

Soil Water Conservation for Enhancing Nutrient Use Efficiency

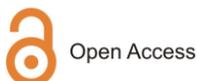
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Open Access

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Available online at
www.sunshineagriculture.vitalbiotech.org

Article History

Received: 5. 1.2026

Revised: 10. 1.2026

Accepted: 15. 1.2026

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INTRODUCTION

Agriculture depends heavily on two vital resources: water and nutrients. While fertilizers supply essential nutrients to crops, their effectiveness largely depends on adequate soil moisture. Nutrient Use Efficiency (NUE) refers to the proportion of applied nutrients that is actually taken up and utilized by plants. In many developing countries, NUE remains low due to poor water management, soil degradation, and improper agronomic practices.

Soil water conservation is the process of managing soil to maintain optimum moisture conditions for crop growth. It helps in improving nutrient availability, reducing nutrient losses, enhancing microbial activity, and promoting better root development. With increasing climate variability, frequent droughts, and declining water resources, conserving soil moisture has become a key strategy for sustainable agriculture.



Source: <https://vlsci.com/blog/water-conservation-in-agriculture>

2. Relationship Between Soil Water and Nutrient Use Efficiency

2.1 Role of Soil Moisture in Nutrient Availability

Soil water acts as a medium for nutrient transport from soil to plant roots. Nutrients move toward roots by:

- **Mass flow** (nitrate, calcium, magnesium, sulfur)
- **Diffusion** (phosphorus, potassium, zinc, iron)
- **Root interception**

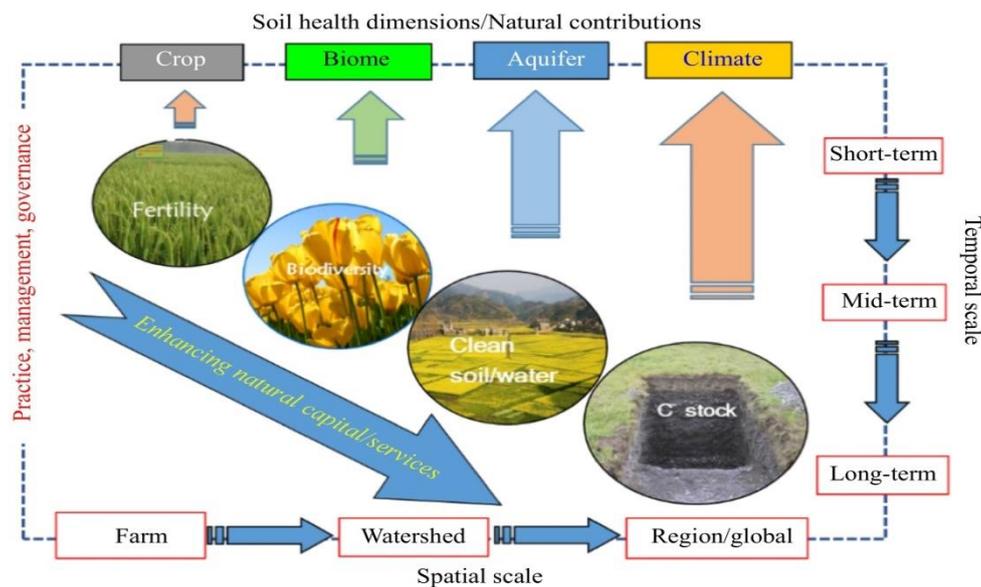
Adequate soil moisture enhances these processes, whereas moisture stress limits nutrient mobility and reduces nutrient uptake.

2.2 Effect of Water Stress on Nutrient Uptake

Under drought conditions, soil moisture becomes insufficient to support normal physiological and biological processes in the soil–plant system. Restricted root growth limits the exploration of soil volume, thereby reducing access to available nutrients. Nutrient diffusion toward plant roots declines due to reduced soil water films. Microbial activity responsible for nutrient mineralization is suppressed, resulting in lower availability of nitrogen and other nutrients. Consequently, crops exhibit nutrient deficiency symptoms even when fertilizers are adequately applied.

2.3 Nutrient Losses Under Poor Water Management

Excess or poorly managed irrigation significantly increases nutrient losses from agricultural soils. Highly mobile nutrients such as nitrogen and potassium are easily leached beyond the root zone, reducing their availability to crops and contaminating groundwater. Phosphorus is mainly lost through surface runoff along with soil particles, especially under heavy rainfall or over-irrigation. Waterlogged conditions promote denitrification, where nitrate is converted into gaseous forms and lost to the atmosphere. Additionally, soil erosion removes nutrient-rich topsoil, further reducing soil fertility. Therefore, balanced water management is essential for maximizing fertilizer benefits.



Source: <https://www.maxapress.com/article>

3. Soil Water Conservation Techniques for Improving NUE

3.1 Mulching

Mulching involves covering the soil surface with organic or inorganic materials to conserve moisture and improve soil conditions. It reduces evaporation losses, maintains favorable soil temperature, and protects the soil from erosion, thereby conserving nutrient-rich topsoil. Mulching also enhances microbial activity, which supports nutrient mineralization and improves soil fertility. As a result, fertilizer use efficiency is significantly increased. Common types of mulch include crop residues such as

straw and stubble, organic mulches like compost and dry leaves, and plastic mulch widely used in vegetable cultivation. Residue mulching, in particular, promotes nitrogen mineralization and improves phosphorus availability to crops.

3.2 Conservation Tillage

Conservation tillage involves minimal soil disturbance while retaining crop residues on the soil surface to protect and improve soil health. This practice enhances soil structure, increases organic matter content, and improves water infiltration, thereby reducing surface runoff and nutrient losses. Crop residues act as a protective cover that conserves soil moisture and supports

beneficial microbial activity, leading to gradual and sustained nutrient release. Common conservation tillage practices include zero tillage, minimum tillage, and strip tillage. These systems significantly improve nutrient use efficiency by maintaining favorable moisture conditions and improving nutrient retention in the root zone for better crop uptake.

3.3 Contour Farming and Terracing

On sloping lands, uncontrolled runoff leads to severe loss of soil and nutrients, reducing crop productivity. Contour farming involves performing field operations across the slope rather than up and down, which slows down runoff velocity and enhances water infiltration into the soil. This helps in conserving moisture and reducing nutrient losses. Terracing converts steep slopes into step-like structures, effectively controlling erosion and allowing water to be retained in the root zone. By minimizing soil and nutrient displacement, both practices improve nutrient availability and are highly effective for sustainable crop production in rainfed hilly regions.

3.4 Cover Cropping and Crop Rotation

Cover crops are grown during fallow periods to protect the soil from erosion and nutrient losses while improving soil health. They help prevent nutrient leaching, increase soil organic matter, and enhance soil structure, which improves moisture retention. Leguminous cover crops such as cowpea and clover fix atmospheric nitrogen, thereby enriching soil fertility. Mustard is also commonly used as green manure to improve nutrient availability. Crop rotation further enhances nutrient cycling, breaks pest and disease cycles, and improves soil water-holding capacity. Together, these practices create favorable soil moisture and nutrient conditions, leading to improved nutrient use efficiency and sustainable crop productivity.

3.5 Organic Matter Management

Soils rich in organic matter have better water-holding capacity, improved nutrient retention due to higher cation exchange capacity (CEC), and greater populations of beneficial microorganisms. These microbes play an

important role in nutrient cycling and mineralization, making nutrients more available to crops. Organic matter management practices include the application of farmyard manure (FYM), compost addition, green manuring, and biochar incorporation. These inputs improve soil structure, enhance moisture conservation, and reduce nutrient losses. Organic matter also serves as a slow-release source of nutrients, ensuring a continuous supply to plants and significantly improving nutrient use efficiency under both irrigated and rainfed conditions.

3.6 Efficient Irrigation Management

Irrigation methods have a strong influence on nutrient use efficiency by controlling soil moisture in the root zone. Micro-irrigation systems such as drip and sprinkler irrigation supply water in a controlled and uniform manner, which reduces nutrient leaching and surface runoff. These systems help maintain optimal soil moisture conditions, promoting better root activity and nutrient absorption. An additional advantage is fertigation, where fertilizers are applied along with irrigation water, ensuring precise nutrient delivery. Proper irrigation scheduling based on crop growth stages and soil moisture sensor data further synchronizes water and nutrient supply, resulting in significantly improved nutrient uptake efficiency and reduced fertilizer losses.

4. Integrated Soil–Water–Nutrient Management Approach

Maximum benefit is achieved when soil water conservation is integrated with nutrient management.

4. Integrated Soil–Water–Nutrient Management Approach

4.1 Site-Specific Nutrient Management

Site-specific nutrient management focuses on matching fertilizer doses with existing soil moisture and nutrient status of the field. When fertilizers are applied under optimum moisture conditions, nutrient dissolution and movement toward plant roots are improved, resulting in better nutrient absorption. This approach minimizes losses due to leaching, runoff, and volatilization, and ensures that nutrients are

supplied according to crop demand and field variability. It also helps in avoiding over-fertilization, thereby improving fertilizer recovery efficiency and reducing environmental pollution.

4.2 Balanced Fertilization

Balanced fertilization involves the proper and timely application of nitrogen, phosphorus, potassium, and essential micronutrients in correct proportions. Excess nitrogen application under moisture-stressed conditions leads to low nutrient uptake and increased losses through volatilization and leaching. Deficiency of other nutrients also limits the efficient utilization of applied nitrogen. Therefore, balanced nutrient supply synchronized with adequate soil moisture promotes healthy plant growth, efficient nutrient utilization, and higher yields.

4.3 Precision Agriculture Technologies

Precision agriculture technologies such as soil moisture sensors, remote sensing, and variable rate fertilizer application systems enable real-time monitoring of soil and crop conditions. These tools help farmers apply nutrients only where soil moisture conditions support effective uptake, preventing wastage of fertilizers. Precision inputs improve input-use efficiency, reduce production costs, and enhance nutrient use efficiency while promoting environmentally sustainable farming practices.

5. Role in Climate-Resilient Agriculture

Climate change has increased the frequency of droughts, erratic rainfall events, and heat stress, all of which negatively affect crop growth and nutrient availability. Under such conditions, maintaining adequate soil moisture becomes critical for sustaining nutrient uptake and crop productivity. Soil water conservation practices reduce crop vulnerability by improving soil structure and enhancing the capacity of soils to retain moisture during dry periods. These practices also help stabilize nutrients in the root zone, minimizing losses caused by heavy rainfall or prolonged dry spells. As a result, crops are able to maintain better growth and yield even under stress conditions. Techniques such as mulching reduce evaporation, conservation

agriculture improves infiltration and soil organic matter, and agroforestry systems enhance microclimate regulation and nutrient recycling through deep-rooted trees. Together, these approaches strengthen the resilience of farming systems by improving both moisture retention and nutrient cycling, making agriculture more adaptable to changing climatic conditions.

6. Benefits of Soil Water Conservation on Nutrient Use Efficiency

Soil water conservation significantly improves nutrient use efficiency by maintaining adequate moisture in the root zone, which enhances root growth and access to nutrients. It reduces fertilizer wastage by minimizing nutrient losses through leaching, runoff, and volatilization. Improved soil moisture also stimulates beneficial microbial activity, which accelerates nutrient transformations and increases nutrient availability to crops. As a result, fertilizer recovery efficiency is enhanced, leading to better crop growth, higher yields, and improved produce quality. Additionally, reduced nutrient losses help in lowering environmental pollution of water bodies and the atmosphere. Long-term soil water conservation practices also improve soil structure, organic matter content, and overall soil health, ensuring sustainable agricultural productivity.

7. Challenges and Limitations

Despite the proven benefits of soil water conservation practices, their large-scale adoption faces several constraints. Lack of awareness and limited access to technical information among farmers reduce acceptance of improved practices. Initial investment costs for micro-irrigation systems, machinery, and residue management tools can be high, especially for smallholders. In many regions, crop residues are used as livestock feed, limiting their availability for mulching. Precision irrigation and nutrient management also require technical skills and reliable advisory services. In addition, policy support and institutional coordination are often inadequate. Therefore, strengthening extension services, capacity building, and farmer training programs is essential to promote widespread adoption.

8. Future Prospects and Research Needs

- Development of moisture-efficient crop varieties
- AI-based irrigation scheduling
- Soil moisture–nutrient interaction modeling
- Long-term field experiments
- Integration of biochar and nanofertilizers with moisture conservation
- Climate-smart soil management policies

CONCLUSION

Soil water conservation is a cornerstone of improving nutrient use efficiency in sustainable agriculture. Efficient moisture management enhances nutrient availability, minimizes losses, supports microbial activity, and improves fertilizer recovery by crops. Integrating soil conservation practices with balanced fertilization and modern irrigation technologies can significantly increase productivity while conserving natural resources. In the face of climate change and water scarcity, soil water conservation offers a practical and eco-friendly pathway to achieve higher nutrient efficiency, better soil health, and resilient farming systems.

REFERENCES

- Waraich, E. A., Ahmad, R., Ashraf, M. Y., Saifullah, & Ahmad, M. (2011). Improving agricultural water use efficiency by nutrient management in crop plants. *Acta Agriculturae Scandinavica, Section B-Soil & Plant Science*, 61(4), 291-304.
- Singh, R., Kundu, D. K., & Bandyopadhyay, K. K. (2010). Enhancing agricultural productivity through enhanced water use efficiency. *Journal of Agricultural Physics*, 10(2), 1-15.
- Viets Jr, F. G. (1966). Increasing water use efficiency by soil management. *Plant environment and efficient water use*, 259-274.
- Chaudhary, R. S., Singh, R. K., Hati, K. M., & Biswas, A. K. (2015). Strategies for promoting water and nutrients use efficiencies. *JNKVV Res. J*, 49, 347-365.
- Hatfield, J. L., Sauer, T. J., & Prueger, J. H. (2001). Managing soils to achieve greater water use efficiency: a review. *Agronomy journal*, 93(2), 271-280.