Green Asia Report Series

No.1

Driving Sustainable Food Systems Transformation in the Asia-Monsoon Region with Science, Technology and Innovation

background and key issues for "Green Asia" project

Miyuki Iiyama, Norihito Kanamori, Shintaro Kobayashi, Yasuro Funaki

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September 2023

This work is a product of JIRCAS staff with external contributions and is based on a study conducted under the project "Accelerating application of agricultural technologies which enhance production potentials and ensure sustainable food systems in the Asia-Monsoon region", funded by the Ministry of Agriculture, Forestry and Fisheries, Japan.

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Abstract

The Asia-Monsoon region includes the economies of eastern, southeastern, and southern Asia. Under the arbitral delineation of the Asia-Monsoon region for this study, an estimated 3.34 billion people or 44% of the world population as of 2018 lived in areas corresponding to 9% of the world total land area, while accounting for 28% of the global GDP. With the projection that the regional population will increase by at least 420 million by 2050, the region still needs to boost food production to ensure food security and poverty alleviation, with serious trade-offs in reducing the non-CO_2 greenhouse gas (GHG) emissions from the agricultural sector, whose region's share in the global total amounts to 40%. Since a paradigm shift toward sustainable agricultural practices is becoming an inevitable global trend, the region's food systems urgently need to identify science, technology, and innovation (STI) that can drive sustainable food systems transformations by simultaneously mitigating environmental impacts and enhancing food productivity.

The key features of the agricultural sector of the Asia-Monsoon region, namely, a hot and humid climate, rice paddy farming, and small-scale farmers, form an environment conducive to highly intensive farming systems. The intensiveness of the region's farming systems is also different from that of other regions of the world, such as Europe and the Americas. These distinguishing features of the agricultural sector of the Asia-Monsoon region should be considered when identifying and devising effective STI interventions to contribute to environmental sustainability without sacrificing productivity in climate emergencies and environmental crises.

The agricultural sector of the Asia-Monsoon region is increasingly exposed to climate emergencies, and environmental crises negatively affect the productivity and quality of products. At the same time, the region is responsible for 40% of the global non-CO_2 GHG emissions from the agricultural sector, major sources including rice paddies for CH_4, and inefficient fertilizer use for N_2O. Thus, it is urgent for the region to accelerate the deployment of STI to reduce the environmental footprint without sacrificing productivity. Within the Asia-Monsoon region, there are many common features that may provide enabling conditions to realize the swift implementation of food systems transformation by scaling up scalable agronomic practices with fine-scale tailoring to locally specific contexts. By taking advantage of these common features, the Asia-Monsoon region should pursue economies of scale for technology application by leveraging collective actions to share knowledge.

Given the collective significance of the Asia-Monsoon region, the success of the regional food systems transformation should have enormous global impacts to demonstrate the potential of synergies for climate change mitigation and sustainable agricultural production. There are significant opportunities for the region to realize the rapid transformation of food systems if an enabling environment is in place for co-learning experiences to test and disseminate STI. The Ministry of Agriculture, Forestry and Fisheries (MAFF) Japan, which announced its national strategy for a sustainable food system "MIDORI" in May 2021, has decided to initiate a project, "Accelerating application of agricultural technologies which

enhance production potentials and ensure sustainable food systems in the Asia-Monsoon region.” MAFF assigned the Japan International Research Center for Agricultural Sciences (JIRCAS) to take charge of the project, which is managed under the name ‘Green Asia’. This project aims to accelerate the application of fundamental agricultural technologies in the region. As a mechanism to achieve the aim of the project, the project conducts the collection, analysis, management, and dissemination of research results and outputs useful in and applicable to the region, including those from Japan. It is expected that the results and outputs of this project could serve as a reference for various stakeholders, including government officials, researchers, extension officers, producers, and the private sector, thereby contributing to sustainable food systems transformation in the Asia-Monsoon region and beyond.

1: Introduction

Current global food systems face many challenges which threaten the planetary health (Rockström et al. 2009). Agriculture is responsible for approximately 25% of the anthropogenic greenhouse gas (GHG) emissions, mainly carbon dioxide (CO_2) from land use change and deforestation, methane (CH_4) from rice paddies, enteric fermentation, and nitrous oxide (N_2O) from chemical fertilizer use; the figure can amount to 30% of the emissions if the whole food systems are considered (Tubiello et al. 2021). At the same time, food systems are among the sectors most affected by climate extremes, which can spur food and nutrition insecurity, and whose impacts can be transmitted globally through the intricate networks of food supply chains (Willet et al. 2019).

The United Nations Food Systems Summit held in September 2021 showed that it is essential to transform to sustainable food systems. Food systems include the entire range of actors and their interlinked value-adding activities involved in the production, aggregation, processing, distribution, consumption, and disposal (loss or waste) of food products originating from agriculture (including livestock), forestry, fisheries, and food industries, along with the broader economic, societal, and physical environments in which these activities are embedded (von Braun et al. 2021). Building sustainable food systems should involve transformational changes in diets that inextricably link human health and environmental sustainability, thus a paradigm shift is required to move away from business as usual at all stages of the systems, from production to consumption (Willet et al. 2019). In turn, diet is deeply embedded in specific socio-economic and cultural contexts; thus, its system-level transformation can only be induced through behavioral changes of stakeholders that require intensive science–policy dialogues aided by evidence. Given the heterogeneity of interests among stakeholders of the food systems, institutional innovation process should be consultative while inevitably time consuming.

In the meantime, where possible, technological innovations, or the application of agronomic science, technology, and innovation (STI) should be urgently promoted to build food systems' resilience to extreme events and climate variability. Accelerated adoption depends on properly addressing stakeholders' needs and constraints. Therefore, agronomic STI that should be promoted can not only reduce environmental footprints, such as GHG emissions, by promoting efficient resource use and the regeneration of biodiversity, but also enhance food productivity and ensure improved profitability for stakeholders. In turn, given the heterogeneity of agronomic environment, there is 'no one-size-fits-all' approach; some mitigation options can have trade-offs with other sustainable development goals, unless locally specific needs are addressed. The identification and customization of appropriate sets of STI to locally specific agroecological and socioeconomic conditions are critical to overcome trade-offs and achieve win–win outcomes.

According to Clift and Plumb (2008), almost two-thirds of humanity lives within regions that are influenced by monsoons. Of these, the Asia-Monsoon region includes the economies of eastern, southeastern, and southern Asia. Smallholder paddy rice farming systems associated with hot and humid climates are the basis for intensive food production in the region, necessitating STI to address context-specific challenges. In turn, given the region's significant diversity in agroecological and socioeconomic conditions defining agriculture, forestry, and fisheries sectors, the principle of 'no one-size-fits-all' approach should also be applied intra-regionally.

The latest IPCC reports (IPCC 2021a, 2021b) indicate that the region is expected to experience extreme weather events more frequently at varied temporal and spatial scales, as witnessed in August 2022 alone: record-breaking heatwaves and droughts in southern China and catastrophic floods caused by almost 10-fold average monsoon precipitation in Pakistan. The accelerated application of STI is critical for the region to improve the resilience of food systems at minimum environmental footprints while adapting to and mitigating climate emergencies.

Given the importance of the Asia-Monsoon region to the global economy, the success of sustainable food systems transformation has global significance. Within the Asia-Monsoon region, there are many common features that may provide enabling conditions to realize a swift implementation of food systems transformation through the scaling up of STI with fine-scale tailoring to locally specific contexts. For example, while Japan has been geared toward promoting its food systems transformation to achieve both productivity and sustainability through STI, some practices could be applicable to other countries and economies within the region if modified for local needs. From these perspectives, Japan has a role to play in contributing to the region through strengthening networks among various partners and sharing science-based information that would be useful in and applicable to the Asia-Monsoon region.

The objectives of this study are fourfold: (i) to define the Asia-Monsoon region to contextualize its significance in global food systems; (ii) to highlight key features of the region's agricultural sector, especially the hot and humid climate, paddy rice agriculture, and the dominance of small-scale farmers; (iii) to call for STI to address the region's challenges in an era of climate emergencies and environmental crises; and (iv) to introduce the government of Japan's new national strategy for sustainable food systems under which a forum or network center is established to generate and disseminate science-based information among various stakeholders to facilitate the acceleration of innovations in the Asia-Monsoon region.

2: Defining the Asia-Monsoon Region

Despite the region’s prominence in the global context, there seems to be no consensus or officially agreed upon definition of the region. A more concrete definition in terms of geographical boundaries may be needed to estimate the region’s global shares in terms of demography, economy, GHG emissions, and so on, with updated reliable statistics. In this section, we attempt to provide our definition of the region to enable the estimation of its demographic and economic position in the global context, while also noting its intra-regional diversity.

2.1: What is the Asia-Monsoon Region?

The word “monsoon” is derived from the Arabic word “mausim,” meaning the season of winds that change their direction by nearly 180 degrees throughout the year (Kyuma 2009). The characteristics of precipitation in monsoon climates are mostly reflected in the seasonal cycle of alternating rainy and dry seasons during the year, namely, hot and humid summers and dry winters (Liu et al. 2015; Zurbenko and Luo 2015). According to the Annex V: Monsoon, of the IPCC report (IPCC 2021a, 2021b), the global monsoon is defined as an area in which the annual range (local summer minus local winter) of precipitation is greater than 2.5 mm/day. The Asia-Monsoon region encompasses eastern, southeastern, and southern Asia. The tropical and temperate climatic zones, according to the Köppen-Geiger classification, cover a greater part of the region (Figure 1). Humid and hot climatic conditions accommodate large populations, making the region the most populated in the world (Figure 2).

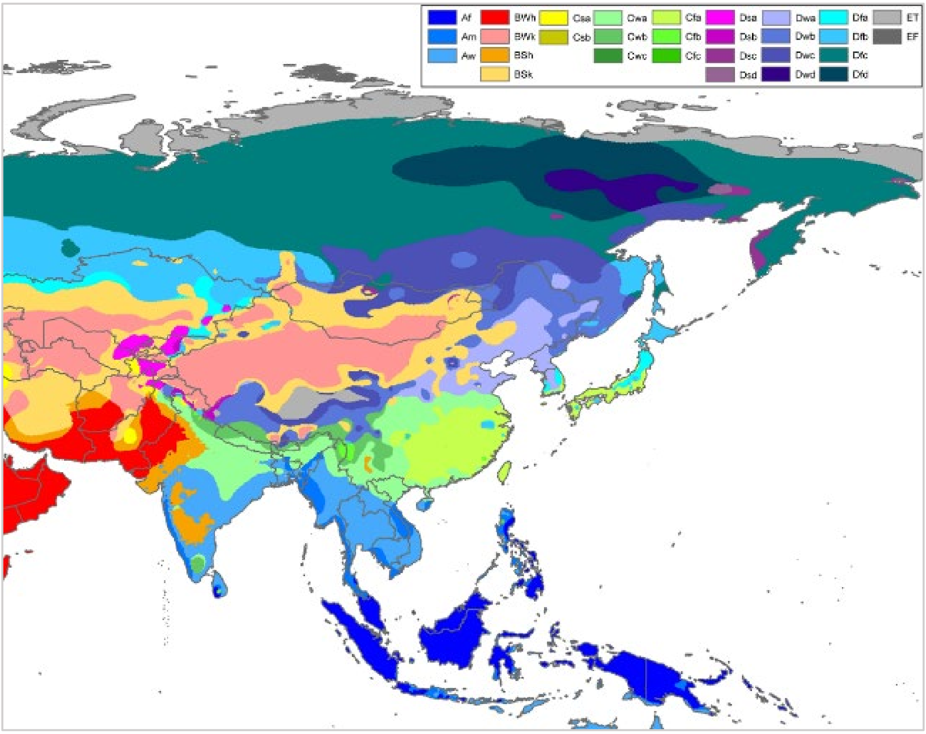


Figure 1: Köppen-Geiger climate map for Asia
https://www.worldmap1.com/asia-koppen-map

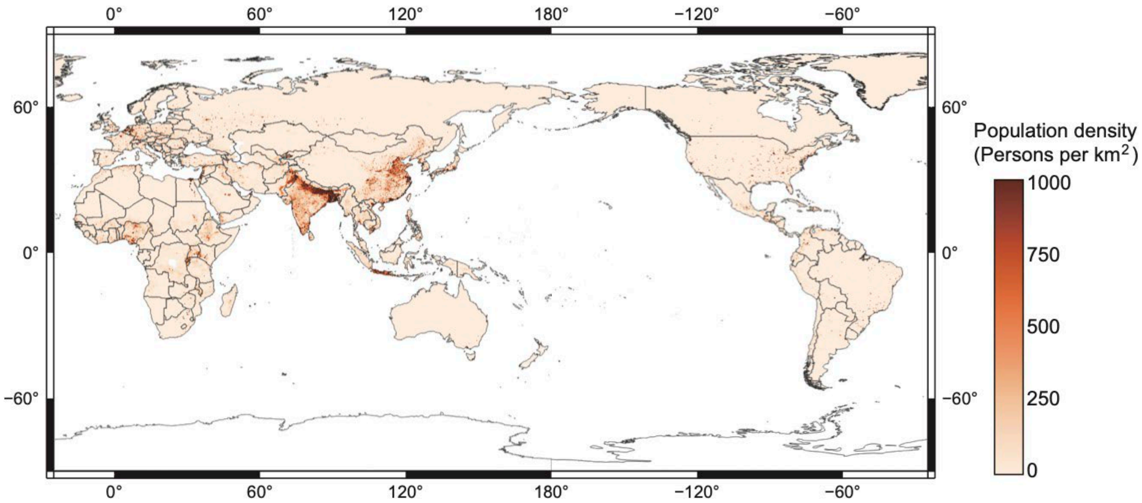


Figure 2: Population density map
https://sedac.ciesin.columbia.edu/data/set/gpw-v4-population-density-rev11

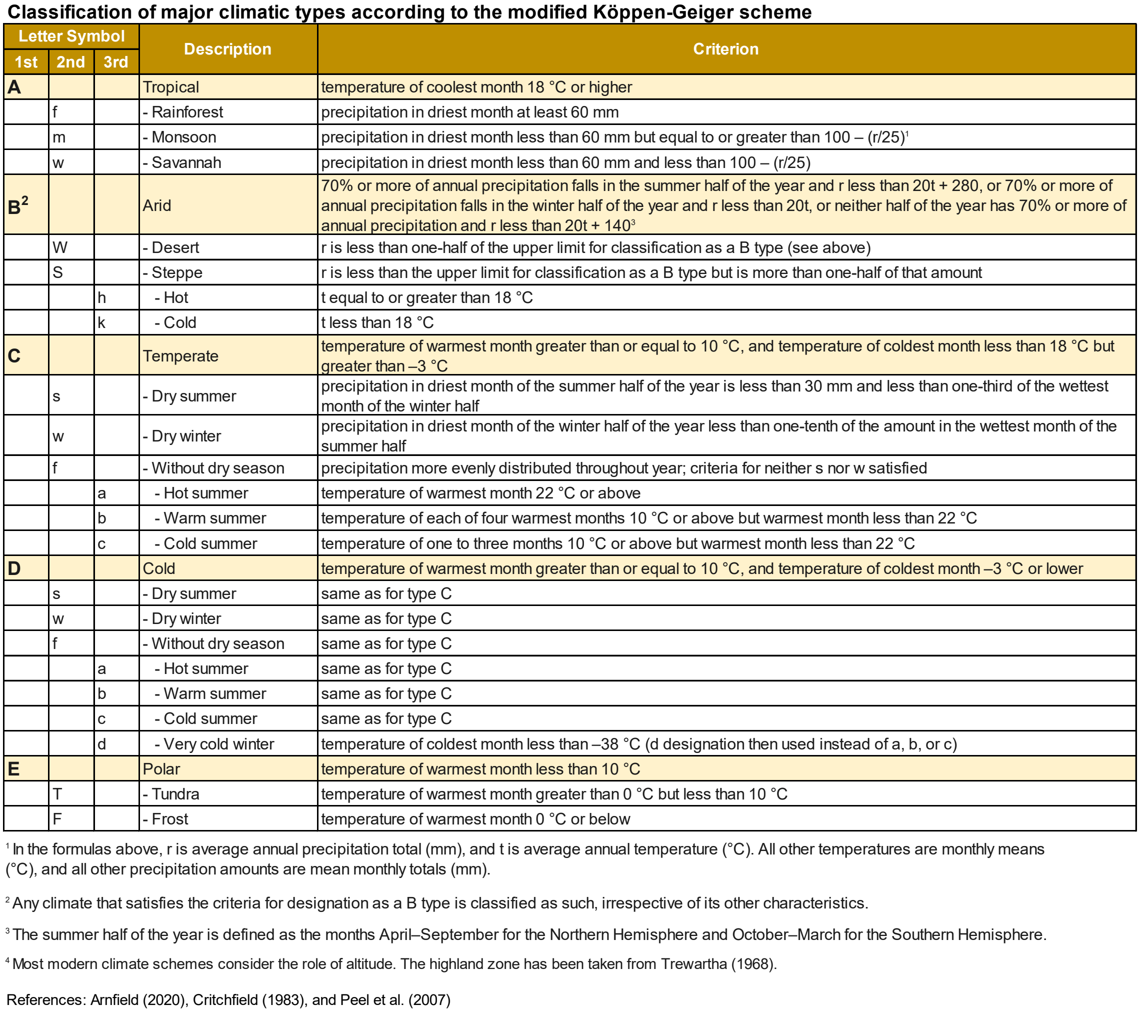
Kyuma (2009), in his estimation, accounted for 50% of the land area and 90% of both the population and cultivated area of China as part of the Asia-Monsoon region. Without a consensus on the boundaries, in turn, it is difficult to discuss the region's evolving position from the past to the present and into the foreseeable future within the global context for sustainable food systems transformation.

Challenges in defining the region include the fact that climatic zone boundaries do not necessarily correspond to political or administrative boundaries, which become the basic units for essential demographic and economic statistics. Therefore, specifically for the purpose of this study, which is to contextualize the region’s significance in global food systems, we propose our ad hoc definition of the Asia-Monsoon region by compromising climatic and administrative boundaries.

2.2: Geographic Boundaries of the Asia-Monsoon Region

We primarily refer to climate classification to define spatial boundaries, in which agroclimatic boundaries somewhat correspond to specific administrative boundaries. For example, types of agriculture, forestry, and fisheries are strongly influenced by local climate (temperature and precipitation) which determines local vegetation. The climate classification of Köppen (1884), which was originally proposed to classify world regions based on local vegetation, is one of the most cited systems. The modified Köppen-Geiger scheme divides the world into five climate zones based on criteria, usually temperature, and each zone is further subdivided based on temperature or dryness (Table 1).

Table 1: Classification of major climatic types according to the modified Köppen-Geiger scheme



Classification of major climatic types according to the modified Köppen-Geiger scheme

Letter Symbol			Description	Criterion
1st	2nd	3rd		
A			Tropical	temperature of coolest month 18 °C or higher
	f		- Rainforest	precipitation in driest month at least 60 mm
	m		- Monsoon	precipitation in driest month less than 60 mm but equal to or greater than 100 – (r/25)[1]
	w		- Savannah	precipitation in driest month less than 60 mm and less than 100 – (r/25)
B[2]			Arid	70% or more of annual precipitation falls in the summer half of the year and r less than 20t + 280, or 70% or more of annual precipitation falls in the winter half of the year and r less than 20t, or neither half of the year has 70% or more of annual precipitation and r less than 20t + 140[3]
	W		- Desert	r is less than one-half of the upper limit for classification as a B type (see above)
	S		- Steppe	r is less than the upper limit for classification as a B type but is more than one-half of that amount
		h	- Hot	t equal to or greater than 18 °C
		k	- Cold	t less than 18 °C
C			Temperate	temperature of warmest month greater than or equal to 10 °C, and temperature of coldest month less than 18 °C but greater than –3 °C
	s		- Dry summer	precipitation in driest month of the summer half of the year is less than 30 mm and less than one-third of the wettest month of the winter half
	w		- Dry winter	precipitation in driest month of the winter half of the year less than one-tenth of the amount in the wettest month of the summer half
	f		- Without dry season	precipitation more evenly distributed throughout year; criteria for neither s nor w satisfied
		a	- Hot summer	temperature of warmest month 22 °C or above
		b	- Warm summer	temperature of each of four warmest months 10 °C or above but warmest month less than 22 °C
		c	- Cold summer	temperature of one to three months 10 °C or above but warmest month less than 22 °C
D			Cold	temperature of warmest month greater than or equal to 10 °C, and temperature of coldest month –3 °C or lower
	s		- Dry summer	same as for type C
	w		- Dry winter	same as for type C
	f		- Without dry season	same as for type C
		a	- Hot summer	same as for type C
		b	- Warm summer	same as for type C
		c	- Cold summer	same as for type C
		d	- Very cold winter	temperature of coldest month less than –38 °C (d designation then used instead of a, b, or c)
E			Polar	temperature of warmest month less than 10 °C
	T		- Tundra	temperature of warmest month greater than 0 °C but less than 10 °C
	F		- Frost	temperature of warmest month 0 °C or below

[1] In the formulas above, r is average annual precipitation total (mm), and t is average annual temperature (°C). All other temperatures are monthly means (°C), and all other precipitation amounts are mean monthly totals (mm).

[2] Any climate that satisfies the criteria for designation as a B type is classified as such, irrespective of its other characteristics.

[3] The summer half of the year is defined as the months April–September for the Northern Hemisphere and October–March for the Southern Hemisphere.

[4] Most modern climate schemes consider the role of altitude. The highland zone has been taken from Trewartha (1968).

References: Arnfield (2020), Critchfield (1983), and Peel et al. (2007)

According to the modified Köppen-Geiger scheme of climatic classification (Figure 1), the large parts of eastern, southeastern, and southern Asia fall into the temperate (C) and tropical (A) climate zones, while their distributions vary depending on not only the distance from the equator or the latitude, but also other geographical conditions, such as the presence of mountains, the distance from coasts, and the influence of coastal currents (Liu et al. 2015).

The climate of Japan, with its land extensively stretching from the north to the south, is predominantly temperate (C), with most administrative units (prefectures) falling into Cfa (temperate, without a dry season, hot summer) (Online Appendix 1). While Hokkaido and Nagano prefectures are classified as dominantly cold climate Dfb (cold, without a dry season, warm summer), for this study, we regard Japan predominantly under a temperate climate zone without a dry season but with hot summer as part of the Asia-Monsoon region. Most of the eastern Asian countries and economies have at least their dominant land areas falling into either Cfa (temperate, without a dry season, hot summer) or Cw (temperate, dry winter) of the temperate climate zone (C), except Mongolia, which falls mainly under cold (D) and dry (B) climates, and North Korea, which falls under cold (D) climates.

Many countries and economies in southeastern Asia have tropical climates (A). There is only one country in the sub-region, Myanmar, whose representative climate is Am (tropical monsoon) (Table 2). Many other southeastern Asian countries have substantial proportions of areas falling under the categories of Af (tropical rainforest) and Aw (tropical savanna). Southern Asia is largely divided into two groups: one predominantly under a tropical climate (Bangladesh, Sri Lanka, and Maldives) and the other mostly under a temperate climate (Bhutan, India, Nepal, and Pakistan), while Pakistan has significant areas under extremely dry climates.

For this study, we considered eastern, southeastern, and southern Asian economies, with areas falling predominantly under the climatic types of either Af (tropical rainforest), Am (tropical monsoon), Aw (tropical savannah), Cw (temperate, dry winter), Cfa (temperate, without a dry season, hot summer), or Cfb (temperate, without a dry season, warm summer), as part of the Asia-Monsoon region, in which 23 countries and economies are included (Table 2).

2.3: Region's Demographic and Economic Shares in the Global Context

Potential problems of overestimating the demographic and economic significance of the Asia-Monsoon region by classifying the countries and economies with this definition arise in countries and economies with large land areas and populations, especially China and India. Their territories have covered distinctive 'monsoon' climatic zones, while having significant portions of their countries out of the 'monsoon' climate classifications: either too dry (B) or too cold (D). Therefore, for these two countries, we examined the data at administrative (province or state) levels and considered that those administrative units falling under the Köppen climatic types of Af, Am, Aw, Cw, Cfa, or Cfb would be included in the Asia-Monsoon region (Online Appendix 2).

If the whole area of 23 countries and economies is considered, 3.99 billion or 52% of the global population live in 15% of the world's total land area and earn 33% of the global GDP (Table 3). For China and India, administrative units falling under the Köppen climatic types of Af, Am, Aw, Cw, Cfa, or Cfb corresponded to 33% and 69% of the total land area, respectively. In turn, in both countries, proportionally more people and economic activities are concentrated in the 'monsoon' climates, making their population and GDP shares 75% and 78% in China and 77% and 73% in India, respectively. Under this arbitral delineation of the Asia-Monsoon region for this study, an estimated 3.34 billion people or 44% of the world's population as of 2018 live in areas corresponding to 9% of the world's total land area, while accounting for 28% of the global GDP.

In other words, the Asia-Monsoon region, occupying merely one-tenth of the world's land area, has a significant global demographic and economic presence. The population density of the Asia-Monsoon region stands at 292 persons per square kilometer (3.34 billion population living in an area of 11,445, 000 km^2), almost five-fold that of the world average (59 persons per square kilometer, derived from 7.63 billion people divided by 130,000,000 km^2).

Table 2: The list of countries/economies that constitute the Asia-Monsoon region in reference to the Köppen Climate Classification

Region	Country/Economy	Annual mean temperature (1991-2020)	Annual precipitation (1991-2020)	Köppen climate classification																				
				A: Tropical climates			B: Dry climates		C: Temperate climates					D: Continental climates									E: Polar climates	
				Af	Am	Aw	BW	BS	Cs	Cw	Cfa	Cfb	Cfc	Ds	Dwa	Dwb	Dwc	Dwd	Dfa	Dfb	Dfc	Dfd	ET	EF
Eastern Asia	Japan	12	1800								◎	○								○				
	Korea	12	1668							◎	○				○									
	Chinese Taipei	23	2405								◎													
	Hong Kong	23	2400							◎														
	China	8	644		○			○	○	◎					○	○							○	
Southeastern Asia	Singapore	28	2253	◎																				
	Brunei	27	3661	◎																				
	Malaysia	26	3239	◎	○																			
	Thailand	27	1494	○	○	◎																		
	Philippines	26	2333	◎	○																			
	Indonesia	26	3097	◎	○	○																		
	Vietnam	25	1750		○	○				◎	○													
	Cambodia	28	1871		○	◎																		
	Laos	24	1512		○	◎				○														
	Myanmar	24	1940		◎	○				○														
	Timor-Leste	25	1043			◎																		
Southern Asia	Bangladesh	25	2477		○	◎				○														
	Bhutan	12	2053							◎							○						○	
	India	25	1169		○	○		○	○	◎		○					○			○	○			
	Nepal	13	1375							◎														
	Pakistan	21	397				○	○	○		◎													
	Sri Lanka	28	1607	◎	○	○																		
	Maldives	28	2365	○	◎																			

(note) ◎: Representative climate classfication in the country, ○: other climate classfications in the country

Table 3: The area, population, and GDP of the countries/economies corresponding to the Asia-Monsoon region and their global shares

Region	Country/Economy	Total Area (1,000 km^2)	Total Population (10,000 in 2018)	Total GDP (billion USD in 2018)
Eastern Asia	Japan	378	12,720	5,037
	Korea	100	5,178	1,725
	Chinese Taipei	32	2,373	609
	Hong Kong	1.11	737	361
	China	3,146 [33%]	104,536 [75%]	10,783 [78%]
Southeastern Asia	Singapore	0.7	564	376
	Brunei	6	42.1	13
	Malaysia	330	3,200	359
	Thailand	514	6,641	506
	Philippines	299	10,098	347
	Indonesia	1,920	26,700	1,042
	Vietnam	329	9,762	245
	Cambodia	181	1,630	24
	Laos	240	701	18
	Myanmar	680	5,141	67
	Timor-Leste	15	126.1	2
Southern Asia	Bangladesh	147	16,555	274
	Bhutan	38	75.4	2
	India	2,154 [69%]	101,606 [77%]	2,091 [73%]
	Nepal	147	2,970	33
	Pakistan	796	20,777	315
	Sri Lanka	66	2,103	88
	Maldives	0.3	53.4	5
Region Total		11,445	334,289	24,321
Global		130,000	763,100	86,274
Region's Share (%)		9	44	28

(note) For China and India, only administrative units falling under the Köppen climatic types of Af, Am, Aw, Cw, Cfa, or Cfb, would be included in the Asia-Monsoon region, with their shares in the countries indicated in the parentheses.

The region's economy is destined to grow, and food insecurity remains a persistent problem. According to recent UN estimates (FAO, IFAD, UNICEF, WFP, and WHO 2022), while globally between 702 and 828 (768 as median) million people were affected by hunger, over half of them were found in Asia at 425 million (9.1% of the regional population) and 278 million in Africa (20.2%); 10.5% of the Asian population suffered from severe food insecurity.

According to the UN World Population Prospects, under the medium variant scenario, over the course of the 21st century, the global share of the Asia-Monsoon region population (the populations of China and India were estimated at 75% and 77% of that of the countries, respectively) will gradually decrease from 44% in 2020 to 40% in 2050 and to 31% in 2100 (Figure 3), due to the growing share of that of Africa in the coming decades. Under the UN's medium variant scenario, until 2050, the absolute regional population will grow by 420 million to reach 3.88 billion.

Therefore, the region still needs to boost food production to meet the growing food demand to ensure food security and poverty alleviation and a shifting diet corresponding to the projected economic development and urbanization.

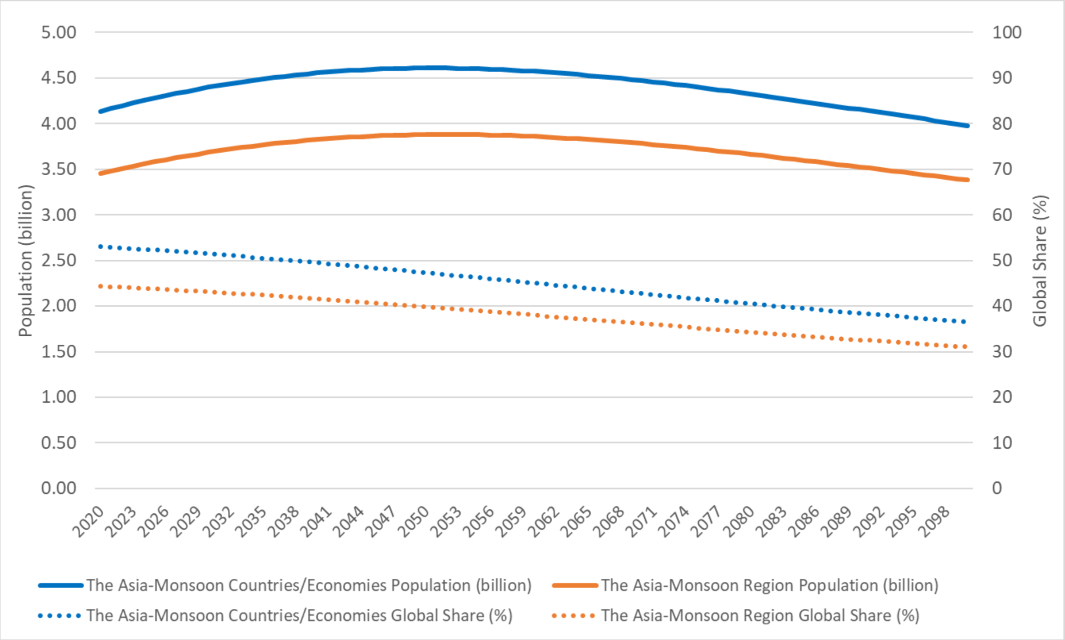


Figure 3: The Asia-Monsoon region population

(Source)UN World Population Prospects 2019.
(note) The populations of China and India falling in the Asia-Monsoon region were estimated at 75% and 77%, respectively, of that of the countries in reference to Table 3.

2.4: Intra-regional Diversity in Socioeconomic Conditions

While the region collectively boasts a significant global position, it is also true that the Asia-Monsoon region encompasses countries and economies that are socioeconomically diverse. For example, food and nutrition security status and the level of economic development vary significantly across the Asia-Monsoon region. While some countries face an acute humanitarian crisis, others are members of the G20. At the same time, the Asia-Monsoon region comprises countries and economies that present extreme diversity in demography, from those almost 100% urban to those still predominantly rural, and from those with rapidly aging populations to those with huge populations of youth. Indeed, the societies of eastern Asian countries and economies and city-states of southeastern Asia are very urban and aging. Particularly in Japan, the aging process has progressed dramatically over the past 20 years, with the old-age dependency ratio increasing from 25% in 2000 to 50% in 2018, which is even predicted to reach 80% by 2050 (World Bank WDI; OECD Data). By contrast, in some countries in southeastern and southern Asia, the populations are still relatively rural and young.

Reflecting the heterogeneity in socioeconomic and demographic conditions, the share of agriculture, forestry, and fishery sectors in the GDP of the region as of 2020 also varies from less than 1% in the city states (Singapore) , just around 1% in highly industrial countries (such as Japan) to 23% (Nepal, Pakistan), with many of the upper-middle and lower-middle income countries of southeastern and southern Asia being at over 7%, higher than the world average of 4.3% (World Bank WDI).

3: Characterizing the Agricultural Sector of the Asia-Monsoon Region

The Asia-Monsoon region is blessed with abundant precipitation and high temperatures (Tanaka 2006), which conditions land use and demographic patterns and characterizes the agricultural sector. This section describes the key features of the agricultural sector in the Asia-Monsoon region, especially those defining its intensive farming system. Other important agri-food commodities in the Asia-Monsoon region that have comparative advantages in the world are also listed.

3.1: Key Features of the Region's Agricultural Sector

The most notable features of the region's agricultural sector are its hot and humid climate, rice paddy farming, and a high concentration of small-scale farmers, which are indeed closely interrelated to each other, as described below.

Hot and Humid Climate

The Asia-Monsoon climate is known for its high temperatures and humidity. According to Liu et al. (2021) who studied anthropogenic influence on the intensity of extreme precipitation in the Asia-Australian monsoon region (Figure 4), the Asia-Monsoon region is characterized by abundant summer monsoon rainfall, which provides freshwater resources for high-density populations.

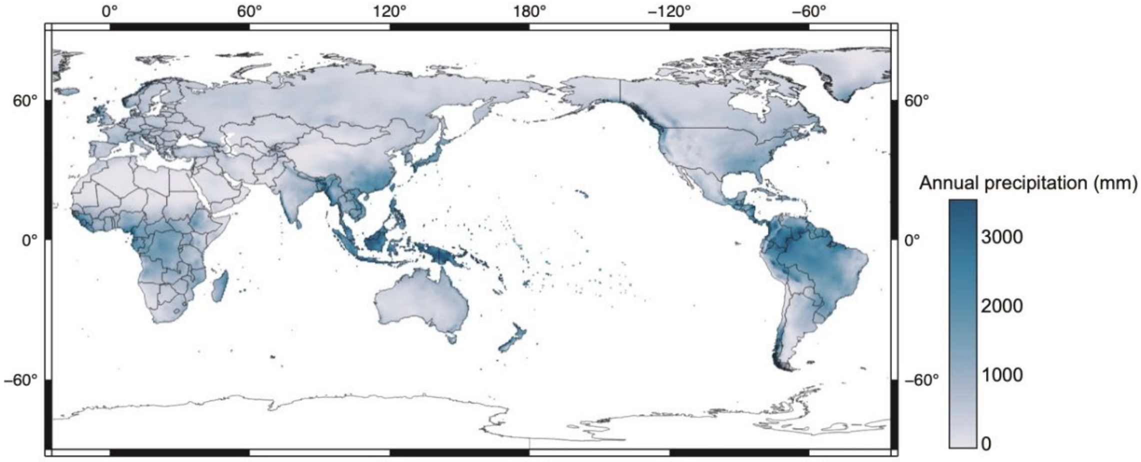


Figure 4: Countries by average annual precipitation
https://climateknowledgeportal.worldbank.org/download-data

The hot and humid climate of the region greatly affects agricultural production, especially under rain-fed conditions. While the interannual variation in rainfall, either droughts or floods, impacts production, the phase of the intra-seasonal variation between wet and dry spells within a season vis-à-vis the different phenological stages of the crop also has an impact on the growth and yield of rain-fed crops (Gadgil & Kumar 2006). The hot and humid climate also provides an environment for weeds to thrive, competing with crops for light and nutrients, thus challenging farmers to control weeds with capital and labor (Chauhan 2013).

The hot and humid climate, especially when combined with similar cropping patterns over large areas, makes many pests and diseases a serious threat to affected areas (Gadgil & Kumar 2006). In the humid climates of the Asia-Monsoon region, there are many plant pests and diseases that are transboundary, complicating effective treatment and allowing pests and diseases to obtain resistance. Long dry spells are conducive for some insects, such as leaf miners, while wet spells attract many fungal diseases, causing large losses of agricultural products (Gadgil & Kumar 2006).

Rice Paddy Farming

Another distinguishing feature of the Asia-Monsoon region, associated with its hot and humid climate on the one hand, and the extensive occurrence of lowlands on the other, is the dominance of the rice paddy farming system as a basis for food production (Kyuma 2009). *Oryza sativa* L., the dominant rice worldwide, is believed to have originated from this region (Gadgil & Kumar 2006). Rice grows well in a tropical rainy climate characterized by high temperatures, high humidity, low light intensity, and abundant rainfall. The total water requirement for cultivation over rain-fed areas is 20 cm per month or 1,000 mm per year. An important feature of rice cultivation is transplantation, which is performed approximately one month after sowing and is dependent on rainfall during that period (Gadgil & Kumar 2006).

Much of the world's rice is grown in the Asia-Monsoon region, where monsoon rains and tropical storms coincide with the major rice-growing season (Nelson 2016, Figure 5). Rice cultivation initially emerged as an adaptation to extensively inundated lowlands, but over time it was expanded even to land that could support rice only with irrigation (Kyuma 2009). For example, though the reference is old, in China, the main rice growing areas, with more than 90% of the total rice area and production, were south of the Qinling Mountains and the Huai River, which tend to be subtropical or tropical (Defeng 2000), and thus fall into this report's definition of the Asia-Monsoon region. In India, rice is mainly grown in rain-fed areas that receive heavy annual rainfall, but also in areas under irrigation; rice is the staple food of the eastern and southern parts of India (Siddiq 2000).

In the Asia-Monsoon region, the rainfall pattern is considered the most important limiting factor for rice production in southern and southeastern Asia, while temperature and radiation are more important for the higher latitude region in eastern Asia, especially in northeastern and northern Japan (Gadgil & Kumar 2006). Over the past several decades, changes in rice-growing techniques, such as the introduction of modern rice varieties with shorter growing periods, have transformed rice-based cropping patterns in the tropical parts of the region, such as the Mekong Delta, from single-cropping patterns to double-cropping systems, resulting in significant intensification of rice-growing systems (Tanaka 2006).

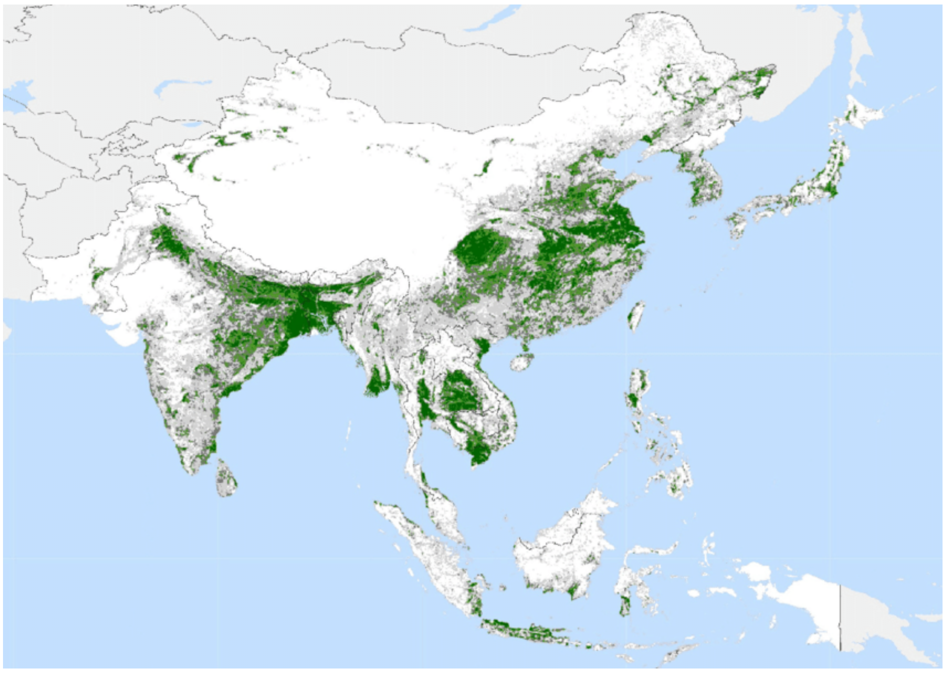


Figure 5: Major rice growing areas in Asia, circa 2000–2010

(Source) Nelson 2016.
https://www.researchgate.net/figure/Major-rice-growing-areas-in-Asia-circa-2000-2010-from-MODIS-Based-on-Figure-3-from-47_fig4_301698869

Table 4: The prominence of the Asia-Monsoon region for rice in the global share

Region	Country	Land Cultivated with Rice (ha) 2018	Rice Production (t) 2018	Rice Yield (t/ha) 2018	Export rice paddy, milled equivalent (t) 2018	Import rice paddy, milled equivalent (t) 2018
Eastern Asia	Japan	1,470,000	10,606,000	7.1	44,041	609,538
	Korea	737,673	5,195,437	6.9	64,124	386,490
	Chinese Taipei	271,506	1,949,796	7.1	56,847	101,551
	Hong Kong	0	0		16,959	325,803
	China	30,189,450	212,129,000	6.9	2,062,304	3,027,372
Southeastern Asia	Singapore				40,098	287,092
	Brunei	783	1,569	2.0	2,103	37,208
	Malaysia	699,980	2,639,202	3.7	19,654	808,055
	Thailand	10,647,941	32,348,114	3.0	11,073,000	14,946
	Philippines	4,800,406	19,066,094	3.9	212	1,764,329
	Indonesia	11,377,934	59,200,534	5.1	3,211	2,253,746
	Vietnam	7,570,741	44,046,250	5.7	5,244,394	66,448
	Cambodia	3,036,117	10,892,000	3.5	505,178	39,084
	Laos	848,174	3,584,700	4.2	41,817	28,943
	Myanmar	7,149,311	27,573,589	3.8	1,616,758	3,192
	Timor-Leste	17,694	57,000	3.2	98	90,057
Southern Asia	Bangladesh	11,515,000	54,416,000	4.7	8,254	1,012,158
	Bhutan	15,082	63,890	4.2	16	71,504
	India	44,156,450	174,716,730	3.9	11,579,628	6,502
	Nepal	1,469,545	5,151,925	3.5	10	739,476
	Pakistan	2,810,030	7,201,966	2.5	3,912,607	8,149
	Sri Lanka	1,040,954	3,929,831	3.7	4,891	197,993
	Maldives					31,992
Region Total		139,824,771	674,769,627	4.8	36,296,204	11,911,628
Global		165,751,531	759,066,702	4.5	46,050,442	46,295,837
Region's Share (%)		84	89		79	26

(source) FAOSTAT. For this table, the country data for China and India were not adjusted for the Asia-Monsoon region.

Kyuma (2009) described that the Asia-Monsoon region was naturally regarded as the rice granary of the world, with its shares of the area and production of rice amounting to 90% of the total global acreage and annual output. While the figures may overestimate without excluding the share of non-monsoon administrative units of China (such as Beijing) and India (such as Panjab), Table 4 clearly indicates the region's significance in rice production and trade in the global share: 84% of the land cultivated, as well as 89% of the production, and 79% of the exports in terms of quantity, confirming that Kyuma (2009)'s claim still holds.

Small-scale Landholding

As shown in Section 2.3, the Asia-Monsoon region is characterized by an extremely high population density. Small farms constitute the vast majority of agricultural holdings in many countries in the region (Figure 6). While the data are limited to the distribution of farm size, in many countries in the region, farms with less than 1 ha of land are dominant (Lowder et al. 2014; Yamaguchi 2021; Giller et al. 2022). China, Indonesia, Vietnam, India, Nepal, and Japan had the largest share of total producers farming less than 1 ha of land (OECD/FAO 2017). This general trend of small farm size combined with rice paddy farming systems naturally results in high land and labor use intensity (Tanaka 2006; Kyuma 2009). Thus, the region has no more land to further expand for cultivation and has to focus on sustainably intensifying production on existing farmland (Kyuma 2009).

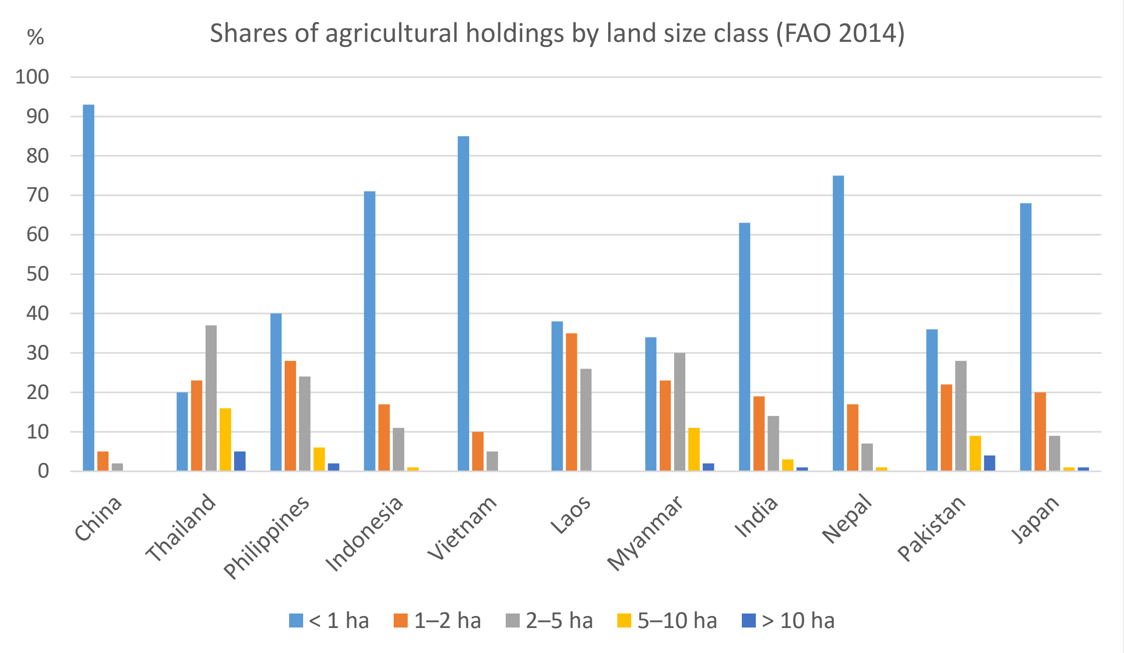


Figure 6: Shares of agricultural holdings by land size class
(Source) FAO 2014.

3.2: Other Important Agri-Food Commodities

Per the definition of this report, the Asia-Monsoon region encompasses six distinctive temperate and tropical climatic zones in which further significant intra-zone diversity in agroecological conditions prevails owing to locally specific geographical features. Therefore, the agricultural sector, together with forestry and fishery, can accommodate the production of diverse agro-food products to provide not only nutritious food to the regional population and the world through trade but also strategically important industrial commodities.

Wheat

While rice has a dominant position as the staple food for the Asia-Monsoon region, wheat is also an important crop for China, India, and Pakistan, which ranks as the top (18%), second (14%), and seventh (3%) global producers, respectively, as of 2018 (FAOSTAT). While the most suitable regions for wheat may lie outside of the monsoon climate, the rice–wheat cropping system is the major agri-food system occupying an area of 13.5 million ha in the Indo-Gangetic Plains of south Asia, out of 24 million ha worldwide (Chhokar et al. 2007; Jat et al. 2021), mostly in India (10 million ha), and it is the most widely used cropping pattern in Nepal (Gautam et al. 2021).

Agricultural Commodities

Furthermore, its agroecological niches also provide comparative advantages to grow certain agricultural commodities, especially palm oil, with 88% of the 2018 global production, for which Indonesia, Malaysia, and Thailand account for 60%, 24%, 4%, respectively, and tea with 77% of the global production, for which China and India account for 29% and 20%, respectively (FAOSTAT). The region also accounts for 80% of the global production of what FAOSTAT defines as "fruit, tropical freshness" (other tropical fresh fruits are not identified separately because of their minor relevance at the international level). In some countries, mangoes, avocados, pineapples, dates, and papayas are reported in this general category, with the top six producers being India (24%), China (15%), Philippines (13%), Thailand (11%), Indonesia (9%), and Bangladesh (4%). To a lesser extent, some of the Asia-Monsoon countries and economies rank among the top 10 global producers, including for sugarcane (41%: India 20%, Thailand 7%, China 6%, Pakistan 3%, etc.) and coffee (29%: Vietnam 15%, Indonesia 7%, etc.).

Livestock

The Asia-Monsoon region's share of the global meat production was 16% for cattle, 28% for chicken, and 57% for pork in 2015 (FAOSTAT, Table 5). China alone accounted for 47% of the global production of pork, along with 9% for cattle and 12% for chicken. In turn, the growth of meat production in the region over the period of 2000–2015 exceeded that of the global production. For example, Myanmar recorded a 400–630% growth in the production of cattle, chicken, and pigs, and the growth rates of chicken production in southern Asian countries exceeded 200%. India stood for its high global share of milk production (19% of the global total).

Table 5: The Asia-Monsoon Region's livestock production in the global context

Region	Country/Economy	Livestock (Meat) production					
		Cattle 2015 tonne	△% from 2000	Chicken 2015 tonne	△% from 2000	Pigs 2015 tonne	△% from 2000
Eastern Asia	Japan	481,019	-9	2,131,974	78	1,254,283	0
	Korea	323,000	6	790,000	111	1,217,000	33
	Chinese Taipei	6,400	31	533,073	-16	832,183	-10
	Hong Kong	6,900	-62	25,348	-61	122,354	-24
	China	5,552,010	20	12,075,000	44	56,454,000	42
Southeastern Asia	Singapore	36	-3	77,680	-9	21,341	2
	Brunei	482	-85	23,491	109	52	6
	Malaysia	43,672	198	1,511,442	133	222,598	39
	Thailand	144,702	11	1,629,034	56	936,356	35
	Philippines	205,708	8	1,185,914	122	1,775,712	46
	Indonesia	506,661	49	2,030,884	153	330,213	-20
	Vietnam	299,700	219	700,873	137	3,491,600	146
	Cambodia	55,470	-2	16,794	-14	111,618	6
	Laos	31,828	94	26,465	173	73,438	166
	Myanmar	357,261	404	1,505,000	605	863,235	631
	Timor-Leste	1,317	-2	922	-11	11,393	78
Southern Asia	Bangladesh	191,649	11	185,500	97		
	Bhutan	4,483	-25	1,063	366	704	-45
	India	931,645	-6	3,263,810	278	361,686	-22
	Nepal	50,108	4	45,458	259	20,135	37
	Pakistan	882,000	110	1,074,000	228		
	Sri Lanka	22,774	-21	164,450	160	1,694	-3
	Maldives						
Region Total		10,098,825	25	28,998,175	85	68,101,595	43
Global		63,434,353	14	103,773,808	77	119,320,818	33

(source) FAOSTAT. For this table, the country data for China and India were not adjusted for the Asia-Monsoon region.

Table 6: The Asia-Monsoon Region's aquaculture production in the global context

Region	Country/Economy	Aquaculture production			
		2000 (mt)	2010 (mt)	2018 (mt)	2018 as a factor of 2000
Eastern Asia	Japan	1,291,735	1,151,101	1,032,675	0.8
	Korea	667,883	1,377,233	2,278,850	3.4
	Chinese Taipei				
	Hong Kong	4,988	4,338	4,133	0.8
	China	29,749,708	47,789,756	66,135,060	2.2
Southeastern Asia	Singapore	5,112	3,499	5,702	1.1
	Brunei	113	500	1,116	9.9
	Malaysia	167,898	581,243	391,977	2.3
	Thailand	738,155	1,286,122	890,864	1.2
	Philippines	1,100,902	2,545,967	2,304,361	2.1
	Indonesia	993,727	6,277,925	14,772,104	14.9
	Vietnam	513,517	2,701,317	4,153,323	8.1
	Cambodia	14,430	60,000	254,050	17.6
	Laos	42,066	82,100	108,200	2.6
	Myanmar	98,912	852,791	1,131,706	11.4
	Timor-Leste	0	1,554	1,610	
Southern Asia	Bangladesh	657,120	1,308,515	2,405,416	3.7
	Bhutan	30	46	224	7.5
	India	1,942,531	3,790,021	7,071,302	3.6
	Nepal	15,023	28,230	59,000	3.9
	Pakistan	12,485	140,101	159,083	12.7
	Sri Lanka	4,420	8,058	30,921	7.0
	Maldives				
Region Total		36,729,020	69,990,417	103,191,677	2.8
Global		41,724,570	78,020,020	114,500,000	2.7

(source) WDI. WDI does not refer to the data of Chinese Taipei

For this table, the country data for China and India were not adjusted for the Asia-Monsoon region.

Forestry

The Asia-Monsoon region has 13% of the total world forest area, while their intra-regional patterns have been heterogeneous (World Bank WDI), aside from the diversity of trees, from temperate, sub-tropical, and tropical species. For example, Japan has been endowed with forested mountainous landscapes, covering 68% of its land area over the last two decades. Some countries seemed to have increased their forest areas through afforestation campaigns, including Vietnam (from 38% to 49%), Bhutan (from 65% to 71%), and China (from 19% to 23%). In turn, others have experienced deforestation on a massive scale, notably Indonesia (from 56% to 49%), Cambodia (from 61% to 48%), and Myanmar (from 53% to 44%).

Fisheries

Aquaculture is another major feature of the Asia-Monsoon region, accounting for almost 90% of the global production (World Bank WDI, Table 6), along with 64% of the global inland water capture fisheries (FAO 2022). However, its global share and trends are diverse across countries and economies. China, the world's largest aquaculture producer, accounted for 71% of the global production in 2000. While China is still an important player, the relative global share has declined to 58% over the past 18 years despite the 2.2-fold increase in volume, as the shares of other countries and economies have grown. Especially notable is Indonesia, which has increased its production volume 15-fold since 2000, with its global share increasing from 2% in 2000 to 13% in 2018.

3.3: Intensiveness of Farming Systems

In summary, while acknowledging intra-regional heterogeneity, the key features of the agricultural sector of the Asia-Monsoon region described in Section 3.1 form an environment conducive to highly intensive farming systems. Intensive farming systems have supported many populations for centuries on one hand (Kyuma 2009). On the other, a hot and humid climate has necessitated intensive agronomic practices, especially weeding and pest and disease control throughout the crop calendar, with input demand peaking for respective tasks (Chhokar et al. 2007; Jat et al. 2021), while small farm size requires labor-intensive cultivation (Otsuka 2013).

The intensiveness of the region's farming systems, conditioned by the region's unique agroecological (especially hot and humid climate) and socio-economic (small landholding sizes) factors, is distinguished from those in other regions of the world, such as Europe and the Americas (Giller et al. 2022). For example, upland crop systems and livestock grazing are operated over large farms in some parts of continental Europe and North America (Giller et al. 2022). While farms with a size of less than 1 ha are common in many countries and economies of the Asia-Monsoon region, farms of more than 100 ha are common in Europe and the Americas, where operations are highly mechanized (Yamaguchi 2021).

As discussed in the next section, these distinguished features of the agricultural sector of the Asia-Monsoon region should be considered when identifying and devising effective STI interventions to contribute to environmental sustainability without sacrificing productivity in climate emergencies and environmental crises. STI practices that are effective under agroecological and socioeconomic conditions of the agricultural sectors in Europe and the Americas would not necessarily work in the Asia-Monsoon region. Instead, within the Asia-

Monsoon region, there are many common features, such as a hot and humid climate, rice paddy farming, and small farms as main food producers, which may provide enabling conditions to realize a swift implementation of food system transformation by scaling up scalable agronomic STI practices through fine-scale tailoring to locally specific contexts.

4: Addressing Food Systems Transformation Challenges: STI Opportunities for the Asia-Monsoon Region

Global food systems face many challenges posed by anthropogenic climate change. The Asia-Monsoon region is no exception and is increasingly exposed to extreme events that negatively affect agricultural production. STI are urgently needed to make food systems resilient to climatic and environmental disasters without compromising food and nutrition security for the growing population while simultaneously reducing environmental footprints. In turn, the region's success in food system transformation with STI tailored to address its context will have a global impact. This section discusses the challenges and opportunities for food system transformation in the Asia-Monsoon region.

4.1: Climate Emergency and Environmental Crisis

The agricultural sector is among the most vulnerable to climate variability and extreme events, potentially leading to reduced yields and quality changes. This also applies to the Asia-Monsoon region.

In the Asia-Monsoon region, annual monsoons are a critical source of rainfall for agriculture. However, some changes in patterns have been observed across the sub-regions to varying degrees, while they are associated with a crucial increase in both drought and flooding (Clarke et al. 2022). According to a recent study (Rentschler et al. 2022), out of 1.81 billion people (23% of the world's population) directly exposed to 1-in-100-year floods, 1.24 billion are located in southern and eastern Asia. In turn, as increased precipitation is expected to occur over fewer days of more intense rainfall, the worsening of droughts also becomes more likely (Clarke et al. 2022), resulting in increased water stress with spatial and temporal variation over the Asia-Monsoon region (Kim et al. 2020).

Particular climate risk hotspots include lowland deltas that are home to rice farming and are prone to flooding, soil and water salinization, and coastal erosion as a consequence of the rising sea level due to climate change (Lenton et al. 2019; Kontgis et al. 2019; Smajgl et al. 2015). This threat is greater than previously thought, as recent research suggests that the elevation of some deltas is much lower than previously estimated, and that land in some deltas is sinking due to land subsidence caused by unsustainable groundwater extraction and drainage (Minderhoud et al. 2019; Kulp & Strauss 2019; Rentschler et al. 2022).

The increase in temperature due to global warming alone poses a serious challenge by altering the phenology of plants. As a recent global study indicated (Yoshimoto et al. 2022), while well adapted to a wide range of climates, rice is highly susceptible to heat during flowering, resulting in heat-induced spikelet sterility, especially in wetter climates, typical of those in the Asia-Monsoon region.

An increase in temperature can also expose farmers to higher risks of pests and diseases, whereas warming climates can expand the host range and geographical distribution of some pests (IPCC Secretariat 2021). One study estimated that on a global scale, significant yield losses of major grains are projected to increase by 10% to 25% per degree of global mean surface warming, with most acute impacts in areas where warming increases both the population growth and metabolic rates of insects (Deutsch et al. 2018). The same study projected a 19% increase in yield losses of rice, which is an important staple in the Asia-Monsoon region, due to pest pressure under a 2 °C temperature increase, bringing estimated losses of 92 megatons per year (Deutsch et al. 2018).

According to an FAO study, between 2008 and 2018, global disasters resulted in losses of approximately USD 108.5 billion due to a decline in crop and livestock production in developing countries. In absolute terms, Asia (not limited to the Asia-Monsoon region) accrued the largest loss from the decline in crop and livestock production, equivalent to USD 49 billion, followed by USD 30 billion for Africa (both sub-Saharan and North Africa), and slightly lower for Latin America and the Caribbean at USD 29 billion (FAO 2021). Given the increasing observation of rising temperatures and extreme events in recent years, the impacts of climate change on the agricultural sector will intensify in the coming years.

4.2: GHG Emissions from the Agricultural Sector

The agricultural sector is not only subject to the vagaries of climate and environmental crises, but are also major contributors to anthropogenic GHG emissions, with the Asia-Monsoon region collectively accounting for a significant global share. Overall, Asia accounted for 44% of the global GHG emissions from the agricultural sector (FAO 2016), while the countries and economies of the Asia-Monsoon region were responsible for 40% of the global non-CO_2 or CH_4 and N_2O emissions from the agricultural sector (Figure 7).

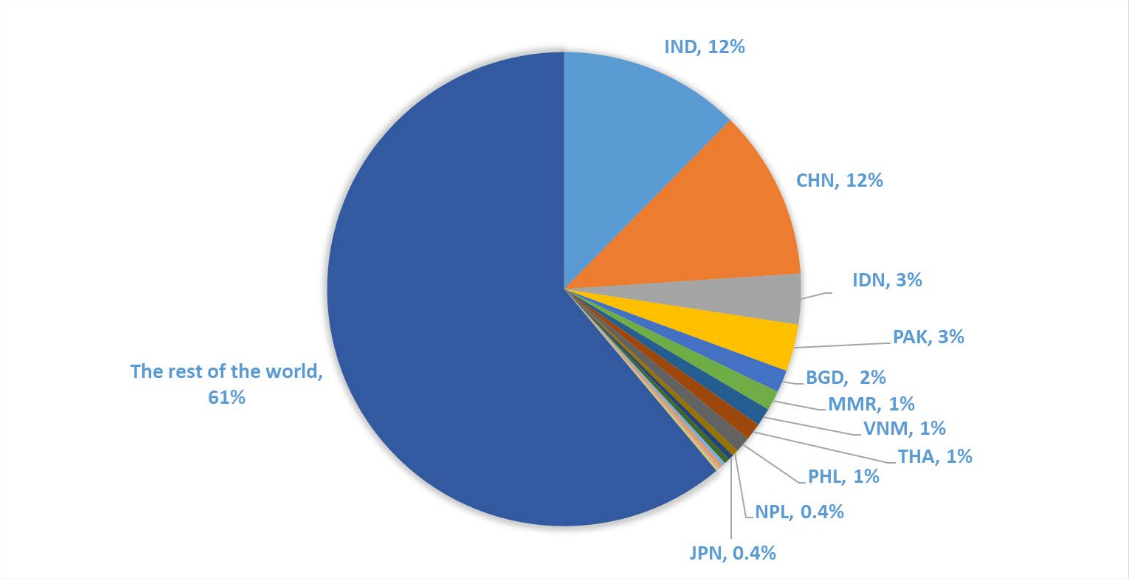


Figure 7: Methane (CH_4) and nitrous oxide (N_2O) emissions combined from the agricultural sector in the global share
(Source) World Development Indicators.
(note) WDI does not refer to the data of Chinese Taipei.

Major sources of GHG emissions in the agricultural sector of the countries and economies forming the Asia-Monsoon region include CH_4 emissions (41% of the global total), mainly from rice paddies and the enteric fermentation of livestock manure, and N_2O due to inefficient nitrogen fertilizer use (36% of the global total), along with CO_2 from deforestation and land use changes (Tubiello et al. 2021; World Resources Institute). Populous countries, namely, India and China, occupy a large share of the emissions of CH_4 and N_2O in the region (Figures 8 and 9). The major sources of GHG emissions from food systems in the Asia-Monsoon region are briefly reviewed below.

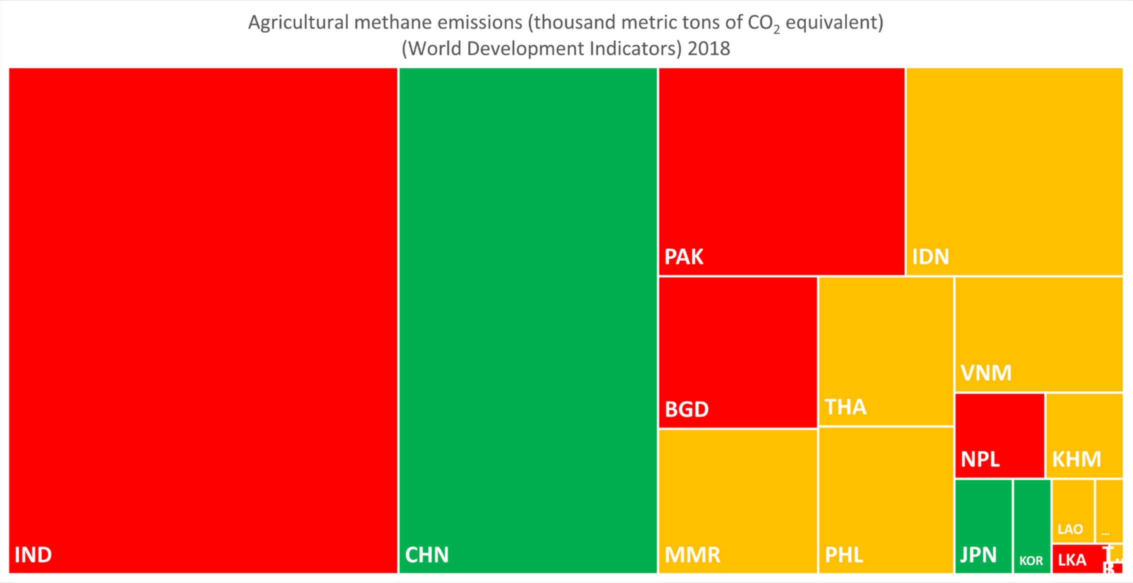


Figure 8: Methane (CH_4) emission from the agricultural sector in the Asia-Monsoon region

(Source) World Development Indicators.

(note) WDI does not refer to the data of Chinese Taipei.

Color codes: Green – Eastern Asia; Orange – Southeastern Asia; Red – Southern Asia.

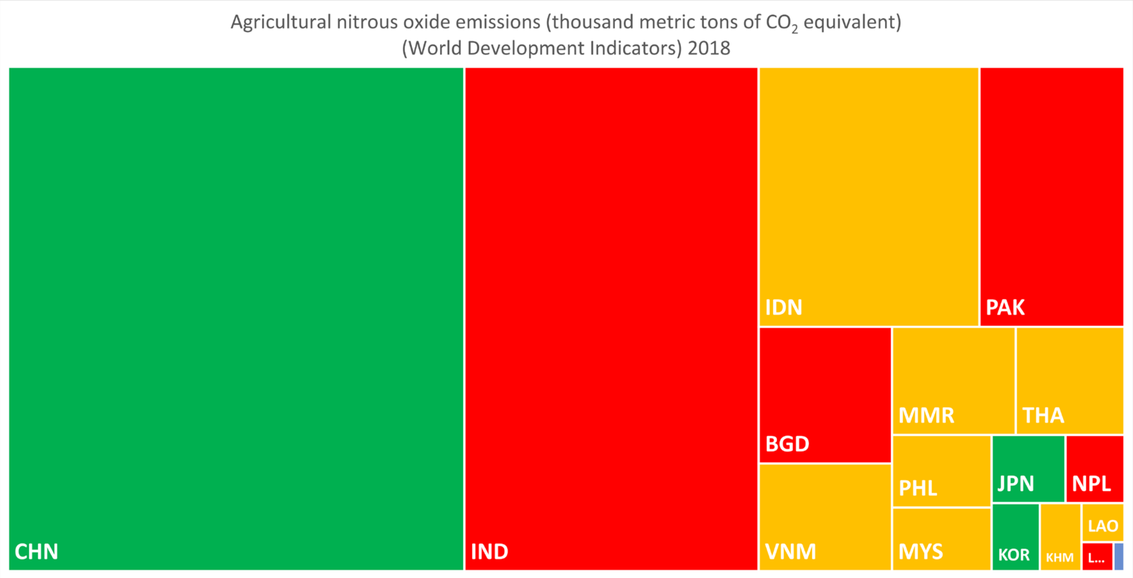


Figure 9: Nitrous oxide (N_2O) emissions from the agricultural sector in the Asia-Monsoon region

(Source) World Development Indicators.

(note) WDI does not refer to the data of Chinese Taipei.

Color codes: Green – Eastern Asia; Orange – Southeastern Asia; Red – Southern Asia.

As already discussed, rice is by far the most important food staple for most of the Asia-Monsoon region, with over 50% of the total cultivated land in most of the countries and economies dedicated to rice (Kyuma 2009). With almost 90% of the world's rice produced in the Asia-Monsoon region, 90% of CH_4 emissions in the world's paddy fields originate from this region (Smith et al. 2014). Although the sustainability of these systems has been proven for centuries, paddy fields under submergence are one of the most important artificial sources of CH_4 emissions, which have 25 times greater global warming potential than CO_2 (IPCC 2007, 2014). The increasing demand for animal-based food in response to income growth and urbanization (Asia Development Bank 2021) is another concern because livestock is a major source of CH_4 emissions, and ruminant production is estimated to emit much higher GHG emissions per unit weight than plant-based food (Xu et al. 2021).

N_2O is a very strong GHG, with almost 298 times more powerful greenhouse effects than CO_2 (IPCC 2014). Synthetic fertilizer application has been increasing in crop production, which entails higher N_2O emissions from the field. Increasing food production and reducing nitrogen fertilizer-use has a strong trade-off with productivity, as nearly 50% of fertilizer applied is not taken up by crops but leached out to groundwater as a powerful pollutant or to the air as GHG (Subbarao et al. 2021). The excessive use of chemical fertilizers and pesticides also pollute water and soil, leading to biodiversity loss.

4.3: Region as the Context for Scaling the STI Approach

With growing concerns about climate emergencies and environmental crises affecting the agricultural sector with catastrophic consequences (IPCC 2021), the region urgently needs to identify ways to accelerate the reduction of GHG emissions from the agricultural sector without sacrificing the food and nutrition security needs of the Asia-Monsoon region and beyond. The application of STI, which could address the Asia-Monsoon region's specific climatic and environmental challenges, is urgently needed. Therefore, it is critically important to accelerate the identification of STI practices that best solve local problems.

A paradigm shift toward sustainable agricultural practices is becoming an inevitable trend worldwide. While the countries and economies of the Asia-Monsoon region have already undertaken various initiatives to promote investment in STI, it is important for the region to learn from other countries and regions. Many countries and regions have already set ambitious quantitative targets toward carbon neutrality, and their commitments also encompass low emission targets for food systems. For example, the EU has proposed a 'Farm to Fork Strategy' to build a food chain that works for consumers, producers, the climate, and the environment by (1) ensuring sustainable food production; (2) ensuring food security; (3) stimulating sustainable food processing, wholesale, retail, hospitality, and food services practices; (4) promoting sustainable food consumption and facilitating the shift to healthy, sustainable diets; (5) reducing food loss and waste; and (6) combating food fraud along the food supply chain (EU 2020, European Commission 2020). In the US, the Biden administration signed the Inflation Reduction Act into law in August 2022, which included the promotion of climate-smart farming practices that will reduce GHG emissions and increase carbon storage in soils and trees (The White House 2022).

In turn, STI approaches advocated in specific contexts do not necessarily work elsewhere; there is 'no-one-size-fits-all'. As emphasized in Section 3 of this paper, the Asia-Monsoon region has distinctive agroecological and socioeconomic conditions. Therefore, the food systems transformation efforts in the Asia-Monsoon region's agricultural sector should address the context-specific constraints of the region’s intensive farming systems characterized by a hot and humid climate, rice paddy farming, and small-scale size, in reducing GHG emissions without compromising the food and nutrition security needs of the populations. Rather, by taking advantage of these common features, the Asia-Monsoon region should pursue economies of scale for technology application by leveraging collective actions to share knowledge and mobilize commitments.

Given the shared characteristics of countries and economies in the Asia-Monsoon region, some agricultural technologies developed and applied in Japan, as well as those developed for the countries and economies in the region through various international collaborative research with national agricultural research institutes in Japan as well as universities, are expected to be applicable to this region if modified to address local needs. Various agricultural smart technologies, including digital technologies that have already been developed and demonstrated in Japan by Japanese national agricultural research institutions and universities, may also be considered, depending on the agroecological and socioeconomic environment in the Asia-Monsoon region.

From this perspective, it would be desirable to develop a “Technology Catalogue” that is a compilation of the technologies that have been developed by Japanese agricultural institutes in recent years. The catalogue, which will be developed by the Japan International Research Center for Agricultural Sciences (JIRCAS) with cooperation of other Japanese agricultural research institutes, will contain these scalable agricultural technologies applicable in the region, including technologies using alternate wetting and drying (AWD) and biological nitrification inhibition (BNI) wheat (Figure 10), among others. The technology catalogue will serve as a reference for various stakeholders in the Asia-Monsoon region, including government officials, researchers, extension officers, producers, and the private sector. However, it should be noted that there is ‘no one-size-fits-all’ solution for establishing sustainable food systems, and even if scalable agricultural technologies have been developed, it is necessary to optimize and coordinate these technologies among countries and regions with different environments.

Agriculture, Forestry and Fisheries Technology Catalog for the Asia-Monsoon region

Greenhouse gas emission reduction technology with the combination of biogas effluent application and multiple drainage in a rice paddy

Production | Demonstration | Item: Paddy rice | GHG emission reduction

Outline

This technology, which combines biogas effluent application and multiple drainage, can reduce the emission of greenhouse gases (GHGs) including methane (CH_4), and the usage of synthetic fertilizer in rice paddy fields without yield loss when compared with the local conventional practice in which the effluent is unutilized and discharged into rivers.

Background/effect/note

This technology, which combines cattle biogas effluent (used as a fertilizer) and multiple drainage practices, can reduce 1) GHG emission and synthetic fertilizer usage in rice paddy fields and 2) environmental pollution associated with the discharge of untreated biogas effluent into rivers. In a triple-rice cropping system in the Mekong Delta, Vietnam, this technology using the multiple drainage practices, i.e., alternate wetting and drying (AWD; a water-depth-dependent irrigation) or midseason drainage followed by intermittent irrigation (MiDi; a day-number-dependent irrigation) (Fig. 1) reduced CH_4 emission by 11%–13% and nitrous oxide (N_2O) emission by 35%–54% without yield loss (Fig. 2). The proposed technology can be applied to the rice-producing areas using livestock biogas effluent as fertilizer.

AWD and MiDi are water management practices that save water by repeatedly flooding and draining water in paddy fields and reduce CH_4 emission by increasing oxygen concentration in the soil.

Fig. 1. The technology proposes to reduce greenhouse gas emission from rice paddy fields without yield loss

Fig. 2. Comparative analysis of the performance of the proposed combination technology and the conventional practice

GWP: CO_2-equivalent of combined CH_4 and N_2O emissions

Technical details:
https://www.jircas.go.jp/en/publication/research_results/2021_a01

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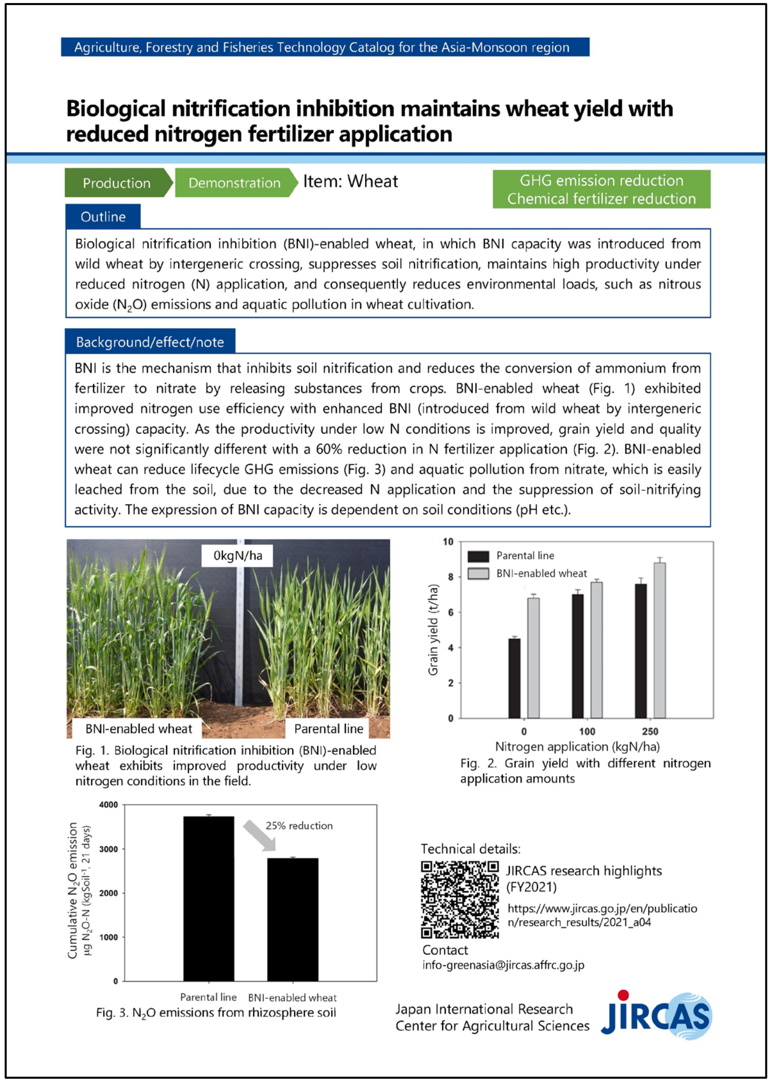
Japan International Research Center for Agricultural Sciences



Agriculture, Forestry and Fisheries Technology Catalog for the Asia-Monsoon region

Biological nitrification inhibition maintains wheat yield with reduced nitrogen fertilizer application

Production | Demonstration | Item: Wheat | GHG emission reduction
Chemical fertilizer reduction

Outline

Biological nitrification inhibition (BNI)-enabled wheat, in which BNI capacity was introduced from wild wheat by intergeneric crossing, suppresses soil nitrification, maintains high productivity under reduced nitrogen (N) application, and consequently reduces environmental loads, such as nitrous oxide (N_2O) emissions and aquatic pollution in wheat cultivation.

Background/effect/note

BNI is the mechanism that inhibits soil nitrification and reduces the conversion of ammonium from fertilizer to nitrate by releasing substances from crops. BNI-enabled wheat (Fig. 1) exhibited improved nitrogen use efficiency with enhanced BNI (introduced from wild wheat by intergeneric crossing) capacity. As the productivity under low N conditions is improved, grain yield and quality were not significantly different with a 60% reduction in N fertilizer application (Fig. 2). BNI-enabled wheat can reduce lifecycle GHG emissions (Fig. 3) and aquatic pollution from nitrate, which is easily leached from the soil, due to the decreased N application and the suppression of soil-nitrifying activity. The expression of BNI capacity is dependent on soil conditions (pH etc.).

Fig. 1. Biological nitrification inhibition (BNI)-enabled wheat exhibits improved productivity under low nitrogen conditions in the field.

Fig. 2. Grain yield with different nitrogen application amounts

Fig. 3. N_2O emissions from rhizosphere soil

Technical details:
JIRCAS research highlights (FY2021)
https://www.jircas.go.jp/en/publication/research_results/2021_a04

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Figure 10: Technology catalog contributing to production potential and sustainability in the Asia Monsoon Region Ver.1.0

5: Conclusion

The world has been moving toward the realization of a decarbonized society. In the case of Japan, in May 2021, the Ministry of Agriculture, Forestry and Fisheries (MAFF) formulated the “Strategy for Sustainable Food Systems, MIDORI" to achieve both increased productivity and sustainability in the food and agriculture industries through innovation.

To succeed, such initiatives must be based on scientific infrastructure and facilitated through the application of appropriate STI to make food systems resilient, while reducing environmental impacts without compromising food and nutrition security. Given the heterogeneity in agroecological and socioeconomic conditions characterizing diverse farming systems across different regions of the world, it is essential to bear in mind that there is ‘no one-size-fits-all’ approach in the application of STI. As this study has shown, the Asia-Monsoon region, of which Japan is a part, is characterized by a hot and humid climate, rice paddy farming, and small-scale farming. Reducing GHG emissions without affecting productivity necessitates the identification and customization of appropriate sets of STI to locally specific agroecological and socioeconomic conditions to address the specific challenges that producers face.

In turn, countries and economies sharing similar agroecological and socioeconomic conditions can greatly benefit from sharing the experiences of potential STI to achieve scalable impacts. In the case of countries and economies in the Asia-Monsoon region that share the characteristics of climate conditions and production structures, there are significant opportunities to facilitate such sharing experiences of potential STI to realize the rapid transformation of food systems by establishing a forum or network center to generate and disseminate science-based information among various stakeholders.

In view of these developments, in November 2021, JIRCAS, whose mandate is to contribute to the enhancement of agricultural technologies in developing regions by conducting collaborative research projects, organized an international symposium titled “The Role of Science, Technology and Innovation in Achieving Sustainable Food Systems in the Asia Monsoon Region: A Platform for International Collaboration.” The discussion of the symposium summarized that a regional platform that provides information and fosters a consensus on the challenges and opportunities of the region’s food systems transformation, contributing to mobilizing commitments among stakeholders, would be a requisite.

In April 2022, MAFF Japan decided to initiate a project titled, “Accelerating application of agricultural technologies which enhance production potentials and ensure sustainable food systems in the Asia-Monsoon region.” MAFF assigned JIRCAS to take charge of the project, which is managed under the name ‘Green Asia’. ‘Green Asia’ hosts the International Center for Strategy “MIDORI,” which collects and analyzes the existing and latest information on agricultural, forestry, and fisheries technologies under the advice from the International Scientific Advisory Board for Strategy “MIDORI” composed of prominent outstanding scientists and executive officials of leading agricultural research institutes and universities.

While Strategy "MIDORI" tries to promote an enabling environment for innovations mainly in Japan, the Green Asia project is aimed at facilitating the acceleration of such innovations in the Asia-Monsoon region through a mechanism for the collection, analysis, management, and dissemination of research results and outputs for the region, including those developed by Japan's national agricultural research institutions and universities. The International Center for Strategy "MIDORI" should be the center of a network that is not limited to researchers of national agricultural research institutions, universities, and international agricultural research institutions, but also various stakeholders including government officers, extension officers, producers, and the private sectors in Japan and the Asia-Monsoon region. Thus, the information generated by the Center should be scientifically sound but simultaneously accessible to various stakeholders.

Even though the Center will not function as a regional platform as described above, *per se*, it is expected to play a significant role in contributing to the region's food systems transformation through strengthening networks among various partners in the region and sharing science-based information that can be useful in and applicable to the Asia-Monsoon region and disseminating them utilizing the network of JIRCAS and other national institutes. Given the collective significance of the Asia-Monsoon region, the success of the regional food systems transformation should have enormous global impact to demonstrate the potential of synergies for climate change mitigation and sustainable agricultural production. The results and outputs of the project could serve as a reference for various stakeholders, thereby contributing to the sustainable food systems transformation in the Asia-Monsoon region and beyond.

Figure 11: Green Asia conceptual framework

Author contribution statement

M.I., N.K., S.K, and Y.F. conceived the presented idea, conducted the reviewing of the literature, compiling the data, and writing the manuscripts.

Acknowledgement

This Background Paper was based on a study conducted under the project "Accelerating application of agricultural technologies which enhance production potentials and ensure sustainable food systems in the Asia-Monsoon region", which has been financially supported by the Ministry of Agriculture, Forestry and Fisheries. The authors are especially grateful to the following:

- The members of the International Scientific Advisory Board for Strategy "MIDORI" for their valuable comments and guidance on the manuscript
- Mr. Sridhar Dharmapuri of FAO, Dr. Jon Hellin of IRRI, Mr. Yasunari Ueda of JICA, Dr. Yasuhiro Shirato of NARO, Dr. Keiichi Hayashi of JIRCAS for their valuable inputs on the original idea of this paper, especially on the need for a regional knowledge-sharing platform in the Asia-Monsoon region
- Mr. Koichi Hayashida, Mr. Noriyuki Kubo, Mr. Asuka Deki, Mr. Koki Nishimoto of PwC for the generation and compilation of data for climate zone classification
- Dr. Toru Sakai of JIRCAS for creating the population density and rainfall maps.

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