

The Soil-Water Connection: Managing Moisture for Better Crops

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Introduction

Soil and water form the foundation of all agricultural production. The ability of soil to capture, store, and supply water directly determines how well crops grow, resist stress, and produce yield. When soil moisture is balanced, plants receive the water and nutrients they need for healthy growth. However, too little moisture causes drought stress, while excess water limits aeration and root development. As climate variability increases and water resources become more limited (Pinke *et al.*, 2022), understanding the soil–water relationship has become essential for farmers, researchers, and extension workers. Effective soil moisture management not only improves crop performance but also enhances water-use efficiency, making it a key strategy for sustainable agriculture.

Why Soil Water Matters

Water in the soil performs three critical functions simultaneously: it supplies plants with water lost through transpiration, dissolves and transports nutrients to roots, and shapes soil physical structure and biological activity. When soil moisture remains within a crop's optimal range, photosynthesis and nutrient uptake proceed efficiently; when moisture is too low or too high, growth is constrained and yields decline. Understanding how much water a soil can store and when that water is available to plants is therefore central to crop management (Allen *et al.*, 1998).

The Basics: Retention, Infiltration, and Movement

Three fundamental physical processes determine how water behaves in soil.

Soil Water Retention

Different soils retain different amounts of water at varying tensions. The relationship between soil water content and matric potential, represented by the soil-water retention curve, defines key thresholds such as field capacity and permanent wilting point. Mathematical formulations such as the van Genuchten model are widely used to describe this relationship and predict plant-available water (Ghanbarian-Alavijeh *et al.*, 2010).

Infiltration and Percolation

Water must first infiltrate the soil surface following rainfall or irrigation. Infiltration rates depend strongly on soil texture and structure: sandy soils allow rapid infiltration but retain less water, while clay soils infiltrate more slowly yet store more water. Surface crusting and compaction can severely reduce infiltration, whereas good aggregation and organic matter improve water entry and reduce runoff (USDA NRCS, Infiltration Fact Sheet).

Hydraulic Movement and Redistribution

Once water enters the soil, it moves through gravity and capillary forces. In coarse-textured soils, water drains rapidly downward, whereas in fine-textured soils capillary forces redistribute moisture laterally and upward. Root systems and soil heterogeneity further modify these patterns, making localized monitoring and management essential.

How Much Water Do Crops Need?

Crop water requirements are commonly estimated using evapotranspiration (ET), which combines evaporation from the soil surface and transpiration from plants, along with crop coefficients that adjust reference ET to specific crops and growth stages. International guidelines such as FAO Irrigation and Drainage Paper No. 56 provide standardized methods for estimating ET and converting it into irrigation schedules (Allen *et al.*, 1998; FAO, 1977). Proper irrigation planning aligns water supply with crop demand and minimizes waste.

Practical Soil Moisture Management Techniques

No single approach suits all farms, but several well-established practices help maintain soil moisture within an optimal range.

Improve Soil Organic Matter

Incorporating composts, manures, and cover crops increases soil organic matter, improving aggregation and water-holding capacity. Higher organic matter allows soils to store more water during wet periods and release it slowly during dry spells, enhancing crop resilience (Pinke *et al.*, 2022).

Mulching and Surface Covers

Mulches and crop residues reduce evaporation, moderate soil temperature, and protect surface structure. These practices are especially beneficial in semi-arid and irrigated systems, where evaporation losses can be substantial (FAO, 1977).

Conservation Tillage and Reduced Disturbance

Reduced tillage preserves soil pore networks and surface residues that enhance infiltration and moisture retention. Long-term studies show that conservation tillage systems often maintain higher soil moisture than conventional tillage (USDA NRCS).

Irrigation Scheduling and Matching Method to Need

Modern irrigation management emphasizes scheduling based on crop growth stage, recent weather conditions, and soil moisture status rather than fixed calendars. Both ET-based scheduling and soil moisture-based scheduling can substantially improve water productivity when properly implemented (Allen *et al.*, 1998; Ebstu *et al.*, 2025; Kumar *et al.*, 2025).

Deficit Irrigation and Stage-Targeted Watering

For some crops, applying less than full water requirements during non-critical growth stages while ensuring adequate water during sensitive stages such as flowering can conserve water without major yield penalties. This strategy requires detailed knowledge of crop sensitivity (FAO, 1977; Allen *et al.*, 1998).

Physical Soil Amendments and Structure Management

Amendments such as gypsum improve infiltration in sodic soils, while deep ripping or subsoiling can alleviate compaction. Raised beds and furrows help direct water into the active root zone, increasing irrigation efficiency (USDA NRCS).

Technology: Sensors, Models, and Precision Irrigation

Soil moisture monitoring tools now range from simple tensiometers to capacitance probes and wireless IoT-based sensor networks. These technologies allow real-time tracking of soil moisture and enable automated or decision-supported irrigation. Recent reviews demonstrate that sensor-based irrigation scheduling often outperforms calendar-based approaches in terms of water savings and yield stability, particularly when sensors are calibrated to local soil conditions (Ebstu *et al.*, 2025; Kumar *et al.*, 2025).

Decision-support models and smartphone applications that integrate weather data, crop coefficients, and soil properties are increasingly accessible to farmers and extension systems, translating measurements into actionable irrigation advice.

Soil Texture and Crop Selection: Work with What You Have

Soil texture imposes physical limits on water management. Sandy soils require frequent, small irrigations and benefit greatly from organic matter additions, whereas clay soils require careful management to prevent surface sealing and poor drainage. Matching crop species and varieties to soil water dynamics is a practical and cost-effective strategy (FAO, 1977; Allen *et al.*, 1998).

The Yield Connection: How Soil Moisture Translates to Production

Research consistently shows a strong, often nonlinear relationship between soil moisture and crop yield. Water deficits during sensitive growth stages can sharply reduce yields, whereas modest deficits during tolerant stages may have minimal impact. Improved irrigation timing, moisture-conserving soil practices, and crop varieties adapted to local moisture regimes increase water productivity, defined as yield per unit of water used (Pinke *et al.*, 2022).

Climate Change and Uncertainty: Why Soil Water Resilience Matters

As rainfall variability and extreme events increase, soils that store and gradually release water provide critical buffering against droughts and intense rainfall (Pinke *et al.*, 2022). Building soil resilience through organic matter enhancement, improved structure, and surface protection is therefore a climate-smart investment that supports both short-term productivity and long-term sustainability.

Practical Checklist for Farmers and Extension Workers

- ❖ Know your soil through texture and organic matter testing to estimate available water capacity.
- ❖ Time irrigation to crop growth stages, avoiding stress during flowering and fruit set.
- ❖ Build soil organic matter with cover crops and composts.
- ❖ Protect the soil surface with mulches and residues.
- ❖ Match irrigation method and frequency to soil texture.
- ❖ Use FAO guidelines and local extension advice, and calibrate sensors for local conditions.

Conclusion

The soil–water connection is simple in principle but complex in practice. Small improvements—such as increasing organic matter, adopting sensor-based irrigation, or refining irrigation timing—can deliver substantial gains in yield and water savings. Farmers who understand their soils and integrate traditional knowledge with modern monitoring tools achieve both higher productivity and more efficient water use. In an era of growing water scarcity and

climate uncertainty, effective soil moisture management is both sound agronomy and responsible stewardship.

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