A report for:

Economic Water Productivity in Fruit Production

Insights from Arid and Water-Abundant Regions

by Víctor Muñoz Aravena

2022 Nuffield Scholar

November 2025

Nuffield International Project No 2206

Supported by:

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Executive Summary

Water is no longer a cheap or unlimited input in agriculture—it is a strategic resource shaping the future of fruit production. This report introduces Economic Water Productivity (EWP)—the economic return per cubic meter of irrigation water—as a practical framework for guiding decisions in both arid and non-arid regions. Through comparative case studies, it offers actionable insights for producers, policymakers, and supply chain stakeholders.

Key Findings

- Value per drop matters more than volume. EWP helps align production decisions with both profitability and resource use. In Chile's Coquimbo Region, citrus and cherries generate significantly higher economic returns per cubic meter than olives or table grapes.
- Scarcity drives innovation. In water-stressed areas like Israel and Chile, limited water availability has led to advances in drip irrigation, reuse of treated wastewater, and governance reforms—enhancing both productivity and long-term resilience.
- Constraints go beyond water. In water-abundant regions, other limitations take center stage: labor scarcity (Florida, Netherlands), energy dependence (Singapore), and land fragmentation (Japan). These conditions require productivity models rooted in resilience, diversification, and high-value outputs.
- New business models build resilience. Initiatives like agrotourism in Florida, multifunctional farms in the Netherlands, Israel and Japan, and export cooperatives in Brazil highlight how producers are adapting by expanding income sources and reducing dependence on volume-based growth.

"Water is only the first limit—economic and institutional decisions shape what comes next."

Recommendations

- Adopt EWP as a baseline tool in public programs, guiding subsidies, crop selection, and irrigation investment in both water-scarce and water-abundant regions.
- Empower small and medium producers with access to technology, cold chain infrastructure, and cooperative platforms that lower risk and increase market access.
- Support diversified business models that incorporate retail, tourism, processing, or sustainability branding—especially in high-cost or constrained environments.
- Promote cross-regional collaboration between countries with shared crops but different constraints (e.g., Chile and Brazil in grapes) to scale adaptable, climate-smart innovations.

"Maximizing EWP is not just about using less water—it's about producing smarter, with purpose and resilience."

Contents

Foreword

In 2015, during one of the worst droughts in northern Chile, I attended a seminar in Ovalle, Limarí Province. There, a question repeated by fruit growers resonated deeply: *"What should we grow with the little water we have?"* It was a question not only technical, but existential—one that would go on to shape my academic focus, professional path, and ultimately, this Nuffield report.

Over the past 15 years, I have worked at the intersection of fruit production, water management, and sustainability in arid and semi-arid zones of Chile. I hold a degree in Agricultural Engineering (Universidad de Chile), a Master's in Water Resources Management for Arid Zones (Universidad de La Serena), and in 2022, I was honored to become one of Chile's first five Nuffield International Scholars.

My career has included roles in agricultural research, agtech innovation, and public-private development programs. Currently, I serve as Program Manager for the Strategic Regional Program for Sustainable Fruit Production in Coquimbo—one of Chile's most water-stressed regions. There, we support growers in adapting to a new reality of scarcity, risk, and transformation.

The concept of Economic Water Productivity (EWP) emerged early in my work as a way to link agronomic decisions with financial outcomes under water constraints. My Master's thesis revealed that the returns per cubic meter of irrigation water could vary drastically—from less than 1 USD/m³ in olives to over 5 USD/m³ in mandarins—depending on the crop and context.

Through the Nuffield Scholarship, I was able to expand this analysis globally. I visited water-scarce leaders like Israel and Chile, as well as countries facing other constraints—labor, energy, land, or logistics—including Japan, Singapore, the Netherlands, Brazil, and the U.S. I spoke with farmers, researchers, policymakers, and entrepreneurs to understand how different systems define and pursue "productivity."

This report is the outcome of that journey. It explores how EWP can be used not only to measure efficiency, but to guide investment, crop choice, business models, and public policy. It is intended to help fruit producers—small and large—make better decisions in a world where water is just one of many emerging constraints.

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Acknowledgments

I am deeply grateful to Nuffield International Farming Scholars for the opportunity to grow personally and professionally through this experience. I especially thank PSP Investments and the Chris Reichstein Philanthropy Fund, whose generous support made my scholarship possible. Their belief in the importance of global agricultural leadership and innovation has empowered me to pursue this work with greater purpose.

I also wish to thank Frutas de Chile and CORFO for their ongoing support, and to the growers of Coquimbo, whose resilience inspires me every day. I hope this report returns value in the same spirit with which it was conceived.

I am especially thankful to my family—my wife Marta and our daughter Maite, whose love, patience, and encouragement have sustained me through every stage of this journey. To my parents and siblings, thank you for your unwavering support and belief in the path I've chosen.

Finally, I offer my sincere thanks to all the people—farmers, entrepreneurs, researchers, and government officials—who generously opened their gates, offices, and minds throughout this journey. Your lessons, your questions, and your courage in the face of change are what made this report possible.

I. Objectives and Guiding Questions

This report aims to explore how the concept of Economic Water Productivity (EWP)—defined as the economic return per cubic meter of water used—can support the sustainable transformation of fruit production systems. By comparing water-scarce and water-abundant contexts, it seeks to identify strategies that optimize resource use, enhance profitability, and promote long-term resilience. This research is structured around four core questions:

1. How do fruit-producing regions adapt to water scarcity through crop choice, governance, and technology? Case studies from Israel, Chile, and California illustrate how constraints in water availability drive institutional, agronomic, and technological innovations.

2. In contexts where water is not the critical constraint, what other pressures shape productivity? Countries like Brazil, the Netherlands, Japan, and Singapore reveal how energy, labor, logistics, culture, and market access reshape agricultural strategies beyond irrigation. What cross-cutting tools, frameworks, and lessons can be applied across geographies?

3. What common tools and strategic approaches can be shared across geographies? Despite differing constraints, many regions converge around cross-cutting innovations: value-added diversification, cooperative governance, circular resource use and digital agriculture.

4. How can EWP serve as a practical decision-making tool for farmers, investors, and policymakers? While this report emphasizes EWP (USD/m^3), the metric offers actionable insights into crop prioritization, irrigation investment, and long-term resource allocation.

II. Introduction

Water is no longer just a vital input for agriculture—it is a defining constraint that shapes the sustainability, profitability, and resilience of fruit-growing systems. This is especially relevant in fruit production, a sector characterized by high water requirements and high economic value. As climate variability intensifies and competition for freshwater increases, the efficient use of irrigation water has become a strategic imperative.

According to FAO (2024), global fruit production reached 968 million metric tons in 2023, spanning 81.5 million hectares. China, India, and Brazil led in both production and area. Chile, though 29th in volume, stood out as the 5th largest exporter by value in 2024, reaching USD 8.28 billion—5.2% of the global export market (TRADEMAP, 2025). Chile's performance highlights the importance of strategic positioning and logistics, especially given its average export distance of over 13,000 km.

Fruit crops are economically significant. While they account for about 9–10% of total crop volume, they consistently generate 16–17% of global crop value (Figure 1). Chile's shift from table grapes to a diversified fruit portfolio (including cherries, apples, kiwis, avocados, and blueberries) illustrates how high-value crops have reshaped its export economy and inspired similar models elsewhere in Latin America.

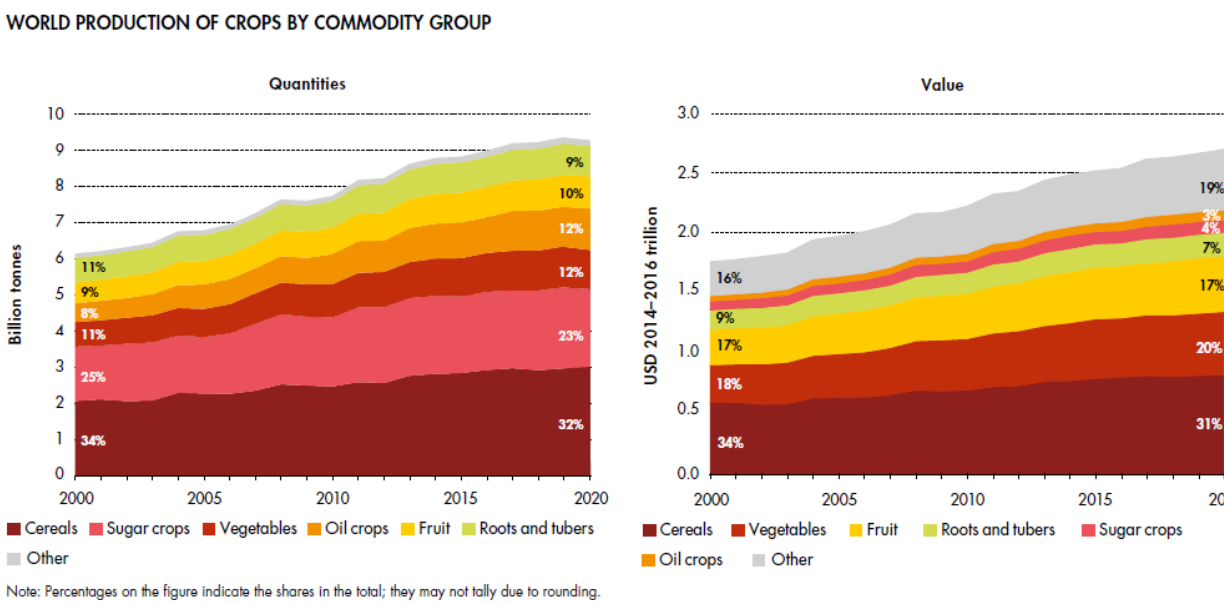

Figure 1. World crop production by commodity group, 2000–2020. Quantities (left) in billion tonnes; value (right) in USD trillions. Source: FAO Statistical Yearbook 2022.

Yet this economic relevance is only one side of the story. Strategic diversity in fruit systems varies widely. Figure 2 maps countries by their average fruit price and the share of fruit in their crop value. Chile and New Zealand show high specialization and price, while countries like Japan produce high-value fruit with low national specialization. The Netherlands, a logistics hub, ranks 4th in export value but 98th in production. This diversity influences how countries respond to constraints such as water.

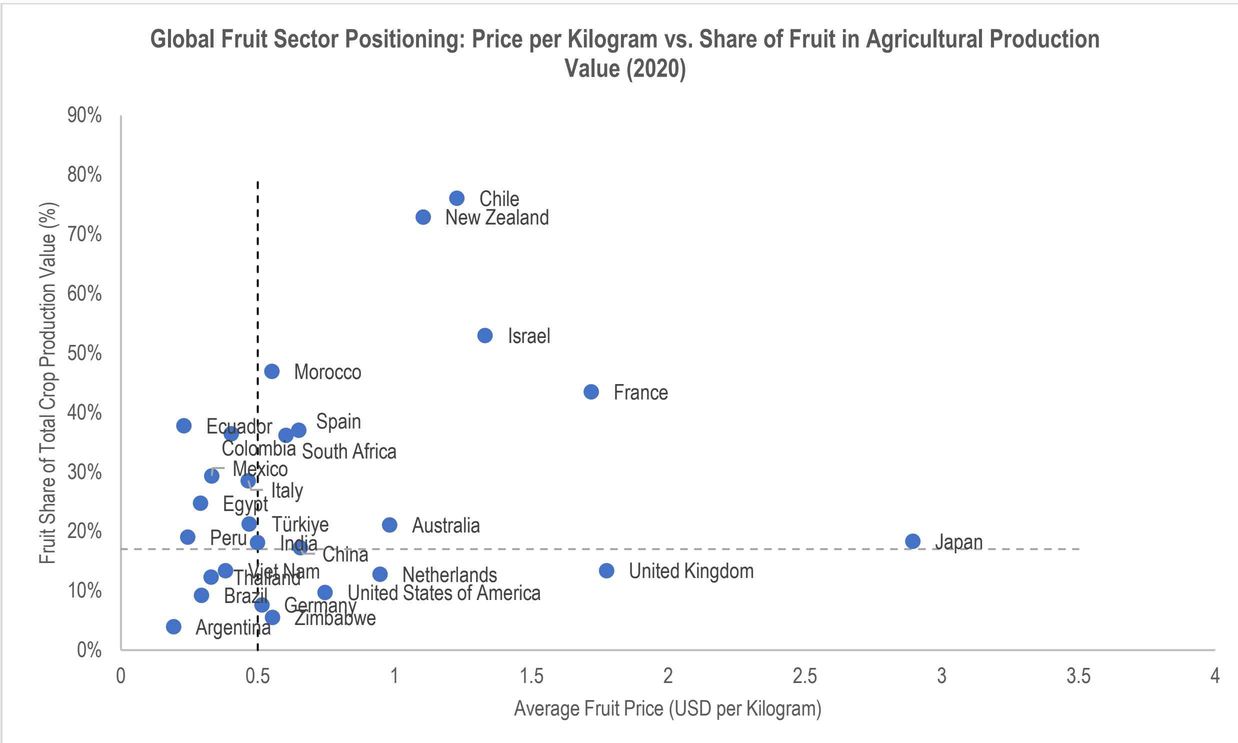

Figure 2. Positioning of selected countries in the global fruit sector, based on average fruit price (USD/kg) and fruit's share of total crop production value (%). Data from FAO (2022); prices estimated by dividing 2014–2016 production value by 2020 volume. Dashed lines indicate global averages: 0.50 USD/kg and 17% crop value share.

Per capita fruit availability also varies greatly (Figure 3), often shaped less by production than by population and trade orientation. Countries like Ecuador, Spain, and Chile show high per capita supply, while India and China exhibit low availability despite their massive output.

Beneath these patterns lies a common denominator: water. Fruit crops are particularly sensitive to water deficits, especially during critical phenological stages. Over 95% of the water absorbed by fruit crops is transpired back into the atmosphere (Taiz et al., 2015), making efficient water use vital to maintaining yield and quality.

In arid and semi-arid regions, long-term droughts, unpredictable rainfall, shrinking snowpacks, and rising competition from urban users exacerbate vulnerability. These pressures are pushing producers and policymakers to reconsider how agricultural productivity is defined—not just by yield, but by economic value per unit of water.

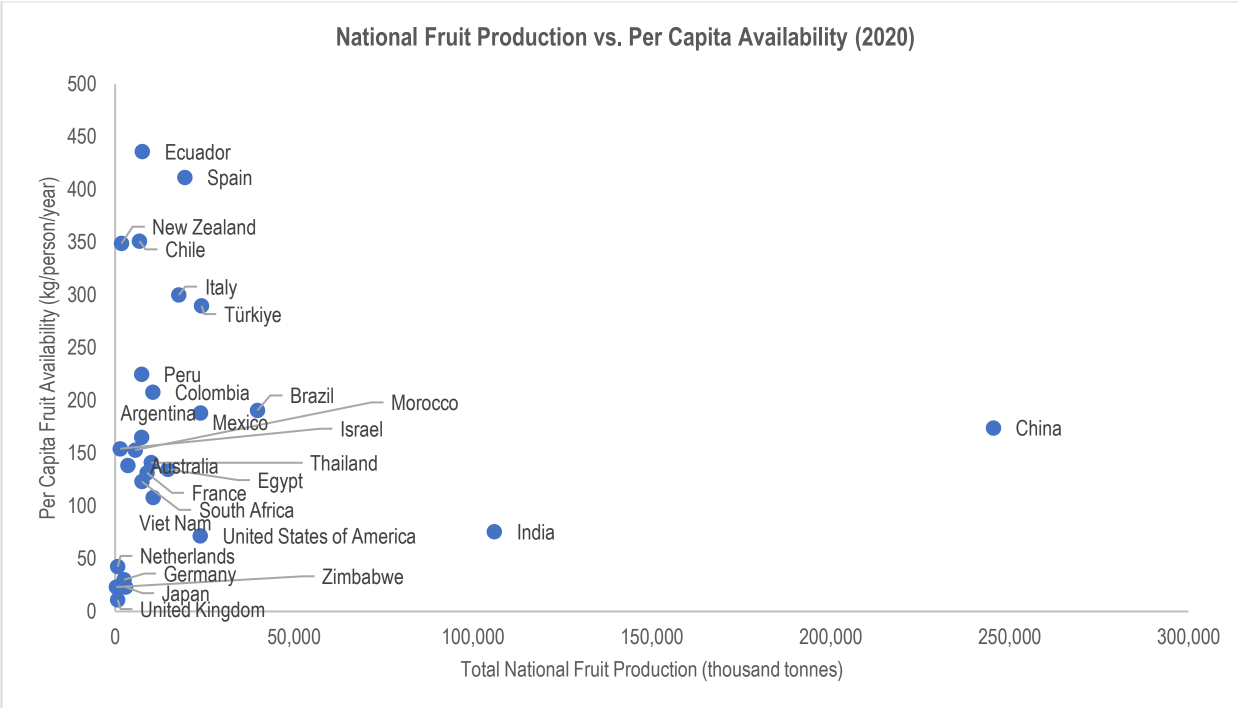

Figure 3. National Fruit Production vs. Per Capita Availability (2020)
Source: FAO Statistical Yearbook 2022 (Table 17 – Production of Primary Crops by Group, 2020) and World Bank – Population Estimates (2020).

A key tool in this reconsideration is Economic Water Productivity (EWP)—the gross economic return (USD) per cubic meter of irrigation water. Unlike traditional productivity metrics (e.g., kg/m³), EWP introduces a market-oriented perspective: Yield × Price / Water Used. While this report uses a simplified version of EWP without including costs, it remains a powerful proxy for guiding policy, investment, and diversification.

EWP becomes especially relevant when comparing crops. In Chile's Limarí Province, for example, mandarins yielded over USD 5/m³ while olives returned less than USD 1/m³. These differences highlight not just agronomic performance but also the strategic relevance of each crop in water-scarce contexts.

The fieldwork for this study was conducted under the Nuffield International Farming Scholarship and included visits to Israel, Chile, California, Florida, the Netherlands, Brazil, Japan, Singapore, and the UK. These regions illustrate contrasting realities:

- In hyper-arid areas like northern Chile, Israel, and California, producers have embraced micro-irrigation, reclaimed water, and water governance to improve returns per drop.
- In more water-secure regions, other constraints dominate: energy (Singapore), labor (Florida, Netherlands), or land (Japan). These shifts suggest a broader understanding of productivity—one that considers energy inputs, logistics, and consumer preferences alongside water.

Even within a country like Chile, production systems vary. Many growers depend on a single harvest (e.g., grapes or citrus), leaving them vulnerable to market and climate shocks. Diversification through short-cycle crops or multi-season horticulture can enhance both income stability and water-use efficiency.

Ultimately, EWP offers a strategic framework to address the fundamental question: *What should we grow, where, for whom, and under what constraints?* It guides crop selection, investment, and risk management by translating water use into economic return.

Most global water indicators, such as those from FAO AQUASTAT or SDG 6.4 (FAO, 2025), report on agriculture in general. However, fruit crops—which often represent a high share of economic value—demand crop-specific metrics. In highly specialized countries like Chile, Israel, and Spain, agriculture accounts for over 60% of national water use. Without crop-level tools like EWP, these numbers obscure the strategic decisions growers face.

By examining EWP across diverse contexts, this report aims to inform smarter, more adaptive decision-making. It argues that water may be the first limiting factor—but never the last. Labor, energy, infrastructure, and governance all matter. Productivity must be reframed not as output alone, but as a function of value creation, resource resilience, and institutional capacity in a world of evolving constraints.

III. Understanding Economic Water Productivity

A. Conceptual Framework

In arid and semi-arid regions, where water—not land—is often the scarcest resource, agricultural planning must shift its focus. Traditional metrics like yield per hectare or profit per area are no longer sufficient. A new lens is required: **Economic Water Productivity (EWP)**, which measures the economic return per cubic meter of irrigation water used.

EWP provides a way to compare crops, varieties, and production systems based not only on output, but on value per unit of water—a vital decision tool for growers, policymakers, and investors operating under increasing resource constraints. As is often said in water-scarce areas: *"We have plenty of land—what we lack is water."*

There are two main ways to calculate EWP:

- **Gross EWP**: Gross EWP = (Yield×Price) / Water Used (m^3)

  This version excludes costs and is useful for comparing species or guiding diversification in short time frames.

- **Net EWP**: Net EWP = ((Yield×Price)−Costs) / Water Used (m^3)

  It offers a deeper view of financial viability, incorporating inputs like labor, energy, and postharvest handling.

Both metrics are complementary: gross EWP allows quick comparisons, while net EWP brings sustainability and risk into focus—especially important in semi-arid regions like Chile's Coquimbo Region.

Although annual water demand in irrigated fruit systems tends to be stable—driven by relatively predictable evapotranspiration (ET_0)—yields and prices can vary considerably. Factors like alternate bearing (e.g., in avocados), varietal differences (e.g., new table grape cultivars), and market volatility (e.g., global price drops in almonds and walnuts) all influence EWP.

As shown in Figure 4, inflation-adjusted grower prices for nuts have declined over the past decade, highlighting how market trends can reduce both gross and net EWP, even when yields and water use remain stable.

Water productivity is not determined by volume alone, but also by timing, technique, and intended product. For example, Chartzoulakis and Bertaki (2015) demonstrated that drip irrigation produced the highest water-use efficiency (WUE) in kiwifruit trials. In olives, deficit irrigation yielded high oil output per unit of water—suggesting that moderate water stress can even enhance EWP, depending on the target marketable product (e.g., oil vs. fresh fruit).

These findings reaffirm that efficient water use in fruit production requires crop-specific strategies tailored to local conditions and economic goals. EWP provides a powerful, adaptable framework to navigate these trade-offs—supporting smarter resource allocation in both technical and policy domains.

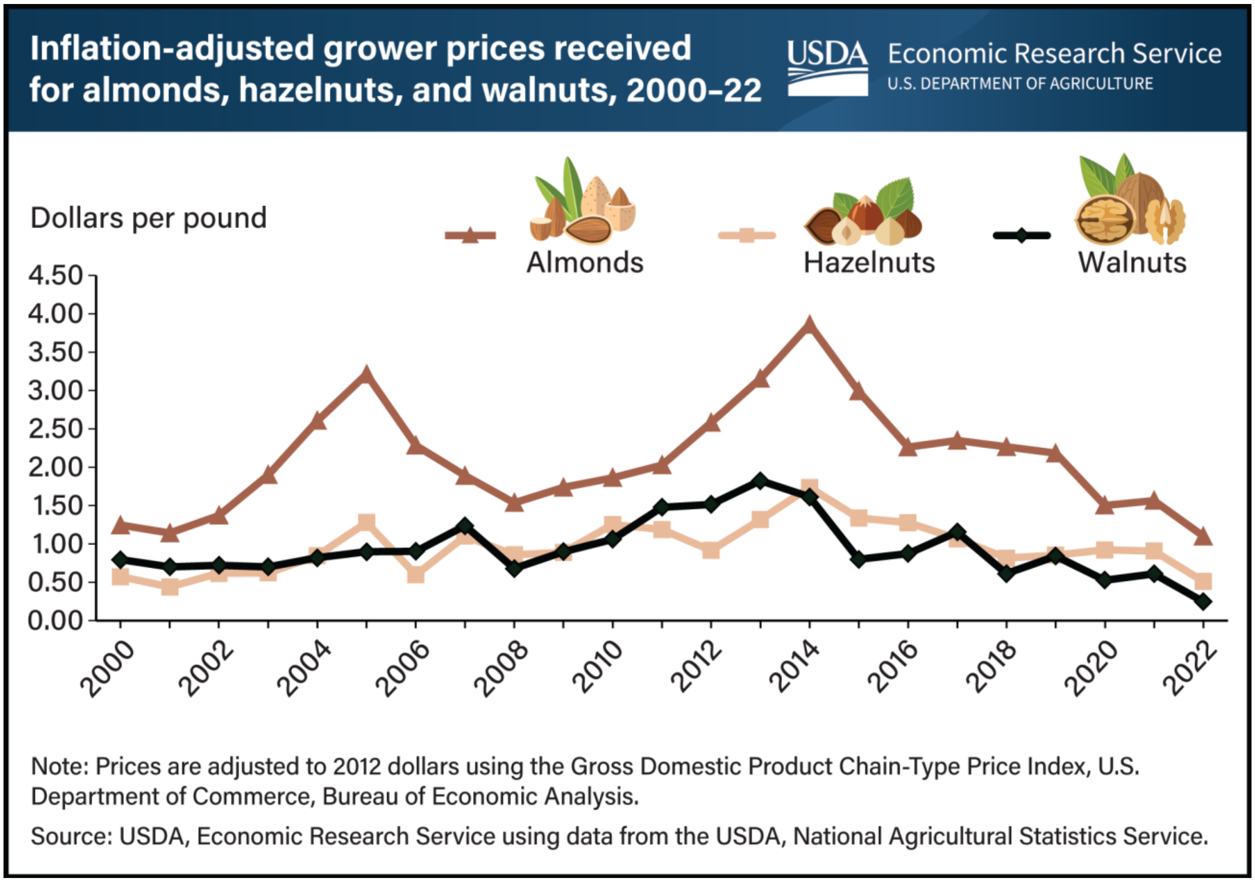

Figure 4. Inflation-adjusted grower prices for almonds, hazelnuts, and walnuts (2000–2022), in 2012 dollars. The chart highlights price cycles and post-2015 declines in almonds and walnuts, with implications for Economic Water Productivity. Source: USDA ERS (2023), based on NASS data.

B. Variables Influencing EWP

Economic Water Productivity (EWP), whether gross or net, is shaped by multiple interconnected factors—biophysical, economic, technological, and institutional. Crop and variety selection plays a central role. In Chile's Coquimbo Region, for instance, lemon orchards can yield over 56,800 kg/ha, while table grapes average 24,500 kg/ha and avocados reach about 10,800 kg/ha. Traditional olive orchards, in contrast, produce less than 5,000 kg/ha (CIREN, 2024) . These differences directly affect the volume of economic output generated per cubic meter of water, influencing profitability and crop viability. Newer varieties—especially of table grapes—have also proven more productive and export-competitive, particularly when targeting early-season market windows.

Market access and price dynamics further shape EWP outcomes. Premium prices for early shipments can enhance returns but also increase exposure to volatility. Recent years have seen sharp price declines for key species like grapes, cherries and citrus (Figure 5), driven by overproduction, exchange rate shifts, and phytosanitary disruptions. Export concentration is another key factor. While over 95% of Chilean mandarins are shipped to the U.S., crops like grapes, lemons and walnuts reach more diversified markets (Figure 6). This distribution can stabilize income but also complicate logistics and quality control.

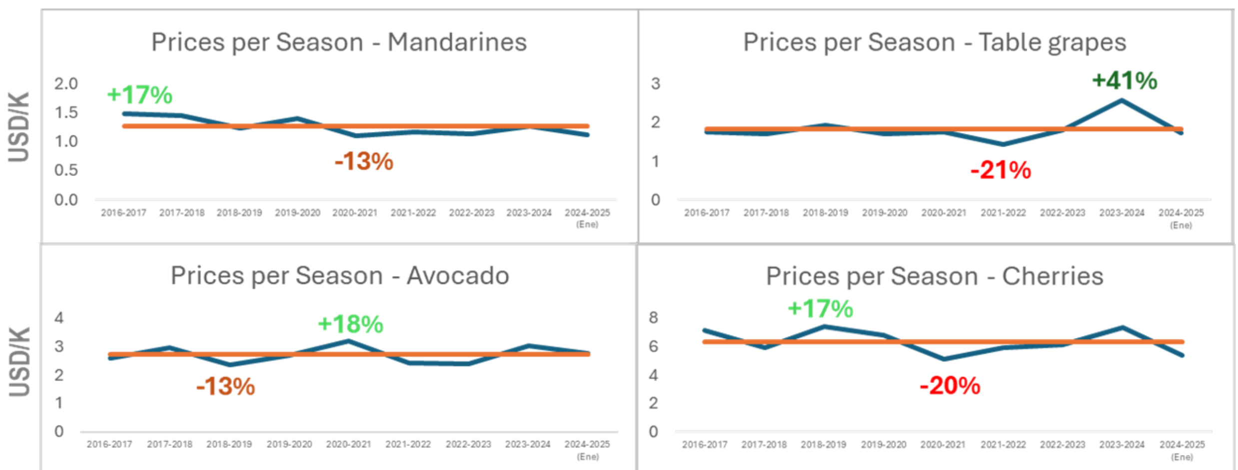

Figure 5. Seasonal and long-term trends in export prices (USD/kg FOB) for selected fruits (2014–2023). Blue lines show seasonal values; orange line, 9-year average. Green/red labels indicate deviations from the average. Source: Internal analysis using ODEPA data (2025).

Irrigation technology is a major driver of water efficiency. Drip systems offer field application efficiencies of 90–95%, significantly higher than sprinkler (70–80%) or surface irrigation (40–60%) (FAO, 2002). However, the costs of installation, maintenance, and training can limit adoption among smaller growers, affecting short-term Net EWP despite long-term gains in water use and yield.

Climate remains a foundational variable. Precipitation, temperature, and evapotranspiration (ET_0) all affect crop performance and irrigation needs. As shown in Figure 7, the Coquimbo Region receives less than 150 mm of annual rainfall, placing it among the driest agricultural zones globally. In contrast, regions like the Netherlands or Homestead (Florida) receive over 1,200 mm. However, ET_0 in Coquimbo is moderate (1,200–1,400 mm/year; Figure 8) compared to Israel or inland Australia (>2,000 mm). The Aridity Index (P/ET_0; Figure 9) integrates these elements—Coquimbo, California, and Israel score below 0.2, indicating severe water stress, while the São Francisco Valley in Brazil, despite its low rainfall, benefits from regulated irrigation infrastructure, aligning it more with humid production zones. These metrics are summarized in Table 1.

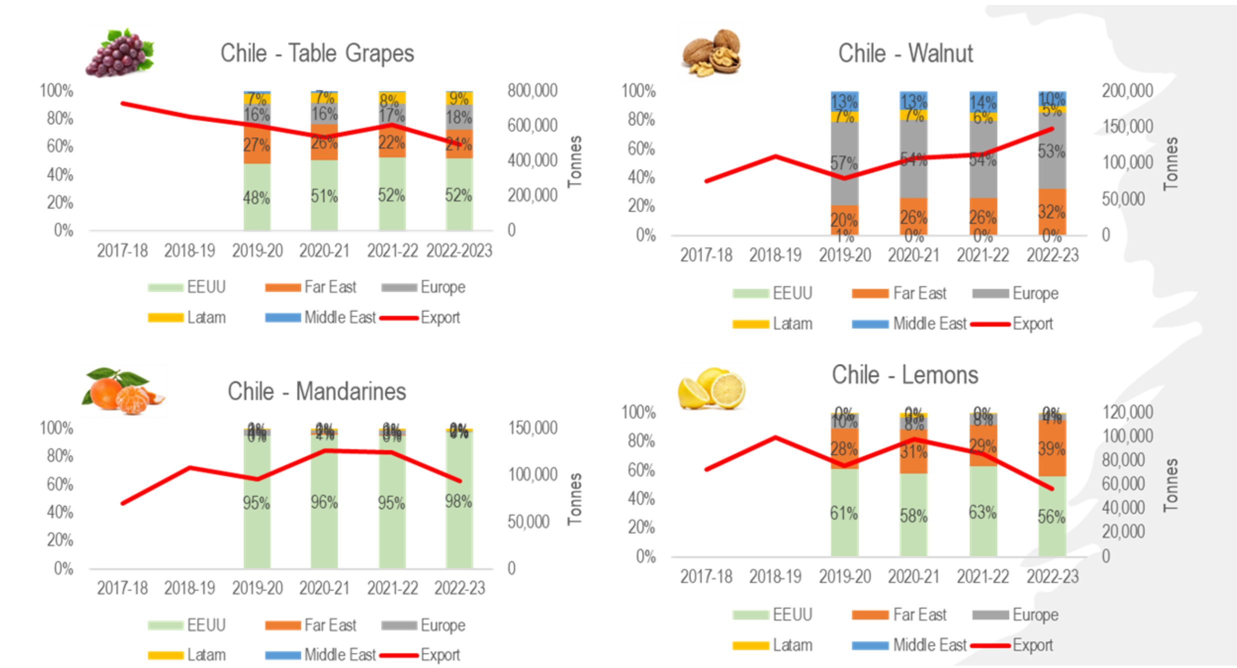

Figure 6. Export volume and destination share of selected Chilean fruits (2017–2023). Bars show percentage by region; red line indicates total volume (tonnes). Source: Author's elaboration based on Expordata (ASOEX & Decofrut, 2020–2023).

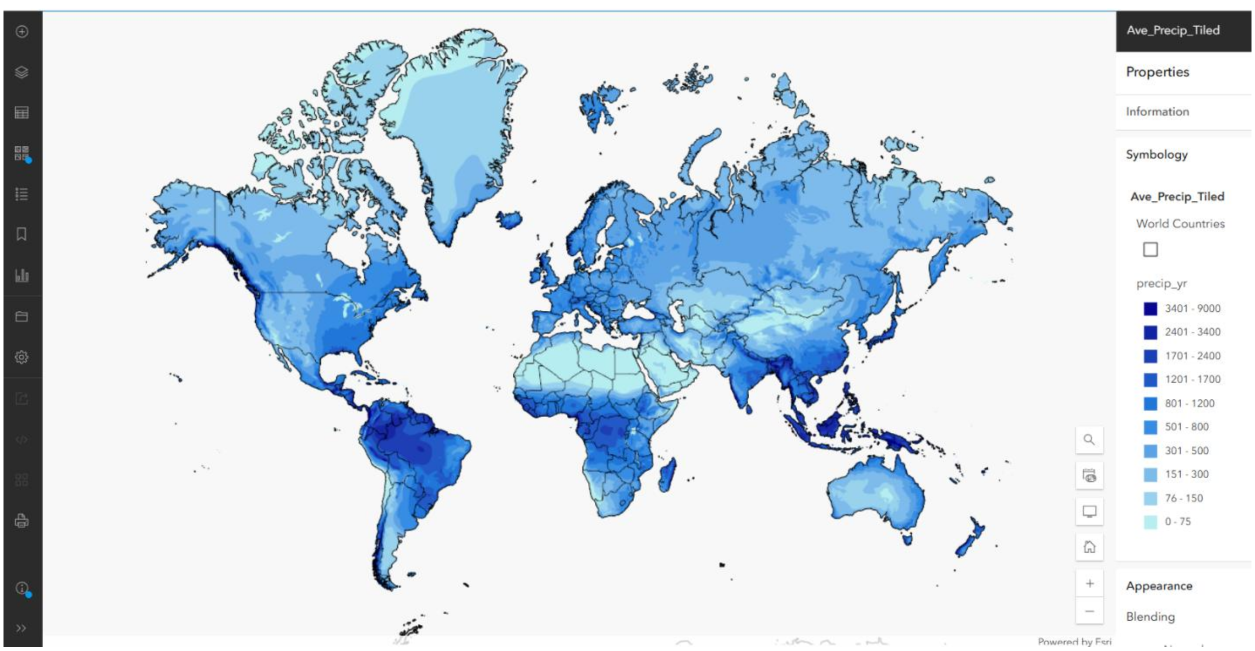

Figure 7. Global average annual precipitation (mm/year). Light shades indicate driest zones (<150 mm/year), including Coquimbo, Negev, and parts of California. Source: Adapted from Esri (2023). Available at https://education.maps.arcgis.com/apps/mapviewer/index.html

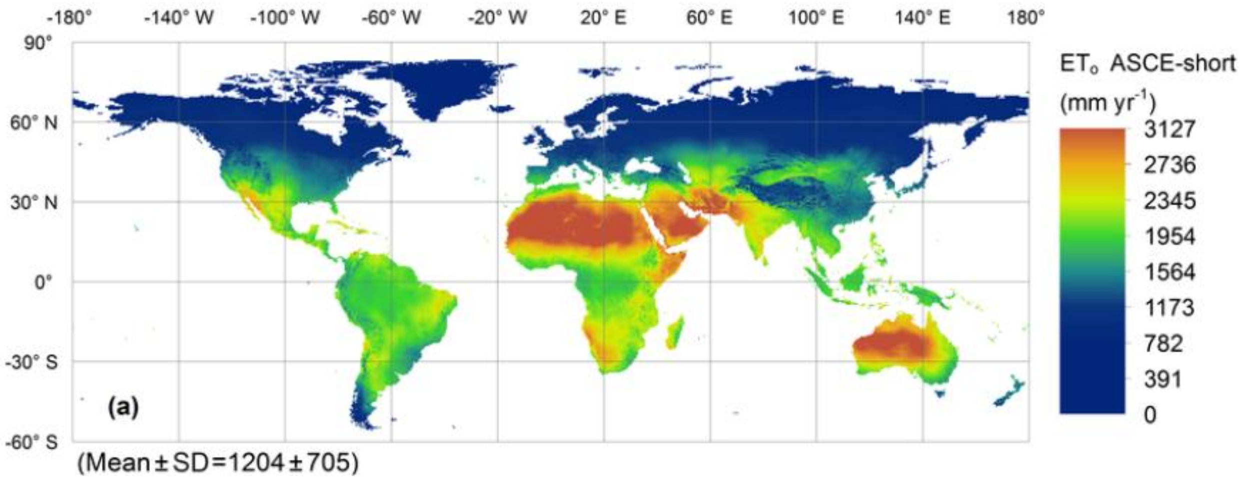

Figure 8. Mean annual reference evapotranspiration (ETo, mm/year) using the ASCE-short method (1950–2000). Reflects moderate atmospheric demand, consistent with Coquimbo field data. Source: Adapted from Landeras et al. (2017).

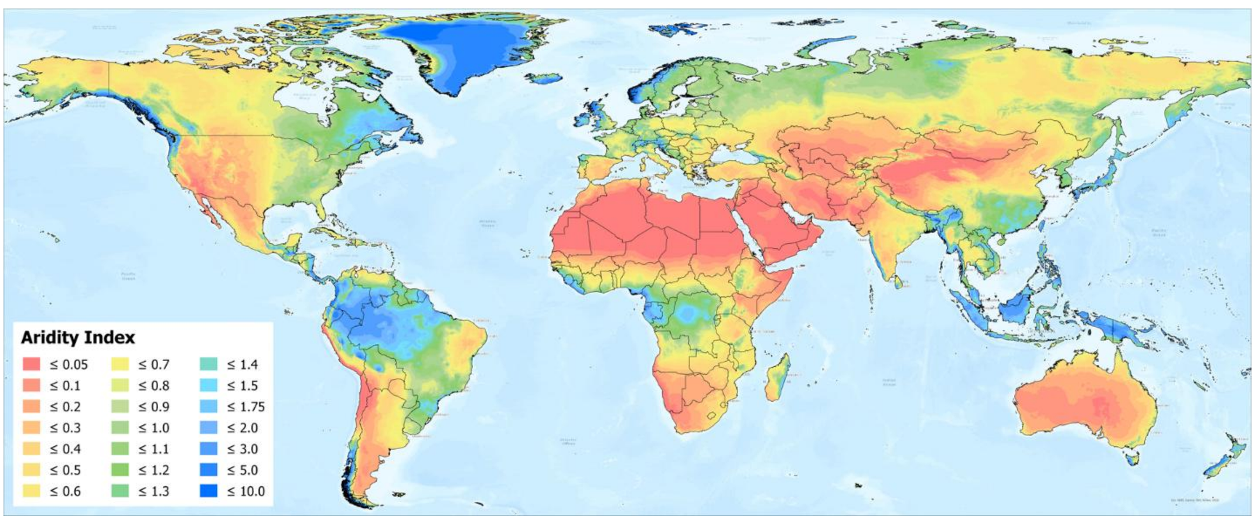

Figure 9. Global Aridity Index (AI), showing the ratio of annual precipitation to reference evapotranspiration (ET_0). Arid zones (in red/orange) include key fruit-producing areas like Coquimbo, California, and Israel. Source: CGIAR-CSI, based on Trabucco & Zomer (2022).Table 1. Climatic comparison of selected global locations based on precipitation, reference evapotranspiration (ETo), and aridity index (P/ETo).

Production costs also weigh heavily on Net EWP. Labor—often the largest cost in fruit systems—varies dramatically across regions. Table 2 and Figure 10 compare minimum wages: while Australia and California exceed USD 120 per 8-hour day, Brazil and Chile remain under USD 30. These disparities influence not only cost structures, but also orchard design and varietal choices. For instance, in high-wage regions like California or the Netherlands, mechanization and labor-efficient cultivars are priorities. Conversely, growers in Chile or Brazil still benefit from lower wages but face rising scarcity, especially during harvest peaks.

Location	Annual Precipitation (mm)	Annual Reference Evapotranspiration (ETo, mm)	Aridity Index (P/ETo)
Coquimbo (Chile)	100	1300	0.08
California Central (USA)	300	1400	0.21
Israel	400	1800	0.22
San Francisco Valley (Brasil)	600	1600	0.38
Netherlands	800	1000	0.8
Homestead (Florida, EE.UU.)	1500	1200	1.25
Tokio, Japan	1500	900	1.67
Singapure	2200	1000	2.2

Table 2. Hourly Minimum Wage and 8 Hour Day Cost (USD) per Country/Region.

Country / Region	Hourly Minimum Wage (USD)	8-Hour Day Cost (USD)
Australia	18.12	144.96
California (USA)	15.50	124.00
Netherlands	11.98	95.84
Florida (USA)	11.00	88.00
Israel	10.00	80.00
Japan	8.67	69.36
Singapore	7.45	59.6
Chile	3.46	27.68
Brazil	1.49	11.92

Sources: World Population Review, 2025 (https://worldpopulationreview.com/country-rankings/minimum-wage-by-country), U.S. State-specific minimum wage map (https://www.visualcapitalist.com/minimum-wage-around-the-world), Singapore estimation using https://www.mom.gov.sg/employment-practices/hours-of-work-overtime-and-rest-days.

Input prices—particularly fertilizers and energy—are also critical. Volatility in fertilizer markets (Figure 11) has eroded profit margins, especially for input-intensive crops like citrus and grapes. Likewise, energy costs for water pumping—especially in deep-well systems like those in Coquimbo—can significantly affect Net EWP. Pest and disease management, governed by strict export standards, adds another layer of cost and technical complexity.

Institutional context and water governance influence EWP across all regions. In Israel, a centralized system manages all water resources (OECD, 2022), applying tiered pricing and promoting reuse and efficiency (Figure 12). Nearly 90% of irrigation relies on reclaimed water, priced at USD 0.28–0.32/m³ (Greenwald, 2022), enabling high Net EWP. Chile, in contrast, has historically applied a market-based system with tradable rights ((Bauer, 2004). Although reformed in 2022 (Dirección General de Aguas [DGA], 2022), governance remains fragmented, especially in drought-affected areas like Coquimbo, where smallholders lack modern infrastructure and enforcement remains weak (Cortés, 2016; Donoso, 2021).

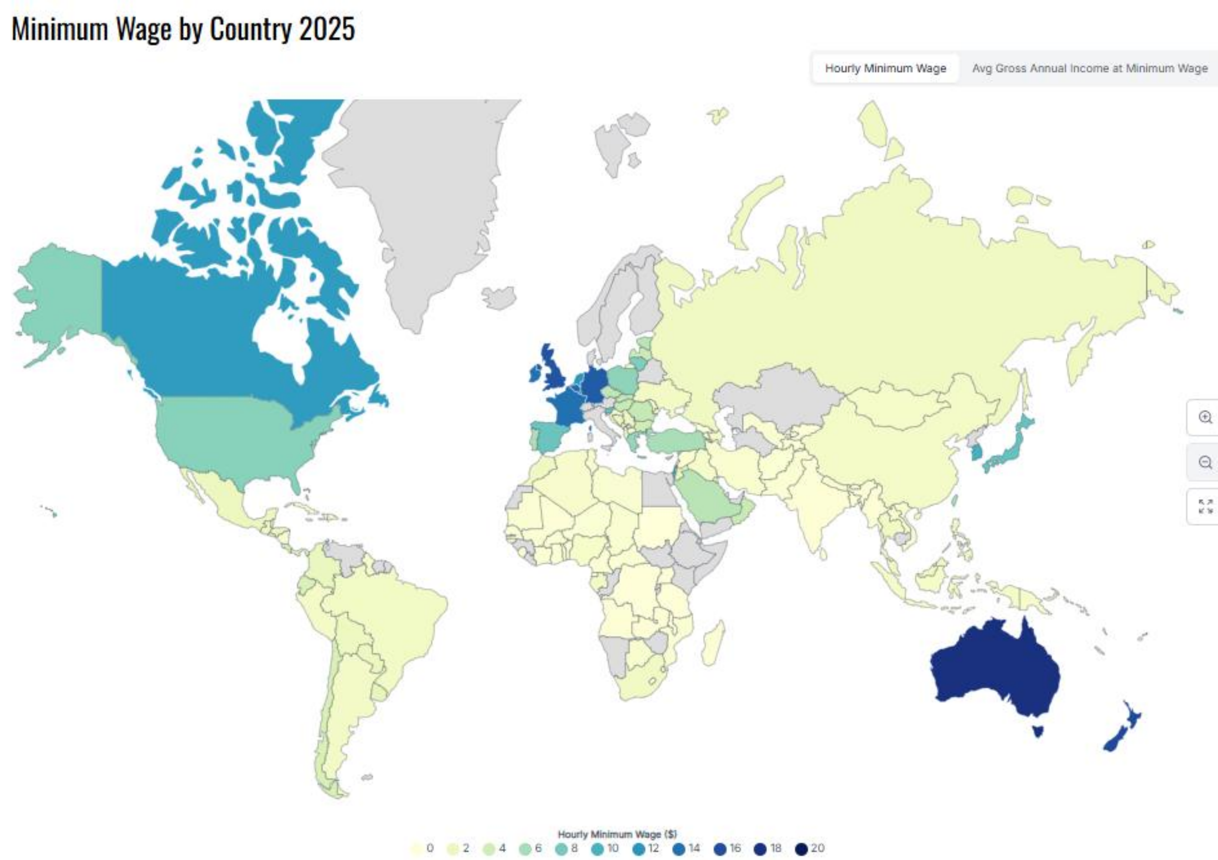

Figure 10. Minimum Wage by Country 2025 Map (USD/hour). https://worldpopulationreview.com/country-rankings/minimum-wage-by-country.

California illustrates the influence of regional hydrology and regulation. The north has more stable water supply, while the Central and Southern Valleys depend heavily on groundwater. Legislation like the Sustainable Groundwater Management Act (SGMA; California Department of Water Resources, 2025) aims to restore aquifer balance by 2042, yet high energy and conveyance costs continue to pressure Net EWP (Figure 13).

In Brazil's São Francisco Valley, large-scale irrigation supported by federal programs (CODEVASF) and the Sobradinho Dam has enabled export-oriented fruit production despite semi-arid conditions (Figure 14). However, smaller producers still face inequitable access and overuse of groundwater is an emerging concern (Costa de Barros, 2023).

Homestead (Florida) shows a more utility-driven model, where agricultural users access water via municipal networks at modest, regulated rates (USD 1.02–3.01 per 1,000 gal), with state-level cost-share programs supporting efficiency (City of Homestead, 2023). This contributes to predictable Net EWP, though hurricane risks and urban expansion remain threats ((Northwest Florida Water Management District, 2025).

In Japan, irrigation is governed by smallholder Water User Associations, supported by public subsidies and shared operation (Satoh and Ishii, 2021). Although pricing remains low to support food security, the participatory model promotes system resilience. Yet underfunding may limit modernization (Kunimitsu, 2006). In the Netherlands, water boards ensure infrastructure maintenance and flood control, though low water pricing is increasingly being questioned in sandy, water-stressed zones (OECD, 2014; Waterlution, 2017).

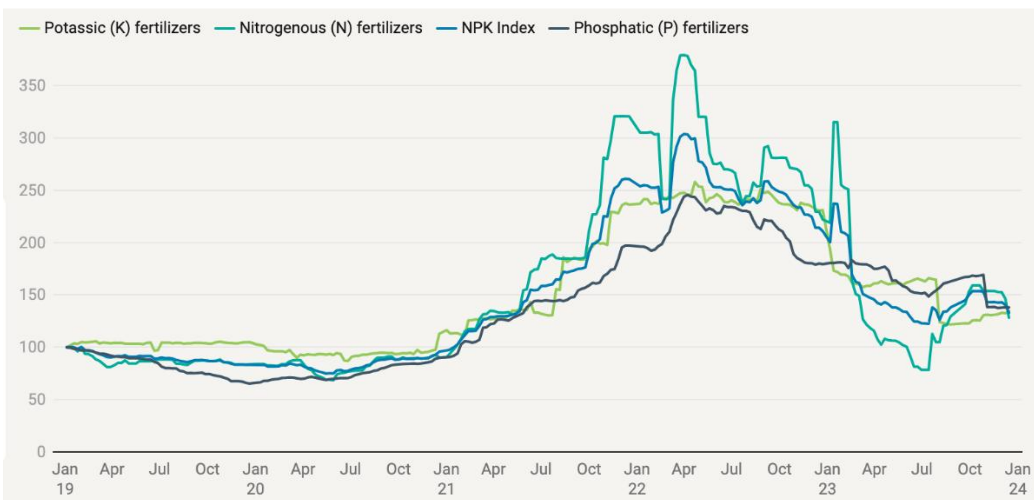

Figure 11. Trends in international fertilizer prices by nutrient (https://ssa.foodsecurityportal.org/node/2733).

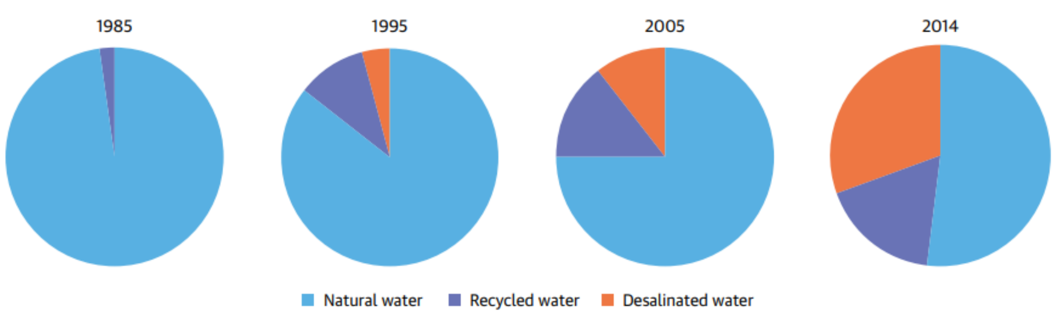

Figure 12. Breakdown of Water Sources in Israel (1985, 1995, 2005, 2014; World Bank, 2017).

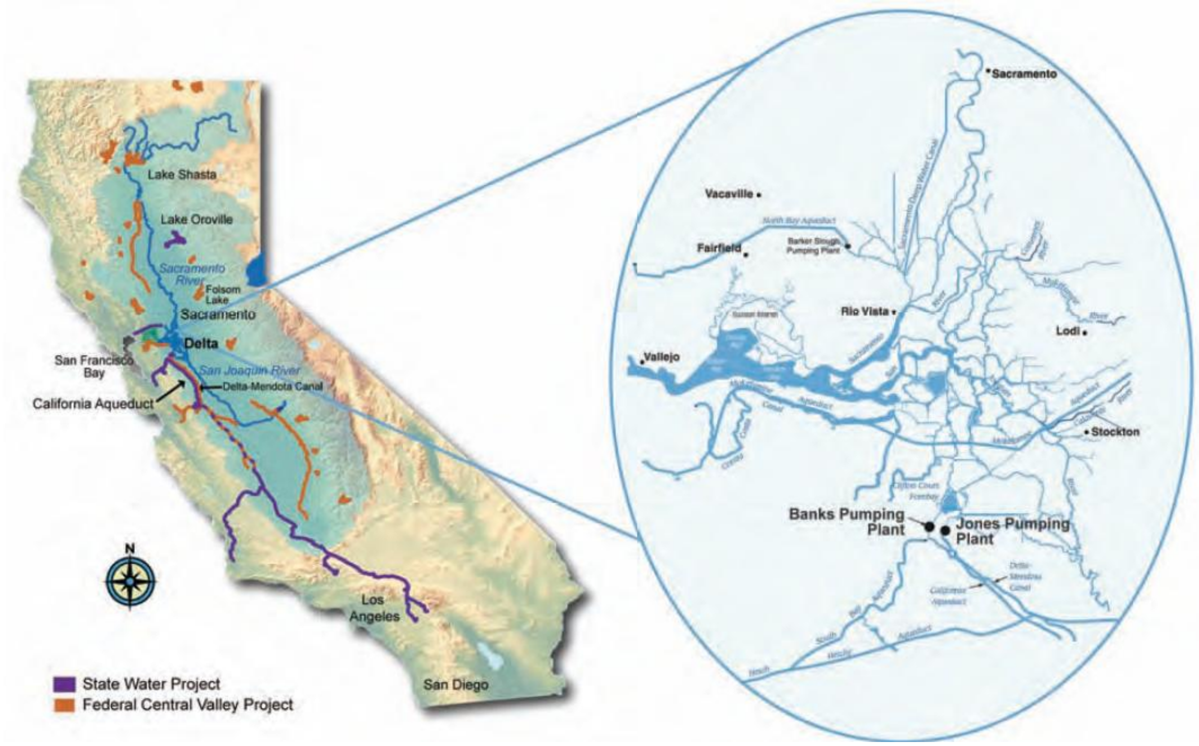

Figure 13. Major water conveyance systems transporting water from Northern to Southern California, including the State Water Project and Central Valley Project (Anderson et al., 2009).

Singapore, while not a major fruit producer, demonstrates the value of integrated governance. Its "Four National Taps" approach (rainwater, imported, desalinated, and recycled water) underpins a diversified and resilient supply strategy, supported by full-cost pricing and conservation incentives (Public Utilities Board [PUB], n.d);. Although its domestic fruit area is minimal, Singapore is a key premium destination for high-value exports thanks to robust infrastructure and consumer trust.

Finally, postharvest logistics influence EWP by protecting the economic value of water embedded in fruit. Cold chain systems, centralized packing, and proximity to ports can make or break Net returns—especially in export-reliant countries like Chile, where fruit must travel over 13,000 km to market (Figure 15). A breakdown in postharvest quality means not only lost fruit, but wasted water. The contrast between Chile's advanced cold chain and Brazil's informal systems (Figures 16a–16b) highlights how postharvest strategy impacts overall water productivity.

In sum, EWP is shaped by a mosaic of crop biology, market forces, labor and input dynamics, governance structures, climate, and postharvest systems. Maximizing returns per cubic meter of water demands integrated planning across all of these dimensions.

Figure 14. San Francisco River and its drainage network (Encyclopedia Britannica, n.d.).

List of exporters for the selected product in 2024
Product : 08 Edible fruit and nuts; peel of citrus fruit or melons

Table | Graph | Map | Companies

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1 2 3 4 5 6 7 8 9

HS4	Exporters	Value exported in 2024 (USD thousand)	Trade balance in 2024 (USD thousand)	Annual growth in value between 2020-2024 (%)	Annual growth in value between 2023-2024 (%)	Share in world exports (%)	Average distance of importing countries (km)	Concentration of importing countries
	World	160,385,716	-11,598,105	4	12	100	4,704	0.06
⊞	United States of America	16,420,916	-9,603,632	3	10	10.2	7,092	0.09
⊞	Spain	11,244,635	6,545,679	-1	6	7	1,563	0.14
⊞	Mexico	9,563,912	7,545,152	7	10	6	2,090	0.82
⊞	Netherlands	9,388,174	514,871	3	11	5.9	746	0.15
⊞	Chile	8,289,353	7,895,884	8	24	5.2	13,400	0.21
⊞	Viet Nam	7,806,479	3,378,265	18	26	4.9	5,612	0.28
⊞	China	7,211,550	-12,846,337	0	22	4.5	4,189	0.08
⊞	Thailand	6,650,673	5,089,571	11	-4	4.1	2,993	0.75
⊞	Peru	6,470,056	6,332,841	13	18	4	8,539	0.23
⊞	Türkiye	6,296,395	4,849,142	5	17	3.9	2,831	0.06
⊞	South Africa	4,946,288	4,747,223	5	13	3.1	9,235	0.1
⊞	Italy	4,590,156	-57,246	1	7	2.9	1,536	0.12
⊞	Ecuador	4,267,536	4,120,220	3	4	2.7	9,525	0.09
⊞	Belgium	3,148,450	-442,333	5	8	2	664	0.15
⊞	New Zealand	2,878,206	2,534,248	0	34	1.8	9,928	0.13

Figure 15. Leading fruit-exporting countries and their average distance to importing markets (ITC TradeMap, 2025).

Figures 16a (left) and 16b (right). Postharvest contrast at CEAGESP: (16a) Imported fruit like Chilean grapes stored refrigerated; (16b) Local tropical fruit displayed without cooling—revealing infrastructure and market value differences.

C. Methodological Challenges

While Economic Water Productivity (EWP) offers a powerful framework for evaluating irrigation efficiency in economic terms, its application in real-world settings poses several methodological challenges that affect accuracy, comparability, and policy relevance.

Data limitations are among the most critical constraints. Reliable estimates of yield, water use, prices, and costs are often inconsistent—especially among smallholders or in countries lacking robust monitoring systems. Studies report discrepancies over 30% in farm-level water and yield data, making it difficult to benchmark EWP across crops or regions (Giordano et al., 2017).

Price and input cost volatility further complicate EWP estimation. A crop may appear efficient in terms of water use one season but yield poor net returns if fertilizer, labor, or fuel prices surge unexpectedly. The fertilizer price spike of 2021–2022 and its rapid decline in 2023–2024 (World Bank, 2024) exemplify how EWP values can vary dramatically, even when yields and water inputs remain stable.

In diversified farm systems, allocating shared costs—such as machinery or labor—to specific crops is rarely straightforward. Misallocation leads to distorted Net EWP values, especially in small- and medium-scale operations (Cazcarro & Bielsa, 2020).

Moreover, standard EWP calculations exclude value-chain and ecosystem externalities. Postharvest performance, branding, rural employment, or environmental benefits (like pollination or carbon sequestration) are rarely monetized—despite their contribution to farm resilience and sustainability. Ignoring these broader outcomes can lead to overly narrow definitions of efficiency (Cazcarro & Bielsa, 2020; Giordano et al., 2017).

Contextual aggregation adds another layer of complexity. Averaging EWP data across regions or river basins may obscure key differences in farm size, climate, or technology uptake. This has been documented in cases like the Colorado River Basin, where aggregated indicators often fail to reflect on-the-ground variability (Frisvold & Atla, 2024).

These challenges have led to calls for expanding EWP beyond its conventional definitions. The Extended EWP framework incorporates non-market outcomes such as jobs, sustainability branding, or multifunctional landscapes. Integrated EWP seeks to combine gross revenue, net profitability, and broader socio-environmental values into a unified assessment lens—particularly useful for guiding policy or investment decisions in climate-stressed regions.

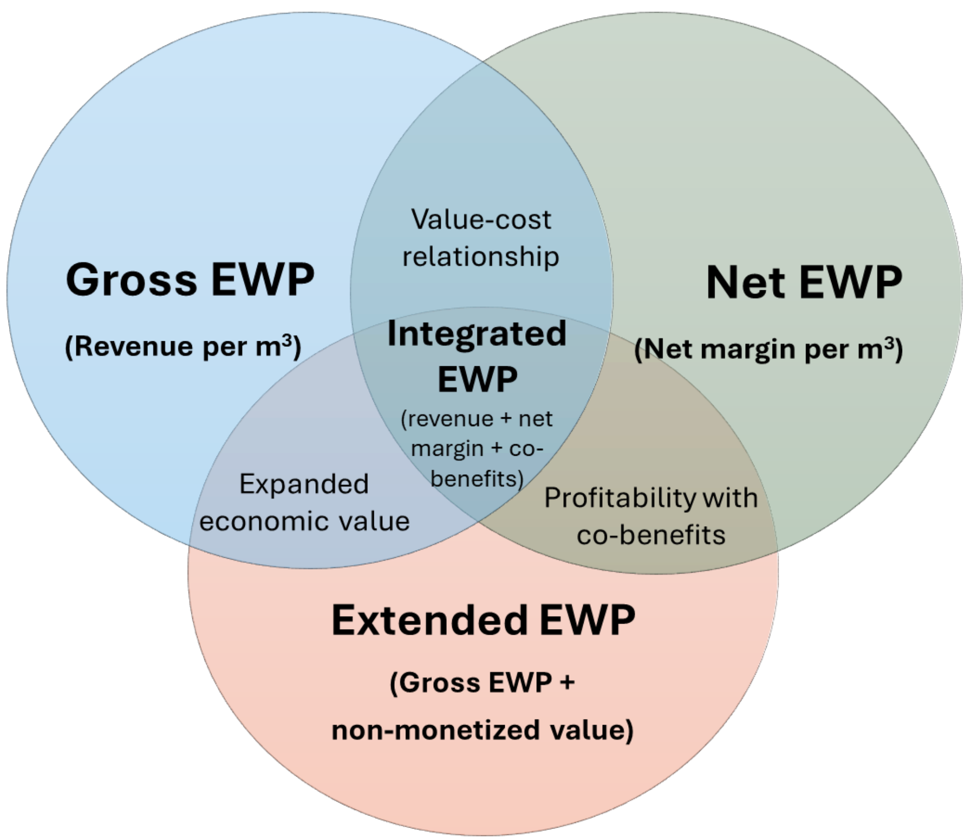

Figure 17. Conceptual intersections of Gross, Net, and Extended Economic Water Productivity (EWP).

This Venn diagram illustrates how EWP can be viewed at different levels:

- Gross EWP: revenue per m^3, excluding costs. Useful for comparing crops and setting initial priorities.
- Net EWP: subtracts costs, offering a profitability view. Relevant for investment decisions and farm planning.
- Extended EWP: integrates ecosystem services, branding, or social benefits. Important for sustainability-oriented systems.

The intersection of all three—Integrated EWP—represents the optimal balance between revenue, cost-efficiency, and long-term resilience. While difficult to quantify precisely, this perspective aligns with the increasing need for agriculture to deliver not just yield, but value per drop, across economic, social, and environmental dimensions.

IV. Water-Scarce Contexts: Adapting Under Constraint

Innovating Under Pressure: How Agricultural Systems Transform Under Severe Water Scarcity

A. Israel: Policy-Driven Efficiency and Innovation at the Edge of Viability

Israel is a global reference for water-scarce agriculture. Receiving less than 300 mm of annual rainfall, its transformation into a highly productive and technologically advanced agricultural system has been driven by three pillars: infrastructure, regulation, and innovation. Israel's National Water Carrier, integrating desalination, groundwater, surface water, and treated wastewater, allows flexible and reliable distribution. Over 85% of municipal wastewater is recycled, mainly for agriculture (IMFA, 2018), making it a world leader in reuse.

Volumetric pricing by source and quality creates strong economic incentives for water efficiency. Drip irrigation, fertigation, and remote sensing are standard. According to Giordano et al. (2017), Israel achieves some of the highest economic water productivity (EWP) values in fruit crops globally, especially in citrus, avocado, and dates—driven by technology adoption, reuse practices, and market integration.

Innovation is underpinned by public institutions like the Volcani Center and companies such as Netafim. R&D is aligned with on-farm needs, ensuring rapid translation into practice. Universities and extension services complete a powerful ecosystem. Figure 18 shows how Israel shifted from oranges to avocados, mandarins, grapes, and dates from 1961–2023. Export patterns mirror this, with dates and avocados dominating fruit exports (Figure 19).

Site visits confirmed this transformation. Neot Semadar Kibbutz (Figure 20) exemplifies circular, diversified farming in the desert, combining orchards, dairy, tourism, processing, and art. The date plantations (Figure 21) showcase the adaptability of desert crops to efficient irrigation. At Netafim (Figures 22–23), advanced R&D is paired with commercial applications. Figure 24 depicts a vertically integrated nursery-orchard system, reducing cost and risk.

Mahane Yehudah Market (Figure 25) illustrates that proximity between production and consumption remains central—even in tech-intensive systems. In Israel, EWP is not abstract—it is the organizing logic of both public policy and farmer practice. Water scarcity has been transformed into a design constraint that fosters systemic efficiency and innovation.

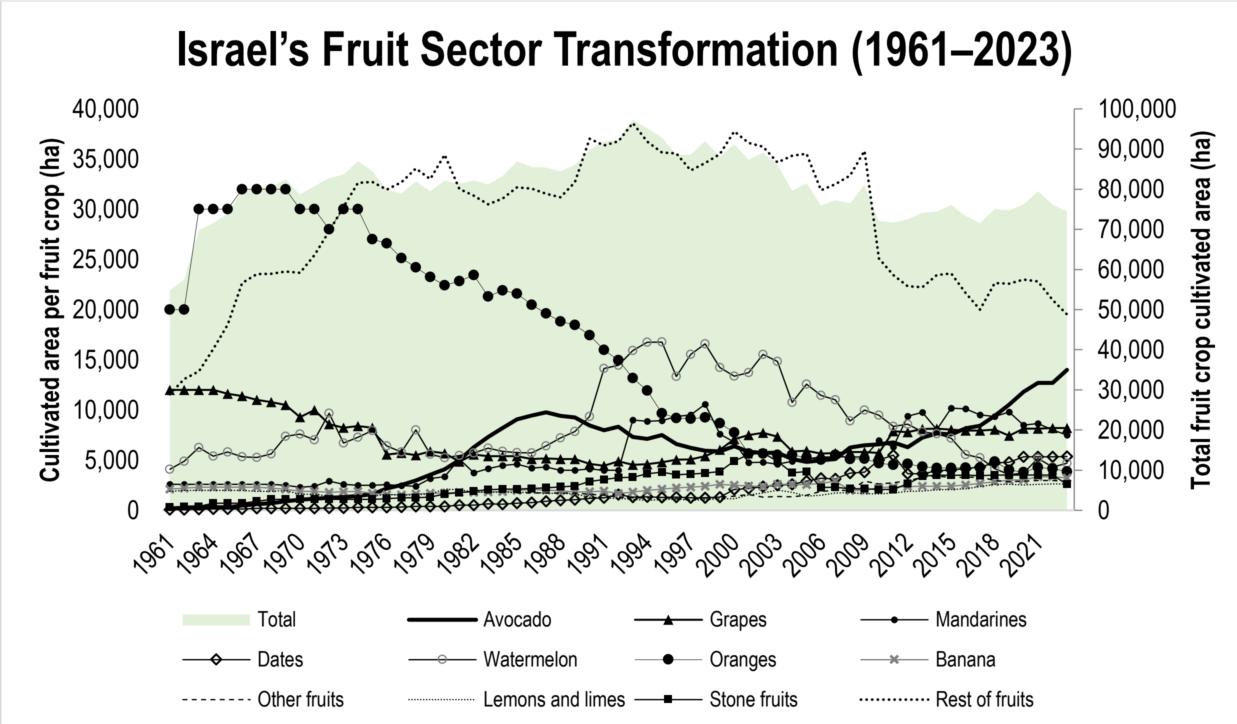

Figure 18. Israel’s Fruit Sector Transformation (1961–2023)
Source: Author, based on FAOSTAT (https://www.fao.org/faostat/en/#data/QCL)

List of products exported by Israel
detailed products in the following category: 08 Edible fruit and nuts; peel of citrus fruit or melons

Unit : US Dollar thousand

Table | Graph | Map | Companies

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HS6	Code	Product label	Exported value in 2020	Exported value in 2021	Exported value in 2022	Exported value in 2023	Exported value in 2024
	0804	Dates, figs, pineapples, avocados, guavas, mangoes and mangosteens, fresh or dried	343,025	429,260	469,788	546,419	533,590
	0805	Citrus fruit, fresh or dried	222,500	213,043	202,751	272,271	154,845
	0810	Fresh strawberries, raspberries, blackberries, back, white or red currants, gooseberries and . . .	29,291	24,339	26,453	23,046	15,804
	0811	Fruit and nuts, uncooked or cooked by steaming or boiling in water, frozen, whether or not . . .	37,735	49,525	34,226	10,649	5,632
	0813	Dried apricots, prunes, apples, peaches, pears, papaws "papayas", tamarinds and other edible . . .	214	97	51	129	140
	0812	Fruit and nuts, provisionally preserved, e.g. by sulphur dioxide gas, in brine, in sulphur . . .	7	26	38	33	26
	0802	Other nuts, fresh or dried, whether or not shelled or peeled (excl. coconuts, Brazil nuts and . . .	2,110	120	462	970	25
	0801	Coconuts, Brazil nuts and cashew nuts, fresh or dried, whether or not shelled or peeled	1	2	3	181	6
	0806	Grapes, fresh or dried	360	0	304	19	4
	0809	Apricots, cherries, peaches incl. nectarines, plums and sloes, fresh	0	6	0	0	1
	0803	Bananas, incl. plantains, fresh or dried	0	0	0	0	0
	0807	Melons, incl. watermelons, and papaws "papayas", fresh	65	96	38	70	0
	0808	Apples, pears and quinces, fresh	65	0	0	0	0
	0814	Peel of citrus fruit or melons, incl. watermelons, fresh, frozen, dried or provisionally preserved . . .	427	320	0	18	0

Sources: ITC calculations based on UN COMTRADE statistics.

Figure 19. Fruit exports by Israel under HS08 – Edible fruit and nuts (2024)
Source: TRADEMAP (https://www.trademap.org)

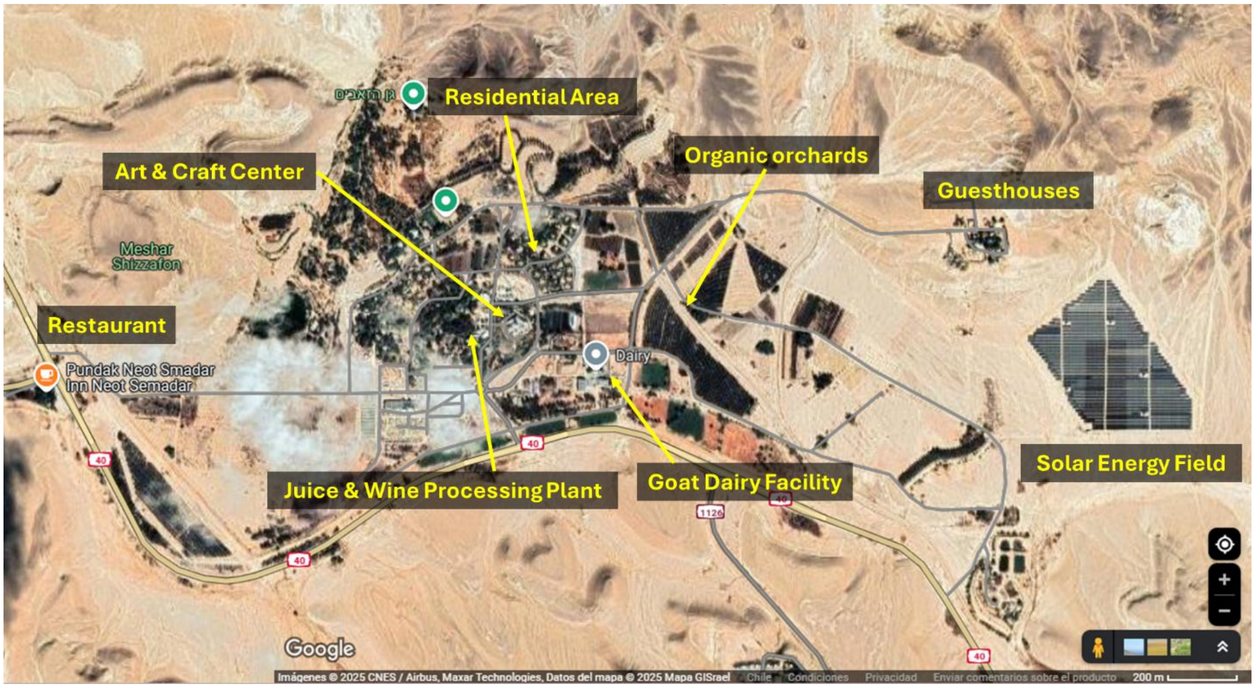

Figure 20. Aerial view of Neot Semadar Kibbutz. A diversified desert community combining agriculture, processing, energy, tourism, and arts. https://neot-semadar.com/en/

Figure 21. Date palm plantation in the Negev Desert. Traditional high-value crop adapted to arid conditions, managed with precision irrigation.

Figure 22. Netafim Research & Training Park, Hatzerim. Global hub for smart irrigation innovation and collaboration in desert agriculture.

Figure 23. Demonstration orchard with soil and plant sensors. Advanced monitoring tools optimize water use and crop performance.

Figure 24. Avocado nursery inside a commercial orchard. Integrated production: growers propagate their own trees for on-farm expansion.

Figure 25. Mahane Yehudah Market, Jerusalem. Fresh, high-quality fruits close to consumers—small-scale farms, big impact.

B. California (USA): Transforming Under Stress—Structural Change in the Age of Water Scarcity

California produces over 13% of U.S. agricultural output by value, with a fruit sector rooted in almonds, pistachios, grapes, and citrus. Historically supported by generous water allocations, this model is now in transition. SGMA (2014) requires sustainable aquifer management by 2040, responding to decades of overuse and intensifying drought cycles. Mount et al. (2021) document increasing drought severity and temperature rise (Figure 26).

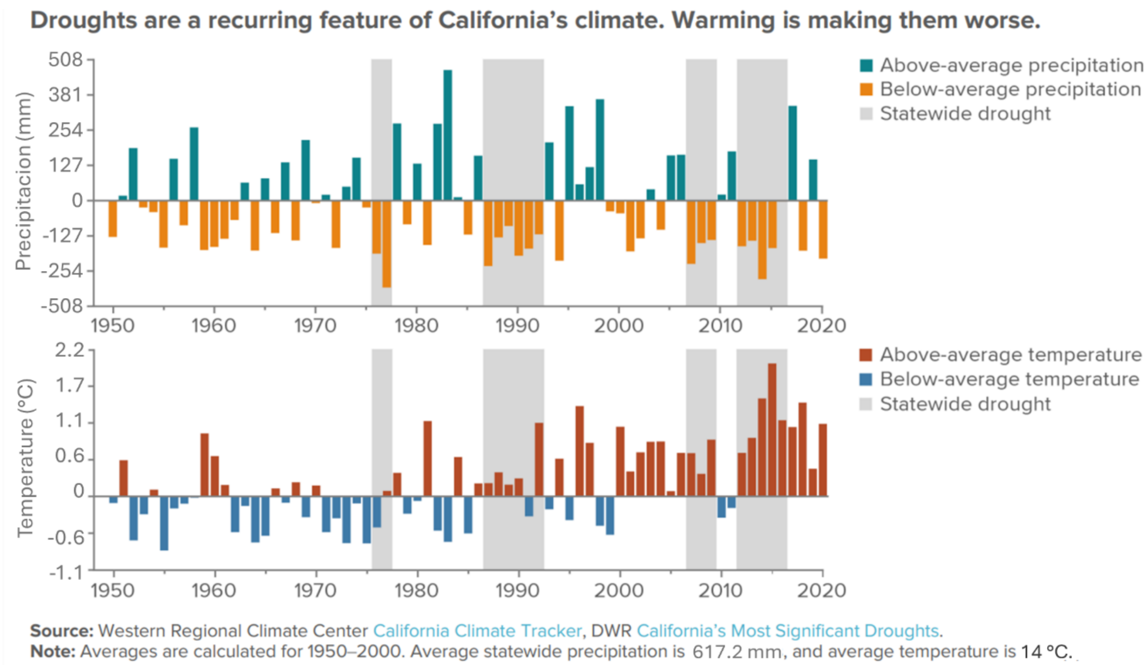

Figure 26. California Droughts, Precipitation, and Temperature Trends (1950–2020) Source: Mount et al. (2021). Droughts in California. Public Policy Institute of California.

Farmers have responded with structural change. Almonds and pistachios now dominate acreage in several counties (Figures 27–28), favored for export value, mechanization, and drought resilience. In 2024, the U.S. exported USD 16.4 billion in fruits and nuts, led by these crops (Figure 29). Imports (USD 26 billion; Figure 30) highlight global interdependence and domestic supply gaps.

Field observations in the Central Valley confirmed both stress and innovation. Large infrastructure like the State Water Project (Figure 31) coexists with on-farm adaptation such as the Meyers Water Bank (Figure 32). Yet social tensions persist—evident in protest signs like "Is growing food wasting water?" (Figure 33), reflecting competition among agricultural, urban, and environmental needs.

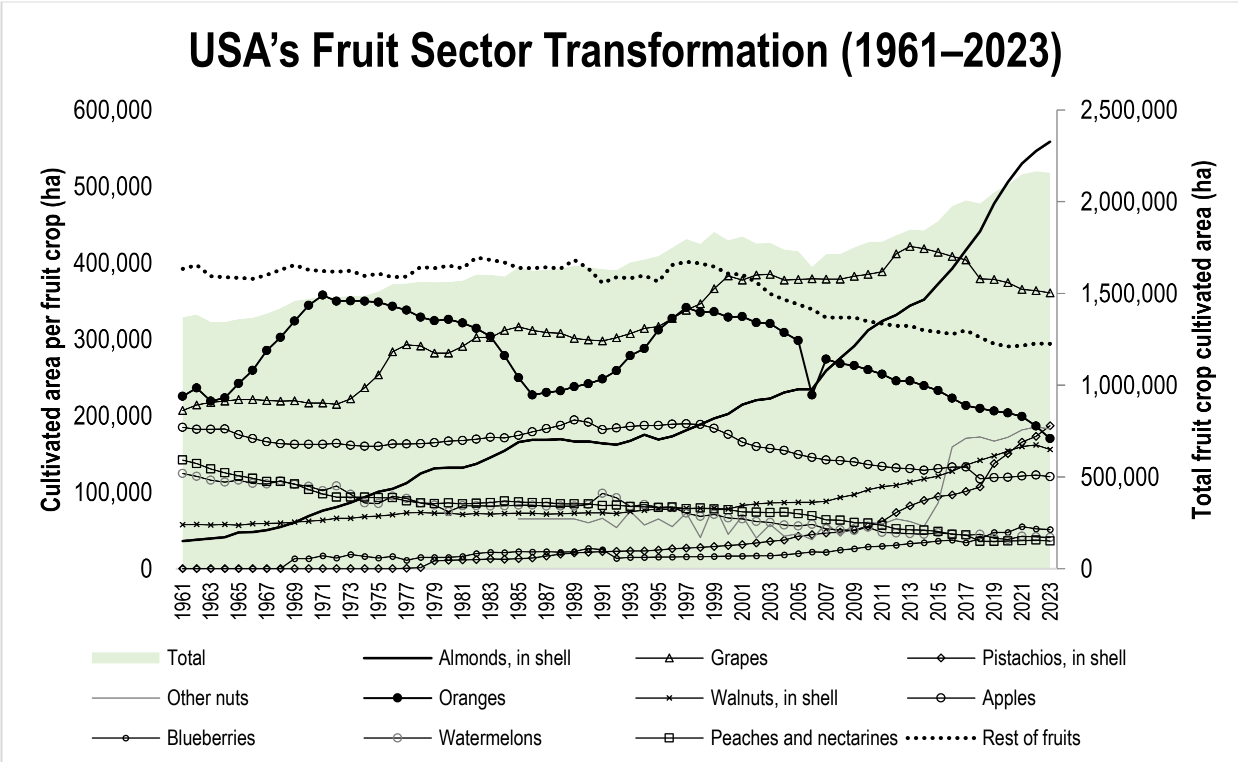

Figure 27. USA's Fruit Sector Transformation (1961–2023)
Source: Author, based on FAOSTAT.

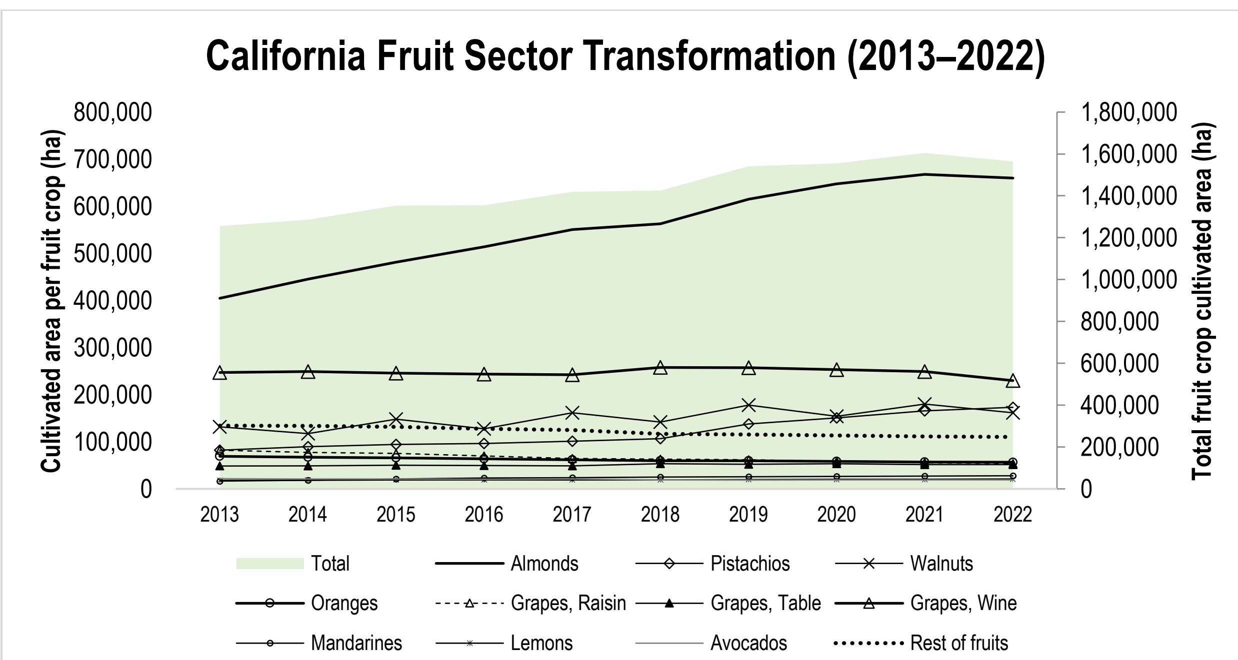

Figure 28. California Fruit Sector Transformation (2013–2022)
Source: Author, based on California Department of Food and Agriculture (CDFA), 2023).

List of importing markets for the product exported by United States of America in 2024
Product: 08 Edible fruit and nuts; peel of citrus fruit or melons
United States of America's exports represent **10.2%** of world exports for this product, its ranking in world exports is **1**
The average distance of importing countries is **7092 km** and the export concentration is **0.09**

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1 2 3 4 5 6 7 8 9

Select your indicators

Bilateral trade at 4-digit	Importers	Value exported in 2024 (USD thousand)	Trade balance 2024 (USD thousand)	Share in United States of America's exports (%)	Growth in exported value between 2020-2024 (%, p.a.)	Growth in exported value between 2023-2024 (%, p.a.)	Ranking of partner countries in world imports	Share of partner countries in world imports (%)	Total imports growth in value of partner countries between 2020-2024 (%, p.a.)	Average distance between partner countries and all their supplying markets (km)	Concentration of all supplying countries of partner countries	Average tariff (estimated) faced by United States of America (%)
	World	16,420,916	-9,603,632	100	3	10		100	5			
⊞	Canada	4,199,212	3,638,372	25.6	4	5	7	3.5	4	4,572	0.19	0
⊞	Mexico	1,371,520	-9,708,083	8.4	9	19	19	1.2	15	2,991	0.57	0
⊞	India	1,160,838	1,090,441	7.1	5	4	10	2.7	9	7,835	0.09	32.2
⊞	China	950,478	824,901	5.8	4	-15	2	11.7	12	7,817	0.18	14.6
⊞	Germany	722,833	713,112	4.4	-5	30	3	7.8	2	4,759	0.07	10
⊞	Korea, Republic of	700,709	647,514	4.3	-4	13	18	1.2	4	9,025	0.16	18.1
⊞	Japan	627,603	626,039	3.8	-8	0	15	1.8	-3	7,739	0.14	10.3
⊞	Spain	606,329	579,271	3.7	-4	15	8	2.7	6	5,837	0.07	10
⊞	United Arab Emirates	594,373	590,462	3.6	12	30	17	1.4	12	6,905	0.11	1.4
⊞	Viet Nam	525,600	-568,225	3.2	16	53	12	2.6	0	6,089	0.18	17.4
⊞	Türkiye	520,850	289,744	3.2	23	4	25	0.8	13	6,826	0.16	62.9
⊞	Netherlands	481,277	481,053	2.9	1	26	4	5.2	1	6,215	0.06	10

Figure 29. U.S. Fruit and Nut Exports (HS08) – Top Destinations (2024)
Source: TRADEMAP (https://www.trademap.org)

List of supplying markets for the product imported by United States of America in 2024
Product: 08 Edible fruit and nuts; peel of citrus fruit or melons
United States of America's imports represent **15.1%** of world imports for this product, its ranking in world imports is **1**
The average distance of supplying countries is **4487 km** and the market concentration is **0.22**

Table | Graph | Map | Companies

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1 2 3 4 5 6 7 8 9

Select your indicators

Bilateral trade at 4-digit	Exporters	Value imported in 2024 (USD thousand)	Trade balance 2024 (USD thousand)	Share in United States of America's imports (%)	Growth in imported value between 2020-2024 (%, p.a.)	Growth in imported value between 2023-2024 (%, p.a.)	Ranking of partner countries in world exports	Share of partner countries in world exports (%)	Total exports growth in value of partner countries between 2020-2024 (%, p.a.)	Average distance between partner countries and all their importing markets (km)	Concentration of all importing countries of partner countries	Average tariff (estimated) applied by United States of America (%)
	World	26,024,548	-9,603,632	100	7	7		100	4			
⊞	Mexico	11,079,603	-9,708,083	42.6	7	2	3	6	7	2,090	0.82	0
⊞	Peru	2,976,394	-2,934,447	11.4	14	12	9	4	13	8,539	0.23	0
⊞	Chile	2,512,074	-2,465,096	9.7	3	18	5	5.2	8	13,400	0.21	0.1
⊞	Guatemala	1,749,945	-1,694,301	6.7	6	-2	28	1	8	3,474	0.75	0
⊞	Costa Rica	1,478,713	-1,452,391	5.7	7	7	16	1.7	6	6,630	0.23	0
⊞	Viet Nam	1,093,825	-568,225	4.2	-3	33	6	4.9	18	5,612	0.28	2
⊞	Ecuador	865,179	-856,998	3.3	9	24	13	2.7	3	9,525	0.09	1.3
⊞	Colombia	561,781	-514,394	2.2	20	33	24	1.1	7	7,747	0.13	0
⊞	Canada	560,840	3,638,372	2.2	8	-5	36	0.5	4	3,070	0.55	0
⊞	Honduras	431,655	-412,237	1.7	5	-5	47	0.2	5	3,283	0.79	0
⊞	South Africa	266,700	-249,477	1	8	6	11	3.1	5	9,235	0.1	0
⊞	Argentina	254,344	-248,032	1	5	13	39	0.4	-6	7,043	0.18	1.3

Figure 30. U.S. Fruit and Nut Imports (HS08) – Top Suppliers (2024)
Source: TRADEMAP (https://www.trademap.org)

Fresno County leads in agricultural value (Figure 34), with farms like Bowles Company showing diversification across crops and management systems (Figure 35). At HMC Farms, varietal renewal, mechanization, and sustainable packaging redefine competitiveness. Technological tools—subsurface irrigation, sensors, trunk dendrometers—are widely adopted (Figure 36).

Markets are equally important. Sprouts Farmers Market (Figures 37–38) exemplifies rising demand for organic, healthy, and value-added products. Farmers now adapt to retail trends, not just climate. Flexibility is key: annual crops expand in wet years; perennial fruit holds priority in dry seasons. California's model is complex, decentralized, and often fragmented—but it is moving toward higher-value, climate-smart systems shaped by market forces and regulation alike.

Figure 32. Groundwater Recharge Basins – Meyers Water Bank, Mendota. On-farm water banking to recharge aquifers using surface allocations, increasing drought resilience through managed aquifer recharge.

Figure 33. Abandoned Orchard with Sign: "Is Growing Food Wasting Water?" Visual representation of water-use conflicts in times of drought, where agriculture competes with urban and environmental demands.

Figure 34. Fresno County Farm Bureau. Top 10 Agricultural Commodities in Fresno County. Main crops include almonds, grapes (table, raisin, wine), pistachios, poultry, and milk—highlighting the region's diversity and economic scale.

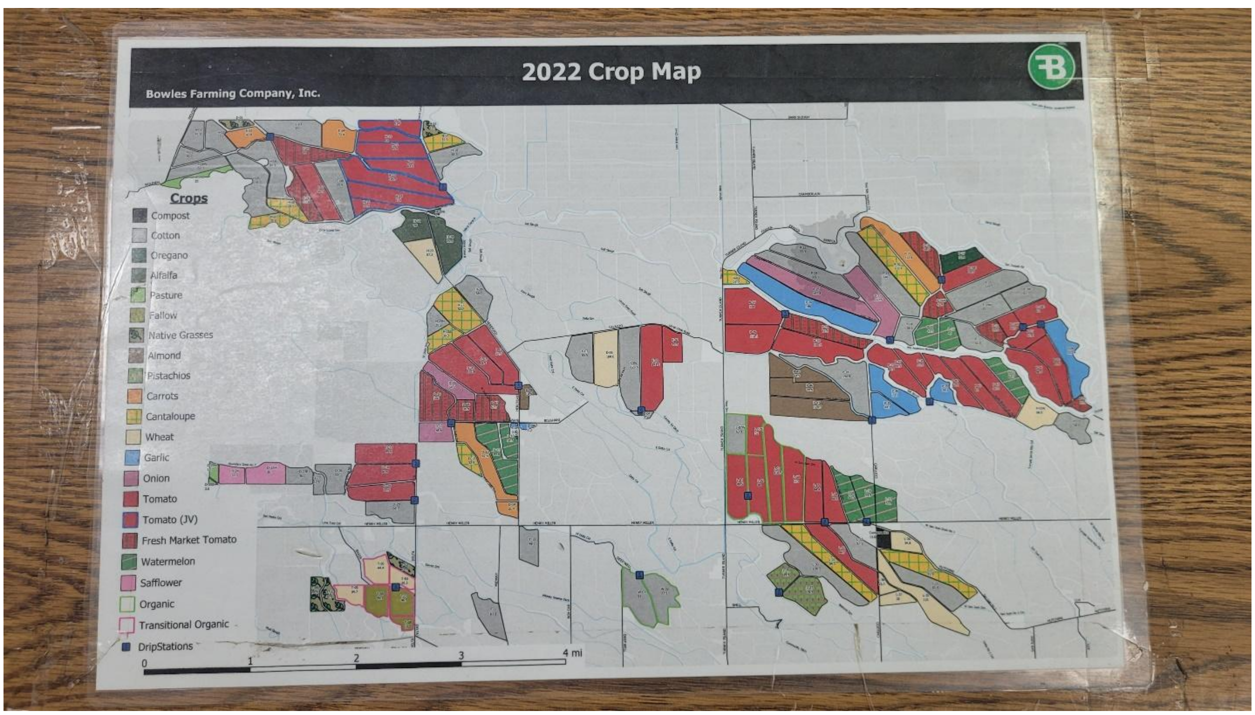

Figure 35. 2022 Crop Map – Bowles Farming Company. Diversified production system integrating vegetables, cotton, and fruits with both conventional and organic management, including sustainable practices such as composting and native grass cover.

Figure 36. Almond Orchard with Precision Irrigation and Soil Sensors. Use of trunk dendrometers, soil moisture probes, and cover crops to enhance irrigation efficiency and soil health.

Figure 37. Sprouts Farmers Market. Retail chain specializing in fresh, healthy, and differentiated products—organic fruits and value-added foods for health-conscious consumers.

Figure 38. Sprouts Farmers Market. Value-added fruits.

C. Chile, Coquimbo Region: Building Resilience through Diversification and Collective Action

Chile's fruit sector has expanded dramatically since the 1960s, with recent shifts toward high-value crops like cherries and hazelnuts (Figures 39–40). However, the Coquimbo Region tells a more constrained story—defined by drought, limited infrastructure, and mounting market pressure.

Fifteen years of hydrological drought have slashed precipitation (Figure 41) and water reserves in the La Paloma Reservoir (Figure 42). Coquimbo's fruit mix historically centered on table grapes, yet recent years have seen diversification into mandarins, lemons, and olives—species more compatible with declining water availability and changing market dynamics (Figure 43).

While the region still accounts for 17% of table grape and nearly half of mandarin production in Chile, it faces declining competitiveness. Average export prices fell to just 68% of the national average by 2024 (Figure 44).

Still, Coquimbo has demonstrated notable breakthroughs. In 2024, the first organic table grapes were exported to the U.S., achieving a 2.2× price premium over conventional grapes (Figure 45). This was possible also with the implementation of the Systems Approach protocol, allowing fumigation-free exports of table grapes to the U.S., improving fruit quality and logistic.

Water economics has become a guiding force in decision-making. A 2018 study (Muñoz, 2023) estimated the average gross Economic Water Productivity (EWP) in Limarí Province at 3.52 USD/m³, with mandarins and cherries leading in value per drop. A 2021 update from the PER Fruticultura Sustentable Coquimbo included costs and labor, estimating net margins per m³ of water. Cherries and lemons topped the chart with net margins of 1.92 and 1.79 USD/m³, respectively, reflecting their rising dominance in new plantings (Figure 46).

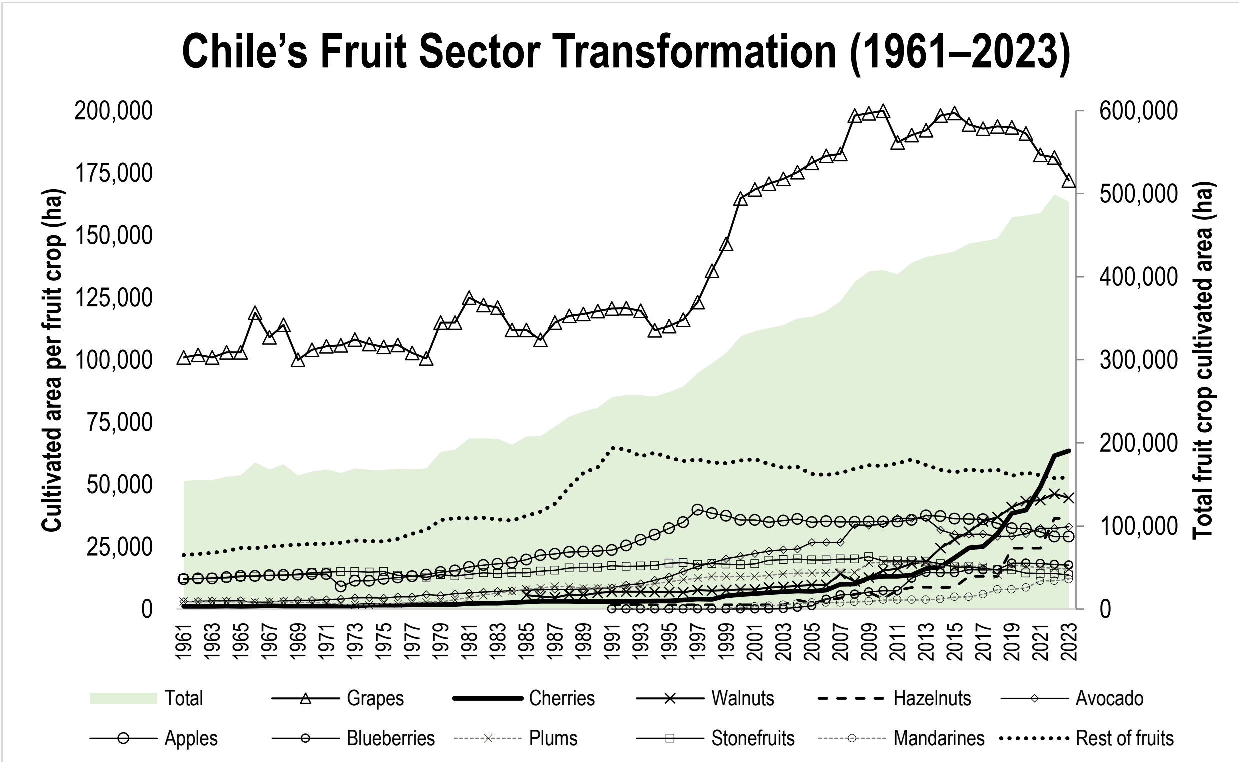

Figure 39. Chile's Fruit Sector Transformation (1961–2023). Source: Author, based on FAOSTAT.

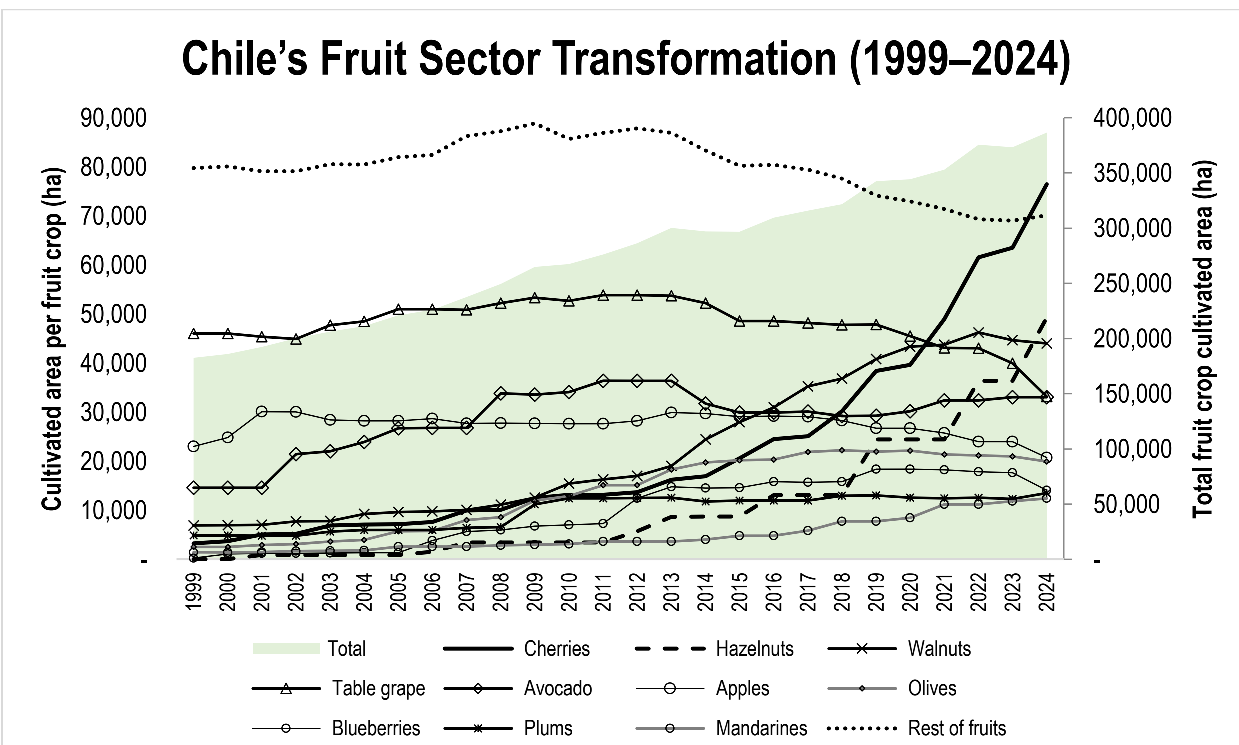

Figure 40. Chile's Fruit Sector Transformation (1999–2024). Source: Author, based on ODEPA.

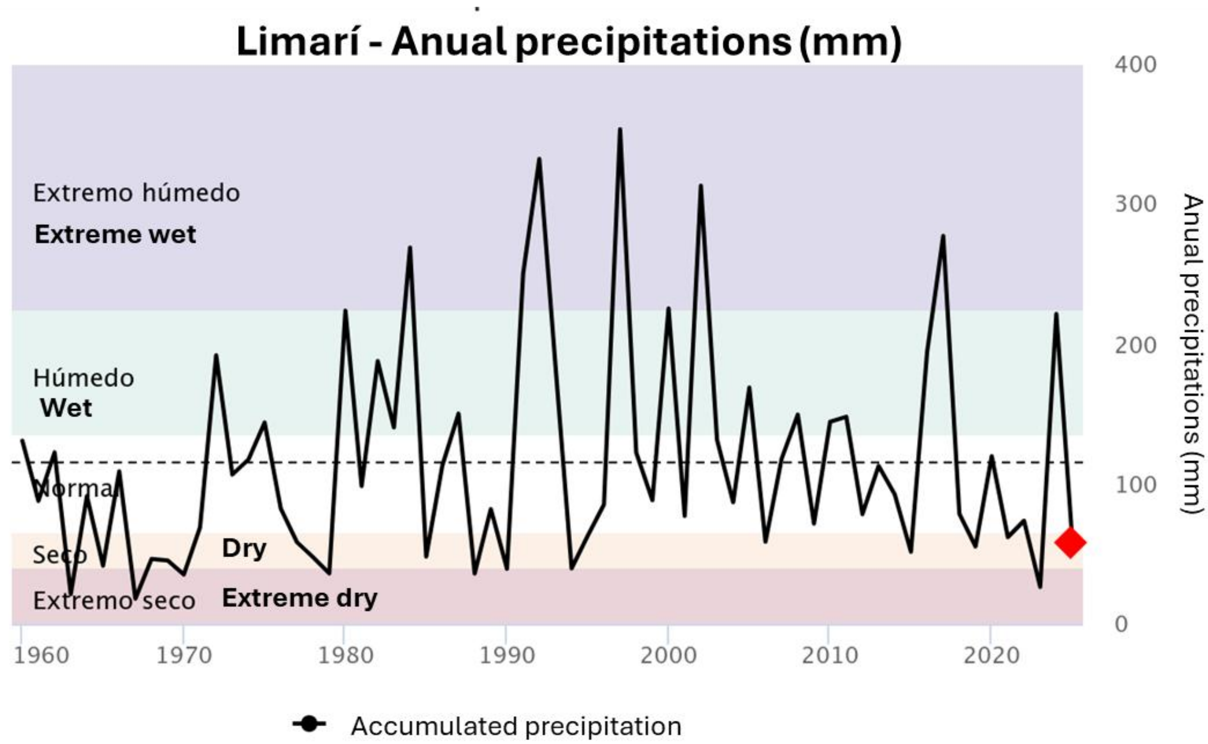

Figure 41. Annual Precipitations in Limarí Basin (1961–2024). *Source: CR2 Water Security Platform (https://seguridadhidrica.cr2.cl/monitor/)*

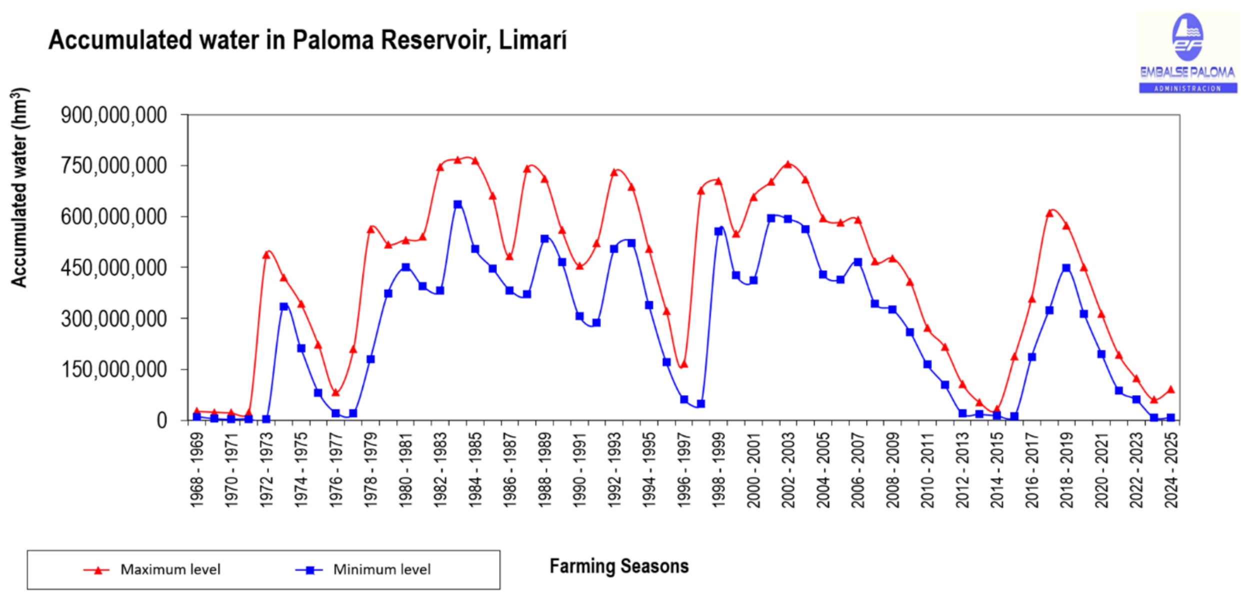

Figure 42. Accumulated Water in La Paloma Reservoir, Limarí (1968–2025). Source: Paloma Reservoir Administration.

Table grapes remain economically relevant but under pressure. While socially important due to their employment intensity, they show modest water productivity. Enhancing their competitiveness requires varietal renewal, cost-efficient irrigation, and niche strategies such as early-season or organic production.

Lemons are a quiet success story. They are harvested year-round, yield over 100 tons/ha under optimal management, and can be targeted to local and international high-value windows. Domestic consumption exceeds 12 kg/person/year in Chile, providing a robust local base, while exports serve markets like Asia and the U.S.

Avocados also play a strong role despite their higher water requirements. About 50% of Chilean production is consumed domestically, and prices have increased steadily, making them attractive even with slightly lower EWP. Efficiency in irrigation and consistent market demand have made them viable in Coquimbo despite constraints.

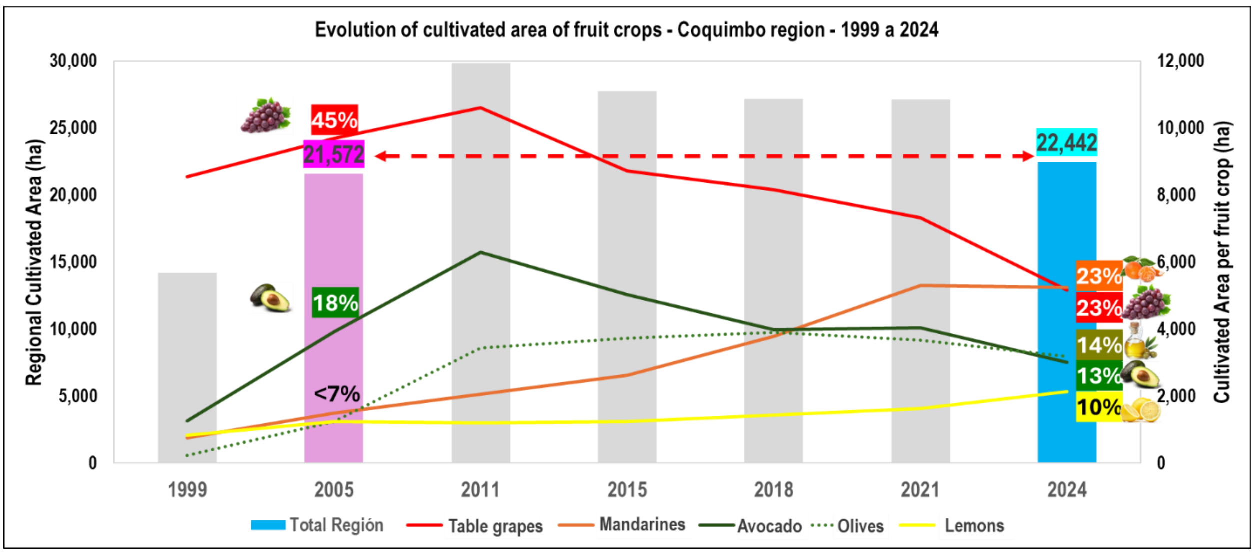

Figure 43. Coquimbo Region: Fruit Crop Surface Evolution (1999–2024). *Source: Author, based on ODEPA and CIREN.*

Beyond individual crop strategies, regional coordination has emerged as a key lever for resilience. The Regional Strategic Program for Sustainable Fruit Production in Coquimbo (PER Fruticultura Sustentable, www.frutascoquimbo.cl) was launched in 2022 with support from CORFO and the Regional Government. Its mission: to build a high-value, inclusive fruit economy rooted in sustainability and competitiveness.

PER's work includes support for applied R&D, genetic improvement, workforce training, digital technologies, and new market access (e.g., organic, early-season, or institutional channels). By supporting local governance and producer engagement, the program embodies the shift from reactive adaptation to proactive transformation.

The Coquimbo case proves that drought does not doom agriculture—it forces evolution. The region's ability to retool its crop mix, modernize its practices, and invest in shared strategies offers a replicable model for other water-scarce regions facing climate and market shocks.

Año	Chile			Coquimbo			Coquimbo v/s Chile
	MM de USD	M Ton	USD/K	MM de USD	M Ton	USD/K	
2015	$ 3,979	2,367	$ 1.68	$ 375	221	$ 1.70	**101%**
2016	$ 4,856	2,637	$ 1.84	$ 566	309	$ 1.83	**99%**
2017	$ 4,437	2,555	$ 1.74	$ 509	269	$ 1.89	**109%**
2018	$ 5,168	2,829	$ 1.83	$ 521	320	$ 1.63	**89%**
2019	$ 5,497	2,684	$ 2.05	$ 482	273	$ 1.77	**86%**
2020	$ 5,151	2,566	$ 2.01	$ 411	248	$ 1.66	**83%**
2021	$ 5,334	2,617	$ 2.04	$ 447	295	$ 1.52	**74%**
2022	$ 5,202	2,615	$ 1.99	$ 317	219	$ 1.45	**73%**
2023	$ 5,642	2,410	$ 2.34	$ 460	281	$ 1.64	**70%**
2024	$ 7,640	2,740	$ 2.79	$ 408	215	$ 1.90	**68%**

Figure 44. Fresh Fruit Export Price Trends: Chile vs. Coquimbo (2013–2024). *Source: Author, based on ODEPA.*

Figure 45. First Organic Table Grape Export from Chile (Coquimbo, 2024).

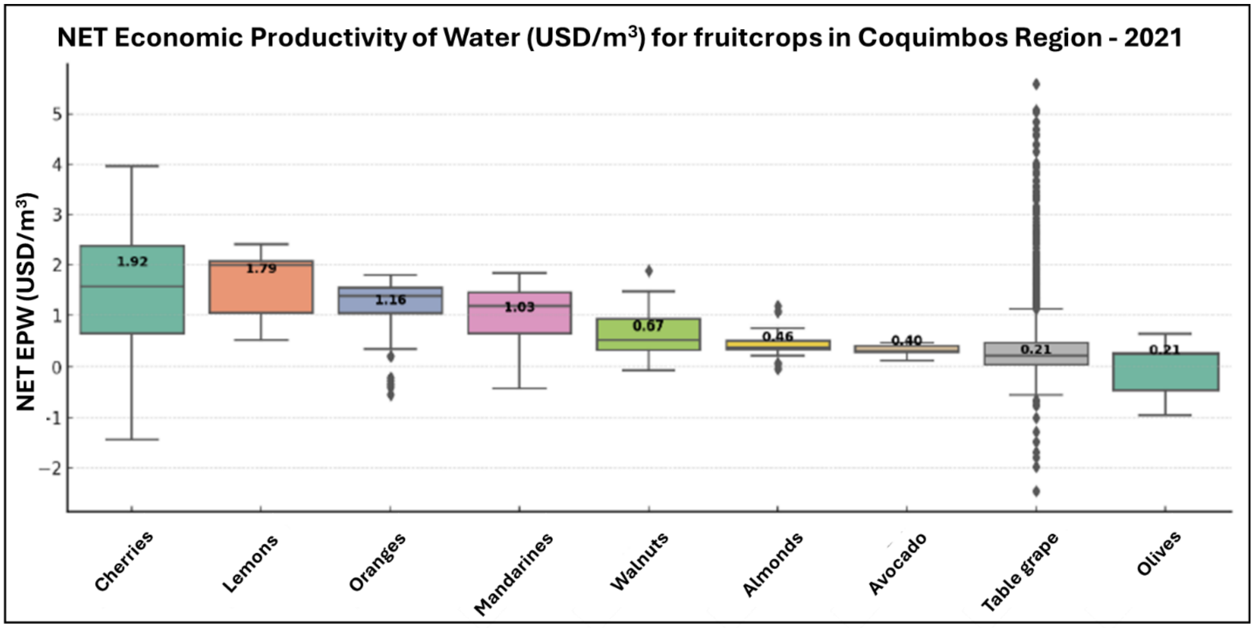

Figure 46. Distribution of Net Margin (USD/m³) by Fruit Crop – Coquimbo Region, 2021 *Source: PER Fruticultura Sustentable Coquimbo.* *https://www.frutascoquimbo.cl/wp-content/uploads/2025/07/ExpoAgryd-2025-La-Serena-Evaluando-que-plantar.pdf*

D. Synthesis: Strategic Convergence in Arid Agricultural Systems

Despite operating in different contexts, Israel, California, and Coquimbo exhibit a shared strategic response to water scarcity—turning constraint into transformation. Five key pillars emerge from the comparative analysis:

1. Efficiency-Driven Irrigation: Drip systems, fertigation, and remote sensing tools are now standard practice. These technologies not only reduce water use but improve productivity per cubic meter, helping align agronomic performance with economic returns.

2. Crop Portfolios Informed by EWP: Each region has realigned its fruit mix to prioritize crops that generate high returns per m³ of water. Lemons and cherries in Chile, almonds and pistachios in California, and avocados and dates in Israel reflect market-smart, climate-adapted choices.

3. Institutional Adaptation and Governance: Israel's volumetric pricing, California's SGMA framework, and Chile's water user associations all represent institutional responses to scarcity. These systems reshape incentives, clarify rights, and promote more efficient allocation.

4. Innovation Ecosystems: Innovation is not accidental—it is institutionalized. From Israel's R&D centers to California's university extension system and Coquimbo's public-private PER program, all three cases demonstrate how coordinated innovation ecosystems enable rapid diffusion of best practices.

5. Resilience as Strategy: Across the board, there is a shift from short-term adaptation to long-term resilience. Whether through groundwater recharge, crop diversification, organic transition, or

export reorientation, these regions are investing in systemic strategies to future-proof their agricultural systems.

Together, these lessons show that arid regions need not imitate water-abundant systems. They can chart their own path—leaner, smarter, and more resilient—by focusing on value per drop, institutional alignment, and shared innovation. Water scarcity, when met with intelligence and collaboration, can drive not collapse, but reinvention.

Chapter V. Water-Abundant or Non-Critical Contexts: New Frontiers in Productivity

When Water Is Not the Problem: New Constraints in Fruit Agriculture

In regions where water is not the most pressing constraint, agriculture is shaped by a different set of pressures—land availability, labor costs, energy, infrastructure, pests, and regulatory risks. This chapter presents five case studies where fruit production systems adapt to these alternate constraints, using strategies that redefine productivity and resilience

A. Florida (USA): Adapting to Labor Pressures and Crop Decline through Value-Added Strategies

Florida's fruit sector, long known for its dominance in citrus production, has undergone a profound transformation. The twin pressures of rising labor costs and the spread of citrus greening disease (Huanglongbing, or HLB) have caused a 50% reduction in citrus acreage over the past two decades. Many producers have exited the industry or diversified into tropical fruits, vegetables, or agrotourism.

During my visit to Homestead in southern Florida, I observed various adaptation strategies firsthand. At the University of Florida's Tropical Research and Education Center (TREC, Figure 47), researchers emphasized Florida growers' competitive disadvantage relative to Mexican producers, particularly regarding labor costs: while Mexican farmworkers earn approximately $10 USD per day, their Floridian counterparts are paid around $15 USD per hour. This disparity—amplified by trade conditions under NAFTA—has driven many Florida farmers to consider selling their land.

To reduce harvest costs, small farms like Martha's You Pick rely on U-Pick models (Figures 48 and 49), where customers harvest their own produce. Diversification into local markets, ethnic communities, and neighboring producers also supports resilience.

Other experiences include:

- "Robert is Here": a tropical fruit market and smoothie bar that also runs a petting zoo and farm space for tourists—free of charge. This model blends retail, education, and tourism, providing multiple revenue streams and showcasing Florida's rich fruit biodiversity (Figure 50).
- Tropical Fruit and ornamental trees in Homestead, for farmers and general public (Figure 51).

- Costco (Miami) and Sprouts Farmers Market, which offer high-quality refrigerated displays of fresh and organic fruit, respectively. Sprouts features significant shelf space for organic citrus and tropical fruits, reflecting a growing demand for clean-label produce (Figures 52, 53 and 54).

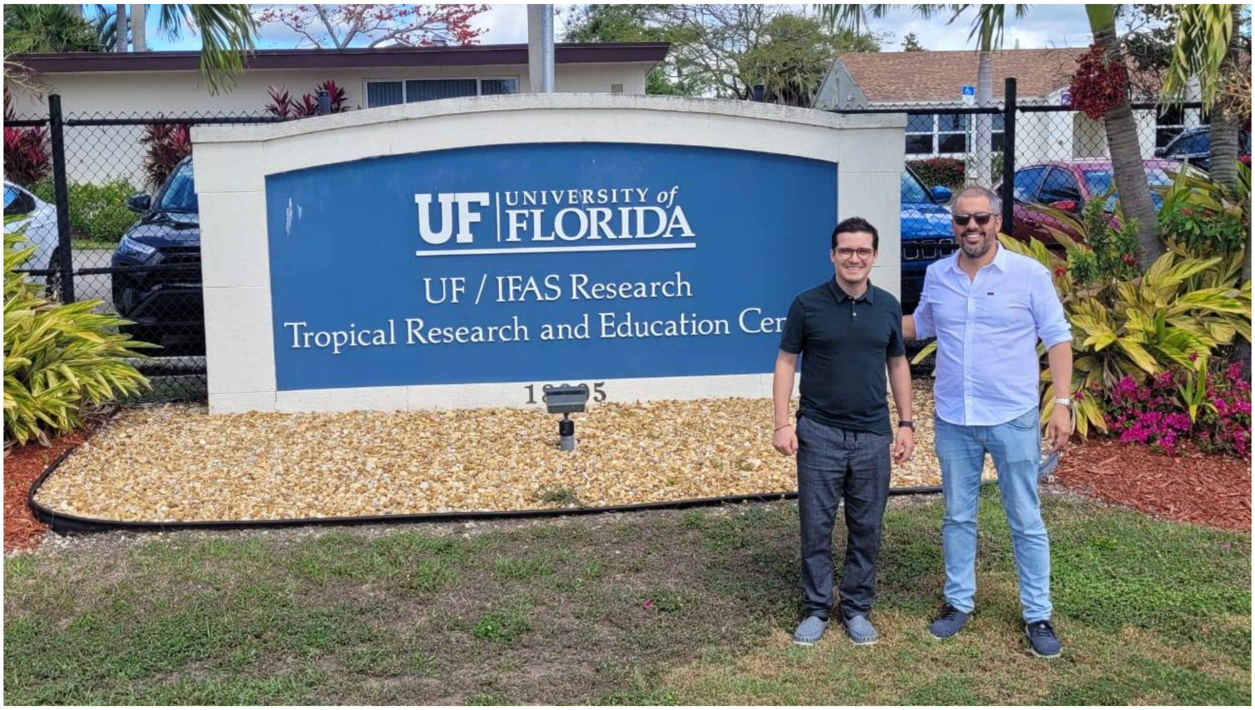

Figure 47. Meeting with Dr. Malek Hammami, Assistant Professor, Production Economics & Marketing. University of Florida, UF/IFAS Tropical Research and Education Center.

Figure 48. Martha’s You Pick: On-Farm Market and Farm Owner (Miami-Dade County).

Figure 49. Strawberry and Vegetable Picking – U-Pick Experience in Florida.

Figure 50. “Robert Is Here”: Farm Stand, Smoothies, and Petting Zoo.


Figure 51. Tropical Fruit Tree Nursery in Homestead, Florida.

Figure 52. Refrigerated Storage of Fresh Fruit in Costco, Miami.

Figure 53. Organic Fruits in Sprouts, Miami, Florida.

Figure 54. Value-Added Fruit Products in Sprouts, Miami, Florida.

Florida's fruit sector exemplifies how labor economics and plant disease can drive shifts not only in crops, but in the structural configuration of farm businesses. While export competitiveness is increasingly constrained—particularly in berries and tomatoes—the region is leveraging its proximity to major markets, consumer preferences, and innovations in value-added services.

This transition highlights the strategic importance of adaptation—combining crop diversification, direct marketing, and experiential models—as a pathway toward resilience in high-cost, high-risk agricultural environments.

B. Brazil (São Francisco Valley): Infrastructure, Domestic Demand, and Cooperative-Driven Scale

The São Francisco Valley in northeastern Brazil is one of Latin America's most productive tropical fruit regions. Located in a semi-arid zone, it benefits from government-supported irrigation infrastructure and year-round sunshine. While water is not currently a limiting factor, key challenges now lie in labor availability, logistics, and market access—especially for smallholders.

During my visit to the 2025 Fruit Attraction São Paulo trade fair, I observed the region's dual orientation: robust domestic consumption and targeted export (Figures 55a, 55b, 56a, 56b, 57a, 57b). Brazil's wealthiest 7% match the size of Chile's population, and its upper-middle class exceeds 47 million people—fuelling demand for varieties like the black-seeded Vitória grape, popular locally but absent in Chile. About 80% of the region's fruit is consumed domestically; exports focus on mangoes and grapes..

Figures 55a (left) and 55b (right). Fruit Attraction São Paulo 2025: Entrance signage (left) and Vitória table grape tasting stand (right).

Figures 56a (left) and 56b (right). Brazilian fruit diversity: Flag display made with local fruit (left) and State of Bahia promotional stand (right).

Figures 57a (left) and 57b (right). Tropical fruit industry in Brazil: Fresh fruit and derivatives stand (left) and ABRAFRUTAS association booth (right).

Retail infrastructure reflects this internal demand. Oba Hortifruti (Figure 58a–b) resembles high-end U.S. stores like Sprouts, a model not yet present in Chile. At CEAGESP, Latin America's largest wholesale market, I noted a contrast between imported refrigerated fruit (e.g., Chilean apples, Figures 59a–b) and ambient-temperature displays of local produce—highlighting Brazil's cold chain limitations.

Cooperatives play a central role in mitigating structural constraints. At Coopexvale (https://coopexvale.com.br) in Petrolina, I learned how 37 growers manage 600 hectares of grapes through shared logistics, cold storage, marketing, and branding—while retaining on-farm autonomy. Supported by institutions like SEBRAE and OCB, the cooperative model enhances quality, scale, and cost efficiency.

Figures 58a (left) and 58b (right). *Retail insights: Fresh fruit display at Oba Hortifruti supermarket (left) and ready-to-eat fruit packs (right).*

Figures 59a (left) and 59b (right). *Wholesale logistics at CEAGESP: Chilean apples arriving in refrigerated truck (left) and imported refrigerated fruit in cold storage (right).*

Federal concessions facilitate land access: qualified citizens can apply for 6-hectare irrigated plots with long-term payment plans. Many farmers scale up to 100 hectares or more, achieving up to 45 tons/ha annually in double cropping systems. Still, persistent challenges include labor shortages, rising costs of living, and weak rural generational renewal.

Despite its strengths, the region faces digital and infrastructure gaps that limit precision agriculture adoption. As irrigation and land cease to be bottlenecks, the São Francisco Valley underscores how productivity now hinges on human capital, logistics, and cooperative coordination.

C. Netherlands: Innovation Beyond Water—Energy, Inclusion, and Diversified Value

The Netherlands is globally recognized for its high-tech, resource-efficient agricultural systems. While water is not a key constraint, challenges such as limited arable land, labor shortages, and volatile energy prices have driven innovation across multiple dimensions—technology, social inclusion, and business diversification.

Greenhouses are emblematic of Dutch agricultural efficiency. These controlled-environment systems reduce water use by up to 90% and deliver yields far above global averages (Figure 60). However, they are highly energy-dependent. The 2022 energy crisis, triggered by surging gas prices, forced many producers to delay planting or temporarily shut down operations. A Wageningen University survey revealed that nearly 40% of greenhouse growers feared insolvency due to energy costs (Wageningen University & Research, 2023). In response, many have accelerated investments in automation, AI monitoring, and energy-efficient systems.

Figure 60. High-tech hydroponic greenhouse for bell pepper production in the Netherlands.

Beyond greenhouse production, Dutch agriculture demonstrates strong integration with society and services. At De Buytenhof, a multifunctional organic farm (https://debuytenhof.nl/), I observed a diverse model combining crop production, U-Pick activities, biodiversity preservation (Figures 61-62), a farm shop (Figure 63), café (Figure 64), and employment programs for people with disabilities. This approach fosters both economic resilience and community connection.

Figure 61. Crop and biodiversity map at De Buytenhof multifunctional farm, illustrating crop rotation and landscape diversity.

Figure 62. Organic apple orchard with natural weed control and pollinator-friendly management at De Buytenhof.

Figure 63. Farm store at De Buytenhof selling fresh, seasonal, and locally processed products.

Figure 64. Café and restaurant at De Buytenhof, an important source of income within the diversified farm business model.

Another example is Koppert Cress, a global leader in microgreens and edible flowers for high-end gastronomy (Figure 65). Their hydroponic greenhouses include cutting-edge technologies—LED lighting, heat recovery, automated logistics, and underground thermal energy storage. The company aims for climate-positive operations by 2026 while targeting premium markets through product differentiation and culinary innovation.

Figure 65. Gourmet microgreen tasting station at Koppert Cress, showcasing high-value edible plants for haute cuisine.

Dutch infrastructure also amplifies agricultural value. At Royal Flora Holland, the world's largest flower auction, visitors can observe global trade and logistics from elevated walkways (Figure 66). Similarly, the Maasvlakte terminal at the Port of Rotterdam handles large volumes of fruit re-exports across Europe, including Chilean produce (Figure 67). Both facilities show how the Netherlands has turned functional spaces like packhouses and ports into tourism and education experiences—a model that regions like Coquimbo could adapt to highlight their own agricultural strengths.

Despite low domestic fruit output, the Netherlands ranks among the world's top fruit exporters, highlighting its role as a strategic logistics and re-export center. Chilean fruit typically enters Europe through Dutch ports, benefiting from efficient customs, inspection, and redistribution networks.

Figure 66. Auction floor and logistics platform at Royal Flora Holland, the world's largest flower distribution center.

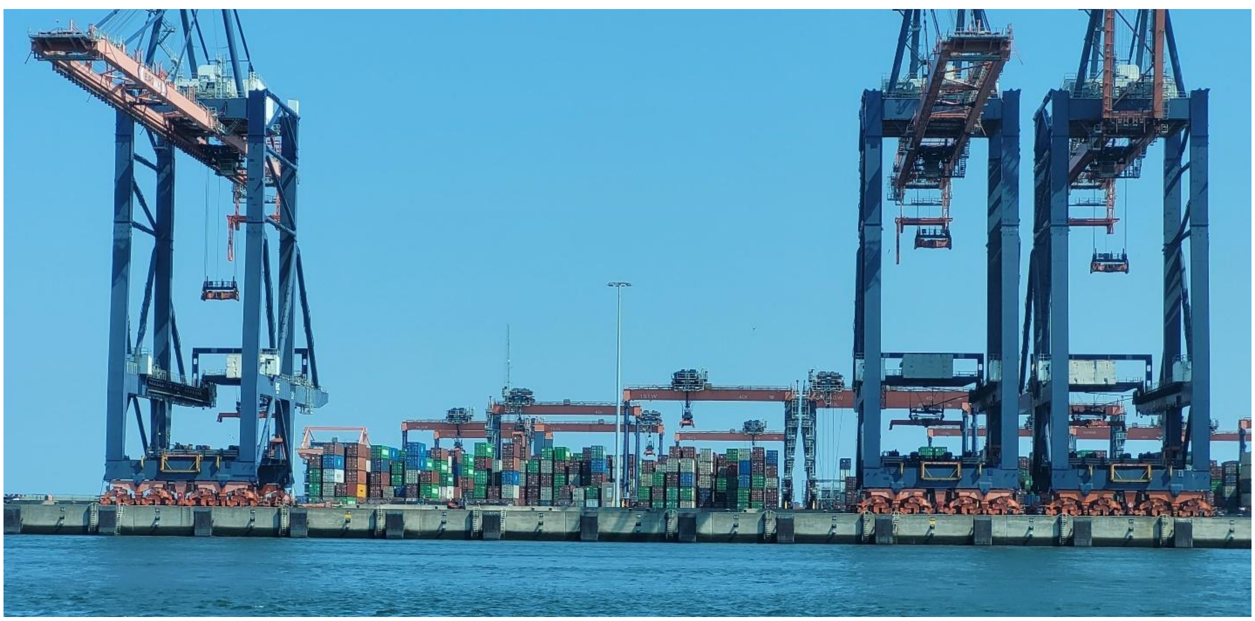

Figure 67. Container terminal at Maasvlakte, Port of Rotterdam—strategic hub for the re-export of fruit and agricultural goods across Europe.

Chile has begun experimenting with value-added models such as juices and dried fruit, but integration of tourism, gastronomy, and social services remains limited in the fruit sector. While "enotourism" has been embraced by wine and pisco producers, similar experiences are rare for table grapes, avocados, or citrus. Regions like Coquimbo could tap into this potential to diversify income streams and revitalize rural economies.

In sum, the Dutch case illustrates that post-water productivity is not just about technological efficiency. It is about reimagining farms as multifunctional spaces that deliver economic value, environmental stewardship, and social inclusion. This holistic model offers valuable lessons for fruit-producing regions navigating new constraints beyond water.

D. Japan: Ultra-Premium Fruit, Cultural Capital, and Value Beyond Scale

Japan's fruit sector operates under a distinct model where productivity is measured less by scale or efficiency and more by symbolism, cultural value, and perfection. Water availability is not a key constraint, yet the sector faces significant pressures from fragmented land tenure, an aging farmer population, and increasing climate volatility—such as typhoons, hailstorms, and unseasonal rain impacting fruit quality.

Figure 68. Rain and hail protection for grapevines.

Most Japanese fruit farms are small, family-run, and passed down through generations. Limited land consolidation hinders large-scale mechanization, encouraging specialization in ultra-premium fruits like Shine Muscat grapes, Shizuoka melons, and Yubari King cantaloupes. Cultivation involves meticulous practices such as hand-pollination, thinning, and individual fruit wrapping.

These products can exceed USD 100 per kg, with some fetching even higher prices at ceremonial auctions or gift markets.

During my visit, I observed this emphasis on premium value in Tokyo's upscale food halls and markets, where fruit was consistently sold in small, perfectly presented units. Dedicated showcases highlighted origin and farm identity (Figures 69, 70, and 71).

Packaging plays a central role in Japan's fruit value system. Fruits are often wrapped in foam nets, plastic covers, decorative boxes, and branded paper, elevating perceived hygiene and aesthetic appeal. This contrasts with global moves toward compostable or plastic-free alternatives, revealing Japan's prioritization of formality and cleanliness, even at the expense of sustainability (Figures 72, 73, and 74).

Another standout cultural feature is the widespread use of mascots and regional branding. In Kumamoto, for example, the mascot Kumamon appears on fruit packaging, signage, and promotional materials, reinforcing local identity and product recognition (Figures 75, 76, and 77).

Despite low yields per hectare, Japan's fruit sector delivers extremely high returns per kilogram. This reflects not only product quality, but also the cultural resonance of fruit as a gift, symbol, or luxury item. Figure 2 underscores this: Japan has one of the world's highest average fruit prices (over USD 3/kg), while fruit contributes less than 20% to the country's total crop value—unlike countries such as Chile or Morocco, where fruit plays a major economic role.

Japan also demonstrates innovation in value-added fruit processing. I found mandarin segments in syrup, raisins still on the stem, preserved lemons, and sugar-coated citrus segments—exquisitely packaged and sold at premium prices (Figures 78–81).

Beyond retail, diversified business models have emerged. A compelling case is Kubo Farm in Hiroshima, a dairy farm turned multifunctional enterprise. Initially focused on milk, the farm expanded into yogurt, cheese, ice cream, and agrotourism. Visitors pay for entry to green spaces, participate in activities, and shop in the farm café and store—creating multiple revenue streams and deeper community engagement (Figures 82–85).

While Chile's fruit sector is largely export-oriented and volume-driven, Japan shows how emotional, cultural, and symbolic dimensions can elevate value. Incorporating such elements into branding and consumer engagement may help producers in regions like Coquimbo move beyond commodity markets.

In summary, Japan offers a model where agricultural productivity centers on meaning, exclusivity, and aesthetics. In an era of economic and ecological uncertainty, this approach demonstrates how cultural capital and consumer trust can generate stable, high-value returns—even in the absence of scale.

Figure 69, 70 and 71. Ultra-premium fruit on display in Tokyo’s luxury markets.

Figure 72 (left), 73 (center) and 74 (right). Citrus, melons and mangoes in regular supermarket sections, each with elaborate packaging.

Figures 75 (left), 76 (center) and 77 (right). “Welcome to Kumamoto” sign with Kumamon; peaches and strawberries grown in Kumamoto with Kumamon-themed branding.

Figures 78 to 81. Examples of fruit-based value-added products available in Japanese supermarkets and convenience stores.

Figures 82 (left) and 83 (right). Grazing cows at Kubo Farm and its branded dairy products, including low-temperature pasteurized milk and yogurt drinks.

Figures 84 (left) and 85 (right). Recreational spaces and farm shop at Kubo Farm, exemplifying the fusion of agriculture and tourism.

E. Singapore: Rethinking Agriculture in a Fully Urban Food Hub

Singapore offers one of the world's most extreme cases of agricultural land scarcity. With over 90% of its food imported and only 2 hectares allocated to fruit production—the smallest national fruit area globally (FAO, 2025)—the country has reframed agricultural productivity around technology, logistics, and food security, rather than land or water availability.

Although water reuse and desalination are key to national resilience, water is not a limiting factor for fruit, which is virtually nonexistent at commercial scale. Instead, Singapore's "30 by 30" strategy aims to meet 30% of nutritional needs through local production by 2030, focusing on leafy greens, fish, and eggs—foods with short cycles and high consumption (Teng & Montesclaros, 2019). This goal is supported by the Singapore Food Agency (SFA) and advanced urban farms like

Sky Greens (https://www.skygreens.com/) and Sustenir Agriculture (https://sustenir.com/), which produce crops such as lettuce and herbs in vertical, climate-controlled systems.

During my visit, I observed how Singapore integrates imported fruit into its food system. Premium varieties—such as citrus, cherries, berries, apples, grapes, and tropical fruits—are prominently displayed in refrigerated cases, often with high-end packaging (Figures 86, 87, 88). Japanese imports in particular occupy a luxury segment, presented with ornate packaging and strong branding (Figures 89, 90, 91). The backbone of this system lies in its logistics infrastructure. Cold storage and distribution centers—like those seen in major wholesale hubs and port terminals—ensure quality preservation and efficient regional re-export (Figures 92, 93, 94).

In this hyper-urban context, energy—not land or water—is the main constraint. As such, agricultural resilience is increasingly measured per kilowatt-hour, not per hectare or cubic meter. For Chilean exporters, Singapore offers a valuable case study: a premium niche market with strong consumer trust and a strategic logistics hub for Southeast Asia.

Figures 86, 87 and 88. Imported fruit from different countries on display in premium retail outlets.

Figures 89, 90 and 91. Premium imported fruit from Japan in Singaporean supermarket.

Figures 92, 93 and 94. Cold storage and imported fruit logistics in Singapore.

F. Cross-Case Analysis: What Comes After Water?

The five case studies in this chapter demonstrate that when water is no longer the primary constraint, fruit agriculture becomes shaped by other critical pressures—rooted in geography, demographics, markets, and governance. While water scarcity remains a major global issue, productivity challenges are increasingly linked to:

- Labor availability and cost: In Florida and the Netherlands, high wages and worker shortages have triggered shifts toward automation, agrotourism, and U-Pick models that reduce labor dependence.
- Land fragmentation: Japan exemplifies how small-scale, aging farms limit scalability but enable ultra-premium markets based on cultural value.
- Energy and infrastructure: In Singapore and the Netherlands, energy—not water—is the key constraint, especially for high-tech systems, raising concerns about cost and sustainability.
- Logistics and institutions: Brazil's São Francisco Valley shows that water abundance alone is insufficient without reliable cold chains, transport, and cooperative organization.
- Biological threats and climate volatility: Florida's citrus sector has been reshaped by HLB disease and extreme weather, requiring entirely new crop and business strategies.

Across all regions, the concept of productivity is evolving. Simple ratios like yield per hectare or cubic meter are giving way to more multidimensional indicators:

- Resilience per kilowatt-hour
- Value added per unit of labor
- Nutritional output per square meter
- Consumer trust per dollar earned

Strategic responses cluster around three pillars:

1. Technology adoption: From Dutch greenhouses to vertical farms in Singapore, innovation enables more output with fewer inputs—but creates new dependencies.
2. Institutional innovation: Cooperative and governance models help organize production and mitigate systemic risks.
3. Business model diversification: Examples from Florida, Hiroshima, and the Netherlands show how experiential services and value-added products can sustain rural economies.

In a post-water context, productivity is no longer about maximizing a single ratio—it's about balancing profitability, sustainability, and societal connection. These cases highlight a shift toward integrated, resilient agricultural systems for a more complex future.

VI. Lessons Across Contexts

A. Lessons from Water-Scarce Regions

Regions like Israel, Coquimbo (Chile), and California show that water scarcity—far from being a barrier—can become a catalyst for innovation. These areas have pioneered:

1. Precision irrigation technologies (e.g., drip systems, soil sensors).
2. Crop selection aligned with high Economic Water Productivity (EWP).
3. Governance models that incorporate pricing, monitoring, and public investment.
4. Collaborative ecosystems, including government, research institutions, and producers.
5. Forward-looking strategies, such as aquifer recharge, reuse of treated water, and climate adaptation.

These experiences underscore that managing water as a strategic, economic resource fosters not just efficiency, but also long-term resilience.

B. Lessons from Water-Abundant or Non-Critical Contexts

Regions where water is not (yet) the limiting factor—like the Netherlands, Brazil's São Francisco Valley, Japan, Florida, or Singapore—face other challenges: labor shortages, aging farmer populations, energy volatility, infrastructure gaps, or land scarcity. In these places, agricultural transformation is driven by:

1. Technology-based intensification (e.g., vertical farming, hydroponics, automation).
2. Business model diversification, integrating agrotourism, processing, logistics, or education.
3. Institutional innovation, such as cooperatives, user associations, and urban planning.
4. These regions teach us that future constraints often emerge beyond water, and productivity must be redefined to include energy use, labor value, consumer trust, and resilience to disruption.

C. Shared Tools and Strategic Convergence

Across diverse contexts, a set of common enablers emerges:

1. Governance and institutions: Cooperatives, public-private alliances, and planning agencies shape how resources are used and value is distributed.
2. Technology and data: Remote sensing, automation, and digital monitoring increase EWP but require connectivity and skills.

3. Business model diversification: U-Pick farms in Florida, agro-tourism in Hiroshima, and multifunctional Dutch farms show that adding revenue streams is as important as boosting yields.
4. Cultural and market intelligence: Premiumization, storytelling, and consumer engagement (as in Japan) reveal that value can also be intangible—and yet deeply profitable.

VII. Conclusion

This report shows that the next frontier in fruit production is not just about using water more efficiently—but about rethinking how productivity is defined. From water-scarce deserts to ultra-urban hubs, productivity today is shaped by multidimensional forces: governance, energy, labor, culture, logistics, and consumer trust.

Chile, and the Coquimbo Region in particular, stands at a strategic crossroads. While the country has long positioned itself as a leader in water-efficient fruit exports, global competitiveness now depends on the ability to integrate broader value dimensions—diversification, traceability, experiential agriculture, and logistics infrastructure. The global cases explored in this report offer not templates, but trajectories: each region is crafting its own version of post-water productivity. This transition will require not only technical innovation, but also strategic coordination between growers, institutions, and markets to fully realize the potential of post-water productivity in Chile.

VIII. Recommendations

To operationalize the findings of this report, the following targeted recommendations are proposed:

A. For Water-Stressed Regions (Chile, Israel, California)

- Prioritize high-EWP crops through updated zoning and incentives.
- Strengthen water governance institutions with transparent metrics and capacity building.
- Promote digital irrigation systems and benchmarking platforms to track water returns.
- Enable transition support (technical, financial, regulatory) for producers shifting out of low-EWP crops.
- Support diversified and adaptive production models: Encourage crop diversification, processing, and direct marketing to reduce climate and market risks.

B. For Water-Abundant or Non-Critical Regions (Brazil, Japan, Netherlands, Singapore)

- Anticipate emerging constraints (labor, energy, logistics) before they become binding.
- Promote culturally grounded, multifunctional farming models that integrate agriculture with education, tourism, and local identity
- Invest in traceable, high-value value chains that reward quality, identity, and consumer trust.
- Develop climate-smart energy strategies to sustain controlled-environment production.

C. For Global Stakeholders (researchers, investors, policymakers)

- Treat EWP as a guiding metric for climate-smart investment and crop prioritization.
- Support comparative studies across arid and non-arid regions to foster strategic learning.
- Fund scalable pilots that blend technology, governance, and business model innovation.
- Encourage dialogue between countries with shared fruit sectors but divergent challenges (e.g., Chile and Brazil in table grapes, or Japan and Florida in citrus).

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