WATER AND PLANT NUTRITION

Managing Two Inseparable Resources for a Food-Secure World

Executive Summary

Water security and food security are inseparable. Agriculture accounts for approximately 70% to 72% of global freshwater withdrawals, making it central to achieving sustainable water management. There is no credible pathway to Sustainable Development Goal (SDG) 6 - ensuring clean water and sanitation for all - without transforming the way water and nutrients are used in agriculture. Equally, there is no pathway to SDG 2 on zero hunger in a world of escalating water insecurity or insufficient nutrient use. Fertilizers and improved agronomy are essential to sustaining the agricultural productivity needed to feed a growing global population, making the efficient management of water and plant nutrients increasingly important to future food security. The two agendas succeed together or fail together.

Yet in many countries, the governance and management of agricultural resources remain fragmented: water, plant nutrition, soil health, and crop productivity are often addressed through separate policies and programs, limiting opportunities to improve both water use efficiency and water quality.

This white paper argues that managing water and plant nutrition together is one of the most effective - and most underestimated - opportunities to strengthen agricultural resilience while making more efficient use of increasingly scarce water resources.

The argument rests on a simple fundamental agronomic reality: water and nutrients are closely linked. Water enables crops to absorb, transport and assimilate nutrients, while balanced plant nutrition (supplying crops with the right combination and amounts of plant nutrients according to crop needs and local soil conditions) helps plants regulate their water use, develop deeper root systems, and withstand water stress. Water Use Efficiency (how effectively plants convert available water into biomass or yield) and Nutrient Use Efficiency (the proportion of applied or available nutrients taken up and converted into useful crop output) are mutually reinforcing rather than independent objectives. At the same time, losses of nutrients - particularly nitrogen and phosphorus - from agricultural systems can degrade the freshwater, groundwater, and coastal ecosystems on which all life depends. Reducing those losses requires water and nutrients to be managed as interconnected resources rather than as separate inputs.

The white paper examines this water-plant nutrition nexus through a suite of solutions and identifies the enabling conditions needed to support the adoption and scaling of approaches that are already technically feasible: aligning governance around shared water and nutrient outcomes (Section 3.1), investing in integrated and circular resource systems (Section 3.2), measuring and rewarding combined performance (Section 3.3), making integrated management practical for farmers (Section 3.4), and organizing partnerships around implementation (Section 3.5).

1. The Water - Food Nexus: Setting the Stakes

1.1 Water Under Pressure: Agriculture's Growing Thirst

Water is essential to food production: globally, producing one person's daily food needs requires about 3,000 liters of water, while producing one kilogram of wheat requires around 1,500 liters, and one kilogram of rice about 3,000-5,000 liters. Agriculture is estimated to account for around 70% of global freshwater withdrawals. Irrigated farming covers only 20% of cultivated land but produces a large share of the world's food (commonly cited estimates range from 18% to 50%), yet more than 60% of irrigated cropland is already exposed to high water stress[1]. In fact, half of the global irrigation expansion in the twenty-first century has occurred in regions that were already water-stressed in 2000[2]. More recent assessments indicate that these pressures are becoming increasingly structural: around three billion people and more than half of global food production are located in areas where total water storage is already declining or unstable[3].

Rising temperatures are disrupting precipitation and the water cycle, intensifying scarcity, floods, droughts and water-quality risks. Both rainfed and irrigated agriculture are therefore under growing pressure, making better water management essential to resilient and sustainable food production.

1.2 Water Security and Food Security Must Advance Together

Water and food security cannot be pursued separately: agriculture is simultaneously the world's largest water user and one of the sectors most vulnerable to water scarcity. At the same time, advances in irrigation, agronomy, crop nutrition, soil management and agricultural technologies are improving how water is managed and used across many farming systems. Building on and accelerating this progress will be essential as pressure on water resources continues to grow. Around 3.2 billion people live in agricultural areas facing high or very high-water shortages or scarcity, including 1.2 billion in severely water-constrained areas. Recognizing the interconnections between water, food, energy, and ecosystems offers a pathway to enhance agricultural productivity and resilience, improve farmers' livelihoods, and reduce pressure on increasingly scarce freshwater resources. In over-allocated basins, efficiency gains do not automatically free up water for other users: unless allocation limits are set, water saved on one field can be taken up by expanded or intensified production, so real savings have to be secured through basin-level allocation rather than assumed.

[1] Gleick, P.H. et al. (2014). The World's Water: The Biennial Report on Freshwater Resources. Washington, DC: Island Press. Cited in Our World in Data: https://ourworldindata.org/water-use-stress
[2] Mehta et al. (2024), Half of Twenty-First Century Global Irrigation Expansion Has Been in Water-Stressed Regions, Nature Water, 2(3): 254–261. https://doi.org/10.1038/s44221-024-00206-9
[3] Madani (2026), Global Water Bankruptcy, UNU-INWEH https://dx.doi.org/10.53328/INR26KAM001

2. Where Nutrients Meet Water: The Nexus in Practice

Fertilizer management plays an important role in agricultural water optimization because water and nutrients are closely linked. Water Use Efficiency and Nutrient Use Efficiency should therefore be treated as complementary objectives within resilient agricultural production. Managing these resources together improves water use efficiency, protects water quality and strengthens agricultural resilience.

2.1 Improving Water Use Efficiency Starts with Better Plant Nutrition

Nutrient Use Efficiency is one of the most overlooked opportunities to improve agricultural water resilience. Balanced plant nutrition supports stronger root development and crop growth, enabling a greater share of available water to contribute to productive transpiration rather than being lost through soil evaporation. As a result, improvements in nutrient management can reduce the Water Footprint (the amount of water used per unit of crop yield) without necessarily increasing total seasonal water use. These interactions highlight why water and nutrient management should be planned as complementary objectives. The 4R Nutrient Stewardship framework - applying the right nutrient source, at the right rate, at the right time, and in the right place - provides a practical foundation for integrating nutrient and water management. When combined with irrigation scheduling, soil testing, weather forecasting, and crop monitoring, it helps synchronize water and nutrient availability with crop demand. This integrated approach improves both Water Use Efficiency (WUE) and Nutrient Use Efficiency (NUE), enhances crop productivity and resilience on existing arable land, and reduces nutrient losses to the environment.

The relationship is bidirectional: inadequate water limits nutrient mobility, root uptake and fertilizer efficiency, while excess water increases nutrient losses through leaching, runoff and denitrification. Improving nutrient-use efficiency, therefore, depends not only on the right nutrient source, rate, timing, and placement, but also on matching nutrient supply with water availability.

The 4R framework gains additional value when linked explicitly to water management. The right rate depends on expected yield and water availability, soil nutrient status and nutrients supplied through irrigation water; the right time depends on rainfall, irrigation scheduling and crop demand; and the right place depends on root distribution, soil structure and the risk of runoff or leaching[4]. Accounting for the nutrient composition of irrigation water can therefore be important when determining fertilizer requirements and interpreting crop response.

[4] Sharma, A. K., Zotarelli, L., & Sharma, L. K. (2025). "Interactive study of phosphorus and sulfur application in potato for sandy soils." *Agrosystems, Geosciences & Environment*, 8, e70086. https://doi.org/10.1002/agg2.70086

2.2 Integrated Crop Management Can Make Agriculture More Adaptive

Many agricultural systems continue to rely on fixed irrigation and fertilizer schedules that do not fully reflect changing soil, crops, and weather conditions. New technologies create opportunities to make water and nutrient management more responsive.

Soil moisture monitoring, crop observation, weather forecasting, and digital decision support tools can provide farmers with more timely information about crop needs. Fertigation (the delivery of dissolved nutrients or water-soluble fertilizers through irrigation water), precision irrigation, and variable-rate technologies can then support more targeted delivery of water and nutrients across different crop stages and field conditions. Fertigation can also offer operational and environmental benefits by reducing field operations associated with fertilization and helping minimize water pollution from nutrient leaching[5].

Innovation lies not in any single technology, but in linking information, agronomic knowledge, and delivery systems. Maximizing the value of investments in water, plant nutrition and soil management requires these resources to be managed as an integrated system, with management decisions continuously adjusted in response to changing soil, crop and weather conditions. This can help shift agricultural management from standardized input applications towards more adaptive decision-making, enabling farmers to respond earlier to water stress and use resources more effectively.

Policies and investment strategies should therefore support integrated systems rather than isolated technologies. This includes investment in advisory services, digital infrastructure, local data, farmer training, and affordable access to precision-management tools. For many smallholders, capital-intensive precision tools remain out of reach, so progress depends on a portfolio of context-appropriate solutions, from low-cost agronomic practices to shared or digitally delivered advisory services, matched to local capacity and resources.

2.3 Soil Function Links Water and Nutrient Efficiency

Soil health is a central component of the water-plant nutrition nexus. Soil layering, texture, structure, organic matter, biological activity, and rooting conditions influence how water enters the soil, how long it remains available, and how effectively crops can access nutrients.

Well-functioning soils can help buffer agricultural production against drought, irregular rainfall, and excessive water. They improve the capacity of farming systems to capture and store water, support root development, and maintain crop growth during periods of stress. Balanced plant nutrition contributes to this process by sustaining crop biomass, root growth, and the organic matter that builds soil health. Also, in rainfed systems, improving soil structure, increasing water infiltration and reducing soil-water evaporation are among the most effective ways to improve water use efficiency while reducing nutrient losses. On the other hand, sandy soils with low capacity to store water and nutrients require careful management of irrigation and nutrient applications to supply nutrients in frequent, smaller increments as the crop grows. Building soil organic matter through practices such as retaining crop residues, using cover crops, and

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[5] Fu, X., Liu, G., Zotarelli, L., Sargent, S., Migliaccio, K., & Li, Y. "How to Fertigate Plant Vines via Center Pivots for Commercial Potato Production in Florida." University of Florida IFAS Extension, HS1361.
HS1361/HS1361: How to Fertigate Plant Vines via Center Pivots for Commercial Potato Production in Florida

supporting greater biomass production through balanced plant nutrition can also help improve soil structure and water-holding capacity over time. If that is done right, they can also be very productive.

Soil health should therefore be recognized as a form of natural agricultural infrastructure that must be managed in a tailored manner. Water and nutrient policies should support practices that strengthen soil function, including balanced fertilization, integrated soil fertility management, crop rotations, residue management, and other locally appropriate practices[6].

3. Building an Enabling Environment

Many of the practices and technologies required to improve agricultural water use efficiency, water quality and resilience already exist, including modern fertilizer management programs. Their widespread adoption, however, continues to be constrained by fragmented governance, inadequate investment, limited incentives for adoption and insufficient coordination across sectors.

Overcoming these barriers is essential, requiring more than institutional coordination. An enabling environment must also change what governments, businesses, and other stakeholders measure, value, plan, finance, and deliver. **It should make the currently hidden costs and benefits visible and create mechanisms to recover that value.**

The following five directions illustrate how broad commitments to integrated governance, investment, and partnership can be translated into action. They are not intended as a uniform policy package. Countries and basins can adapt and sequence them according to their water conditions, agricultural systems, institutional arrangements, and development priorities.

3.1 Align Governance Around Shared Water and Nutrient Outcomes

Water governance remains fragmented across institutions, sectors, and levels of government. Water allocation and water quality are often managed by water or environmental authorities, while plant nutrition, soil management and agricultural advisory services fall under separate agricultural institutions. This separation can lead to overlapping mandates, inconsistent policies and missed opportunities to improve agricultural productivity and water resilience simultaneously.

Existing water-planning processes, including national water accounts, basin, watershed and catchment plans and drought-preparedness frameworks, should better recognize the contribution that improved nutrient stewardship, soil management and agronomic practices can make to agricultural water productivity. This could include assessing the water-use efficiency gains that can be achieved through improved crop nutrition, soil management and agronomic practices, alongside conventional options such as additional basins, desalination or reuse. It would help water planners recognize improved plant nutrition as a way to raise agricultural water use

[6] Tang, S., Pan, W., Yang, Y., et al. 2025. "Soil Carbon Sequestration Enhanced by Long-Term Nitrogen and Phosphorus Fertilization." *Nature Geoscience*, 18: 1005–1013. https://doi.org/10.1038/s41561-025-01789-y

efficiency, producing more crop output per unit of water, rather than only as an instrument of water-demand management.

At the basin, watershed or catchment level, institutions could also establish shared water-nutrient objectives, supported by nutrient and water budgets, agronomic expertise in basin planning and recognition of farm-level nutrient stewardship as a water-quality management measure[7].

This does not necessarily require the creation of new institutions. In many contexts, progress can be achieved by broadening existing mandates, strengthening coordination mechanisms and aligning planning and accountability across responsible authorities. Depending on national and basin contexts, this may involve a mix of planning frameworks, incentives, voluntary stewardship approaches, standards and targeted regulations.

3.2 Invest in Integrated and Circular Resource Systems

Many of the technologies needed to strengthen agricultural water resilience are already available. The central investment challenge is to connect them through the infrastructure, institutions, and services required for effective deployment.

Investment priorities should therefore extend beyond individual technologies to integrated systems that combine:

- irrigation and fertigation infrastructure and maintenance;
- soil, crop and water diagnostics;
- digital monitoring and decision-support systems;
- agricultural research and innovation, including crop nutrition R&D and locally adapted water-nutrient management solutions;
- wastewater treatment and safe agricultural reuse;
- nutrient-recovery technologies;
- advisory services, local data and institutional capacity; and
- affordable finance for farmers and value-chain actors.

Wastewater reuse provides a particularly important opportunity to connect the water and nutrient agendas. Reclaimed water can supply both water and agronomic value, while treatment processes can recover phosphorus, nitrogen and other nutrients where technically and economically feasible. However, these opportunities will remain marginal where water-reuse regulation, fertilizer policies and agricultural planning are developed separately.

Water reuse and nutrient recovery should therefore be assessed as elements of a single circular resource system. Reclaimed water supplied to agriculture can be characterized by its nutrient content, recovered nutrient products can be governed through jointly developed agronomic and

[7] Nebraska's Natural Resources Districts (NRDs) provide an example of watershed-based governance integrating groundwater and nutrient management. The 23 NRDs develop locally adapted nitrogen-management guidelines and groundwater-protection measures tailored to watershed conditions. Nebraska Corn Board, "Importance of Nebraska's Natural Resource Districts (NRDs)."
https://nebraskacorn.gov/cornstalk/water-and-resources/importance-of-nebraskas-natural-resource-districts-nrd/

safety standards, and treatment facilities can be evaluated for their potential to function as resource-recovery facilities as well as pollution-control infrastructure.

Safeguards are essential. Reuse schemes must address contaminants and pathogens of emerging concern, salinity, heavy metals, crop-specific safety thresholds, monitoring capacity, farmer guidance and public acceptance. The aim should not be reuse at any cost, but safe circularity: recovering water and nutrients where risks can be monitored, regulated and managed. Some contaminants of emerging concern, such as PFAS and pharmaceutical residues, are not fully removed by conventional treatment, and advanced treatment carries real capital and operating costs; these limits should be acknowledged rather than assumed away.

Investment appraisal should consider these combined benefits, including avoided nutrient losses, reduced pressure on freshwater supplies, lower input requirements, improved water quality and greater resilience of agricultural production.

3.3 Measure and Reward Combined Performance

Governments, industry, grower groups, and research institutions should support the development of realistic indicators that help farmers improve nutrient and water management while protecting water quality. These farm- and production-level indicators should be interpreted in light of available national and contextual information, including seasonal water stress, groundwater conditions and catchment water-quality status. This is not meant to lead to a single universal score but to identify areas of combined water and nutrient pressure and guide better management, when and where needed.

A practical measurement framework could include the following indicators:

Outcome	Possible indicators	Scale
Water use efficiency	Yield, nutritional output or value per unit of water	Field/Farm
Nutrient-use efficiency	Nutrient use efficiency (Outputs/Inputs), Partial factor productivity of applied fertilizer	Field/Farm
Nutrient-loss risk	Nitrogen and phosphorus surplus (Inputs-Outputs); nitrate-leaching risk	Farm/Catchment
Soil function	Organic matter; infiltration; rooting depth	Field/Farm
Water quality	Nitrate, phosphorus, salinity, turbidity	Catchment/Basin

Adoption	Area under integrated water-nutrient plans	Farm/Program
Water access	Reliable access to sufficient water supplies to grow a crop	Field/Farm

Where monitoring systems and institutional capacity are sufficiently developed, governments and basin institutions could progressively link farm-level performance data to catchment-level information on water availability and quality, while relying on simpler proxy indicators in data-constrained settings. This would make it possible to assess whether improvements in agronomic efficiency are consistent with reducing pressure on water resources and nutrient-loss risks, while recognizing that direct causal attribution at the catchment scale is not feasible.

Better measurement could also support better incentives. Farmers frequently bear the cost of improved nutrient and water management, including fertilizer and irrigation systems, while part of the value is captured elsewhere in the supply chain. For example, a fertilizer that is made through nutrient recovery from wastewater is likely to be more expensive than a 'normal' commercial fertilizer. It represents no unique value to a farmer but has high value for water utilities and the general public. Public finance, agricultural credit, insurance, procurement standards, catchment programs can help recognize and share this value. Evidence of combined water and nutrient outcomes can provide the basis for cost-share programs, preferential financing, environmental crediting mechanisms and other incentives that make adoption economically viable rather than merely desirable.

Open and trusted data systems will be essential. Basin-level data commons that connect soil information, crop conditions, water availability, nutrient applications and water-quality monitoring could improve planning while supporting research and innovation.

3.4 Make Integrated Management Practical for Farmers

The effects of institutional fragmentation are ultimately experienced at farm level. Farmers may receive irrigation guidance from one service, fertilizer recommendations from another and drought or weather information from a third. These recommendations may be issued through different platforms, based on different data and delivered according to different calendars. The responsibility for reconciling them falls to the farmer at the moment when decisions must be made.

Governments and other agricultural stakeholders should therefore invest in strengthening and better coordinating public and private extension and advisory services so that farmers can access integrated guidance on water, plant nutrition, soil, weather and crop management. This does not necessarily require a single service or platform; existing services can be connected and coordinated around a common management approach.

Irrigation recommendations should more accurately reflect soil moisture, expected rainfall, irrigation availability and crop water demand, while nutrient recommendations should account for crop nutrient demand as well as nutrient supply from soil and irrigation.

The principle is simple: **one field, one integrated plan**. Farmers should be able to access coordinated guidance that aligns water, nutrients, soil, weather, and crop management decisions.

3.5 Organize Partnerships Around Implementation

Water resilience requires coordinated action across governments, farmers, input suppliers, food and agricultural value-chain actors, industry, research institutions, development partners, financial actors and civil society. Partnerships are most effective when they are organized around clearly defined functions, shared responsibilities and measurable outcomes, rather than institutional boundaries. These may include:

- developing joint water and nutrient assessments;
- training on how to use the 4R nutrient management framework;
- instruction on how to measure and report NUE and WUE;
- piloting integrated basin or catchment programs;
- establishing interoperable data systems;
- investing in irrigation, reuse and nutrient-recovery infrastructure in areas where applicable;
- training in irrigation management and diagnosing system issues;
- strengthening agricultural advisory services;
- demonstrating and evaluating locally appropriate technologies; and
- creating incentive mechanisms that reward farmers for delivering measurable improvements in water use efficiency, water quality, and ecosystem health.

The catchment, watershed or basin can provide a natural and useful scale for such collaboration because it connects upstream agricultural management, downstream water users, ecosystems, municipalities and treatment infrastructure. National frameworks can establish common standards and incentives, while basin and local partnerships adapt implementation to the characteristics of water and farming systems.

Three Resources, One Agenda

- **Manage water, plant nutrition and soil health as one interconnected agenda.** Practices and technologies already exist; the priority is to enable their widespread adoption.
- **Embed water, nutrient, and soil objectives in shared national planning frameworks so agricultural productivity, water availability,** and water quality are addressed together.
- **Direct investment toward connected resource systems,** including efficient irrigation, fertigation, soil and crop diagnostics, water reuse, nutrient recovery and farmer support services.
- **Measure what matters and reward better performance.** Use realistic performance measures and incentives to recognize improvements in water use efficiency, nutrient efficiency and reduced environmental losses.
- **Provide farmers with coordinated, season-specific guidance** that brings together irrigation, plant nutrition, soil conditions, weather and crop needs.
- **Build implementation partnerships at national, basin and local levels** to mobilize finance, strengthen advisory capacity, share data and scale proven solutions.

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