

Agricultural Water Management in Singapore and Japan: Toward Sustainable Design and Innovation

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Abstract

This paper describes a comparative analysis of agricultural water management in Singapore and Japan, two countries with distinct geographies but shared challenges. Singapore, highly urbanized and water-scarce, relies on advanced technologies such as hydroponics, vertical farming, and closed-loop aquaponics, supported by its “Four National Taps” strategy—local catchments, imported water, desalination, and NEWater. Japan has greater freshwater resources but faces seasonal shortages, aging irrigation systems, and climate-induced droughts. Analysis of vegetable production and consumption shows Japan’s practices to be consistently more water-efficient, though on a far larger production scale, while Singapore’s high consumption footprint reflects dependence on imports. Emerging technologies—including smart irrigation, biochar amendments, digital farming, and circular waste-to-resource pathways—are explored as opportunities for cross-national learning. The insights highlight how technology, policy, and innovation could shape sustainable water use in crop farming across urban and rural contexts.

Keywords : Crop farming, recycled water, freshwater, urban agriculture, rural agriculture

1 Introduction

Modern agriculture is greatly dependent on technologies such as irrigation, fertilizers, and pesticides to overcome the limits of natural soil productivity and sustain global food production [1]. This food production dependence underpins water consumption which unfortunately involves inefficient practices in many parts of the world [2]. This leads to a global challenge in which technological progress seeks to provide abundance and creates problematic long-term sustainability issues.

Agriculture is the largest user of freshwater [2]. From the data from the UN Food and Agriculture Organization (FAO) and other water-use studies: about 70% of all freshwater withdrawals worldwide are used for agriculture [3]. This implies 2,500–3,000 cubic kilometers (km³) of water per year, which translates to 2.5–3 trillion cubic meters annually. In water-scarce regions (e.g., parts of Asia, the Middle East, and Africa), agriculture can account for up to 90% of freshwater use; the bulk of this water goes into irrigation, while smaller portions are used for livestock watering and aquaculture.

Table 1 Singapore and Japan: Area, Population, and Density.

Country	Area (km ²) *	Population (million) *	Density (people/km ²) #
Singapore	736	6	7,800
Japan	377,975	123	330

* <https://data.un.org/>; # estimated from area and population data

Table 1 lists the size, population and density of Singapore and Japan. To meet population growth in highly urbanised areas that aligns with mitigating climate change and disruption arising from geopolitical tensions as well as the next epidemic effects, countries like Singapore and Japan approach agricultural sustainability in the following ways. In land-scarce and water-constrained regions like Singapore, the shift from traditional soil-based farming to high-tech urban agriculture requires a re-evaluation of how water—one of the most critical inputs—is sourced, utilized, and conserved; Singapore aspires to locally

produce 30% of its nutritional requirement by 2030 [4]. Japan, while geographically and demographically different, also faces growing pressure to enhance water efficiency across its diverse agricultural systems, albeit some differences. In July 2025, the Tohoku rice-growing region faced record-low rainfall—Yamagata received just 8 mm (~4% of normal), and Niigata only 3.5 mm (~2%). Farmers faced water rationing as a dam turned dry and another dropped to 20% capacity [5]. Extreme heat and drought also caused a rice shortage in 2024, driving inventories to a 25-year low. In response, the government released reserves and began testing heat-resistant rice varieties [6]. Multiple sources point to drought as a recurrent threat to rice yields and food security, with climate change projected to cause ~20% declines in paddy yields by 2100 [6, 7]. Table 2 highlights the areas of interest in the comparative analysis of Japan and Singapore.

Table 2 Water challenges in Japan and Singapore

	Water Scarcity (Agriculture)	Pressures
Singapore	Clearly water-scarce, with limited natural supply and high withdrawals [8]	Full reliance on advanced technology for water supply and recycling; agriculture is minor and technology-intensive [9]
Japan	Not initially water scarce, but faces localized and seasonal water stress affecting agriculture [5]	Regional and temporal shortages; infrastructure inefficiencies; climate-induced droughts; aging farming systems [2]

This paper presents a preliminary comparative analysis of the landscape of agricultural water management for crop farming, as well as insights, in Singapore and Japan. The aim is to draw parallels on sustainable practices that could be of value to each country. Following from the Net Zero Urban Farming workshop, which brought together academics from Singapore Institute of Technology and Newcastle University, where discussion produced an insightful paper [10], this study adds perspectives of Singapore and Japan’s water-focused innovation efforts for examining broader themes of sustainability, technology, and policy in agriculture.

2 Crop farming landscape in Singapore and Japan

Currently understanding of the mechanics of the global circulation of fresh water, i.e. the hydrological cycle, is outlined as follows, with further details described elsewhere [11]. Water evaporates from the oceans into the atmosphere, then condenses and falls back to Earth as dew, mist, rain, snow, or hail. This precipitation either returns directly to the oceans or falls on land, from where it eventually flows back to the oceans through rivers, runoff, or groundwater. The hydrological cycle is important for living things on earth that consumes or uses fresh water, as the cycle controls the amount of fresh water available at any one place at a given time.

Of the water input from all forms of precipitation, only a small fraction, about 25%, falls on land surfaces. Of this potential supply, the amount and form in which the water reaches us depends on the routes by which it is returned to the atmosphere. Almost all land plants depend on water stored in the soil, which they absorb through their roots. Only a very small number of plants get their water directly from the air or other sources. The availability of water for absorption by a plant’s roots depends on the depth of the root zone, which can vary from a few cm to around 15 m, and the ability of the soil to hold or retain precipitation.

Of the total incoming precipitation, some is intercepted by the vegetation cover and held or ‘stored’ long enough to be lost by evaporation before it reaches the land surface. (Infiltration of water into the soil will depend on the amount of precipitation, less than which is intercepted or runs off the surface.) On reaching the land surface, a proportion of this water will leave the land by surface run-off into streams, rivers, lakes, etc, which discharge into the oceans.

Return of water from the soil may be by two routes: (1) evaporation and evapo-transpiration (a process where water taken

up by the plants is returned to the atmosphere), (2) longer and slower route of percolation, as freely draining soil-water, down to ground-water levels from where it eventually seeps into streams, lakes, or directly into the sea.

The total volume of water circulating through a given terrestrial ecosystem, and its distribution among the possible routes it can follow, are determined by prevailing climatic conditions, landforms and the nature of the vegetation cover and the underlying soil. A shift in any of these variable will be reflected throughout the hydrological cycle.

Today the world contains almost eight billion people, with a population doubling time of about 25 years. Energy-driven water technology is needed to raise the productivity of land, a productivity which in some of today's most intensive systems produces fifty times as much protein per hectare as a natural system. In Singapore, by virtual of the limited land, (1) cutting fresh water loss interception and evapo-transpiration, and (2) increase the 'water yield' by capturing the proportion of surface run-off as a result of deforestation (which is replaced by buildings, roads and other infrastructure-related to urbanisation). In Japan, the concern is not increasing overall water yield, since rainfall is abundant, but ensuring reliable storage and distribution. The chief concern are the seasonal and regional imbalance of water, inefficiencies in aging irrigation systems, and climate-induced stresses such as droughts and heat waves, which could disrupt Japan's agricultural supply. Clearly, despite having better knowledge of the hydrological processes, manipulating the hydrological cycle at other than a relatively local scale is limited by our ability to control global climate.

Table 3 Water consumption for food (vegetables) production in Japan and Singapore (<https://www.watertofood.org>)

	Singapore				Japan			
	1990	2000	2010	2016	1990	2000	2010	2016
Unit water footprint of production (m ³ /t)	251	268	228	239	139	142	158	165
Unit water footprint of consumption (m ³ /t)	346	346	317	283	160	164	182	192
Water footprint of production (m ³)	2.2×10^6	3.1×10^6	4.3×10^6	5.2×10^6	5.0×10^8	4.1×10^8	4.6×10^8	4.4×10^8

The price we pay for this intensification may be gauged from Table 3 and Figure 1, which shows the water consumption for food production in Japan and Singapore from 1990 to 2016. Singapore's unit water footprint of vegetable consumption has decreased since 2000, reflecting efficiency gains from hydroponics, vertical farming, and recycled-water use. However, its total production water footprint has increased because overall domestic output has grown. In short, each ton of vegetables now requires less water, but rising production volumes mean that Singapore's aggregate water demand for vegetables is higher. Japan's unit water footprint of vegetable production has risen slightly over time, from 139 m³/t in 1990 to 165 m³/t in 2016, indicating reduced efficiency per ton. At the same time, its total production water footprint shows an overall downward trend, declining from about 496 million m³ in 1990 to 440 million m³ in 2016, with fluctuations in between. This pattern reflects shrinking domestic output and structural changes in agriculture.

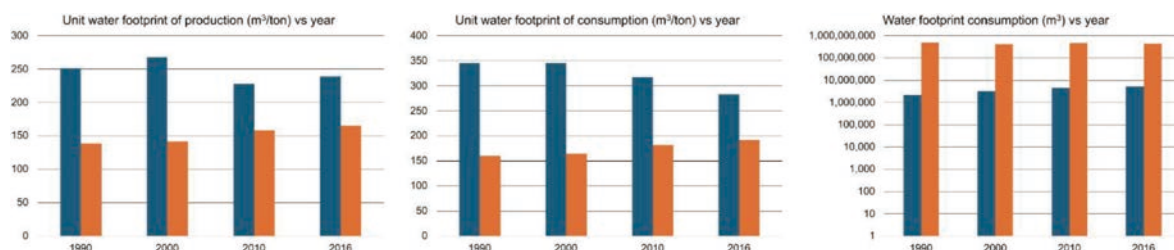


Figure 1 Water footprint of vegetable production and consumption in Singapore (dark blue bars) and Japan (orange bars)

3 How water is delivered to crop farmers in Singapore and Japan

In Singapore, urban crop farming is influenced by spatial and resource limitations. As the 2021 workshop report highlighted, as agriculture occupies less than 1% of Singapore's land; to overcome the land limitation for crop farming and meet scalability, intensive methods such as vertical farms, hydroponics, and controlled-environment systems are used. This requires how water is managed, using recycled or desalinated water. "Closed-loop" systems also combine fish rearing (aquaculture) with vegetable farming, making water use more circular [10].

Water for agriculture in Singapore is regulated by the "Four National Taps", namely local catchment water, imported water, NEWater (i.e. recycled water), and desalinated water. NEWater and desalination are increasingly used in agriculture. Farming technology that requires low water consumption are best able to meet the farmer's bottom line. These technologies are vertical farming, hydroponics, and aquaponics; these technologies use less water than traditional soil-based farming. Hydroponics can reduce water use by up to 90%, as water is recycled within the system [12]. The following paragraph outlined how water is delivered to crop farmers in Singapore.

From the four centralized water sources ("Four National Taps") [9], namely local catchments, where rainwater is collected in reservoirs, imported water, i.e. from Johor, Malaysia, NEWater process creates recycled wastewater for use by farms. Desalination, i.e. where seawater is converted to freshwater, water from these sources is fed into a single national distribution network, managed by the Public Utilities Board. Treated water (potable or NEWater) passes through municipal pressurized pipes which are connected to farms (unlike Japan's canal/ditch systems). At farm-level, water to hydroponics & vertical farms is delivered into nutrient solution tanks; pumps circulate it through growing trays and recycle it in closed loops. Water to aquaponics is circulated between fish tanks and plant beds, with pumps regulating flow. Water to soil-based farms comes through drip irrigation connected directly to the piped supply to reduce loss through evaporation.

In contrast, Japan possesses a relatively abundant of freshwater supply and a wider variety of agricultural landscapes. Japan's efforts include precision irrigation technologies, decentralized water management, and soil moisture sensing in rural farms. The following paragraph outlined how water is delivered to crop farmers in Japan [2].

Water, for example from rain, flows into streams and rivers and is dammed or diverted for storage in reservoirs, ponds,

Table 4 Comparison of water delivery methods for crop farming

	Singapore [9]	Japan [2]
Water Source	PUB's Four National Taps: local catchments, imported water, desalination, NEWater (recycled water). NEWater widely used for farms.	Rainfall-fed rivers, reservoirs, dams, and ponds. Groundwater plays a limited role.
Delivery System	Pressurized piped supply from national water grid directly to farms.	Diversion structures feed water into main, secondary, and tertiary irrigation canals.
Farm-Level Application	Hydroponics (nutrient solutions in closed loops), aquaponics (fish-plant cycles), drip irrigation for limited soil-based farms.	Flood irrigation in paddy fields, distributed through field ditches and gates.
Management	Managed by Public Utility Board (PUB). Farmers pay non-domestic water tariffs; some receive subsidized NEWater for irrigation.	Managed by Land Improvement Districts (LIDs), farmer cooperatives that allocate water and maintain canals.
Efficiency	High efficiency: closed-loop hydroponics recycles up to 90% of water; minimal open evaporation losses.	Lower efficiency: paddy flooding uses large volumes but water is partly returned to rivers/groundwater.
Technology Emphasis	Urban farming, vertical farms, automation, precision dosing, recycling.	Canal infrastructure modernization, rotational irrigation scheduling, multipurpose dam systems.

and multipurpose dams during wet periods. The stored water is then released during the growing season. The water is distributed via canals. The main irrigation canals receive water via large headworks (diversion structures). Secondary & tertiary canals carry water flows from main canals to the farming region. At each farming region, the Land Improvement Districts allocate water to individual farmers in scheduled turns, a practice called warabuchi (rotational irrigation). At the farm level, water enters paddy fields via small ditches or gates; the water spreads across fields and infiltrates the soil. Some water percolates to groundwater or drains back to canals/rivers and this enables the water to be reuse.

This comparison highlights a critical insight: while water is a universal agricultural concern, the socio-environmental framing and technological response differ significantly between urbanized (Singapore) and rural (Japan) geographies.

4 New efficient water and related technologies for crop farming

Over the years, Singapore and Japan have gained valuable experience in sustaining water for farming, but national food supply remains vulnerable to the impacts of global climate variability. This limitation underscores the need for continuous innovation in crop water management. Given these ongoing challenges, the following sections highlight key technological directions emerging from the 2021 SIT-NU workshop [10] that may hold potential for future adoption in Singapore and Japan. For a summary of these technologies, see Table 5.

(1) Crop health and disease management

For Singapore, early detection of root diseases in hydroponic or vertical farms can reduce the need to flush entire water systems, saving both water and nutrients. For example, photonic laser spectroscopy developed in Singapore allows real-time monitoring of crop nutrient levels and stress [13]. For Japan, better control of fungal pathogens in paddy fields helps align irrigation more closely with plant health. Recent work on short-wave infrared hyperspectral imaging enables non-invasive root health monitoring [14].

(2) Low-energy farms

For Singapore, having controlled-environment farms using heat gradients, solar-powered IoT irrigation, such as solar green roofs, and ground-source heat pumps can reduce cooling loads in vertical farms, lowering evapotranspiration and irrigation demand. Such systems reduce evapotranspiration and optimise water use [15]. For Japan, smart greenhouses in regions such as Miyazaki integrate data-driven control of water, heat, and CO₂, reduce water stress linked to heating/cooling needs across seasonal climates [16].

(3) Alternative fertilizers and biostimulants

For Singapore, driving the adoption of clean nutrient sources such as green ammonia and bio-stimulants in hydroponics reduces residues in recycled water loops [17]. For Japan, research into controlled-release fertilizers is underway and shows promise for lowering nutrient runoff into irrigation canals; this could be a step forward to keep the water clean and reduce downstream treatment needs [18].

(4) Sensor networks, IoT and digital farming

For Singapore, IoT and machine learning systems in farms (e.g., AbyFarm) are applied to automate irrigation and optimise nutrient and water dosing in hydroponics, ensuring minimal water waste [19]. For Japan, large-scale canal and paddy irrigation can benefit from digital flow monitoring; this approach can lead to more efficient water allocation to farmers. Paddy field irrigation is being modernised with water-level sensor networks using e-Tape, Arduino, and XBee, allowing precise

irrigation scheduling [20].

(5) Composting and growth media innovation

For Singapore using compost, coir, and biochar as alternatives to perlite/rockwool improves water retention in hydroponic substrates, reducing freshwater demand [12]. For Japan, organic soil amendments (compost, biochar) are expected to increase soil water-holding capacity in upland fields, so as to be able to mitigate drought stress. Biochar soil amendments are tested in rice fields to increase water-holding capacity and improve yields under evaporation stress [21].

(6) Circular Use of Biomass & Waste

For Singapore, biowaste conversion (e.g., hydrothermal carbonisation (HTC)) is expected to support water-energy synergies in urban farms by recycling organic matter. HTC of organic waste into hydrochar is being developed, providing water-energy synergies and new absorbent media for urban farms [22]. For Japan, biomass-based carbon sequestration is expected to improve soil structure and enhances natural water infiltration and retention in farmland so as to be able to support sustainable circular practices in farmland [21].

Table 5 Comparison of new methods for adoption in Singapore and Japan

New methods for adoption	Singapore	Japan
Crop health and disease management	Photonic spectroscopy for hydroponic monitoring [13]	SWIR hyperspectral root health monitoring [14]
Low-energy farms	Solar-powered IoT irrigation systems [15]	Smart greenhouses with data-driven controls [16]
Alternative fertilizers and biostimulants	Green ammonia/hydrogen pathways [17]	Carbon-free fertilizers to reduce runoff [18]
Sensor networks, IoT and digital farming	IoT and ML-enabled smart hydroponic farms [19]	Paddy water-level sensor network [20]
Composting and growth media innovation	Biochar plus perlite mixes improve water retention [12]	Biochar amendments improve paddy water-holding [21]
Circular use of biomass and waste	Hydrothermal carbonisation (HTC) of organic waste into hydrochar [22]	Biochar recycling improves water infiltration [21]

5 Concluding remarks

Singapore and Japan face contrasting water challenges in agriculture: scarcity in Singapore and distribution in Japan. Singapore responds with ‘closed-loop’ systems like hydroponics and NEWater, while Japan relies on extensive irrigation networks that now require modernization under climate stress. Both countries show that efficiency is not only about water supply but also technology (and governance).

The new efficient water and water-related technologies from Singapore and Japan illustrate how emerging technology can shape sustainable water use in very different contexts. In Singapore’s urban farms, advances such as hydroponics, smart IoT irrigation, clean fertilizers, and biowaste recycling are intended to reduce freshwater demand and close resource loops within controlled environments. In contrast, Japan’s rural agriculture emphasizes modernizing paddy irrigation, adopting controlled-release fertilizers, and improving soil water retention; we highlighted these to show how traditional large-scale systems can be adapted to address climate pressures and resource efficiency.

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