rigid or predetermined schedules include: (1) fixed amount, fixed frequency; (2) fixed amount, variable frequency; and (3) varied amount, fixed frequency schedules. Flexible schedules may operate on a demand, frequency-demand or limited rate demand basis. Flexible schedules are generally better suited to meet varying water requirements at the farm level. However, rigid schedules may be necessary where system capacities are limited or administration of the water supply is difficult or inadequate.

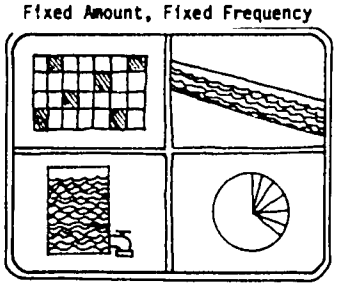


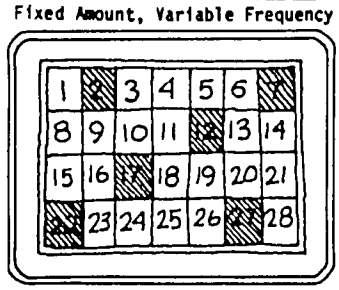
Field Water Delivery Requirement


Fixed Amount, Fixed Frequency

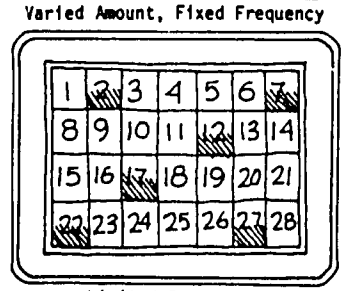

Fixed Amount, Variable Frequency


Varied Amount, Fixed Frequency


Flexible Schedules



Frequency Demand



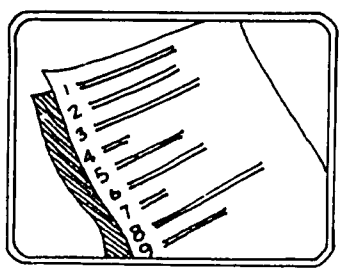
Limited Rate Demand

MODULE 40
IRRIGATION MANAGEMENT PROGRAM AND MANAGING SYSTEMS
WITH WATER SHORTAGES OR EXCESSES

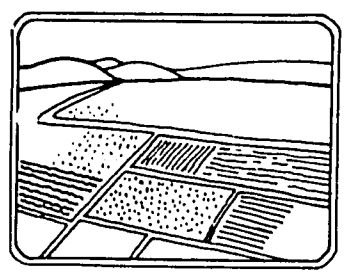
CONCEPTS:

INVENTORY OF RESOURCES
SYSTEM DESIGN
SYSTEM OPERATION
FARM-LEVEL OPERATION
DEFICIT IRRIGATION

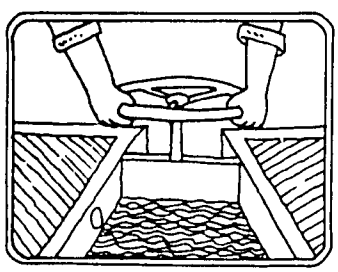
An irrigation management program emphasizes the use of the irrigation water supply as an integral part of the total farm resources. A good program does not necessarily maximize crop yield, but will maximize profits or make the best use of limited resources. Essential elements in devloping an irrigation management program include system design, maintenance and operation. The implementation of a good program considers: (1) the level of water user participation in managing and financing irrigaton project activities; (2) economic benefits; (3) conveyance, distribution and application efficiencies throughout the project; (4) the maintenance program; and (5) evaluation of the irrigation practices, maintenance and operation at farm and project levels. Many aspects of developing a good irrigation management program are detailed in this module, including minimizing the adverse effects of water shortages or excesses.



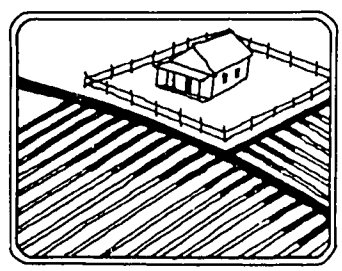
Inventory of Resources



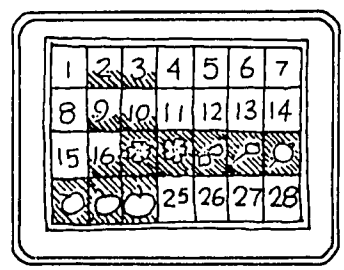
System Design



System Operation



Farm-Level Operation



Deficit Irrigation

47