Concept of water management

Importance of water

Water is the best Solvent in the world. Life without water is impossible.

a. Water is transparent material.
b. Water expands on freezing.
c. Water molecules have cohesion & adhesion nature.

As it is known water is not only a vital source for all natural life but also a natural resource that is at the core of sustainable development. It is critical for socio-economic development, healthy ecosystems and for human survival itself. It is also central to the production and preservation of a host of benefits and services for people. Therefore we should always be aware of that water is a finite and irreplaceable resource in time and space and it is only available if well managed. Where water is reliably available, economic opportunities are enhanced. Where water is unreliable or of inadequate quality, or where water-related hazards are present, there will be drags on growth. Water can pose a serious challenge to sustainable development but if it is managed efficiently and equitably, water can play a key enabling role in strengthening the resilience of social, economic and environmental systems in the light of rapid and unpredictable changes. Many countries particularly those experiencing the impacts of climate change ,have started to make projections on their own water security. The most important reason that requires having a projection on water security being directly linked to social stability, economic growth and development of a country Therefore in order to better understand the importance of water security concepts such as growth, progress, development and sustainability should be considered.

Role of water management in rain fed area

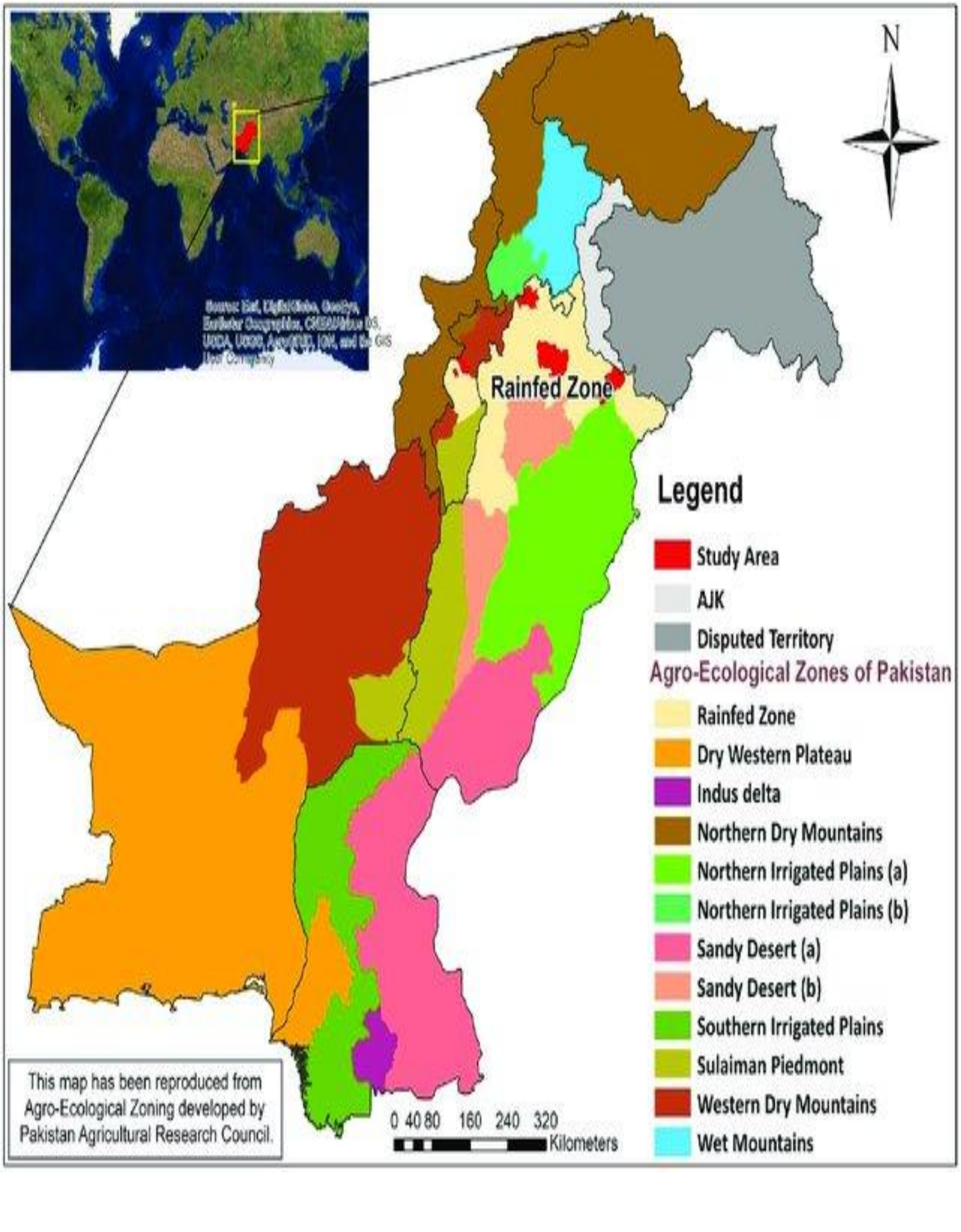
- Facing the **food and poverty** crises in developing countries will require a new emphasis on small scale **water management in rainfed agriculture** involving the redirection of water policy and large new investments.
- Rainfed systems dominate world food production, but water investments in rainfed agriculture have been neglected over the past 50 years.

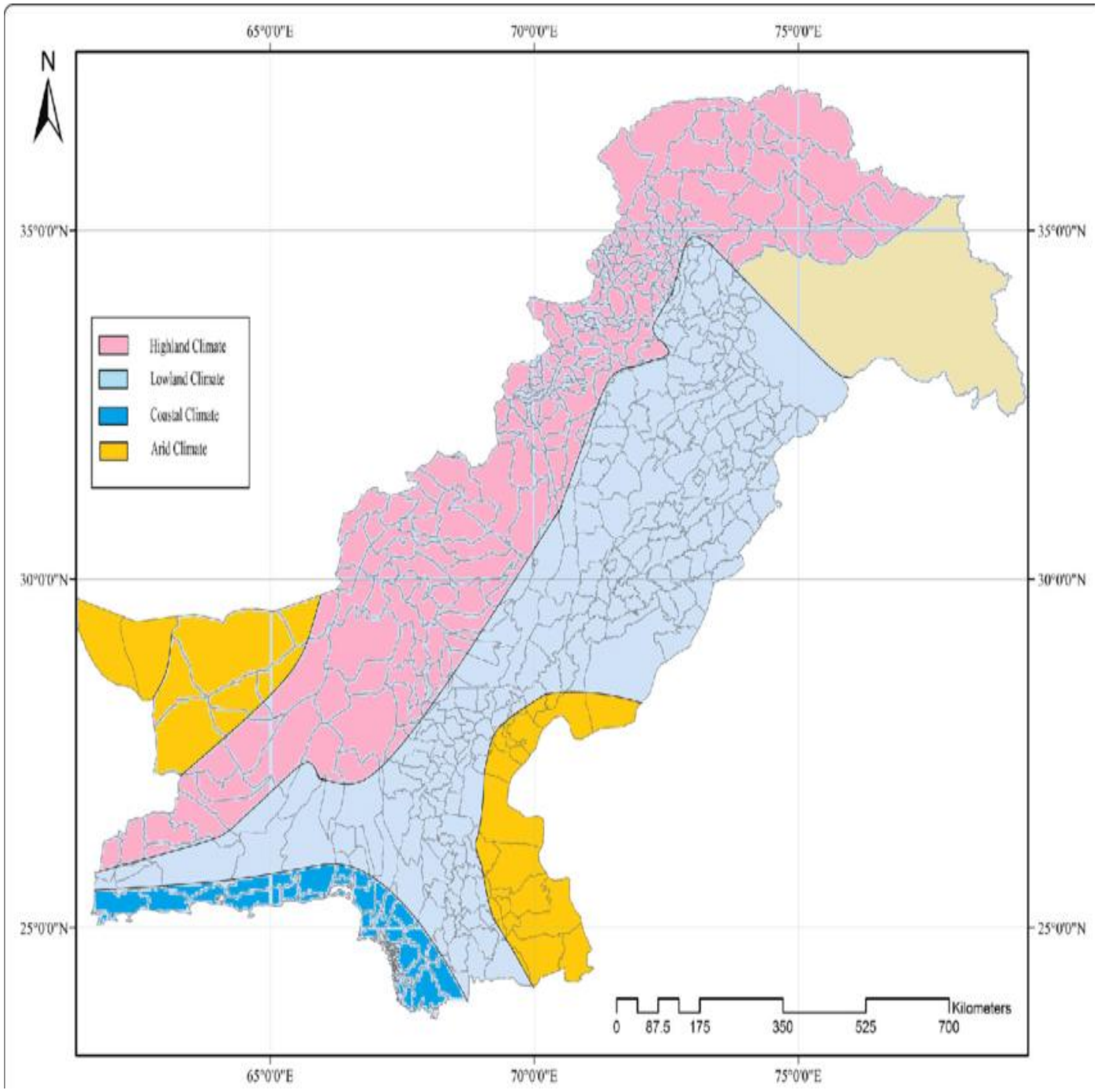
- Upgrading rainfed agriculture promises large social, economic, and environmental paybacks, particularly in poverty reduction and economic development.
- Rainfed farming covers most of the world's cropland (80%) and produces most of the world's cereal grains (more than 60%), generating livelihoods in rural areas and producing food for cities.
- There is a close correlation between hunger, poverty, and water: most hungry and poor people live in regions where water challenges pose a particular constraint to food production.
- The world's hotspots for hunger and poverty are concentrated in the arid, semiarid, and dry subhumid regions of the world.
- There, water is a key challenge for food production due to the extreme variability of rainfall, long dry seasons, and recurrent droughts, floods, and dry spells. These regions cover some 40% of the world's land area and host roughly 40% of the world's population. The water challenge in these rainfed areas is to enhance yields by improving water availability and the water uptake capacity of crops.
- Investments in rainfed agriculture have large payoffs in yield improvements and poverty alleviation through income generation and environmental sustainability. This is an important conclusion of the Comprehensive Assessment of Water Management in Agriculture, given that rainfed agriculture, particularly in the world's most water-challenged regions, is a risky business, with current yields generally less than half of those in irrigated systems and in temperate regions where water risks are much lower. The key challenge is to reduce water-related risks posed by high rainfall variability rather than coping with an absolute lack of water.
- There is generally enough rainfall to double and often even quadruple yields in rainfed farming systems, even in water-constrained regions. But it is available at the wrong time, causing dry spells, and much of it is lost.
- Apart from water, upgrading rainfed agriculture requires investments in soil, crop, and farm management. However, to achieve these, rainfall-related risks need to be reduced, which means that investments in water management are the entry point to unlock the potential in rainfed agriculture.

- A new era of water investments and policy is required for upgrading rainfed agriculture. The focus of the past 50 years on managing rainfall in farmers' fields, through soil and water conservation, cannot alone reduce the risk of frequent dry spells.
- Needed are investments in water resources management in smallholder rainfed farming systems that add new freshwater through local management of rainfall and runoff. Upgrading rainfed agriculture thus involves investments in the continuum between rainfed and irrigated agriculture.
- The potential for improving water productivity is particularly high in smallholder rainfed agriculture, with water savings of 15%–20% already possible over the coming decade. Such large water savings are possible because water productivity is very low in rainfed agriculture in poverty-stricken rural areas.
- Small investments (providing 1,000 cubic meters of extra water per hectare per season) for supplemental irrigation in combination with improved soil, nutrient, and crop management can more than double water productivity and yields in small-scale rainfed agriculture.
- Poor management of rainwater in rainfed systems generates excessive runoff, causing soil erosion and poor yields due to a shortage of soil moisture. Investments to maximize rainfall infiltration and the water-holding capacity of soils minimize land degradation while increasing the water available in the soil for crop growth.
- There is an urgent need for widening the policy scope to include explicit strategies for water management in rainfed agriculture.

Rainfed areas of Pakistan

- ✓ Pakistan is predominantly an arid country with 80 percent falling in the arid and semiarid regions.
- ✓ Today Pakistan stands among the most arid countries with an annual rainfall of below 240 mm.
- ✓ In general,climate is characterized primarily as desert or near desert, half of the country receives less than 250 mm rainfall per annum.
- ✓ The country spreads over a geographical area of 79. 6 million hectares (Mha),only 23 Mha is cultivated.
- ✓ About 75 percent of the cropped area is irrigated and the rest (4.0 Mha) is rain fed playing an important role in the national economy.
- ✓ Forests cover an area of 4. 0Mha, which is 5.0 percent of the total area in the country.
- ✓ In addition,with an area of 28.5 Mha the rangelands occupy about one third(32.4 percent)of the total land mass.
- ✓ In Pakistan, drylands, arid lands and rainfed areas are the terms being used interchangeably to designate the lands not irrigated by canals or tubewells where agriculture relies solely on rainfall.
- ✓ In Pakistan, most parts of Sindh, Balochistan, southern parts of Punjab and Khyber Pakhtunkhwa receive less than 250 mm annual rainfall.


N
Rainfed Zone
Legend
Study Area
AJK
Disputed Territory
Agro-Ecological Zones of Pakistan
Rainfed Zone
Dry Western Plateau
Indus delta
Northern Dry Mountains
Northern Irrigated Plains (a)
Northern Irrigated Plains (b)
Sandy Desert (a)
Sandy Desert (b)
Southern Irrigated Plains
Sulaiman Piedmont
Western Dry Mountains
Wet Mountains
0 40 80 160 240 320
Kilometers
This map has been reproduced from Agro-Ecological Zoning developed by Pakistan Agricultural Research Council.



- ✓ These areas receive very scarce, erratic rainfall during a short rainy season; however, these regions remain relatively dry during the rest of the year.

- ✓ Due to high temperatures and high rain intensity much of the rainfall is being lost through evaporation and runoff.
- ✓ In dry areas, water remains the most limiting factor for flora and fauna. Rainfed areas are concentrated in the Pothwar Plateau, northern mountains and northeastern plains of the country.
- ✓ The rainfall in these areas varies from less than 100 mm in the hot desert to over 1 500 mm in the outer Himalayas. According to Rashid et al (2004), the pattern is bimodal with 60-70 percent of rainfall occurring in the summer from July to September and the remainder occurs in the winter.
- ✓ A large fraction of Pakistan is in the arid and semiarid climatic zones. Pakistan is well known as an agricultural country and its agriculture sector continues to play a pivotal role in the economy.
- ✓ It is still considered to be the second largest sector, accounting for over 21 percent of Gross Domestic Product (GDP), and remains by far the largest employer, absorbing 45 percent of the country's total labor force. Nearly 62 percent of the country's population resides in rural areas, and is directly or indirectly linked with agriculture for their livelihood.
- ✓ In the past, resources were allocated for the development of irrigated areas (high potential)whereas less importance was given to agriculture on rainfed areas(low potential)due to its intrinsic risks. However, rainfed areas are very vast natural resource contributing a very significant share to the national economy.
- ✓ In Pakistan, dryland agriculture is synonymous with rainfed(barani) conditions. It sustains 80 percent of the livestock population and contributes 12 percent of wheat, 27 percent of maize,69 percent of sorghum,21 percent of millet,25 percent of rape and mustard,77 percent of gram,90 percent of groundnut,53 percent of barley and 85 percent of pulses.
- ✓ On the country level, a big yield gap exists for various crops between the average yields and the potential yields.
- ✓ The critical review of yields realized in the last few decades, suggests substantial improvement in crop yields is quite possible in rainfed areas.

- ✓ Rainfed agriculture, therefore, is quite capable with an appreciable potential for meeting the increasing food requirements of the rising population of the country.
- ✓ For this purpose, the factors which affect the productivity of rainfed agriculture need to be properly looked into and managed.

Sources of water

Water sources

It is divided into following types

Surface water

- ❖ Surface water is water in a river, lake or fresh water wetland. Surface water is naturally replenished by precipitation and naturally lost through discharge to the oceans, evaporation, evapotranspiration and groundwater recharge.
- ❖ Although the only natural input to any surface water system is precipitation within its watershed, the total quantity of water in that system at any given time is also dependent on many other factors.
- ❖ These factors include storage capacity in lakes, wetlands and artificial reservoirs, the permeability of the soil beneath these storage bodies, the runoff characteristics of the land in the watershed, the timing of the precipitation and local evaporation rates. All of these factors also affect the proportions of water loss.
- ❖ Human activities can have a large and sometimes devastating impact on these factors. Humans often increase storage capacity by constructing reservoirs and decrease it by draining wetlands. Humans often increase runoff quantities and velocities by paving areas and channelizing the stream flow.
- ❖ The total quantity of water available at any given time is an important consideration. Some human water users have an intermittent need for water. For example, many farms require large quantities of water in the spring, and no water at all in the winter.
- ❖ To supply such a farm with water, a surface water system may require a large storage capacity to collect water throughout the year and release it in a short period of time.

Other users have a continuous need for water, such as a power plant that requires water for cooling. To supply such a power plant with water, a surface water system only needs enough storage capacity to fill in when average stream flow is below the power plant's need.

- Nevertheless, over the long term the average rate of precipitation within a watershed is the upper bound for average consumption of natural surface water from that watershed.

Under river flow

- Throughout the course of a river, the total volume of water transported downstream will often be a combination of the visible free water flow together with a substantial contribution flowing through rocks and sediments that underlie the river and its floodplain called the hyporheic zone.
- For many rivers in large valleys, this unseen component of flow may greatly exceed the visible flow.
- The hyporheic zone often forms a dynamic interface between surface water and groundwater from aquifers, exchanging flow between rivers and aquifers that may be fully charged or depleted.
- This is especially significant in karst areas where pot-holes and underground rivers are common.

Groundwater

- ✓ Groundwater is fresh water located in the subsurface pore space of soil and rocks. It is also water that is flowing within aquifers below the water table.
- ✓ Sometimes it is useful to make a distinction between groundwater that is closely associated with surface water and deep groundwater in an aquifer (sometimes called "fossil water").
- ✓ Groundwater can be thought of in the same terms as surface water: inputs, outputs and storage. The critical difference is that due to its slow rate of turnover, groundwater storage is generally much larger (in volume) compared to inputs than it is for surface water.
- ✓ This difference makes it easy for humans to use groundwater unsustainably for a long time without severe consequences. Nevertheless, over the long term the average rate of

seepage above a groundwater source is the upper bound for average consumption of water from that source.

- ✓ The natural input to groundwater is seepage from surface water. The natural outputs from groundwater are springs and seepage to the oceans.
- ✓ If the surface water source is also subject to substantial evaporation, a groundwater source may become saline.
- ✓ This situation can occur naturally under endorheic bodies of water, or artificially under irrigated farmland. In coastal areas, human use of a groundwater source may cause the direction of seepage to ocean to reverse which can also cause soil salinization.
- ✓ Humans can also cause groundwater to be "lost" (i.e. become unusable) through pollution. Humans can increase the input to a groundwater source by building reservoirs or detention ponds.

Frozen water

- ✓ Several schemes have been proposed to make use of icebergs as a water source, however to date this has only been done for research purposes. Glacier runoff is considered to be surface water.
- ✓ The Himalayas, which are often called "The Roof of the World", contain some of the most extensive and rough high altitude areas on Earth as well as the greatest area of glaciers and permafrost outside of the poles.
- ✓ Ten of Asia's largest rivers flow from there, and more than a billion people's livelihoods depend on them. To complicate matters, temperatures there are rising more rapidly than the global average. In Nepal, the temperature has risen by 0.6 degrees Celsius over the last decade, whereas globally, the Earth has warmed approximately 0.7 degrees Celsius over the last hundred years.

Agriculture

- ✓ It is estimated that 70% of worldwide water is used for irrigation, with 15–35% of irrigation withdrawals being unsustainable.
- ✓ It takes around 2,000–3,000 litres of water to produce enough food to satisfy one person's daily dietary need.
- ✓ This is a considerable amount, when compared to that required for drinking, which is between two and five litres.

- ✓ To produce food for the now over 7 billion people who inhabit the planet today requires the water that would fill a canal ten metres deep, 100 metres wide and 2100 kilometres long.

Soil as a water reservoir

- ✓ The soil acts as a reservoir for water needed by plants but about half the water in the saturated soil moves down through large pores past the root zone and is lost for plant ant use. That lost is called gravitational water.
- ✓ When all of the pore space of a soil is filled with water, it is said to be saturated. The point where drainage ceases and the maximum amount of water is retained in the soil is known as the "field capacity."
- ✓ Approximately one-half of the water that remains in the soil (one-fourth of the total water) is available to plant roots and is known as capillary water. It is free to enter plants and be used for their growth.
- ✓ The remaining one-half of the water that remains in the soil is held so tightly to soil particles that it is unavailable to plant roots.
- ✓ The total amount of unavailable soil moisture identifies the "permanent wilting point" of a given soil.

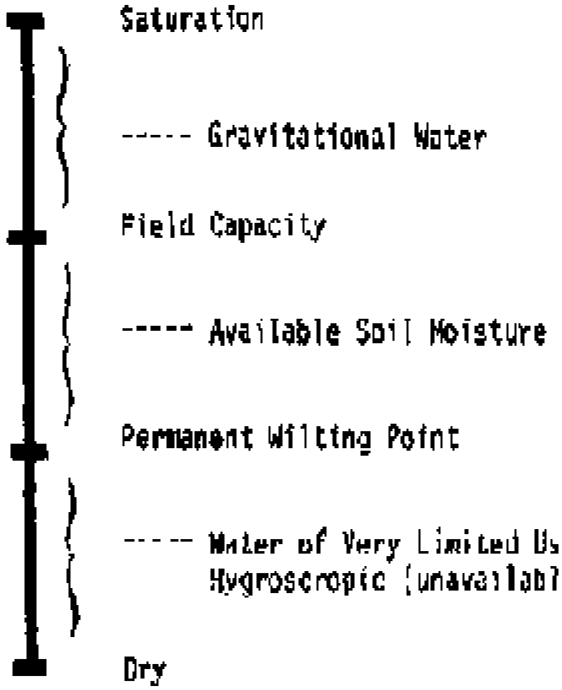
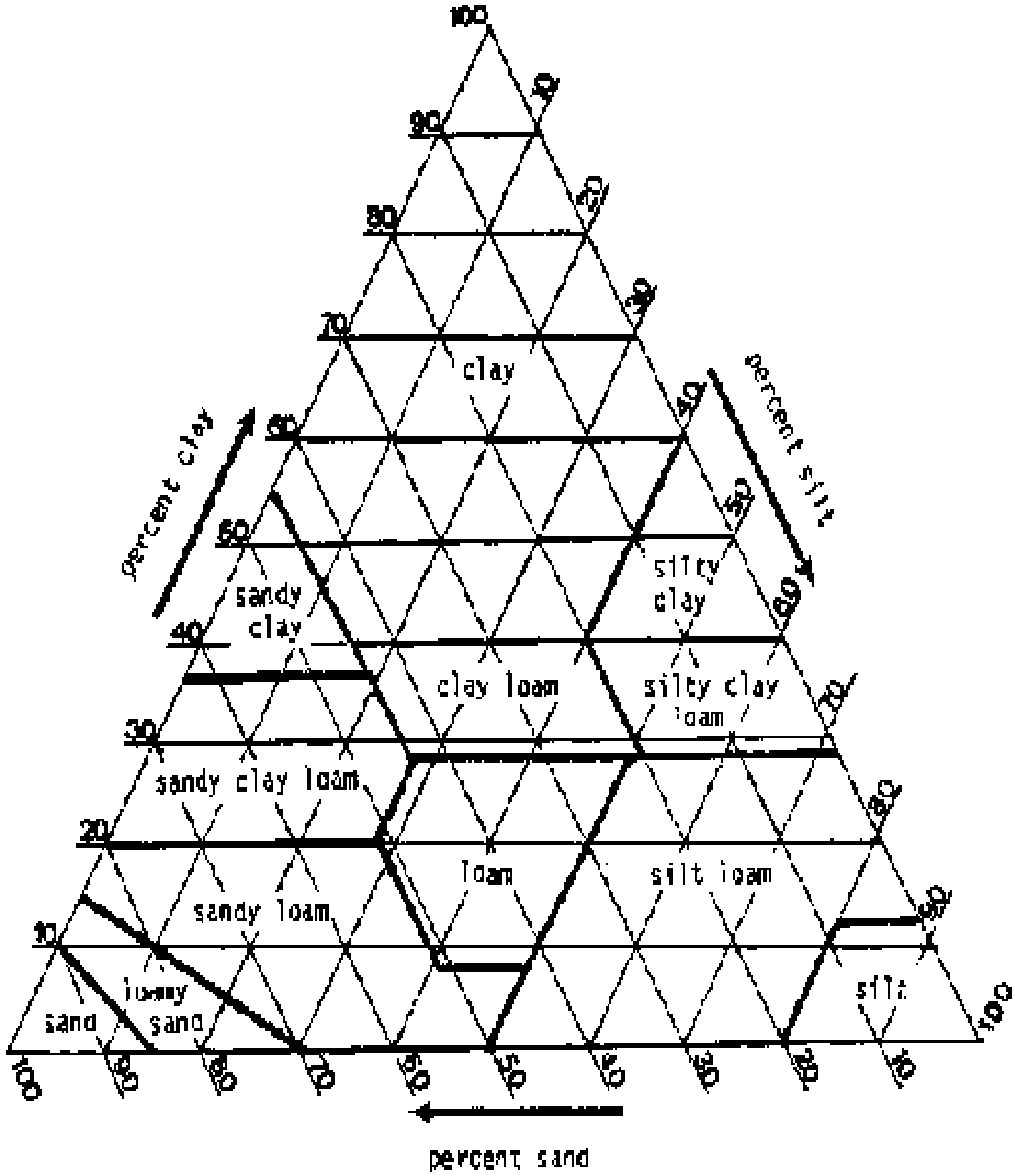


Figure illustrates those soil-moisture concepts.

- ✓ Since irrigation is to provide water to the soil for plants to use, you should examine the soil.
- ✓ A typical soil can be looked upon as a three-phase system with approximately half the space occupied by solid material, one-fourth by gas, and one-fourth by liquid.
- ✓ The solid phase consists largely of inorganic materials known as sand, silt, and clay that range from 2 mm to less than 0.002 mm in diameter. Sand particles are the largest (2.00 mm to 0.05 mm) and consist mainly of quartz.
- ✓ Sand has a gritty feeling when rubbed in the hand. Silt particles (0.05 mm to 0.002 mm) have a velvet-like feeling, while clay (less than 0.002 mm), the smallest size fraction, is sticky when moistened in the hand.
- ✓ Most soils also have a small portion, 0.1 to 10 percent, of organic material which is extremely important because it increases water-holding capacity, improves structure, and provides plant nutrients as it decomposes.
- ✓ The triangle has been divided into regions such as "clay" or "sandy loam" depending upon the relative amounts of various sizes of soil particles present. To read the chart, the

clay lines go horizontally to the right from the clay side of the triangle, the silt lines go down at a 45° slope from the silt side of the triangle, and the sand lines go up to the left at a 45° angle from the bottom (sand) side of the triangle.

- ✓ The various size fractions of the soil are mixed into different combinations called soil textures. For example, a soil texture such as loam consists of 28 to 50 percent silt, 25-52 percent sand, and 7.5 to 27.4 percent clay. Soil containing equal amounts of the three separates is a clay loam.
- ✓ The various textures indicated on the textural triangle are generally grouped into three categories. Sands, loamy sands, and sandy loams are usually referred to as coarse-textured soils. Loams and silt loams are medium textured soils; while clay loams, silty-clay loams, and clays are known as finetextured soil. The fine-textured or clay soils are known as heavy soils, while coarse-textured soils are called light soils.
- ✓ The terms heavy and light soils originated from the ease that tillage implements can be drawn through them. Thus, clays are difficult soils to draw implements through in contrast to sands whose tillage requires less power.
- ✓ The relative proportions of soil particles by size can be shown easily by letting a sample of soil settle in water. Fill a fruit jar about two-thirds full of water. Pour in soil until the jar is almost full. Replace the cover or put one hand tightly over the top of the jar and shake it vigorously. Then put the jar on the table and let the soil settle (Figure 2-3). Allow plenty of time because the very small particles settle slowly.



✓

Figure The soil texture triangle (from Handbook No. 436 U.S. Department of Agriculture, Washington, D.C., 1975)

✓

✓ Soil texture has a large influence on the amount of water it can store for plant use and the rate at which water moves through them (Tables 2-1 and 2-2).

✓ The coarse-textured soil can hold for plant use only 20 to 120 millimeters of water per meter depth of soil. At the other extreme, the fine-textured soil will hold from 140 to 200 millimeters per meter of soil. Familiarity with soil textures makes the irrigation design and operation easier and more efficient.

- ✓ The root zone of plants depends upon the size of the plants. Most major field crops root about 1 to 1¼ meters deep. Most of the roots are nearer the surface, as shown in Figure 2-4. Most water below about 1 meter is essentially unavailable to plants.
- ✓ Wilting points of most soils are from one-third to two-thirds of field capacity. Table 2-1 shows some typical ranges of available soil moisture to be expected with various soil textures. Irrigation in a typical soil would be required immediately when soil moisture declines to 50 percent of field capacity.
- ✓ Table Range of readily available soil moisture for different soil types

	Percent of moisture based on dry weight of soil		
Soil type	**Field capacity**	**Permanent wilting point**	**Available water per unit depth of soil, mm/m**
Fine sand	3- 5	1- 3	20- 40
Sandy loam	5-15	3- 8	40-110
Silt loam	12-18	6-10	60-130
Clay loam	15-30	7-16	100-180
Clay	25-40	12-20	160-300

Table Long term infiltration rates for indicated soil types

Soil type	**Infiltration rate in mm per hour**
Clay	1-5
Clay Loam	5-10
Silt Loam	10-20
Sandy Loam	20-30
Sand	Over 30

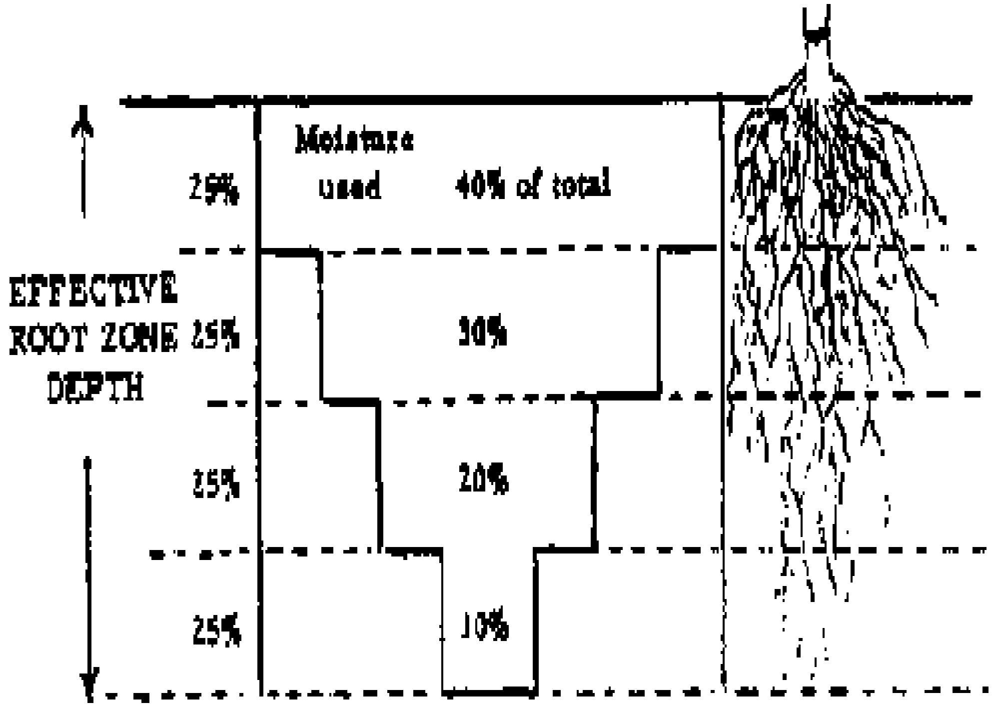


Figure Moisture use in relation to root zone and available moisture (S.C.S. Inf. Bull No. 199)

- Most crops in deep, uniform soils use moisture more slowly from the lower root zone than from the upper soil. The top quarter is the first to be exhausted of available moisture. The plant then has to draw its moisture from the lower three-quarters of root depth. That stresses the plant because adequate moisture to sustain rapid growth cannot be extracted by the roots.
- Soil structure is a term used to describe the arrangement of the soil particles Structure refers to a compounding or aggregation of soil particles into various forms such as platy, blocky, prismatic, etc. The moisture and air relationships of a soil are influenced by structure. An example of this is when soils containing some clay are trampled by animals while it is wet and the clay fills the pore space, thus creating a denser soil. Upon drying, such soil forms a massive structure and is said to be puddled when dry.

Water retention in soils

- ✓ Water is generally considered to be the universal solvent. The water molecule is dipolar, which means that one end of the molecule is negative in charge and the other is positive. Since opposite charges attract each other, this property permits the molecule to adjust to most materials.
- ✓ Another property of water is relatively high surface tension. Surface tension is a measure of cohesion or attraction of water molecules to other water molecules. In contrast to cohesive forces, there are the adhesive forces. Adhesion is the attraction of water molecules to other molecules such as glass or soil.
- ✓ Those soil properties, combined with various soil particle sizes, profoundly influence the movement, storage capacity, and retention of water in soil.
- ✓ Coarse-textured soils consisting of large particles tend to have fewer, but individually larger, diameter pores than fine-textured soils with small particles such as clay. A clay soil will have more total pore space, lower bulk density, and smaller diameter individual pores than a coarse-textured soil such as loamy sand.
- ✓ Having a relatively high adhesive force, water is retained more in the fine-textured soils than in coarsertextured soils. This can be visualized by comparing the ease with which water can be poured through a two-inch diameter pipe to the difficulty of moving water through a capillary tube.
- ✓ The relationship of water adhesion to soil particles can also be considered from the viewpoint of specific surface. Specific surface refers to the amount of surface area exposed to air or water.
- ✓ For example' a solid one-inch cube has a specific surface of six square inches. If the same cube is sliced in three places giving eight one-nalf inch cubes, the total surface will be twelve square inches, so a soil such as clay has a high specific surface and, consequently, a high percentage of the water adhering to the particles.

- ✓ **Water infiltration in soils**
- ✓ The rate that water will move into and through soils is important. Infiltration the rate surface water moves into soil. Percolation is the rate water above field capacity moves downward by gravity.

- ✓ Infiltration is important because under natural rainfall, infiltration indicates how rapidly water will move into the soil. Low infiltration rates lead to more runoff and, frequently, to soil erosion.
- ✓ Percolation rates must be high to sustain high infiltration rates. In many soils, layers of various-textured soils influence infiltration rates over long periods. For example, a clay layer beneath a sandy loam area results in a decreased infiltration rate when the sandy loam area becomes saturated.
- ✓ In some cases, high infiltration rates are not desired. For example, ponds used to store irrigation water should have low infiltration rates. Rice paddies, where permanent flooding is desired, require less irrigation water when infiltration rates are low.
- ✓ Fine-texture soils generally have lower infiltration rates than coarse-textured soils. The long-term infiltration rate refers to the millimeters of water that enters the soil per hour after a constant infiltration rate has been established. Some values are shown in Table 2-2.
- ✓ The infiltration rate of a soil, an important factor when designing an irrigation system, may be measured in several ways. Unless large amounts of water are available, the methods are only approximate because if a small surface area is wetted, water will move vertically and laterally. Hence use as large an area as possible when measuring infiltration to minimize the effects of lateral movement, which might not occur during normal rainfall or irrigation conditions.
- ✓ A measurement technique is to place a wall or dam around a level area to be tested, a 2 to 4 meter square area. Fill the small pond with water and keep the surface of the ground covered. After a length of time, one to a few hours, when ground appears to be well saturated near the surface, determine the rate of infiltration by measuring, usually with a bucket, the rate at which water must be added to keep the surface covered.
- ✓ For one square meter of area, an infiltration rate of 1 liter per hour equals 1 millimeter (mm) per hour. If a stake is placed in the pond, the rate at which water goes down on the stake could be measured but the meniscus (the curvature of the water surface near a wall) makes this difficult to read.

- ✓ As an example, a fence around an area is made of lumber enclosing an area of 4 m^2. After a constant infiltration rate is reached, 50 liters of water must be added to maintain the water level. The infiltration rate is then
- ✓ 50 liters/4 m^2 = 12.5 liters/hr m^2 or 12.5 mm/hr.

Soil moisture storage and availability

A soil is at saturation or near saturation following a heavy irrigation or rainfall in which most or all of the spaces between soil particles are filled by water.

The force of gravity is greater than the force with which soil particles hold water, so between saturation and field capacity, water is free to drain through the soil by the force of gravity.

Field capacity (FC) is the amount of water that a soil can hold against drainage by gravity.

Permanent wilting point (PWP) is the moisture content in a soil at which plants permanently wilt and will not recover.

Available water (AW) is the water content that the soil can hold between field capacity and wilting point.

Readily available water (RAW) is that portion of available water that the crop can use without affecting its evapotranspiration and growth. This portion is often indicated as a fraction of available water (p) and is dependent primarily on the type of crop and evaporative demand. A p value of 0.5 is commonly used. Shallow rooted crops such as most vegetables, however, require high moisture levels for acceptable yields, so p is about 0.3. Deeper rooted crops will generally tolerate higher depletions, so p = 0.6 to 0.7. During critical stages of growth (for example, flowering in corn), less depletion should be allowed than at other stages.

Soil moisture is typically measured as a percent of dry weight of soil, or as a volume percentage. Expression as a volume percentage or depth of water per unit depth of soil is most common and convenient in irrigation management.

The most useful measurement gives available water-holding capacity (AW) as a depth of water per unit depth of soil expressed as mm of water per meter of soil depth (mm/m) or inches of water per foot of soil depth (in/ft).

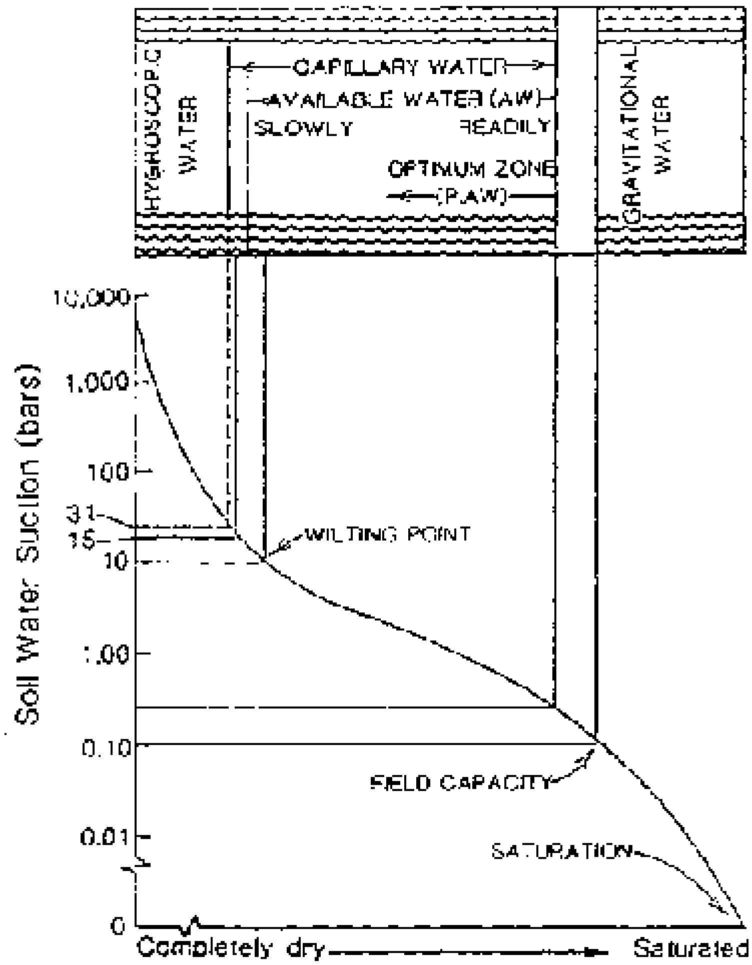


Figure 2.33 Soil Water and its Availability

- Soil Moisture

The **total available water** (TAW) for a crop with root zone depth (D) is the product of the available water-holding capacity (AW) per unit of soil depth and the root depth in the same units, or:

$TAW = D \times AW$

The readily available water in the root zone (RAW) is:

RAW = p × TAW

p = percent of allowable depletion not resulting in crop stress

Permanent Wilting Point

Permanent wilting point can be established by determining the moisture at which plants permanently wilt.

A simple criterion satisfactory for water management is that PWP is 50% of FC for coarse to medium-textured soils and about 67% of FC for clays and clay loams. Typical relationships, such as those illustrated in Figures 2.33 and 2.34 often provide sufficient accuracy in estimating wilting point for water management purposes.

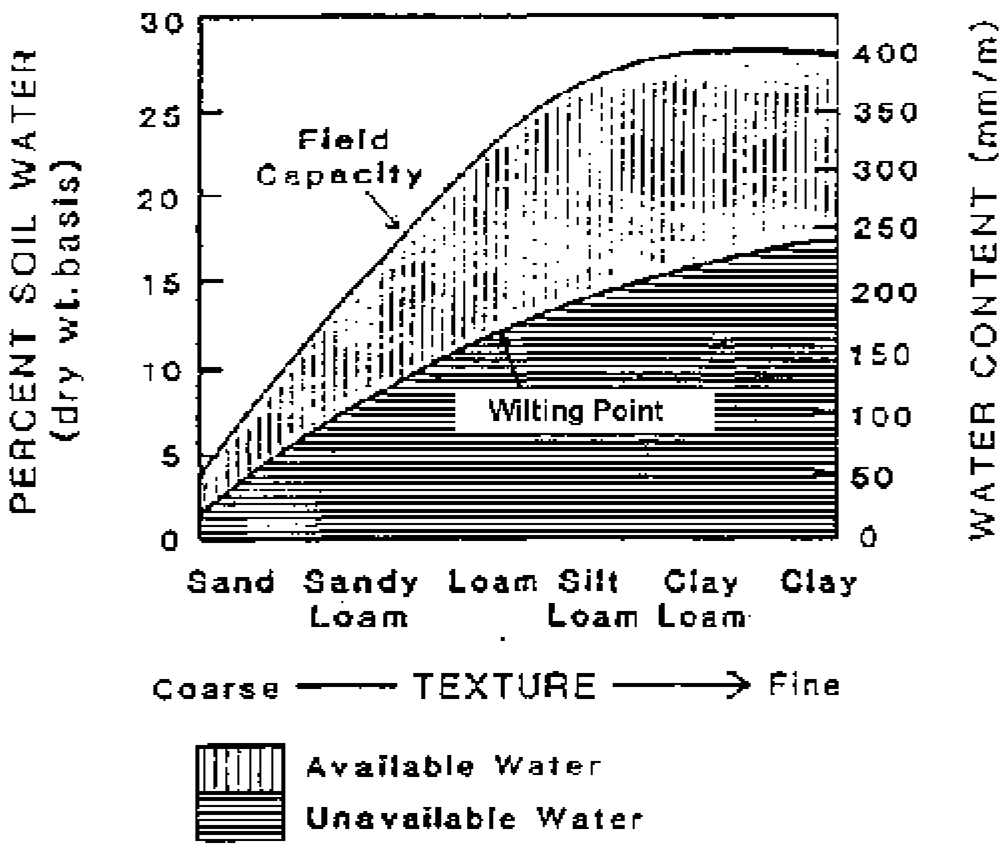


Figure 2.34 Typical Relationship Between Soil Moisture Characteristics and Texture

Available Water

The factors that affect soil available water-holding capacity are:

1) **Soil texture:** as Table 2.4 shows, the smaller the soil particles, the greater the surface area, and hence the greater the area on which water can cling. This results in a higher available soil water holding capacity. In the case of heavy clay soils, the soil water's availability to plant roots is limited by the soil denseness, since the water is so tightly held.

2) **Soil structure** is the arrangement of soil particles into groups or aggregates. The spaces between these aggregates provides places for soil drainage, soil aeration, and root growth. This is especially important in heavy soils with small soil particles. Four common soil structures are:

· **Crumb or Granular:** Roundish aggregates that are porous and easily worked.
· **Blocky:** Blocklike soil aggregates that are relatively porous.
· **Columnar**: Column-like soil aggregates that are relatively porous.
· **Platy**: Platelike, flat soil aggregates that can overlap and impair soil permeability.

A soil with poor structure and drainage will tend to trap water in the profile, increasing soil water-holding capacity, but also creating problems with waterlogging and restricted root development.

3) **Hardpans** are hardened or cemented layers caused by physical or chemical processes and restrict soil drainage. This results in a similar situation as poor structure.

4) **Organic matter** can increase a soil's water-holding capacity, mainly by improving its physical condition.

5) A soil's **salt content restricts** a plant's ability to take up water from the soil solution.

TABLE 2.4 Available Water-holding Capacities for General Soil Types

Coarse sands - gravelly sands	40 - 70 mm/m
Fine sands - loamy sands	70 - 100 mm/m

Sandy loams	120 - 160 mm/m
Loams	180 - 220 mm/m
Silt loams	230 - 270 mm/m
Silty clay loams, silty clays, heavy clays	160 - 200 mm/m

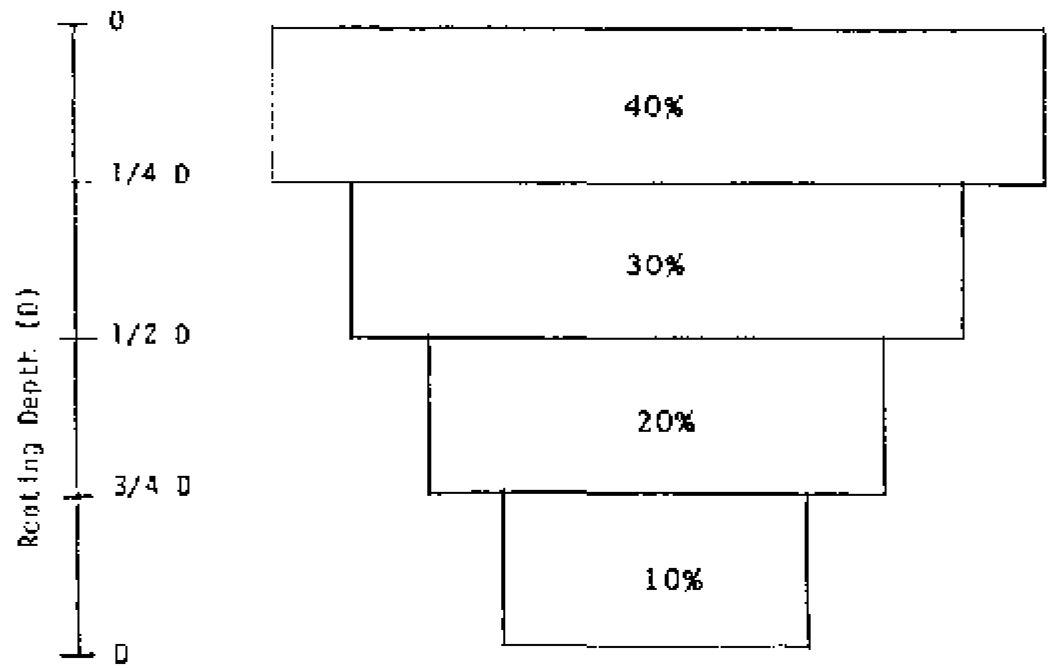


Figure 2.36 Typical Crop Water Extraction Patterns

Development of the soil water reservoir

The soil water reservoir available to the plant changes as the root system develops. Root depth varies with crop and variety, stage of growth, soil chemistry, structure, drainage and management. For example, excessive irrigation or inadequate wetting of the root zone may limit root development. The root system of a plant develops from seed depth at germination to a maximum depth at full vegetative development, or until it encounters impermeable barriers or other obstacles to root development. Typical rooting depths for several crops divided into four groups are described in Table 2.6.

TABLE 2.6 Rooting Depths of Various Crops

Rooting Depth (m)	Crops
0.3 - 0.5	Cabbage, celery, lettuce, onion, pineapple, potatoes, sisal, spinach, leafy vegetables
0.5 - 1.0	Bananas, beans, beets, carrots, peas, clover, groundnuts, peppers, soybeans, sugar beets
1.0 - 1.5	Barley, citrus, cucumber, flax, small grains, maize, melons, sunflower, sweet potato, wheat
1.5 - 2.0	Alfalfa, cotton, deciduous orchard, grapes, sunflower, sorghum, sugar cane

For management purposes such as irrigation scheduling, the root zone is often assumed to develop linearly from planting depth at time of planting, or shortly after, to typical maximum root depth at full cover. In monitoring the moisture on many field crops, the primary rooting system may be assumed to be from one to two times the crop height, or to the depth where hardpans or other obstacles are encountered. Moisture monitoring to the depth of plant height is adequate for many crops other than alfalfa, tree crops, and some other deep-rooted crops.

Soil water availability and crop use patterns

<u>Readily Available Water and Allowable Depletion</u>

The readily available water that can be extracted from the root zone without limiting yield is obtained by multiplying p by the total available water (TAW) to root zone depth.

Fungal and bacterial pathogens proliferate faster at higher moisture levels. Crop quality, such as protein in wheat and color in cotton, may improve with lower available water. Irrigation system flexibility or limited water supplies may dictate allowable depletions. Osmotic potentials created by salts in the soil create the same effects as soil moisture tensions. Salts may inhibit water and nutrient uptake from the soil, therefore, and maintenance of higher moisture levels than those indicated may be desirable in saline soils. Tables 2.7 and 2.8 should serve only as guidelines when water supplies are abundant and flexible.

2.4.5 Soil intake characteristics

Soils that take up water rapidly will wet the root zone rapidly after the onset of irrigation, and thus irrigations will usually be of short duration. The rate at which soils take water is called the **soil intake rate,** and the rate at which water goes into the soil is the **infiltration rate.** The intake rate of a soil will affect such management and design factors as irrigation durations, flow rates to be used, and dimensions of the system.

<u>Factors Affecting Intake Rates</u>

The most important factors influencing the infiltration rate of water into the soil are:

1. **Soil texture and structure.** The coarser the texture and the more highly structured, the higher the infiltration rates.

2. **Soil surface conditions.** Orientation of soil particles and compaction: after water moves over a soil surface, soil particles are rearranged and the soil surface tends to seal.

3. **Soil moisture content and moisture gradients.** Generally, the drier the soil, the faster the infiltration rate.

4. **Time since the start of irrigation.** Infiltration rate decreases with time until the basic intake rate is reached.

5. **Salt content in the water and soil.** Soils high in soluble salts will typically exhibit higher intake rates than soils from which salts have been leached.

6. **High levels of sodium** on the soil's exchange sites will severely affect infiltration if structure collapses. .

- ✓ Infiltration rate, as used in border irrigation and sometimes in furrow irrigation, has the units of velocity (l/t) and is the depth of water entering the soil profile per unit time.
- ✓ It can also be thought of as the volume of water absorbed by a unit area per unit time.
- ✓ The metric units commonly used to express infiltration rate are mm/hr or mm/mint In furrow irrigation, where infiltration rate is expressed as a depth per unit time, an equivalent depth is usually implied since movement is horizontal as well as vertical.
- ✓ The depth is obtained by dividing the volume rate of infiltration per unit of furrow length by the product of unit length and furrow spacing. In furrow irrigation, infiltration rate is commonly expressed as the volume absorbed by a unit length of furrow in a unit time.
- ✓ Most soils exhibit an initially high infiltration rate that decreases with time and eventually reaches a constant or nearly constant rate called the **basic intake rate.** Figure demonstrates the typical infiltration rate behavior with time, as well as cumulative infiltration with time.

The basic intake rates for loamy sands and sands may be 2 to 3 cm per hour or greater. For sandy loams, it is typically 1 to 2 cm per hour. For silt loams and clay loams, it is typically 0.5 to 1.0 cm/hr. For silty clays, it may be 0.2 to 0.5 cm/hr or less. With poorly structured soils, these values may decrease by 25% to 50%. With highly structured and loose soils, the values may be 50% to 100% higher than those indicated.

Because infiltration can change so much during the season, infiltration data should be used with caution, and sound judgment should be exercised in interpreting it. To use such data requires knowledge of crops and cropping history, irrigation methods and management, tillage, soil type and structure, and time of season.

Infiltration Equations

- ✓ In management of irrigations systems, several infiltration equations and methods for establishing these have been used.
- ✓ One common method for estimating infiltration rate uses ring infiltrometers. These are installed by penetrating the soil surface by 15 to 20 cm. They are then covered with plastic film, filled with water, and then the film is removed rapidly.
- ✓ A water level reading is taken immediately on removal of the plastic because water begins to infiltrate the soil at this time. The decline of the water surface is measured as a function of time and these results are recorded and graphed.
- ✓ To obtain an approximation of infiltration rate in a field situation, small 1 m × 1 m basins are constructed with well compacted banks.
- ✓ A sheet of plastic is placed in the basin and 15 to 20 cm of water introduced to the basin. The plastic sheet is removed from the bottom, and the decline of the water surface is measured as a function of time.
- ✓ Results can be graphed to provide an approximation of the time required to infiltrate a certain depth of water. Base infiltration rates may require additional water to be added to the basin.

Effective Rain fall

- Rainwater is highly important for agriculture as well as human beings and animals that fall on the earth surface.
- Pakistan is a land where rainfall not only falls in summer but also in winter. During the summer monsoon period (July to September) easterly systems/depressions form in the Arabian Sea and the Bay of Bengal, produce rainfall over low elevation plains of Pakistan. August is the peak month of that season.
- Nearly 60% of annual rainfall over most parts of Pakistan is received during summer (June to September). Rainfall occurs primarily due to differential heating of the land and sea. Kharif crop largely depends upon the amount and distribution of rain especially during monsoon season.
- In Pakistan, winter precipitation occurs due to the western disturbances which are generally the off-shores of mid latitude frontal systems.
- These disturbances move in the northeasterly direction. These disturbances pick up the moisture from Persian Gulf as well as from the Arabian Sea and not only enhance the winter rainfall but also cause rainfall over the most parts of the Pakistan during winter.
- These rains are very important for Rabi crops in rainfed areas. The primary source of water supply for agriculture in most parts of the world is rainfall.
- The characteristics of rainfall vary from place to place, day to day, month to month and also year to year. In spite of voluminous data on weather, all is not yet known about rainfall variability over temporal and spatial scale.
- Certain simple entities have baffled planners right up to present. One of these is “effective rainfall". In its simplest sense, effective rainfall means useful or utilizable rainfall.
- Rainfall is not necessarily useful or desirable at the time, rate or amount in which it is received. Some of it may be unavoidably wasted while some may even be destructive.

- Just as total rainfall varies, so does the amount of effective rainfall. The useful portion of rainfall is stored while the rest unwanted parts need to be detached or pass on speedily.
- The term effective rainfall has been interpreted differently not only by specialists in different fields but also by different workers in the same field.
- To an irrigation engineer, the rain which reaches the storage reservoir directly and by surface runoff from the surrounding area indirectly is the effective portion.
- Agriculturists consider that portion of the total rainfall as effective which directly satisfies crop water needs and also the surface runoff which can be used for crop production on their farms by being pumped from ponds or wells.
- Most rain water is used in agriculture for crop production. But some part of rainfall is lost.
- These losses includes water intercepted by living or dry vegetation, that lost by evapotranspiration during growth of crops, that lost by evaporation from the soil surface, that fraction which contribute to leaching and percolation.
- Meteorologists can neither solve nor evaluate the problem of effective rainfall merely from the tables of frequency, amount and intensity of rainfall or from physical phenomena in the atmosphere.
- It is a task in which several disciplines and sub disciplines overlap. For example, in the field of agriculture, soil types, cropping patterns and social, economical and management factors all have a direct impact on the extent of effective and ineffective rainfall.

FACTORS AFFECTING RAINFALL AND DIFFERENT SITUATIONS

Effective rainfall depends on the preceding soil moisture status or irrigation amount, crop characteristics (crop root zone depth, crop canopy cover), soil characteristics (water storage capacity of the soil, subsoil condition - sandy or impervious layer), land slope, climatic parameters (e.g. air temperature, humidity, wind speed, etc.) or atmospheric water demand, rainfall characteristics (intensity, amount, frequency, spatio-temporal distribution), and preceding soil-moisture condition or ponding water depth. If rainfall occurs just after an irrigation, maximum of its amount will become non-effective.

Different Situations of Rainfall and its Effectiveness

During extended periods of cool wet weather, less evaporation takes place and the smaller rainfall events may be effective precipitation, and also vice versa.

- Situation 1 – wet periods with small rainfall events During prolonged cool wet periods, precipitation in the form of daily showers can be considered effective. This is because the soil and air temperatures are cooler and humidity is higher allowing the rainfall to soak into the soil before it evaporates. The judgment as to how much rainfall is effective would have to be made after a number of cool days. Soil moisture monitoring could be helpful in determining how much of the rainfall is effective.
- Situation 2 – dry periods with small rainfall events During prolonged dry periods, precipitation in the form of daily showers can be non-effective. This is because the soil and air temperatures are drier and humidity is lower allowing the rainfall to evaporates. The judgment as to how much rainfall is non-effective would have to be made depending on the total situations including crop type (root type- shallow or deep, vegetative cover). Soil moisture monitoring could be helpful in determining how much of the rainfall is effective.
- Situation 3 – large amounts of precipitation Very large rainfall events may supply more moisture than the soil's water holding capacity and daily atmospheric (ET) demand. For large rainfall events, a portion of the precipitation may be lost due to moisture moving deep into the soil below the crop rooting depth, being lost by surface runoff or removed from the field through a subsurface drainage system. A certain (fixed) percent of rainfall is considered effective in some approach/method, which has no scientific basis.

If using water budgeting and ET to schedule irrigation, the budget process must be restarted after large precipitation events.

- From the above discussion, it is clear that, the effective rainfall (Re) should be based on the crop, climate, and soil specific.

Several factors influence the proportion of effective rainfall in the total received and these may act singly or collectively and interact with each other. Any factor which affects infiltration, run-off or evapotranspiration affects the value of effective rainfall

Rainfall Characteristics

- ✓ A soil has a definite and limited water intake rate and moisture holding capacity. Hence greater quantities as well as Intensities of rainfall normally reduce the effective fraction, increasing run-off and lessening infiltration.
- ✓ Similarly, uneven distribution decreases the extent of effective rainfall while an even spread enhances it.
- ✓ A well distributed rainfall in frequent light showers is more conducive to crop growth than heavy downpours. For example, annual rainfall is lower than 100 mm in the Middle Eastern desert countries, so it may all become effective.
- ✓ In countries like India and Pakistan, intensity, frequency and amount are high daring July and August and hence the effective fraction is very low. From November to April, however, most of the rainfall is effective in these countries due to its low intensity, frequency and amount.

Table: FACTORS INFLUENCING EFFECTIVE RAINFALL THROUGH INFILTRATION, SURFACE RUN-OFF AND EVAPOTRANSPIRATION

Factor	**Relevant characteristics**
Rainfall	Amount, intensity, frequency, distribution over area as well as time;
Other meteorological parameters	Temperature, radiation, relative humidity, wind velocity;
Land	Topography, slope, type of use;

Soil	Depth, texture, structure, bulk density, salt and organic matter content;
Soil water	Head, suspended matter, turbidity due to clay or colloids, viscosity, temperature, nature of dissolved salts (Na^+, $N03^-$);
Groundwater	Depth from surface, quality;
Management	Type of tillage, degree of levelling, type of layout (bunding, terracing, ridging), use of soil conditioners;
Channel	Size, slope, shape, roughness and back water effect;
Crops	Nature of crops, depth of root system, degree of ground cover, stage of growth, crop rotations,

Other Meteorological Parameters

- ❖ Potential evapotranspiration is primarily governed by evaporative demand under conditions of abundant water supply.
- ❖ An approximation of evaporative demand can be obtained front the integrated effect of four parameters: temperature, radiation, wind velocity and humidity. Increase in the first three and decrease in the fourth parameter enhance evaporation.
- ❖ Such conditions encourage greater deficits of moisture in the soil and therefore the proportion of effective rainfall in the total increases. The mean monthly values of temperature, radiation, wind velocity and humidity fluctuate less from year to year than total rainfall. Today in some countries, weekly or fortnightly maps of potential evapotranspiration are available which can be used in assessing effective rainfall.

Land Characteristics

- ❖ The time interval between receipt of rain water and its recessation by soakage is known as 'opportunity time'.
- ❖ Water stays longer on flat and levelled land and thus has a longer opportunity time than on sloping land where there is a rapid run-off. Sloping, rolling and undulating lands thus influence opportunity time of rain water for uniform infiltration and consequently the effective rainfall fraction.

- The use to which land is put in the surrounding area - agriculture, road and building construction, play-grounds - also affects the amount of effective rainfall.

Soil Characteristics

- Soil is an important medium between water and plants, acting as a reservoir for the moisture supply to crops.
- Hence its properties of absorption, retention, release and movement of water influence the degree of effective rainfall.
- Intake and water movement in soil are expressed in terms of infiltration rate and permeability. For maximum absorption of rain and reduction of surface run-off, the values of these properties should be as high as possible.
- Permeability depends upon the texture, structure and compactness or bulk density of the soil. The higher the bulk density, the lower the permeability.
- The fraction of effective rainfall increases with increased water holding capacity in a soil. The amount of water held and retained by a soil depends upon its depth, texture, structure and organic matter content; the finer the texture, the greater the storage capacity.
- The amount of water available to plants varies considerably in different soils. It may be about 10 mm per metre depth in sandy soils to about 100 mm in clayey soils.
- The greater the soil depth, the higher the proportion of effective rainfall in the total.
- Initial moisture status in a soil governs the extent of effective rainfall considerably. When a shower falls just after irrigation, it becomes surplus water and is lost through deep percolation or run-off, but if the soil is dry it is recharged with moisture, resulting in a saving in irrigation water. The proportion of effective rainfall is lower in irrigated than in unirrigated areas where there is often a greater deficit of moisture in the soil.

Soil Water Characteristics

- On striking the soil surface, the rain water often becomes run-off water and changes its physical and chemical properties during its flow.

- Hater characteristics influencing effective rainfall are the head or depth of water received directly or indirectly, turbidity, viscosity, temperature, and nature of the salts, such as sodium, nitrates, etcetera, dissolved in it.
- These properties influence infiltration and through this the effective rainfall quantum.

Groundwater Characteristics

- The amount of effective rainfall is greater when the water table is deep than when it is shallow. Water moves upwards in the soil by capillarity, thus reducing the deficit of moisture and hence the amount of effective rainfall.
- The levels of water tables normally fluctuate. Before the onset of rain, the water table may be quite deep; during the rainy season, it may rise to the surface. There are horizontal flows in the sub-soil to or from adjoining regions.
- Because of these variations, the contribution of groundwater to the needs of the crop is variable and the proportion of effective rainfall varies inversely with this contribution.
- If the groundwater is saline, it can be harmful to crop plants especially when it is near the soil surface. The proportion of effective rainfall may then increase since salts are diluted.

Management Practices

- Any management practice which influences run-off, infiltration, permeability or evapotranspiration also influences the degree of effective rainfall.
- Bunding, terracing, ploughing, ridging and mulching reduce run-off and increase effective rainfall; so do well-planned irrigation schedules, while arbitrary or random practices may reduce it.

Drainage Channel Characteristics

- Size, shape, slope and roughness of a channel influence the speed of surface run-off to streams and consequently the time allowed for infiltration and also for direct evaporation at the site of rainfall.
- Hence these factors are also important in influencing effective rainfall.

Crop Characteristics

- Crops with high water consumption create greater deficits of moisture in the soil; therefore effective rainfall is directly proportional to the rate of water uptake by the plant.
- Crop characteristics influencing the rate of water uptake are the degree of ground cover, rooting depth and stage of growth.
- Evapotranspiration is generally high during vegetative growth and the flowering period and then may decline toward maturity.
- Soil moisture stored in deeper layers can be tapped only when roots penetrate to these depths. Deep-rooted crops therefore increase the proportion of effective rainfall in a given area; hence the nature of the crop is an important factor in determining its extent. Rainfall just before harvesting is for most crops a waste or a nuisance and may need to be considered as ineffective.
- Rainfall which reduces the yield (such as downpours which often cause lodging in cereals when the latter are at the grain formation stage) must be regarded as ineffective, and similarly, rains which result in deterioration or actual destruction of a crop. The crop is an important factor in interpreting the basic data.
- Hence the seasonal needs of major crops in a given area should be taken into account when the extent of effective rainfall is assessed.

Rainfall frequency

- The number of times, during a specified period of years, that precipitation of a certain ma gnitude or greater occurs or will occur at a station; numerically, the reciprocal of the freq uency is usually given.

- Many researchers have examined temporal and spatial precipitation distributions, especially the distribution of extreme precipitation values.
- However, worldwide, only an irregular, coarse grid of precipitation measurement data exists, and it is not sufficient to say that mechanisms are fully understood.
- Researchers have attempted to develop a number of geostatistical interpolation methods to obtain reliable rainfall and rainfall-risk maps in mountainous regions with sparse precipitation measurement coverage.

- Other researchers have investigated orographic-induced meteorological mechanisms and statistical orographic rain structures. Only about 6600 stations worldwide archive rain gauge data through the Global Telecommunications Network or other regional or national data collection centers.
- Both precipitation data and data archives are also mostly located in mid- or high-latitude developed countries.
- Consequently, most studies, have focused on mid latitude developed countries, which are more likely to have the necessary high-temporal-resolution rainfall records. In recent years, hydro meteorological networks have been installed in some ungauged high-elevation basins.
- However, only a few studies have examined rainfall characteristics in a tropical region. Tropical countries typically have sparse operational rain gauge networks and extremely limited high-temporal-resolution (1 h or less) precipitation records.
- Rain gauges provide relatively accurate point measurements of precipitation, although rain gauge observations do suffer from systematic errors and biases as caused by wind-induced undercatch, wetting, and evaporation loss.
- Point-to-area and gauge gaps are the biggest problems for gauge analysis. Researchers have used infrared and microwave radiance satellite observations to retrieve precipitation information from many parts of the globe.
- The total rainfall received in a given period at a location is highly variable from one year to another.
- The variability depends on the type of climate and the length of the considered period. In general it can be stated that the drier the climate, the higher the variability of rainfall in time.
- The same hold for the length of the period: the shorter the period the higher the annual variability of rainfall in that period.
- Because of the strong variability of rainfall in time, the design and management of irrigation water supply and flood control systems are not based on the long-term average of rainfall records but on particular rainfall depths that can be expected for a specific probability or return period.

- ❖ Although time series of historic rainfall data are characterized by their average and standard variation, these values cannot be blindly used to estimate design rainfall depths that can be expected with a specific probability or return period.
- ❖ Applying this technique to a data set can produce misleading results since the actual characteristics of the distribution are ignored and it is assumed that they follow a particular distribution.
- ❖ The distribution and variability of rainfall are among the most important climate variables for human society, agriculture, and natural ecosystems, but capturing observed rainfall characteristics remains a challenge for global climate models.
- ❖ Evaluation of rainfall in global climate models is often focused on monthly and interannual time scales.
- ❖ However, the simulation of mean rainfall and monthly to interannual variability requires that models capture the physical processes producing rainfall on the time scale of individual synoptic events.
- ❖ Even if models are able to simulate the correct amount of rainfall at a given location, it is also important that this occurs for the right reason: does the model simulate the observed atmospheric circulation and moisture transport, and does the model simulate the dominant local rainfall processes, such as convective or stratiform precipitation?
- ❖ The use of daily rainfall allows the separation into frequency (fraction of rain days) and intensity (rainfall per rain day) of observed and modeled rainfall.
- ❖ The most models overestimate the frequency of light rainfall and underestimate the intensity of heavy rainfall.
- ❖ The correct mean rainfall, they may not capture the correct combination of frequency and intensity.

Appropriate Cropping pattern and water budgeting

- ❖ A **water budget** is a **water** management tool used to estimate the amount of **water** a landscape will require. It can be calculated for a single irrigation event, on a weekly or monthly basis, or even annually.
- ❖ **Water budgets** provide a means for evaluating availability and sustainability of a **water** supply. A **water budget** simply states that the rate of change

in **water** stored in an area, such as a watershed, is balanced by the rate at which **water** flows into and out of the area.

- A **water budget** reflects the relationship between input and output of **water** through a **region**. The **water balance** graph shows precipitation and potential evapotranspiration both as line graphs. Thus we have a direct comparison of supply of **water** and the natural demand for **water**.
- There are many factors that affect waters use. For example, local water budget factors include: **temperature**, **vegetation**, **wind**, with the seasons.
- A **watershed** is an area of land that feeds all the water running under it and draining off of it into a body of water. It combines with other **watersheds** to form a network of rivers and streams that progressively drain into larger water areas. Topography determines where and how water flows.
- A water budget accounts for all water into and out of a watershed (or subwatershed). This includes precipitation, **evaporation**, transpiration, runoff, as well as the movement of water within the watershed, such as infiltration, recharge to groundwater, and reservoir storage (lakes, wetlands, aquifers).
- **water budget**, **global** The amount of **water** involved in the hydrological cycle each year. Average annual precipitation over the whole globe is about 86 cm, of which 77% falls on the oceans and 23% on land.
- The Crop Water Budgeting (CWB) has been developed to assist communities manage their surface and ground water efficiently without further depleting their resources.
- While working towards improving the supply of water, the effort is to build awareness about efficient demand side management.

- List the crops you are planning to grow and the area for each. Having an understanding of the critical times that each crop will require water will help when considering if you have enough equipment capacity to meet the peak demand period for irrigation of the crops you are growing.

- To budget multiply the area of each crop by the approximate megalitres (ML) of water required per hectare for each crop. (1 ML = 100mm per hectare of water). See the full table below.

- Consider your average rainfall and how much you will rely on this falling. For higher value crops consider treating rainfall as a bonus.

- Ensure that you have enough water to meet the requirements of the crops you are planning.

Crop	Irrigation Depth (mm)	Irrigation (ML/ha)
Potatoes	300 – 400	3.5 – 6.0
Peas	100 – 200	1.0- 2.5
Poppies	150 – 300	1.5 – 2.5
Green Beans	200	2 – 2.5
Pyrethrum	100 – 150	1 – 1.5
Carrots (fresh)	350	3.5
Carrot (seed)	350	4.5 – 5.5
Onions	350 – 400	3.5 – 4.0
Broccoli	200 – 250	2.0 – 4.0
Lucerne	350 – 550	3.5 – 5.5
Pasture	350 - 550	3.5 – 5.5
Wheat	200 - 350	1 - 3

Water Use Efficiencies

- Crop productivity has often been increased by adding inputs, including water, fertilizers and pest control. However, these activities usually increase rather than reduce water use.
- It is therefore more logical to consider increasing crop productivity per unit water, which is generally termed water use efficiency (WUE) or crop water productivity.
- WUE is basically defined at an input/output ratio as a measure of productivity. However, many different definitions of WUE have been offered, which add a high level of confusion and misunderstanding to the concept.
- Mathematically, it is the average slope of the yield: ET curve evaluated at the yield of interest.
- However, because most agronomic studies are not designed to generate these curves, WUE is the generally considered the ratio of the harvested biomass to the water consumed to achieve that yield.
- WUE is the yield of interest (e.g., grain, biomass) divided by the water used to produce that yield.
- Crop scientists express and measure water use efficiency as the ratio of total biomass or grain yield to water supply or evapotranspiration or transpiration on a daily or seasonal basis.
- Biomass yield versus evapotranspiration relations have intercepts on the evapotranspiration axis, which are taken to represent direct evaporation from the soil, and yield can be considered a linear function of transpiration, provided water use efficiency does not vary greatly during the season.
- Linearity of the yield versus evapotranspiration relation denotes that water use efficiency would increase with increase in evapotranspiration as a consequence of increased transpiration/evapotranspiration ratio because the intercept has a constant value.
- For this reason, water use efficiency also increases with increase in crop water supply up to a certain point. Water supply has also been observed to increase

fertilizer use efficiency by increasing the availability of applied nutrients, and water and nutrients exhibit interactions in respect of yield and yield components.

- The irrigation system perspective of water use efficiency depends upon the water accounting where losses occur at each stage as water moves from the reservoir (storage losses), conveyed and delivered at the farm gate (conveyance losses), applied to the farm (distribution losses), stored in the soil (application losses) and finally consumed by the crops (crop management losses) for crop production.
- Depending upon the area of interest, it is possible to measure the water conveyance efficiency, application efficiency, water input efficiency, irrigation water use efficiency and crop water use efficiency.
- Whereas crop water use efficiency compares an output from the system (such as yield or economic return) to crop evapotranspiration the irrigation efficiency often compares an output or amount of water retained in the root zone to an input such as some measure of water applied.
- The term 'water productivity' was an attempt to mediate the prevailing complexity and other inherent limitations of the existing concept. The concept of water productivity (WP) was offered by Kijne et al. (2003) as a robust measure of the ability of agricultural systems to convert water into food.
- So, the basic expression of agricultural water productivity is a measure of output of a given system in relation to the water it consumes, and may be measured for the whole system or parts of it, defined in time and space.
- Water productivity = Agricultural benefit /Water use
- It is normal to represent water productivity in units of kg m-3, where crop production is measured in kg ha-1 and water use is estimated as mm of water applied or received as rainfall, converted to m3 ha-1 (1 mm = 10 m3 ha-1).
- Alternatively, it may be represented as food (kcal m-3) or its monetary value ($ m-3). Agricultural systems are defined by plot, field, sub-basin and basin and the crop(s)/ cropping patterns followed at each component level.
- Water productivity values make better sense when the relative comparisons are made at the component parts of the agricultural system.

- ❖ The time period over which water productivity is estimated is determined by the cycle of agricultural production that drives the system. Normally, this would include at least one complete crop cycle (e.g. rice, wheat, maize, vegetables, etc.) extended over a complete year (rice-wheat, maize-wheat, sugarcane, banana, etc.) to account for productive and non-productive water use.
- ❖ Assessment may be extended over several years to derive estimates of average, minimum or maximum water productivity within each season.
- ❖ Cropping systems provide internal benefits in addition to yield, such as fodder, legumes or soil nutrition, which may significantly influence water productivity in subsequent years.
- ❖ Additionally, the patterns of climate, disease and pest infestation, markets, etc. may induce an estimation error at the time of assessment which may, or may not, be representative of the average situation.

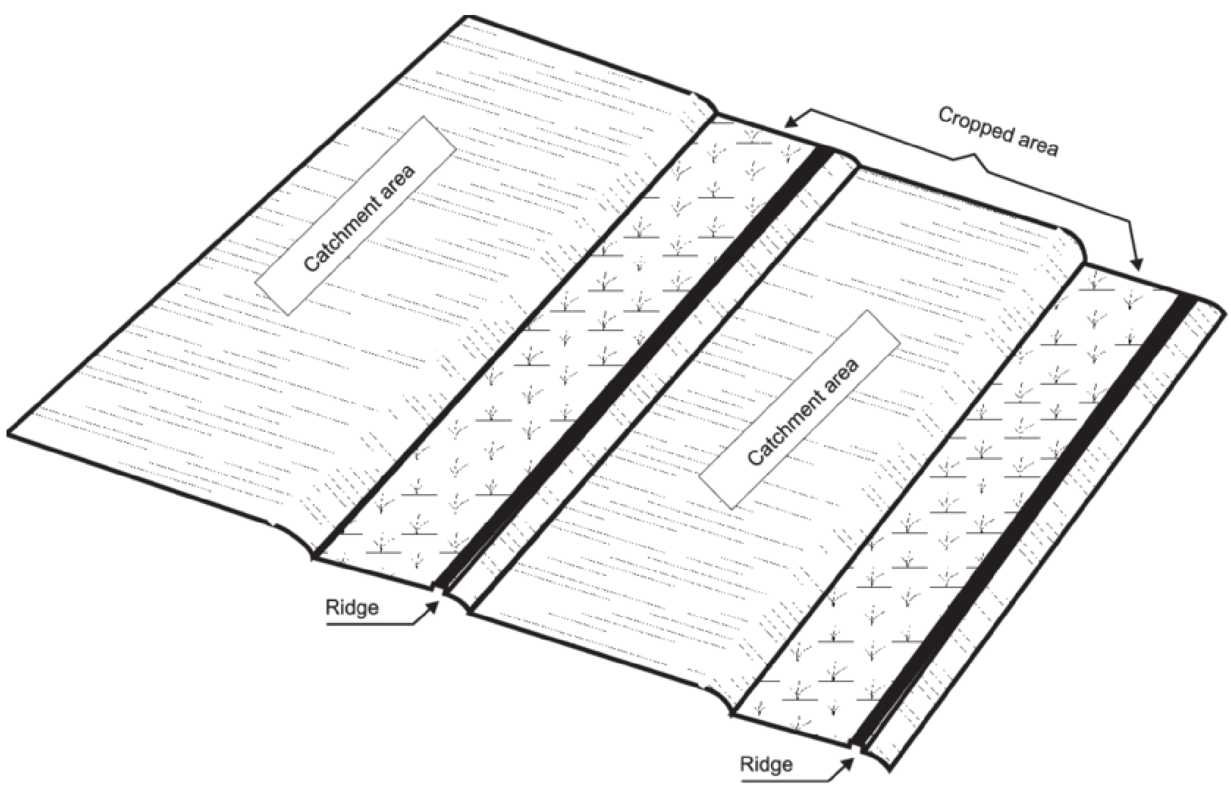
Water harvesting and run off farming

- ✓ In arid areas (i.e., areas with an annual rainfall below 200 mm), it is best to encourage and collect the runoff from a barren catchment area, and lead it to a cropping area in the valley bottom, the method is called runoff farming.
- ✓ "Runoff farming" is identical with "Water Harvesting for Irrigation Purposes". In many dry regions of the world, runoff farming was already an important means of securing sufficient water for agricultural crops or pasture areas two to three millennia ago.
- ✓ In many of those areas, such as in Yemen, runoff irrigation is still practiced today; in other parts of the arid and semi-arid world those systems have been given up, the structures are destroyed and the skills forgotten.
- ✓ The runoff can either be diverted directly and spread on the fields or collected in some way to be used at a later time.
- ✓ The size of the catchment can be (in the case of microcatchment) rather small, in the case of macrocatchment and floodwater it is relatively large and measures must be taken to route the runoff to the collection area and to prevent significant infiltration losses.
- ✓ Runoff farming require relatively large labor inputs and land requirements.

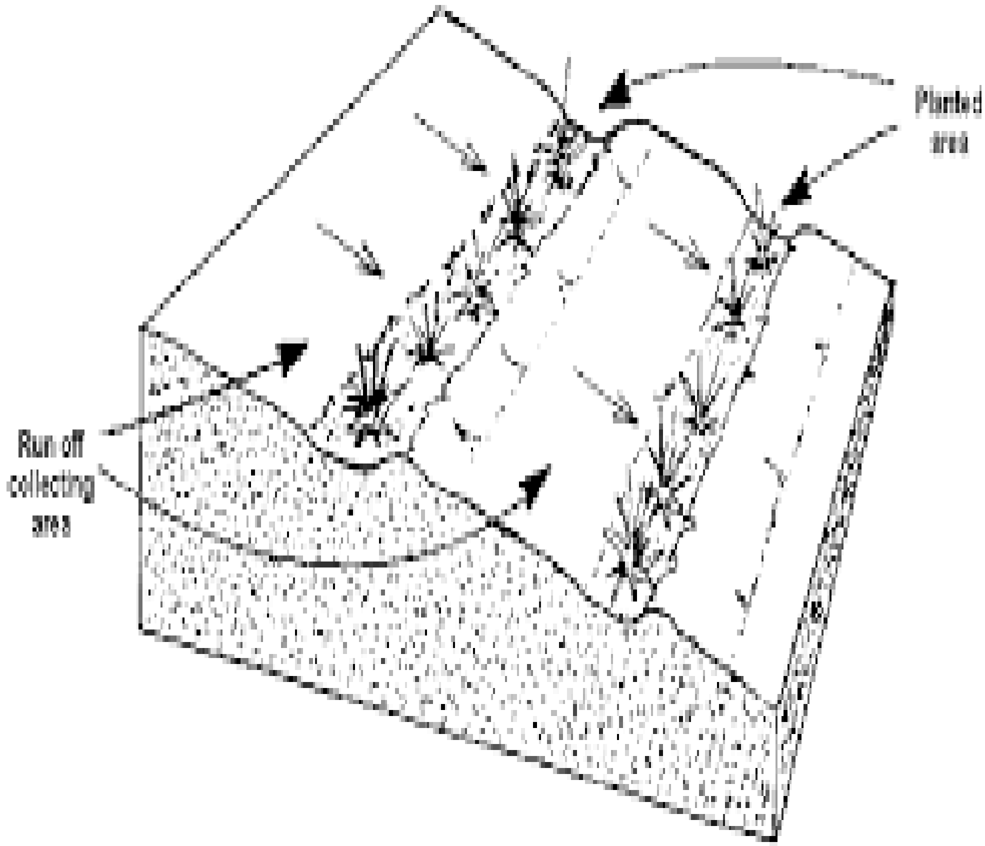
- ✓ The runoff area (catchment) should show a sufficiently high run-off coefficient (impermeability would be optimal) and the "run-on" area, where the accumulated water is stored and/or utilized, should have (for water storage in the soil matrix) a high infiltration rate a high storage capacity, which depends on soil texture, organic matter content and general soil structure, a sufficient soil depth (> 1m) (Lalljee and Facknath 1999, Prinz 1994).
- ✓ The ratio of catchment-to-field can range from 1:1 and from 1:many square kilometers in size according to Micro- or Macro-Catchment or Floodwater runoff farming system. Surface runoff is diverted by means of simple earthen or rock bunds into fields that have been surrounded by ridges and possibly terraced.
- ✓ Some researches restrict runoff farming to situations where the harvested runoff water is diverted directly into the cropped area during the rainfall event, excluding any storage in ponds, cisterns etc.
- ✓ Other authors exclude floodwater harvesting when talking on "runoff farming". The higher the aridity of an area, the larger is the required catchment area in relation to the cropping area for the same water yield.
- ✓ The most suitable areas for runoff farming are those with an average annual rainfall of 300 - 600 mm and with rainfalls during few but relatively intensive rainstorms.
- ✓ Runoff farming in a small watershed can also be encouraged by shaping the catchment and by removing the surface stones. The method was practiced many centuries ago in the Negev Desert.
- ✓ Level terraces were constructed in the valley bottom. These waterspreading terraces are known as "limanim", from a Greek term for port. The water filled the first terrace, and was then drained off at the side through a stone weir or over a low gabion into the field below.
- ✓ **Classification of runoff farming water harvesting techniques**
- ✓ Different authors have classified water harvesting methods in various ways for an extensive review of different classification methods) and a standardized classification system has yet to be developed. According to Nasr (1999), there are two basic types of runoff-farming systems: first, the **direct water application system,** where the runoff water is stored in the soil of the crop growing area during the precipitation, and second,

the * **supplemental water system**, where the collected water is stored offsite in some reservoirs and later used to irrigate a certain crop area.

- ✓ As also according to Critchley and Siegert (1991), generally, two runoff farming water harvesting groups are generally recognized, rainwater harvesting and floodwater harvesting.
- ✓ Rainwater harvesting can be further divided into microcatchment, and macrocatchment runoff farming types.
- ✓ Floodwater harvesting can also be divided into within streambed and through diversion runoff farming types.
- ✓ Rainwater harvesting runoff farming ; Microcatchment runoff farming water harvesting (MIRFWH) systems: Microcatchment runoff farming water harvesting is a method of collecting surface runoff from a small catchment area and storing it in the root zone of an adjacent infiltration area/basin. This infiltration area/basin may be planted with annual crops, or with a single tree or bush.



(a) (b)



Planted area
Run off collecting area

Irrigation systems

Irrigation vs. Rain-Fed Agriculture

There are two main ways that farmers and ranchers use agricultural water to cultivate crops:

- Rain-fed farming
- Irrigation

Rain-fed farming is the natural application of water to the soil through direct rainfall. Relying on rainfall is less likely to result in contamination of food products but is open to water shortages when rainfall is reduced. On the other hand, artificial applications of water increase the risk of contamination.

Irrigation is the artificial application of water to the soil through various systems of tubes, pumps, and sprays. Irrigation is usually used in areas where rainfall is irregular or dry times or drought is expected. There are many types of irrigation systems, in which water is supplied to the entire field uniformly. Irrigation water can come from groundwater, through springs or wells, surface water, through rivers, lakes, or reservoirs, or even other sources, such as treated wastewater or desalinated water. As a result, it is critical that farmers protect their agricultural water source to minimize the potential for contamination. As with any groundwater removal, users of irrigation water need to be careful in not pumping groundwater out of an aquifer faster than it is being recharged.

Types of Irrigation Systems

There are many different types of irrigation systems, depending on how the water is distributed throughout the field. Some common types of irrigation systems include:

Surface irrigation

- ✓ Water is distributed over and across land by gravity, no mechanical pump involved.

- ✓ Localized irrigation; Water is distributed under low pressure, through a piped network and applied to each plant.
- ✓ Drip irrigation; A type of localized irrigation in which drops of water are delivered at or near the root of plants. In this type of irrigation, evaporation and runoff are minimized.
- ✓ Sprinkler irrigation; Water is distributed by overhead high-pressure sprinklers or guns from a central location in the field or from sprinklers on moving platforms.
- ✓ **Center pivot irrigation**; Water is distributed by a system of sprinklers that move on wheeled towers in a circular pattern. This system is common in flat areas of the United States.
- ✓ **Lateral move irrigation**; Water is distributed through a series of pipes, each with a wheel and a set of sprinklers, which are rotated either by hand or with a purpose-built mechanism. The sprinklers move a certain distance across the field and then need to have the water hose reconnected for the next distance. This system tends to be less expensive but requires more labor than others.
- ✓ **Sub-irrigation**; Water is distributed across land by raising the water table, through a system of pumping stations, canals, gates, and ditches. This type of irrigation is most effective in areas with high water tables.
- ✓ **Manual irrigation**; Water is distributed across land through manual labor and watering cans. This system is very labor intensive.
- ✓ **Rodkhohi system; Pakistan** covers about 79.61 million hectares of land, of which about 40% is suitable for agriculture and forestry.
- ✓ Out of total cultivated area of about 21.1 Mha, 16.2 Mha are irrigated through canal and groundwater resources, while the remaining 4.9 Mha (about 23.22% of the total cultivated land) are rainfed. The area commanded by hill torrents has been estimated as 2.34 Mha with an estimated total catchments area of about 40.12 Mha.
- ✓ Hill torrents in various parts of the country drain about 55% of the total area of the Pakistan. There are about 14 hill torrent sites in Pakistan with an average annual run-off of 1.5 Mha-m (12.15 MAF).

- ✓ Currently, the major part of these flows goes wasted because of insufficient hill torrent management facilities.
- ✓ NESPAK (1995) reported that proper management of hill torrents can significantly enhance agricultural production of the country. Rod Kohi irrigation system is practiced in various parts of the world.
- ✓ In Pakistan, it is practiced mainly in Hazara, Bannu, D. I. Khan, Karak, Kohat, D.G. Khan, Kachhi Basin, Khirther Range, Karachi Area, Sehwan and Petaro Area. Rod Kohi system of irrigation is the least known and the most unattended among the irrigation systems in Pakistan, and therefore, remains undeveloped.
- ✓ The major reasons include poor resources of Rod Kohi farmers, ignorance of farmers to advanced irrigation practices, excessively high flows, non-existence of control structures, lack of scientific investigations about the farmers' irrigation practices and performance evaluation.
- ✓ The prevailing Rod Kohi irrigation practices are traditional in nature and provide subsistence based livelihood to the majority of the farmers in the area. The cultivated crops mostly, included wheat, sorghum, pearl millet, grams and oilseed to feed the human beings and their cattle.
- ✓ Production oriented agriculture is not practiced and therefore, crop yields are quite low. Consequently, the average yields per unit area under Rod Kohi irrigation system are far below the national average.
- ✓ The financial condition of the farmers of the Rod Kohi commanded area is generally very poor. They have learnt to live with little basic necessities of life. The Rod Kohi irrigated regions generally lack facilities of roads, schools, hospital, electricity and safe drinking water.
- ✓ The residents usually depend on water storage to meet their domestic water requirements. When a hill torrent comes, its water is stored in deep depressions.
- ✓ The rate of infiltration into the soil is very low because of the presence of hard layer called "Mat" on the soil surface. These kinds of reservoirs are very far from most of the villages and the people have to fetch water daily for drinking and other purposes from these reservoirs.

- ✓ These are open to atmosphere and all the birds and animals such as dogs, donkeys, horses, goats, sheep, cows and buffaloes also drink water from these reservoirs. Now the government has installed pumps for drinking water in some of the villages.
- ✓ No doubt, the efficient conveyance of flows and development of control structures at the main system is a pre-requisite to achieve the goal of efficiently managing Rod Kohi irrigation at tertiary level, the farmer's irrigation practices at field level play an important role in managing the available water resources at the farm.
- ✓ Water losses, at the farm and field levels due to inefficient irrigation management, result in lower crop yield and water productivity. Unfortunately very little or no significant work has been done to evaluate the farmers' irrigation practices and improve the tertiary component of Rod Kohi system.
- ✓ Improving management and crop yields under the Rod Kohi irrigation system requires information regarding the existing irrigation practices of the Rod Kohi farmers. Investigations regarding the irrigation practices of Rod Kohi farmers and their consequences on the use of this precious water resource were carried out in the present study.

Bulk density

Measuring Bulk Density and Soil Moisture

Materials Needed to Measure Bulk Density

- ✓ 3-inch diameter aluminum ring
- ✓ Wood block or plastic insertion cap
- ✓ Rubber mallet or weight
- ✓ Folding trowel
- ✓ Flat-bladed knife
- ✓ Sealable bags and marker pen
- ✓ Scale (1 g precision)
- ✓ 1/8 cup (29.5 mL) measuring scoop
- ✓ Ceramic coffee cup or paper plate
- ✓ 18-inch metal rod, probe or spade (to check for compaction zone)
- ✓ Access to a microwave oven Considerations
- ✓ Bulk density can be measured at the soil surface and/or compacted tillage zone.
- ✓ Bulk density samples should be taken in same location as infiltration and respiration tests. It may be possible to use the infiltration test sample.
- ✓ For sticky clay soils a little penetrating oil applied to the ring makes it easier to remove soil.
- ✓ Step by Step Procedure 1. Carefully clear all residue then drive ring to a depth of 3 inches (2 inches from top;) with small mallet or weight and block of wood or plastic cap (same process as used for infiltration test).
- ✓ Remove ring by cutting around the outside edge with a small 4-inch serrated butter knife and using the small folding trowel underneath of it and carefully lift the ring out preventing loss of soil by holding trowel under it.
- ✓ Remove excess soil from the bottom of cylinder with serrated butter knife. Remove excess soil from bottom of ring.
- ✓ Place sample in plastic sealable bag and label it.
- ✓ Weigh sample in bag and record its weight.

- ✓ Weigh an identical clean, empty plastic bag and record its weight .
- ✓ 7. Weigh empty cup or paper plate to be used in step 8 and record its weight.
- ✓ 8. Either extract a subsample shown in steps 8-10, or dry and weigh entire sample to determine water content and dry soil weight: a. Mix sample thoroughly in the bag by kneading it with your fingers. b. Take a 1/8-cup level scoop of loose soil (not packed down) from plastic bag and place it in the cup weighed in step 7 (use more than one scoop to increase accuracy).
- ✓ Weigh moist subsample in cup before drying and record.
- ✓ Place cup containing subsample in a micro wave and dry for two or more four-minute cycles at medium power.
- ✓ To determine if soil is dry, weigh subsample in cup/plate after each 4-minute cycle. When the weight no longer changes after a drying cycle, it is dry, and record its weight.

Bulk Density Calculation (g/cm3)

Bulk Density = Dry wt of bulk sample ÷ volume of soil core Example 1: bulk density = 385g ÷ 321 cm3 = 1.20 g/cm

Soil Water Content Using a Subsample (g/g) Example 1 (e - g)/(g) (weight of moist soil - weight of oven dry soil) (34g – 27g) = 0.259 g of water/g of soil Weight of oven dry soil

Calculating the Dry Weight of the Bulk Sample Based on Soil Water Content of Subsample (grams) Dry wt of soil bulk sample = [Wt of field moist soil + bag (grams) - Wt of bag (grams)] [1 + Soil Water content (g/g)]

Moisture contents

When deciding what proportions of various materials to mix together in making compost, the moisture of the resulting mixture is one of the critical factors to consider. The following steps outline how to design your intital mix so that it will have a suitable moisture level for optimal composting.

In the composting industry, the convention is to report moisture content on a wet (or total weight) basis, as the formulas below indicate.

1. Calculate the % moisture for each of the materials you plan to compost.
   a) Weigh a small container.
   b) Weigh 10 g of the material into the container.
   c) Dry the sample for 24 hours in a 105-110 degree C oven.
   d) Reweigh the sample, subtract the weight of the container, and determine the moisture content using the following equation:

   $M_n = ((W_w - W_d)/W_w) \times 100$
   in which:
   M_n = moisture content (%) of material n
   W_W = wet weight of the sample, and
   W_d = weight of the sample after drying.

   Suppose, for example, that you weigh 10 g of grass clippings (W_w) into a 4 g container and that after drying the container plus clippings weighs 6.3 g. Subtracting out the 4-g. container weight leaves 2.3 g as the dry weight (W_d) of your sample. Percent moisture would be:

   $M_n = ((W_w - W_d)/W_w) \times 100$
   $= ((10 - 2.3) / 10) \times 100$
   = 77% for the grass clippings