Soil-plant-water relationships

Irrigation Technology and Management Program | Management Technical Guide 4

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Summary

Irrigation water management is the process of applying the right amount of water at the right time to support plant growth while minimizing water, energy, and nutrient losses, and preserving soil quality. Effective irrigation keeps soil moisture within a range that avoids both water stress (too dry) and waterlogging (too wet).

To do this well, irrigators need to understand:

- How water moves into, through and out of the soil
- How climate influences soil moisture
- How much water different crops require for optimal growth at different crop stages

Knowing how to identify and find information about your soil and crop water needs is the first step in developing your irrigation water management plan.

Soils

Soil is a porous medium and is made up of four main components: minerals, organic matter, water and air. The typical composition is approximately 45% minerals, 25% water, 25% air and 5% organic matter, although this varies with climate, soil type and management activities such as tillage. Microorganisms make up only a small fraction by weight, but they play a critical role in nutrient cycling and soil structure.

Each component has a specific function for plant growth.

- The **mineral** component of the soil consists of particles of ***sand***, ***silt*** and ***clay***. The relative percentages of these soil particles give rise to the soil's texture.
- **Air** within the soil matrix provides oxygen for root and microbial respiration.
- **Organic matter** consists of decomposed and decomposing plants and animals. Organic matter has a high capacity to hold and supply the nutrients and water needed to support plant growth.

- **Microorganisms** are the primary decomposers of raw organic matter and are essential for nutrient cycling and overall soil health.

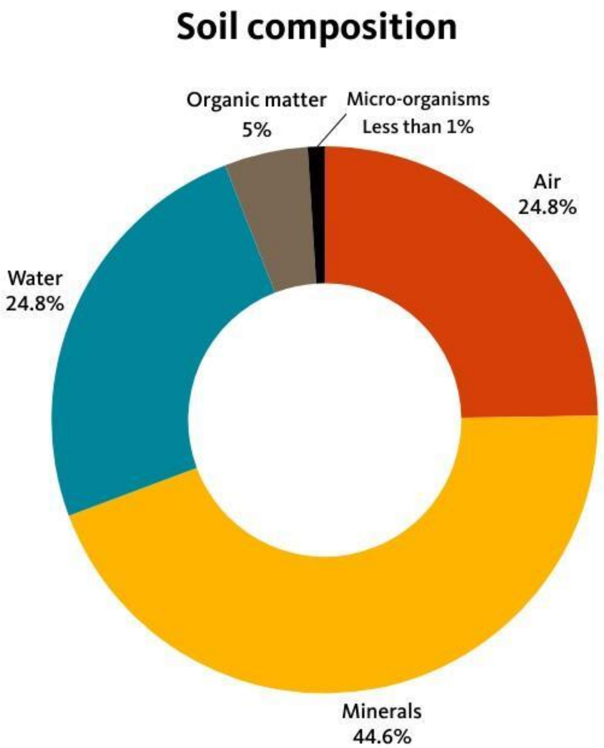


Figure 1. Soil components.

Credit: Adapted from Deschutes Soil and Water Conservation District

Table 1. Particle size

Particle	Diameter (mm)	Specific surface area (cm2/g)
Very coarse sand	2.0–1.0	11
Coarse sand	1.0–0.5	23
Medium sand	0.50–0.25	45
Fine sand	0.25–0.10	91
Very fine sand	0.10–0.05	277
Silt	0.05–0.002	454
Clay		8,000,000

From King et al., 2003

Soil texture

Soil texture affects many properties of the soil, such as infiltration (how quickly water enters the soil), permeability (soil's ability to permit water to flow through its pores), water-holding capacity and storage, aeration and nutrient retention.

- Sandy soils have large pore spaces, allowing water to enter and drain quickly.
- Clay soils have very small pores, causing water to move slowly but increasing water-holding capacity.
- Silt and loam soils fall in between, often providing a good balance of storage and drainage.

To determine the texture of your soil, conduct a simple field test using the texture-by-feel method (https://www.nrcs.usda.gov/sites/default/files/2022-10/texture_feel.pdf) along with the soil texture triangle (Figure 2). This simple field technique helps you estimate your soil's textural class based on the proportions of sand, silt, and clay.

Using the soil texture triangle

The U.S. Department of Agriculture soil texture triangle identifies 12 textural classes based on the percentage of sand, silt, and clay. Each side of the triangle represents one of these three particle types, with values ranging from 0% to 100%. Lines extending from each side show how the percentages intersect to define a soil's texture

- **Sand percentages** increase from right to left across the base of the triangle.
- **Clay percentages** increase upward along the left side.
- **Silt percentages** increase downward from the top right.

To find your soil's textural class, locate the percentage of each particle on the appropriate side of the triangle and trace the lines until they meet. The point where the three lines intersect is your soil's textural class.

Example: Using the textural triangle**,** a soil with 68% sand, 24% clay and 12% silt, where the three lines intersect corresponds to a sandy clay loam.

You can also determine the textural class by using the Natural Resource Conservation Service Soil Texture Calculator (Soil%20Texture%20Calculator). (https://www.nrcs.usda.gov/resources/education-and-teaching-materials/soil-texture-calculator)

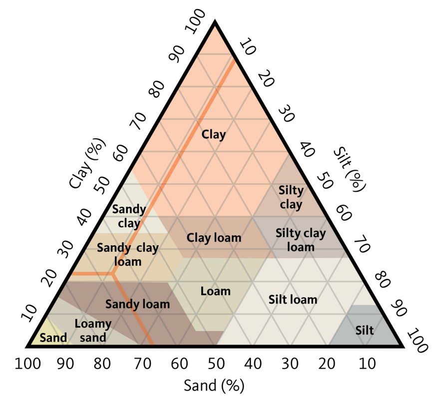


Figure 2. In this soil texture triangle, the spot where the three lines of a soil's components intersect is the textural class of the soil.

Photo: Soil Survey Division staff, 1994; modified by Oregon State University

Pore space, infiltration and permeability

Soil texture influences how water moves through and is stored within the soil profile (Figure 3A–C). Differences in the size and arrangement of soil particles create variations in pore space, infiltration rate, and water holding capacity — all of which determine how irrigation water should be applied.

Soil particle size

Soil particle size strongly influences how water moves through the soil profile, how water adsorbs (holds onto) the particle, and how much water can be stored for plant use.

Soil particles vary widely in size:

- Sand (0.05–2.0 mm) — largest particles
- Silt (0.002–0.05 mm) — intermediate
- Clay (less than 0.002 mm) — smallest particles (Table 1; Figure 3A)

Particles larger than sand, such as gravel (greater than 2mm in size), are considered coarse fragments and can strongly influence water movement by creating large pore spaces.

To visualize the size differences, consider the following animal-size analogy:

- Clay particles are like ants — extremely small and tightly packed.
- Silt particles are like butterflies — small but loosely arranged.

- Sand particles are like dogs — much larger and more separated.
- Gravel particles (if present) are like elephants — very large with wide gaps between them.

Coarse particles (sand, gravel) create larger spaces between particles, while fine particles (clay) pack closely together (Figure 3A).

Pore space

Pore space is the open area between soil particles (Figure 3C). These pores allow air and water to move through the soil.

- Sandy soils have the largest individual pore space, which allow rapid drainage and aeration
- Clay soils have the smallest pore space, which slows water movement but increases water-holding capacity.

Infiltration and permeability

Infiltration rates describe how quickly water enters and passes through the soil (Figure 3C).

Because pore spaces in sandy soils are large, water infiltrates and permeates the soil rapidly.

In clay soils, water enters and moves through the soil profile more slowly (Figure 3C).

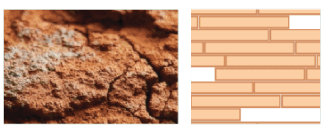
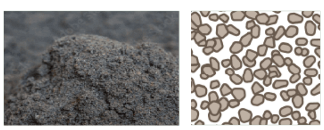
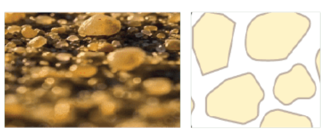
Soil type	Image and close-up	Particle size	Particle size compared to clay
Clay		Less than 0.002 mm	1x
Silt		0.002 mm–0.05 mm	10x
Sand		0.05–2 mm	1,000x
Gravel		2 mm–64 mm	10,000x

Figure 3A. Photos and close-ups of sand, silt, clay and gravel, showing differences in particle size as compared to clay. As particle size increases, pore size increases, allowing water to move faster through the soil.

Credit: © Oregon State University

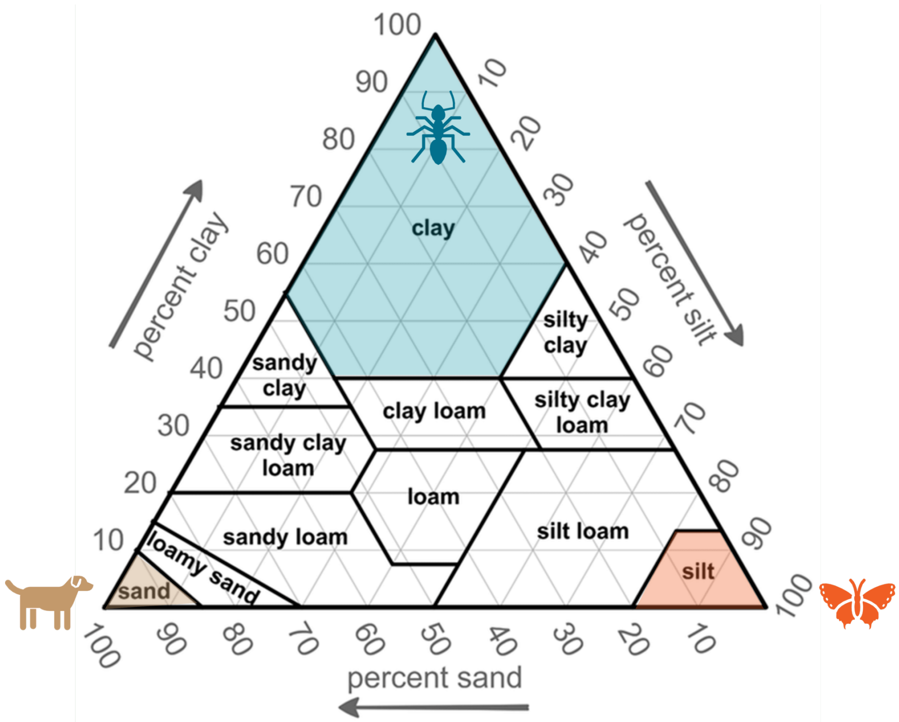


Figure 3B. A soil texture triangle and an animal-scale analogy illustrating relative particle sizes: clay (ant-sized), silt (butterfly) and sand (dog).

Porosity

Porosity refers to the total volume of pores compared to the total volume of the soil.

While individual pore sizes are smaller in clay soils compared to sandy soils, the overall volume of pores is greater in clay soils than in sandy soils, allowing clay soils to retain more water and nutrients (Figure 3D).

Important: These textural differences have direct implications for irrigation management. Coarse-textured (sandy) soils require more frequent irrigations with smaller applications, while fine-textured (clay) soils can be irrigated less often but with larger amounts per event to replenish the root zone.

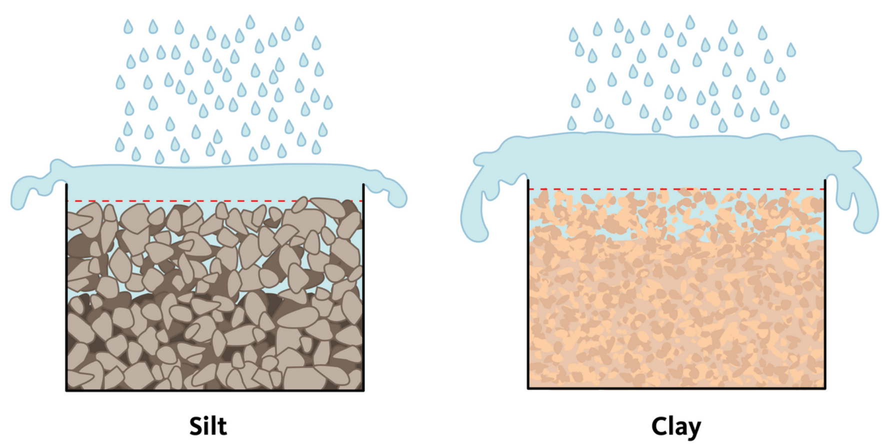


Figure 3C. Water infiltration patterns across soil textures. Sandy soils allow rapid infiltration, silt soils allow moderate infiltration, and clay soils show slow infiltration.

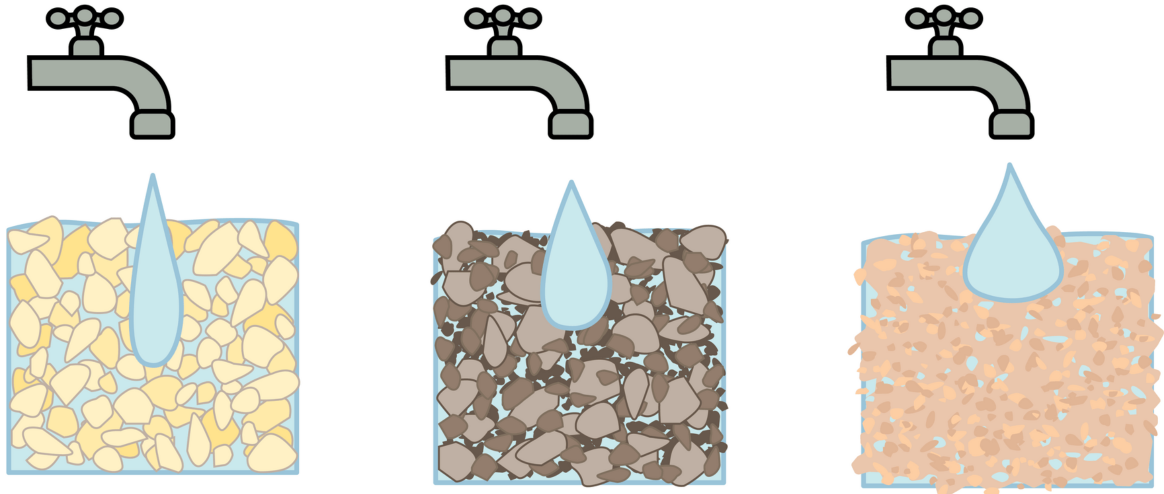


Figure 3D. Soil porosity and water retention differ among soil types. Sandy soils have large pores with low water holding capacity, while clay soils have small pores with high water retention.

Credit: Kellen Grist, © Oregon State University

Irrigation management implications

These textural differences directly influence irrigation strategies:

- Coarse-textured (sandy) soils require more frequent, smaller irrigation applications because water infiltrates rapidly and has low water-holding capacity, increasing the risk of deep percolation losses below the root zone.
- Fine-textured (clay) soils can be irrigated less frequently, but irrigation must be applied slowly (low application rate or multiple cycles) to prevent runoff and ensure water infiltrates into the root zone.

Available water capacity

When rainfall or irrigation water enters the soil, it fills the pore spaces and is held in different ways depending on soil texture and particle-water interactions (Figure 4). Soil water exists in three primary forms relevant to irrigation, according to the USDA National Engineering Handbook:

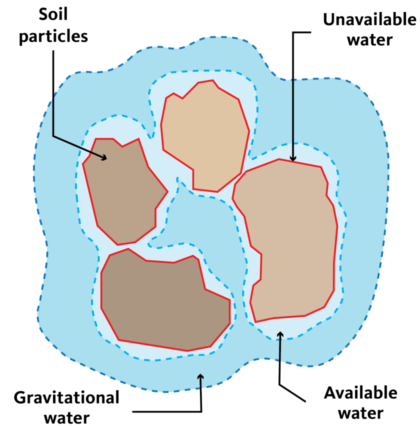


Figure 4. Water retention on soil particles.

Credit: Kellen Grist, © Oregon State University

1. Gravitational water

This is the water that fills all large soil pores immediately after irrigation or heavy rainfall when the soil is fully saturated.

- It drains downward through the soil profile under the force of gravity.
- It is not held by the soil matrix, so plants cannot use it.
- Drainage continues until only capillary-held water remains — this marks field capacity, or FC.

2. Capillary water

Capillary water is the plant-available water held in the soil after gravitational water drains.

- Capillary water is held in small and medium pores by capillary forces and surface tension.
- It moves in response to plant uptake, soil drying, and gradients in water tension (including upward movement during evaporation).
- Constitutes most of the water contributing to plant growth.

3. Hygroscopic water

Hygroscopic water forms a thin water film tightly adsorbed onto the surface of soil particles.

- It is held at very high soil-water tension.
- It cannot be extracted by plants, even under severe stress.
- Hygroscopic water persists even when the soil appears dry.

Soil-water tension (also called *matric potential*) describes how tightly water is held by soil particles — the drier the soil becomes, the higher the tension and the harder it is for plants to extract water.

Field capacity and permanent wilting point

After gravitational water drains, the soil reaches *field capacity* — the point at which the remaining water is held by capillary forces and can be easily extracted by plants. As plants continue to use water, soil-water tension increases.

Soil texture strongly influences how fast this tension increases. Although sandy and clayey soils may contain similar total amounts of water at a given time, clay soils retain a larger portion of that water in small pores and on particle surfaces, holding it at much higher tension. This makes it more difficult for plant roots to extract. In contrast, sandy soils hold water at lower tension, allowing plants to extract water more easily. But sands also store far less plant-available water because they drain quickly.

As soil continues to dry, plant-available water decreases and soil water tension (matric potential) increases. Eventually, the remaining water is held so tightly to soil particles that roots can no longer extract it, even though moisture is present. This point is known as *permanent wilting point*, where plants begin to wilt irreversibly due to insufficient available water.

Available water capacity

Available water capacity, or AWC, is sometimes called soil water-holding capacity. AWC is the water held in the soil between field capacity and permanent wilting point.

- This is the *plant-available* portion of soil water.
- AWC varies by soil texture:
  - Sands: low AWC (large pores, low retention).
  - Loams: moderate AWC.
  - Clays: high total water but high tension — only a portion is available.

Example

If a soil's AWC is 0.14 in/in, then a 24-inch rooting depth can store:

$$AWS = AWC * Soil\ depth$$

$$AWS = 0.14 \frac{in}{in} * 24\ in$$

$$\boldsymbol{AWS = 3.36\ inches}$$

Credit: © Oregon State University

Available water storage

Available water storage, or AWS, is the total amount of plant-available water a soil can hold within a specific depth.

Maximum allowable depletion

To maintain optimal plant growth, irrigators should know how much water can be safely depleted from the soil before the crop experiences stress, impacting growth and yield. Maximum allowable depletion, or MAD, expresses the fraction of total available water that can be depleted before a crop begins to experience yield-reducing stress.

MAD percentages are available for many crop types and growth stages. Once you know the AWC, AWS and the crops' MAD, you can determine how much water is needed to refill the soil profile back to field capacity. Typical MAD values can be found in Crop Evapotranspiration: Guidelines for Computing Crop Water Requirements. (https://www.fao.org/3/x0490e/x0490e00.htm)

Know the soils on your property

The Web Soil Survey (https://casoilresource.lawr.ucdavis.edu/soilweb-apps) is a valuable tool for identifying and understanding the soils on your property. By entering your farm address or site coordinates, you can generate a soil map that identifies your soil map units and provides general descriptions such as soil depth, texture, permeability and available water capacity. Additional information including soil moisture content at field capacity and at permanent wilting point is available under the "Soil Properties" tab.

For more information and guidance in using the web soil survey, contact your local Natural Resource Conservation Service office.

Resources

- Map soils on your property (https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx)
- Step-by-step guide to the Web Soil Survey (https://www.deschutesswcd.org/wp-content/uploads/2024/09/1-soil-survey-step-by-step.pdf)
- Video demonstration (https://www.youtube.com/watch?v=tX_eRTIw1kY)

Plants

Understanding the soil is only part of irrigation water management — you must also understand how your crop grows and how it responds to different levels of soil water availability, including when too much or not enough water is applied. Crops have different soil water requirements. Having enough water in the soil depends on several factors:

- Weather conditions (solar radiation, humidity, temperature, wind)
- Soil type and texture
- Available water capacity
- Infiltration rate
- Permeability
- Crop characteristics such as rooting depth, growth stage and drought tolerance

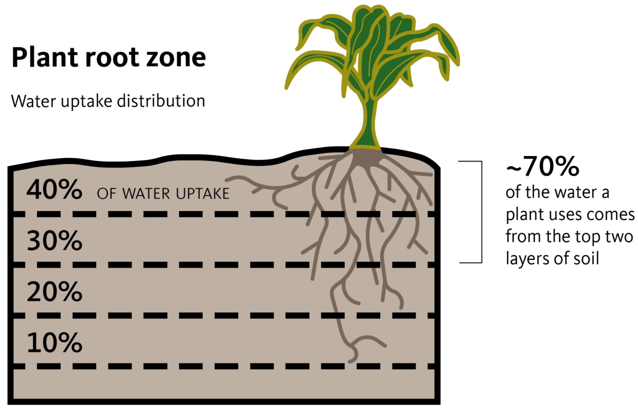


Figure 5. Effective rooting depth.

Credit: Kellen Grist, © Oregon State University. Adapted from National Engineering Handbook, 1997.

Knowing the effective root depth of your crop provides information on how much water to manage in the soil profile for optimum plant growth. The effective root zone is typically the upper half of the maximum rooting depth, where roughly 70% of root water uptake occurs (Figure 5). A deep-rooted crop will have a greater effective root depth than a crop with a shallow root system.

Why this matters: Understanding how plants access and use soil water helps irrigators avoid both water stress and overirrigation by matching irrigation frequency to actual crop demand.

Together, these factors determine how quickly the soil profile dries and how often irrigation will be required.

Evapotranspiration

Evapotranspiration, or ET — sometimes called *crop water use* — is the combined loss of water from the soil and plant surfaces.

Evapotranspiration (ET) = Evaporation + Transpiration (Figure 6)

Evaporation

Evaporation occurs when water at the soil surface or on plant surfaces vaporizes and returns to the atmosphere. This water does not contribute to plant growth because it never enters the plant root system.

Transpiration

Transpiration is the process by which water absorbed by plant roots moves through the plant and evaporates from leaf surfaces.

Plants transpire water primarily through *stomata*, small openings on the underside of leaves (Figure 7).

When the stomata are open:

- Water vapor (H_2O) exits the leaf into the atmosphere.
- Carbon dioxide (CO_2) enters the leaf for photosynthesis.
- Oxygen (O_2) is released as a byproduct.

Because ET determines how fast soil water is depleted — through soil evaporation and plant transpiration — it helps irrigators understand how quickly the soil reservoir (AWC/AWS) is being drawn down between irrigations. This helps irrigators determine both when the next irrigation should occur and how frequently irrigations will be needed during different crop growth stages.

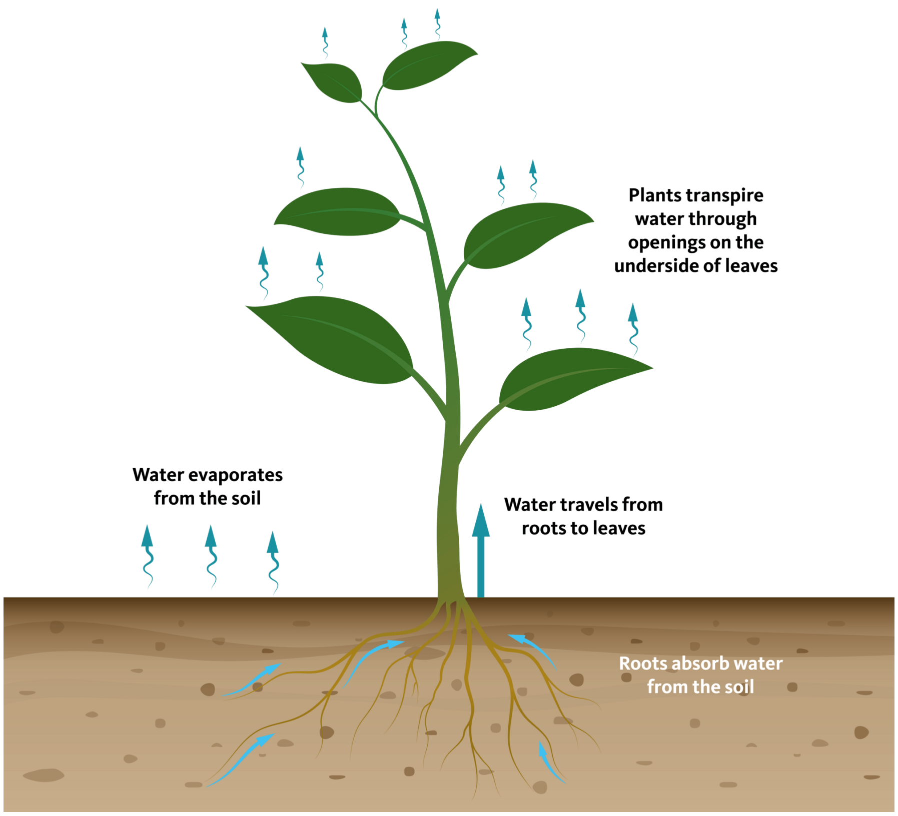


Figure 6. Evapotranspiration is the combination of two main processes: evaporation from the soil and plant surfaces, and transpiration from the plants.

Credit: stock.adobe.com

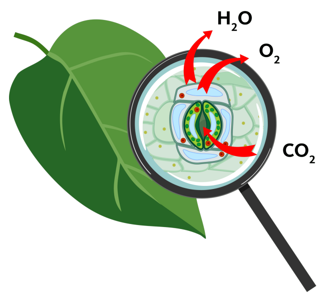


Figure 7. Small openings on the underside of leaves called stomata release water vapor.

Credit: stock.adobe.com

Weather networks: AgriMet

One way to estimate ET is through on-farm weather stations or nearby **AgriMet** (https://www.usbr.gov/pn/agrimet/) stations. AgriMet is an automated agricultural weather network with stations across the Northwest operated by the U.S. Bureau of Reclamation with support from USDA Agricultural Research Service, the USDA National Resource Conservation Service, land grant universities, the Extension Service, electric utilities and other partners.

AgriMet weather stations measure:

- Air temperature
- Relative humidity
- Precipitation

- Wind speed and direction
- Solar radiation
- Soil temperature
- ET
- Other weather parameters

AgriMet provides daily and monthly crop water use estimates for the current and past seasons. AgriMet stations provide valuable data for forecasting and scheduling irrigation.

Table 2. Available water capacity for various soil textures

Textural class	Available water capacity (inches per foot of depth)
Coarse sand	0.25–0.75
Fine sand	0.75–1.00
Loamy sand	1.00–1.20
Sandy loam	1.20–1.40
Fine sandy loam	1.40–2.00
Silt loam	2.00–2.50
Silty clay loam	1.80–2.00
Silty clay	1.50–1.70
Clay	1.20–1.50

Table 3. Effective rooting depth and maximum allowable depletion

Crop (established)	Effective rooting depth (feet)	Allowable depletion (%)
Alfalfa	4.0	60
Beans	2.0	50
Corn	3.0	50
Grapes	3.0	65
Orchard	3.0	50–65
Potato	2.0	30–40
Grass pasture/hay	2.0	60
Small grains	3.0	50

From: Noble Research Institute, 2013.

How soil, plant and water relationships relate to irrigation water management

Soil acts as a reservoir that stores water and nutrients for plant growth. To manage when and how much water to apply, it is critical to know:

- How much water your soil can hold (AWC).
- How deep the crop roots can access that water (effective root depth).
- Your crop water needs.
- How much water has been depleted since the last irrigation or rainfall event (ET or soil moisture data).

Determining these elements will help you better manage and apply irrigation water.

Example: Determining irrigation depth for grass hay on sandy loam soil

1. Determine soil texture and AWC

Identify the dominant soil type in your field and look up the AWC for that soil texture. You can find these values in Table 2 or by using the Web Soil Survey (https://websoilsurvey.nrcs.usda.gov/app/). For this example, we assume the soil is *sandy loam*, which has an AWC of 1.4 inches per foot.

2. Find the crop's effective rooting depth

Use published values or Table 3 to determine the effective rooting depth for the crop. For pasture/grass hay, the typical effective rooting depth is 2 feet.

3. Calculate total available water storage

AWS represents the total amount of plant available water stored within the effective rooting depth at field capacity.

$$AWS = AWC * Effective\ rooting\ depth$$

$$AWS = 1.4\frac{in}{ft} * 2\ ft$$

$$\boldsymbol{AWS = 2.8\ inches}$$

Credit: © Oregon State University

4. Apply maximum allowable depletion (MAD)

The crop's MAD determines the percentage of the available water the crop can use before experiencing stress.

For grass hay, MAD = 60% (Table 3)

*MAD = AWC*MAD*

*MAD = 2.8in*0.60*

MAD = 1.7 inches

The crop can use 1.7 inches of water before irrigation is required.

This 1.7 inches represents the maximum amount of water that can be depleted from the soil before the next irrigation should be applied to avoid stress and yield reduction.

Evaluate your soil-plant-water relationships

Assess your property and knowledge about how soil, plants and water work together.

Download the worksheets (https://oregonstate.box.com/s/q8iv8rmatvaidfekarci9ffbb2brz4mv)

References and resources

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Related publications

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Irrigation Technology and Management Program Management Technical Guides

(https://extension.oregonstate.edu/collection/irrigation-technology-management-program-management-technical-guides)

Water is one of the most limited resources in agriculture. Across the Western United States, drought, rising energy costs and environmental concerns are changing how irrigation must be managed. This 10-part curriculum gives you the tools you need to save water, energy and money.

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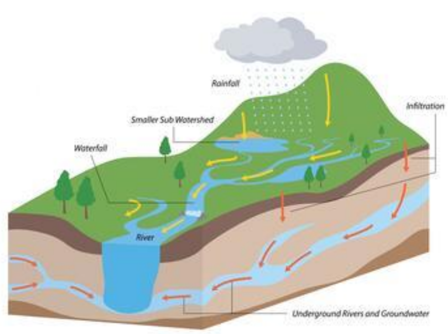

Credit: USDA Natural Resources Conservation Service (Cropped from original)

Irrigation and water quality

(https://extension.oregonstate.edu/catalog/em-9522-irrigation-water-quality)

Monitoring the quality of irrigation water is vital for the health of the environment and the ability of the soil to produce abundant crops. It also helps growers comply with state and federal laws.

Abigail Tomasek, María Isabel Zamora Re, Todd M. Peplin | Apr 2026 | OSU EXTENSION CATALOG Peer reviewed (Orange level) (https://extension.oregonstate.edu/peer-review-guidelines)

Credit: Ruud Morijn, stock.adobe.com (Cropped from original)

Irrigation water: How it's delivered, how it's measured

(https://extension.oregonstate.edu/catalog/em-9612-irrigation-water-how-its-delivered-how-its-measured)

To ensure your crop gets enough irrigation water, you need to be able to understand how water is delivered to plants and how to measure it. Discover methods that can help you achieve optimal plant growth.

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