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El Niño and Rice in South-East Asia: What the Adaptation Evidence Shows

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Abstract

Rice (Oryza sativa L.) in Indonesia, the Philippines, Viet Nam and Thailand is exposed to the El Niño–Southern Oscillation (ENSO), and a strong El Niño was again under way in the third quarter of 2026. This structured narrative review screened 189 index records retrieved on 8 October 2026 and synthesised 43 journal articles published in 2011–2026 with 12 official documents and datasets. Food and Agriculture Organization (FAO) series show that combined paddy output of the four countries fell from 158.9 million tonnes in 2014 to 143.1 million tonnes in 2016 (−10.0%) but only from 150.1 to 149.2 million tonnes between 2022 and 2024 (−0.5%); these are single national totals and carry no measure of variation. In both episodes harvested area, not yield, carried most of the loss in Indonesia, the Philippines and Thailand. The literature agrees that El Niño acts mainly through planted area and crop timing in dry-season and rainfed crops. Evidence for adaptation is uneven: water-saving irrigation has multi-site experimental support, whereas planting calendars, drought-tolerant varieties and pumping rest largely on programme outputs and extrapolation. Outcome evaluations timed to the current event are needed.

Keywords: El Niño–Southern Oscillation; rice production; South-East Asia; drought adaptation; planting calendar; rice trade

Introduction

Rice (*Oryza sativa* L.) is a major staple crop in South-East Asia, where Indonesia, the Philippines, Viet Nam, and Thailand play important roles in regional production and trade. Indonesia and the Philippines are major rice producers that also rely on imports to meet domestic demand, whereas Viet Nam and Thailand are major rice exporters. Together, these four countries produced approximately 149.2 million tonnes of paddy rice in 2024, according to Food and Agriculture Organization (FAO) data (Our World in Data 2026a). Rice production in the region is vulnerable to climatic variability associated with the El Niño–Southern Oscillation (ENSO), particularly through changes in rainfall, water availability, and growing conditions. Previous studies have documented relationships between ENSO and agricultural production across different regions and cropping systems (Heino et al. 2020). More specifically, research on Asian rice production has identified associations between El Niño conditions and reduced rice yields (Sinha et al. 2026), while global analyses have highlighted the exposure of rice-growing areas to ENSO-related compound hot and dry extremes (Gurazada et al. 2026). These findings suggest that ENSO-related climatic

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variability represents an important risk to rice production, although its effects depend on local agroecological and production conditions.

The effects of El Niño on rice production vary across South-East Asian countries and farming systems because of differences in rainfall patterns, irrigation access, cropping calendars, and farmers' capacity to respond to climatic stress. Viet Nam's Mekong Delta illustrates this complexity. El Niño-associated rainfall deficits and reduced freshwater availability can contribute to drought and exacerbate salinity intrusion, particularly in coastal rice-growing areas. The severe drought and salinity intrusion during 2015–2016 affected rice production across parts of the delta, although the magnitude of these impacts varied by location and cropping season (Yen, Quyen, et al. 2019). Changes in rice production may therefore arise not only from reduced yields but also from delayed planting, changes in cropping intensity, and adjustments in agricultural land use. Understanding these different pathways is important for distinguishing climatic impacts from farmers' responses and evaluating adaptation effectiveness.

Two major El Niño events provide a basis for examining recent changes in regional rice production. The Oceanic Niño Index (ONI), based on three-month running mean sea-surface temperature anomalies in the Niño 3.4 region, reached approximately 2.59 °C during November 2015–January 2016 and 1.99 °C during November 2023–January 2024 (NOAA CPC 2026). These events occurred under different climatic and agricultural conditions, making direct comparisons of production outcomes challenging. The 2023–2024 event also coincided with disruptions in international rice trade, including India's restrictions on non-basmati rice exports in July 2023 (Glauber and Mamun 2023). Such developments illustrate how domestic production risks may interact with international market conditions, particularly in rice-importing countries.

Governments and farmers have adopted various measures to address drought and water scarcity associated with El Niño, including adjustments to planting calendars, the use of short-duration and drought-tolerant rice varieties, irrigation improvements, and supplementary pumping. In Indonesia, government responses have included pump distribution, drought-tolerant varieties, and climate-informed planting calendars (Riswan 2026). In Viet Nam's Mekong Delta, adaptation practices have involved adjustments in planting schedules, water management, and farming systems in areas exposed to drought and salinity intrusion (Yen, Quyen, et al. 2019; Diem et al. 2024; Binh et al. 2025). These measures differ in their objectives, ranging from maintaining crop yields under water stress to reducing production risks through changes in planting decisions and agricultural land use. However, evidence on their effectiveness in reducing El Niño-related production losses and improving farm-level economic outcomes remains fragmented across countries and production systems.

This review examines El Niño-related changes in rice production and critically assesses the available evidence on adaptation measures in Indonesia, the Philippines, Viet Nam, and Thailand. Drawing on national production statistics for 2012–2024 and literature published between 2010 and 2026, it considers changes in rice yields, derived harvested area, and cropping calendars, alongside evidence on adaptation outcomes. The review makes two contributions. First, it provides a consistent descriptive decomposition of production changes across periods associated with the 2015–2016 and 2023–2024 El Niño events, distinguishing the contributions of yield and derived harvested area without attributing observed changes solely to ENSO. Second, it synthesises evidence on major adaptation

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measures and distinguishes demonstrated outcomes from observational associations, technical feasibility, and programme implementation. By identifying gaps between adaptation adoption and measured effectiveness, the review highlights priorities for future evaluation and more evidence-based agricultural risk management.

Review Method

Design and scope

This study employed a structured narrative review to synthesise evidence on El Niño-related rice production changes and adaptation measures in Indonesia, the Philippines, Viet Nam, and Thailand. The review focused on two areas: (i) the effects of ENSO-related climatic variability, particularly drought and salinity intrusion, on rice planting and harvested area, cropping calendars, yields, and production; and (ii) the adoption and effectiveness of adaptation measures, including planting-calendar adjustments, drought-tolerant and short-duration rice varieties, irrigation improvements, water-saving irrigation practices, supplementary pumping, on-farm water storage, climate information services, and agricultural insurance. Trade policy responses during the 2023–2024 El Niño event were examined as supplementary context to assess how international rice markets and import policies may influence domestic supply management.

The review followed a structured search and selection process but was not designed as a comprehensive systematic review. Searches were restricted to accessible bibliographic sources, study selection was conducted by a single reviewer, and no formal risk-of-bias assessment was undertaken. These methodological constraints were considered when interpreting the strength and generalisability of the findings.

Search protocol

The literature search was conducted on 8 October 2026 using the Crossref REST API and the Directory of Open Access Journals (DOAJ). Crossref was searched using free-text queries and bibliographic metadata, with results restricted to journal articles published from 2010 onwards. For each query, the first 30–40 records in the relevance-ranked results were screened. All records returned by each DOAJ query were screened.

Three search queries were used in Crossref: “El Nino ENSO rice production Southeast Asia”, “El Niño rice Indonesia drought paddy”, and “India rice export ban 2023 restrictions impact price”. Thirteen queries were used in DOAJ: “El Niño rice production”, “ENSO rice Indonesia”, “El Niño drought rice farmers adaptation”, “drought rice Mekong Delta salinity”, “El Niño rice Philippines”, “El Niño paddy”, “cropping calendar rice Indonesia climate”, “integrated cropping calendar information system”, “cropping calendar climate variability Indonesia”, “drought-tolerant rice varieties adoption farmers”, “drought rice farmers adaptation Indonesia”, “drought rice farmers Philippines”, and “drought rice Thailand farmers”.

Additional searches were attempted through OpenAlex, Europe PMC, Semantic Scholar, and general web search. However, access restrictions or rate limits prevented the retrieval of usable records from these sources. Scopus and Web of Science were not searched. The resulting search strategy was therefore intended to support a structured narrative synthesis rather than an exhaustive identification of all relevant studies.

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Eligibility and selection

Studies were eligible for inclusion if they were journal articles or published conference papers from 2010 to 2026 that examined rice production or adaptation in Indonesia, the Philippines, Viet Nam, or Thailand, or provided relevant regional or global evidence. Eligible studies were required to address at least one of the two review themes: (i) ENSO-related effects on rice production or (ii) adaptation measures in rice farming. Studies focusing exclusively on fisheries, oceanography, forestry, fire, or non-rice crops were excluded. Evidence from outside the four study countries was considered when it provided relevant comparative insights into adaptation measures for which suitable country-specific studies were not identified. Studies addressing international rice trade were included separately to contextualise market and policy responses during the 2023–2024 El Niño event.

The 16 search queries yielded 189 records, including duplicates across queries. Following title and available abstract screening, 43 articles were retained. Abstracts or full texts were accessible for 40 articles, including two studies reviewed in full (Stuecker et al. 2018; Yen, Quyen, et al. 2019). For the remaining three articles (Ismail and Chan 2020; Valera et al. 2024; Antonio et al. 2025), only bibliographic metadata were available. These articles were included to document the existence of potentially relevant research but were not used to support substantive findings. Of the 43 retained articles, 34 addressed at least one of the four study countries, six provided global or extra-regional comparative evidence, and three examined international rice trade.

Production and event data

Annual paddy rice production and yield data for 2012–2024 were obtained from Food and Agriculture Organization (FAO) statistical series accessed through Our World in Data (2026a, 2026b). Harvested area was derived by dividing production by yield after converting both variables to consistent units. This measure, referred to as *derived harvested area* throughout the article, was not obtained from an independently reported area series. National rice production outlooks were obtained from the January and February 2026 country briefs issued by the FAO Global Information and Early Warning System (GIEWS) (FAO 2026a, 2026b, 2026c, 2026d).

El Niño conditions were characterised using the Oceanic Niño Index (ONI) published by the National Oceanic and Atmospheric Administration's Climate Prediction Center (NOAA CPC 2026). An ONI threshold of +0.5 °C was used as an operational indicator of El Niño conditions rather than as the sole criterion for identifying individual events. Information on Indonesia's policy responses in 2026 was drawn from national news-agency reports of official statements and was treated as reported policy information rather than independently verified evidence of programme implementation or effectiveness.

Changes in paddy production, derived harvested area, and yield were examined descriptively. National annual statistics were treated as reported estimates and were not interpreted as direct measures of El Niño impacts. Because the source datasets did not report standard errors or confidence intervals for these observations, no statistical uncertainty estimates were calculated. Accordingly, the analysis identifies observed production patterns and their accounting components without attributing changes causally to El Niño.

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Results

The two events in the production record

Table 1 presents annual paddy production, yield, and derived harvested area for Indonesia, the Philippines, Viet Nam, and Thailand, alongside selected Oceanic Niño Index (ONI) observations. The analysis focuses on production changes between 2014 and 2016 and between 2022 and 2024, corresponding to periods associated with two major El Niño events. The 2018–2019 warm episode provides additional context for interannual variability (NOAA CPC 2026). Because ONI is calculated over overlapping three-month periods, its timing does not necessarily correspond to national calendar-year production statistics.

Table 1. Oceanic Niño Index and annual paddy production, yield, and derived harvested area in four South-East Asian countries, selected years, 2014–2024

Year	ONI, Nov–Jan season starting that year (°C)	Indonesia: production (Mt) / yield (t/ha) / area (Mha)	Philippines: production / yield / area	Viet Nam: production / yield / area	Thailand: production / yield / area	Four-country production (Mt)
2014	0.80	59.06 / 5.15 / 11.47	18.97 / 4.00 / 4.74	44.97 / 5.75 / 7.82	35.94 / 3.07 / 11.70	158.94
2015	2.59	61.03 / 5.36 / 11.39	18.15 / 3.90 / 4.66	45.09 / 5.76 / 7.83	29.66 / 2.92 / 10.16	153.93
2016	−0.37	54.03 / 5.10 / 10.60	17.63 / 3.87 / 4.56	43.11 / 5.57 / 7.73	28.35 / 2.87 / 9.86	143.12
2018	1.05	59.20 / 5.20 / 11.38	19.07 / 3.97 / 4.80	44.05 / 5.82 / 7.57	33.14 / 3.06 / 10.83	155.46
2019	0.75	54.60 / 5.11 / 10.68	18.81 / 4.04 / 4.65	43.50 / 5.84 / 7.45	31.23 / 3.00 / 10.40	148.15
2022	not extracted	54.75 / 5.24 / 10.45	19.76 / 4.11 / 4.80	42.66 / 6.02 / 7.09	32.88 / 2.98 / 11.04	150.05
2023	1.99	53.98 / 5.29 / 10.21	20.06 / 4.17 / 4.82	43.50 / 6.11 / 7.12	33.85 / 2.99 / 11.34	151.39
2024	−0.43	53.14 / 5.29 / 10.05	19.09 / 4.11 / 4.65	43.45 / 6.15 / 7.06	33.55 / 2.98 / 11.25	149.23

Source: ONI from NOAA CPC (2026). Production and yield are FAO data from Our World in Data (2026a, 2026b), rounded to two decimals. Area is derived by the authors as production divided by yield. Mt, million tonnes; Mha, million hectares. No measure of variation is given by the sources.

Table 2 summarises percentage changes in production, yield, and derived harvested area across the two comparison periods. Combined paddy production in the four countries declined from 158.94 million tonnes in 2014 to 143.12 million tonnes in 2016, a decrease of approximately 10.0%. By comparison, production decreased from 150.05 million tonnes in 2022 to 149.23 million tonnes in 2024, equivalent to approximately 0.5%. These differences

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indicate substantially greater aggregate production declines during the earlier comparison period, although they do not establish the proportion attributable to El Niño.

The relative contributions of yield and derived harvested area differed across countries. Between 2014 and 2016, Indonesia and Thailand experienced larger percentage reductions in derived harvested area (7.6% and 15.7%, respectively) than in yield (1.0% and 6.4%). In the Philippines, both components declined, with derived harvested area decreasing by 3.9% and yield by 3.3%. Viet Nam exhibited a different pattern: its 4.1% production decline was associated primarily with a reduction in yield (3.1%), compared with a 1.0% decrease in derived harvested area.

Between 2022 and 2024, production declined in Indonesia and the Philippines, largely reflecting reductions in derived harvested area while yields remained relatively stable. In contrast, Viet Nam recorded a 1.9% increase in production, accompanied by a 2.2% increase in yield despite a slight decrease in derived harvested area. Thailand also recorded higher production, with derived harvested area increasing by 1.9% and yield by 0.2%. These patterns demonstrate that the accounting contributions of harvested area and yield varied across countries and comparison periods.

Table 2. Percentage changes in paddy production, yield, and derived harvested area across two El Niño-associated comparison periods

Country	2014 to 2016: production	2014 to 2016: yield	2014 to 2016: area	2022 to 2024: production	2022 to 2024: yield	2022 to 2024: area
Indonesia	−8.5	−1.0	−7.6	−2.9	+1.0	−3.9
Philippines	−7.1	−3.3	−3.9	−3.4	−0.1	−3.3
Viet Nam	−4.1	−3.1	−1.0	+1.9	+2.2	−0.4
Thailand	−21.1	−6.4	−15.7	+2.0	+0.2	+1.9
Four countries	−10.0	n/a	n/a	−0.5	n/a	n/a

Source: authors' calculations from FAO data in Our World in Data (2026a, 2026b). Changes compare the year before El Niño conditions were established with the year in which the event ended. n/a, not calculated.

Several considerations qualify these descriptive findings. Indonesia's production series exhibited substantial interannual fluctuations that did not consistently correspond to ENSO chronology. For example, production increased by approximately 7.1% between 2017 and 2018 before declining by 7.8% between 2018 and 2019 (Our World in Data 2026a). Differences between statistical sources also warrant caution. Sutardi et al. (2022) reported a rice yield of 5.46 t/ha for Indonesia in 2017, compared with 5.07 t/ha in the FAO-based series (Our World in Data 2026b). Thailand's production decline also preceded the 2015–2016 El Niño event, with output falling from approximately 39.5 million tonnes in 2012 to 35.9 million tonnes in 2014 (Our World in Data 2026a). These observations indicate that production changes cannot be attributed solely to ENSO conditions.

Seasonal timing presents an additional challenge. National annual production statistics aggregate harvests across different cropping seasons, potentially obscuring delayed

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responses to climatic variability. Stuecker et al. (2018), for example, identified an approximately seven-month lag between Niño 3.4 conditions and rice production responses in the Philippines. This finding underscores the importance of accounting for cropping calendars and seasonal exposure when interpreting annual production changes.

FAO country briefs published in early 2026 provide supplementary information beyond the 2012–2024 statistical series. They reported approximately 59 million tonnes of paddy production in Indonesia for 2025 and 43.5 million tonnes in Viet Nam, alongside production forecasts of approximately 19.7 million tonnes for the Philippines and 33.5 million tonnes for Thailand for the 2025/26 season (FAO 2026a, 2026b, 2026c, 2026d). Because these estimates refer to different reporting periods, they are presented as contextual information rather than directly comparable indicators of post-El Niño recovery.

How El Niño reaches the rice crop

The studies summarised in Table 3 identify several pathways through which ENSO-related climatic variability may affect rice production, including rainfall deficits, reduced water availability, agricultural drought, soil moisture depletion, salinity intrusion, and changes in planting decisions. The relative importance of these pathways differs across countries, production systems, and cropping seasons.

Table 3. Characteristics and main findings of country-specific studies on ENSO-related rice production and adaptation (n = 34)

Study	Country and area	Data and approach	Main finding relevant to this review
Utami et al. 2011	Indonesia, four Javanese provinces	Supply analysis, 1987–2006	El Niño and La Niña had no significant effect on paddy supply
Surmaini et al. 2015	Indonesia, 335 districts	Paddy drought impact index against Niño 3.4	Two-month lead; most drought-prone districts in West Java and South Sulawesi
Udayani et al. 2016	Indonesia, Tabanan (Bali)	Copula model	Dependence between rice production and ENSO indicators (Frank copula)
Kirono et al. 2016	Indonesia, Nusa Tenggara Barat	Two stations; six downscaled models	Dry-season rainfall significantly correlated with ENSO
Insanu and Emilya 2021	Indonesia, Gunungkidul	Drought index, 2001–2019	Most rainfed paddy productivity declined in El Niño years
Hannoeriadi et al. 2022	Indonesia, Java and four other provinces	Panel regression, 2009–2017	El Niño significantly reduced rice and maize output; La Niña raised it
Manullang et al. 2023	Indonesia, North Sumatra	67 rain posts, 24 years	Productivity fell in 62.5% of 32 districts during the 2015 El Niño
Dimyati et	Indonesia,	Satellite drought	Agricultural drought followed

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Study	Country and area	Data and approach	Main finding relevant to this review
al. 2024	downstream Citarum	indices	meteorological drought; larger with El Niño and positive Indian Ocean Dipole
Rahma and Ludwig 2024	Indonesia, Magelang	Sub-watershed case study	Extreme El Niño caused prolonged water shortage for rice; season onset hard to predict
Irawan and Komori 2024	Indonesia	Vegetation index, 1 km, 2001–2021	Dynamic dry-season crop calendar with planting, peak and harvest dates
Sumani et al. 2025	Indonesia, Central Java	33 rainfall stations, three elevation zones	Drought frequency did not explain cropping patterns or yields; irrigation infrastructure did
Aziz et al. 2021	Indonesia, North Sumatra	Structural model of farmers' use of the cropping calendar system	Task force, farmer and system characteristics raised implementation
Sutardi et al. 2022	Indonesia	Narrative review	Yield gains sustained by higher cropping index and harvested area
Pratiwi et al. 2018	Indonesia, Cirebon	2015 compared with 2014	Lower production and income in 2015; insurance could offset losses but many were uninsured
Arifah et al. 2022	Indonesia, Bulukumba	55 in-depth interviews	Downstream irrigated farmers faced water shortage and adapted with local and external knowledge
Stuecker et al. 2018	Philippines, national and regional	Quarterly statistics, 1987–2016	About 10% of production anomaly variance linked to soil moisture; area channel important
Gravoso et al. 2014	Philippines, Leyte	Forecast pilot and focus groups	Farmers judged forecasts accurate but relied on their own experience
Sandhu et al. 2017	Philippines and four other countries	23 experiments, 2015–2016	Alternate wetting and drying saved 5.7–23.4% of water without significant yield penalty
Manalo et al. 2020	Philippines, two communities	Qualitative, 87 farmers	Experience and farmer identity shaped responses to drought

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Study	Country and area	Data and approach	Main finding relevant to this review
Enriquez et al. 2021	Philippines	Review of 20 years of scaling	Alternate wetting and drying became policy but had reduced impact in gravity irrigation
Farin et al. 2024	Philippines, Central Luzon	Survey, 969 farmers	Measures against drought and flood adopted only “sometimes”
Bui and Nguyen 2017	Viet Nam, Mekong Delta	Breeding review	New varieties from conventional and marker-assisted selection
Yen, Quyen, et al. 2019	Viet Nam, 13 delta provinces	ORYZA model, 1976–2016 and projections	Winter–spring losses up to 99% in Ben Tre in El Niño years; no adaptation tested
Yen, Son, et al. 2019	Viet Nam, Mekong Delta	Participatory risk mapping	Risk and adaptation maps being applied in 13 provinces
Ho and Shimada 2019	Viet Nam, Mekong Delta	352 households	71% adapted; adaptation associated with 13–14% higher technical efficiency
Hoang-Phi et al. 2020	Viet Nam, Mekong Delta	Radar time series	Sowing 10–30 days earlier in some areas in 2016 and 2020
Diem et al. 2024	Viet Nam, Mekong Delta	Vegetation index, 2014–2018	Planting delayed in 2015/2016, most for the winter–spring crop
Binh et al. 2025	Viet Nam, seven coastal provinces	Land-use change analysis	Largest drought and salinity impacts in 2010–2011, 2015–2016 and 2019–2020
Wang et al. 2025	Viet Nam, Mekong Delta	Attribution of paddy loss	Direct drought and salinity stress explained 25.14% of paddy field loss
Limsakul 2019	Thailand	National series, 1961–2016	Production declines occurred mainly in El Niño years (asymmetric effect)
Hensawang et al. 2021	Thailand, central region	WOFOST crop model	Below-normal yields in the eight months after El Niño; error 752 kg/ha
Saraphirom et al. 2025	Thailand, Khon Kaen	30 years of climate data, projections, interviews	Wells and large ponds work but are unaffordable for most smallholders
Humphries et al. 2025	Thailand	Methods paper	El Niño reduces rainfall; both phases harm rainfed rice
Ismail and Chan 2020	South-East Asia	Bibliographic record only	Not assessed

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Source: compiled by the authors from the abstracts or full texts of the cited studies. Measures of variation were not reported in the abstracts consulted except where shown.

In Indonesia, evidence of ENSO-related production impacts is particularly relevant to rainfed and dry-season rice systems, although findings vary across locations and analytical approaches. Surmaini et al. (2015) identified an approximately two-month lead between Niño 3.4 conditions and subsequent drought impacts across 335 districts, with particularly high exposure in parts of West Java and South Sulawesi. Manullang et al. (2023) reported productivity declines in 62.5% of 32 districts in North Sumatra during the 2015 El Niño event, while Insanu and Emilya (2021) documented lower rainfed rice productivity in Gunungkidul during El Niño years. Using provincial panel data, Hannoeriadi et al. (2022) also identified a statistically significant negative association between El Niño conditions and rice production.

However, findings are not uniform. Utami et al. (2011) reported no statistically significant relationship between ENSO conditions and paddy supply in four Javanese provinces, while Sumani et al. (2025) found that irrigation infrastructure was more closely associated with cropping patterns and yields than drought frequency in Central Java. These findings suggest that local water management and production conditions may influence the relationship between climatic variability and rice production. Nevertheless, studies in Magelang, Bulukumba, and the downstream Citarum basin documented water availability constraints affecting rice cultivation under drought conditions (Arifah et al. 2022; Dimyati et al. 2024; Rahma and Ludwig 2024).

In the Philippines, Stuecker et al. (2018) examined quarterly production statistics for 1987–2016 and identified relationships among ENSO variability, soil moisture, and rice production anomalies. Soil moisture variability accounted for approximately 10% of the variance in national production anomalies, while correlations between soil moisture and production at a three-month lead were 0.33 in irrigated systems and 0.34 in rainfed systems. Production anomalies were generally larger than yield anomalies, indicating that changes in harvested area or cropping activity may contribute to aggregate production variability. This finding is consistent with the descriptive production patterns reported in Table 2, although it does not establish whether planting decisions were directly influenced by ENSO-related water shortages.

In Thailand, Limsakul (2019) identified an asymmetric relationship between ENSO conditions and national rice production, with production declines occurring predominantly during El Niño years. Using crop simulation, Hensawang et al. (2021) reported below-normal rice yields in the months following El Niño conditions. Together, these findings indicate that climatic variability may influence rice production through changes in water availability and crop productivity, although the magnitude and timing of responses depend on regional production conditions.

In Viet Nam, the Mekong Delta illustrates how drought and reduced freshwater availability may exacerbate salinity intrusion and increase production risks in coastal rice-growing areas. Using the ORYZA crop model, Yen, Quyen, et al. (2019) estimated substantial spatial variation in potential winter–spring rice losses under El Niño conditions. Simulated losses reached 99% in Ben Tre and 65% in Tra Vinh, compared with less than 20% in Long An, Tien Giang, and Vinh Long. These estimates represent modelled outcomes rather than observed provincial production losses. Binh et al. (2025) further identified the dry seasons

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of 2010–2011, 2015–2016, and 2019–2020 as periods of substantial drought- and salinity-related impacts across seven coastal provinces.

Despite these regional vulnerabilities, Viet Nam experienced a smaller national production decline than Indonesia or Thailand between 2014 and 2016 (Table 2). This difference should not be interpreted as evidence of lower climate vulnerability, as national statistics may conceal substantial variation in seasonal exposure, irrigation access, and production conditions within the Mekong Delta.

Planted area and crop timing

Changes in planting dates and cropping intensity represent important but insufficiently evaluated dimensions of rice production responses to ENSO-related climatic variability. Remote-sensing studies in Viet Nam's Mekong Delta have documented contrasting shifts in planting dates across locations and cropping seasons. Diem et al. (2024) identified delayed planting during 2015–2016 relative to ENSO-neutral years, particularly for the winter–spring crop in double-rice systems. In contrast, Hoang-Phi et al. (2020) observed planting approximately 10–30 days earlier than usual in some areas during the drought and salinity intrusion periods of 2016 and 2020. These findings indicate that planting-date changes vary across local production conditions and should not automatically be interpreted as deliberate or effective adaptation. Neither study directly established whether the observed adjustments reduced yield losses or improved farm-level economic outcomes.

In Indonesia, Irawan and Komori (2024) developed a spatially explicit rice cropping calendar at a 1-km resolution, identifying planting, peak growth, and harvesting periods and dry-season cropping frequency over 2001–2021. This dataset provides a basis for examining temporal and spatial variations in rice cropping patterns under different ENSO conditions. However, the reviewed literature did not establish whether adjustments to planting calendars reduced production losses during El Niño events. Comparable empirical evidence on planting-date changes in the Philippines and Thailand was not identified through the review protocol. Further research should therefore link observed changes in planting dates and cropping intensity to subsequent production and economic outcomes while accounting for differences in climatic exposure, irrigation access, and farming systems.

Evidence on adaptation measures

The reviewed literature identifies several measures used to address drought and water scarcity in rice production, including water-saving irrigation, irrigation infrastructure, planting-calendar adjustments, drought-tolerant varieties, supplementary pumping, on-farm water storage, seasonal climate information, and agricultural insurance. Table 4 summarises the evidence for these measures, distinguishing demonstrated outcomes from observational associations, technical feasibility, and programme implementation.

Table 4. Strength of evidence for adaptation measures in the reviewed literature

Measure	Strongest evidence retrieved for the four countries	What it shows	What it does not show	Grade
Water-saving irrigation (alternate	Multi-site experiments (Sandhu et	Water saving of 5.7–23.4% without	Performance when supply fails; uptake in	Demonstrated in trials; partly demonstrated

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Measure	Strongest evidence retrieved for the four countries	What it shows	What it does not show	Grade
wetting and drying)	al. 2017); 20-year scaling review (Enriquez et al. 2021)	significant yield penalty in trials	gravity schemes	in use
Irrigation infrastructure	Observational studies (Stuecker et al. 2018; Sumani et al. 2025)	Yield response dampened where irrigated	Protection of planted area; tail-end supply	Partly demonstrated
Combined farm adaptation to drought and salinity	Cross-sectional survey of 352 households (Ho and Shimada 2019)	Adapters 13–14% more technically efficient	Causation; effect in an El Niño season	Partly demonstrated
Planting and cropping calendars	System development and uptake studies (Aziz et al. 2021; Irawan and Komori 2024); observed date shifts (Hoang-Phi et al. 2020; Diem et al. 2024)	Dates move; farmers can be reached	Yield or area gain from following the calendar	Assumed
Drought-tolerant and short-duration varieties	Breeding review (Bui and Nguyen 2017); no adoption impact study retrieved	Varieties exist	Field performance and adoption in El Niño years in the region	Assumed for the region
Pumping, wells and ponds	One local feasibility study (Saraphirom et al. 2025); programme counts (Riswan 2026)	Technical feasibility; delivery of equipment	Area saved, cost per tonne, effect on water sources	Assumed
Seasonal forecasts and insurance	Small qualitative and case studies (Gravoso et al. 2014; Pratiwi et al. 2018)	Forecasts trusted but little used; insurance coverage low	Any production effect	Assumed

Source: authors' assessment of the studies cited.

Water-saving irrigation has the strongest experimental evidence among the adaptation measures reviewed. Across 23 experiments conducted in five Asian countries, alternate wetting and drying (AWD) irrigation achieved water savings of 5.7–23.4% without

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statistically significant yield reductions (Sandhu et al. 2017). However, institutional and irrigation-system constraints may limit its implementation under farmers' field conditions, particularly in gravity-based irrigation systems (Enriquez et al. 2021). Evidence from the Mekong Delta also suggests potential benefits from broader adaptation practices. A survey of 352 rice-farming households found that adaptation to drought and salinity intrusion was associated with 13–14% higher technical efficiency, although the cross-sectional design does not establish causality (Ho and Shimada 2019). Other studies documented local adaptation responses, participatory climate-risk mapping, and changes in rice-growing areas, but provided limited evidence of their effectiveness in reducing El Niño-related production losses (Binh et al. 2025; Yen, Son, et al. 2019; Wang et al. 2025).

Planting-calendar adjustments are widely promoted, particularly in Indonesia, where studies have examined information dissemination and the development of spatially detailed cropping calendars (Aziz et al. 2021; Irawan and Komori 2024). However, evidence that following recommended planting dates reduces production losses remains limited. Research from the Philippines also indicates that farmers' responses to climate information depend on local experience and behavioural factors (Gravoso et al. 2014; Farin et al. 2024). For drought-tolerant and short-duration rice varieties, the regional literature retrieved primarily concerns varietal development (Bui and Nguyen 2017). Studies from Nepal and India report potential yield and risk-reduction benefits under drought conditions, but their applicability to South-East Asian farming systems remains uncertain (Aryal et al. 2022; Raghu et al. 2025).

Supplementary pumping and water storage have received substantial policy attention, particularly in Indonesia. Government reports document large-scale pump distribution and emergency irrigation activities during 2026, but these implementation figures do not establish the area or production losses avoided (Antara 2026b, 2026c; Riswan 2026). Evidence from Thailand suggests that supplementary groundwater and water storage may help maintain rice production under drought conditions, although investment costs can limit accessibility for smallholders (Saraphirom et al. 2025). Finally, crop insurance and behavioural adaptation may influence farmers' resilience and production decisions. Studies from Indonesia and the Philippines highlight limitations in insurance coverage and the importance of farmers' experiences and perceptions in responding to drought risks (Pratiwi et al. 2018; Manalo et al. 2020).

Trade responses in 2023–2024

International rice trade can help address domestic supply shortfalls, particularly in rice-importing countries such as Indonesia and the Philippines. However, developments during 2023–2024 highlighted the vulnerability of international rice markets to export restrictions and price volatility. In July 2023, India introduced restrictions on rice exports amid rising domestic prices. India had exported a record 22.3 million tonnes of rice in 2022, while 42 countries sourced more than half of their rice imports from India (Glauber and Mamun 2023). International rice trade accounts for approximately 11% of global rice production, compared with 27% for wheat, making the rice market particularly sensitive to restrictions imposed by major exporters. Glauber and Mamun (2023) also noted that potential El Niño-related production disruptions could increase import demand in South and South-East Asia while export restrictions constrained international supply.

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Modelling studies illustrate the potential magnitude of market responses to production and policy shocks. Using a partial-equilibrium framework, Koizumi et al. (2026) projected higher domestic indica rice prices in several countries under scenarios reflecting market conditions in 2023/24 and identified export restrictions as a food security risk. Earlier scenario analysis by Lunt et al. (2016) showed that a hypothetical 7% reduction in global rice yields could contribute to an almost fourfold increase in commodity prices under an extreme scenario. These results illustrate potential market sensitivities rather than observed effects attributable to the 2023–2024 El Niño event. Two additional studies addressing rice price responses were identified (Valera et al. 2024; Antonio et al. 2025), but their findings were not assessed because only bibliographic metadata were available.

The Philippines illustrates how domestic production conditions, international trade, and public policy interact. Paddy production declined by approximately 4.8% between 2023 and 2024 (Our World in Data 2026a), while domestic prices of regular and well-milled rice reached record levels in May 2024. The government subsequently reduced rice import tariffs and declared a food security emergency in February 2025, accompanied by the release of public rice stocks. Rice imports were estimated at approximately 3.6 million tonnes in 2025 (FAO 2026b). These developments demonstrate the use of trade and stock-management policies to address domestic market pressures, although the relative contributions of climatic conditions, international restrictions, and other factors cannot be isolated from the available evidence.

Rice-exporting countries experienced different market developments. Thailand exported approximately 9.9 million tonnes of rice in 2024, compared with 7.7 million tonnes in 2025, while Viet Nam exported approximately 8.1 million tonnes in 2025 (FAO 2026c, 2026d). By late 2025, domestic rice prices were approximately 10–15% lower than a year earlier in the Philippines, 10–30% lower in Viet Nam, and around 30% lower in Thailand (FAO 2026b, 2026c, 2026d). These changes indicate substantial adjustments in regional rice markets following the 2023–2024 period, but differences in domestic policies, production conditions, and market structures limit direct comparisons.

Indonesia's reported supply-management strategy provides additional context. Government statements in July 2026 indicated public rice stocks of approximately 5.18 million tonnes and an expectation that rice imports would not be required during the year (Riswan 2026). These statements describe the government's reported policy position rather than independently verified evidence of resilience to ENSO-related production risks.

Discussion

The relative importance of harvested area, yield, and crop timing

The findings of this review suggest that assessments of El Niño-related rice production risks should consider more than yield changes alone. Evidence from the Philippines indicates that production anomalies may exceed yield anomalies, suggesting a role for harvested area and cropping activity (Stuecker et al. 2018). Studies from Indonesia and Viet Nam also documented drought-related damage to rice-growing areas and changes in planting dates during periods of drought and salinity intrusion (Surmaini et al. 2015; Hoang-Phi et al. 2020; Diem et al. 2024). The descriptive comparisons in Table 2 show that changes in yield and derived harvested area differed across countries and periods. During 2014–2016, reductions in derived harvested area were more pronounced than yield declines in

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Indonesia and Thailand, whereas yield declines were relatively larger in Viet Nam. During 2022–2024, reductions in derived harvested area were more pronounced in Indonesia and the Philippines, while production increased in Viet Nam and Thailand. However, these accounting relationships do not establish the causes of production changes or their attribution to El Niño.

Crop timing adds another dimension that annual statistics cannot adequately capture. Changes in planting dates and cropping intensity may affect climatic exposure, harvested area, and total production, but the reviewed evidence does not establish whether these changes reflect deliberate adaptation or production constraints. Consequently, evaluations of adaptation effectiveness should consider planted area, harvested area, cropping intensity, yield, and total production alongside farm income and production costs. Such assessments would provide a more comprehensive understanding of rice production responses to El Niño-related climatic variability.

What the evidence supports

Three findings emerge from the reviewed literature. First, ENSO-related climatic variability is associated with rice production outcomes, particularly in drought-exposed, rainfed, and dry-season systems. Studies from Indonesia, the Philippines, and Thailand identified relationships between ENSO indicators and agricultural outcomes, with reported lead times varying across locations, cropping seasons, and analytical approaches (Surmaini et al. 2015; Stuecker et al. 2018; Hensawang et al. 2021). These findings suggest that ENSO information may support anticipatory agricultural planning, although its practical value depends on forecast reliability, local production conditions, and the timing of farm decisions.

Second, AWD irrigation has demonstrated water-saving potential under experimental conditions without statistically significant yield reductions in the trials reviewed (Sandhu et al. 2017). However, evidence from the Philippines indicates that institutional arrangements and irrigation system characteristics can constrain its implementation and effectiveness under farmers' field conditions (Enriquez et al. 2021). Experimental evidence of water savings should therefore not be interpreted as direct evidence that AWD reduces production losses during El Niño events.

Third, irrigation access and water management appear to influence how climatic variability is associated with rice production. Studies from the Philippines and Indonesia suggest that irrigation conditions may moderate production responses to water stress, although these relationships vary across farming systems (Stuecker et al. 2018; Sumani et al. 2025). Evidence from local farming communities also indicates that water shortages can persist despite the presence of irrigation infrastructure (Arifah et al. 2022; Rahma and Ludwig 2024). Evaluations of irrigation-related adaptation should therefore consider water availability, supply reliability, distribution, and farmers' access rather than infrastructure provision alone.

What remains uncertain

The reviewed literature provides evidence of technical feasibility, adoption, and programme implementation for several adaptation measures, but limited evidence of their effectiveness in reducing El Niño-related rice production losses. Studies on planting calendars document information dissemination and changes in planting dates without establishing their production benefits (Aziz et al. 2021; Gravoso et al. 2014; Hoang-Phi et al. 2020; Diem et al.

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2024). Similarly, evidence on drought-tolerant and short-duration varieties primarily concerns varietal development, while findings from Nepal and India may not be directly transferable to South-East Asia (Aryal et al. 2022; Raghu et al. 2025). Evidence on supplementary pumping and water storage remains limited to programme implementation and local feasibility, with insufficient evaluation of production benefits, economic costs, and environmental consequences (Saraphirom et al. 2025). However, the absence of rigorous impact evaluations should not be interpreted as evidence that these measures are ineffective.

The comparison between the 2015–2016 and 2023–2024 El Niño periods further highlights these uncertainties. Aggregate paddy production across the four countries declined more substantially between 2014 and 2016 than between 2022 and 2024, but this difference cannot be attributed to improved adaptation. The events differed in ENSO intensity and timing, while production was also influenced by other climatic, agricultural, and economic factors (NOAA CPC 2026; Our World in Data 2026a). Moreover, harvested area was derived from production and yield rather than independently observed. Without appropriate counterfactual comparisons, the contributions of climatic conditions, adaptation measures, and other factors to observed production changes cannot be reliably distinguished.

Trade as a potentially constrained buffer

International rice trade can help countries respond to domestic production shortfalls, but its effectiveness as a supply buffer depends on international market conditions and trade policies. Developments during 2023–2024 highlighted these limitations, particularly when India's rice export restrictions coincided with concerns about El Niño-related production risks (Glauber and Mamun 2023). In the Philippines, high domestic rice prices were followed by policy responses involving import tariffs and public stock management (FAO 2026b). These developments illustrate the interaction between domestic supply concerns, international market conditions, and government interventions, although the contribution of El Niño to observed market outcomes remains uncertain.

For rice-importing countries, managing production risks may require coordination among domestic agricultural planning, import policies, and public stock management. The appropriate combination of these measures depends on international prices, storage costs, domestic market conditions, and food security objectives. Indonesia's reported public stock position and import policy in 2026 provide an example of government supply-management measures, although their effectiveness and economic efficiency have not been independently established in the reviewed evidence (Riswan 2026).

For rice-exporting countries, higher international prices may increase export revenues while creating concerns about domestic affordability and supply stability. The distribution of these effects depends on domestic production conditions, market structures, and government policies. Consequently, the economic implications of El Niño-related market disruptions cannot be assessed from production or export volumes alone.

Research priorities and future evaluation

The evidence gaps identified in this review highlight the need for rigorous evaluations of adaptation effectiveness using observed production and economic outcomes rather than adoption rates or programme implementation indicators alone. Future studies should assess whether supplementary irrigation, pumping programmes, and planting-calendar

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adjustments reduce production losses and improve farm income under El Niño conditions. Evaluations should consider planted area, harvested area, cropping intensity, yield, and total production, using seasonal data and appropriate comparison groups. Satellite-derived cropping information combined with farm-level and irrigation-system data could support these assessments (Irawan and Komori 2024). Experimental or quasi-experimental approaches may also help address selection bias and differences in climatic exposure, irrigation access, and farming conditions.

Further research should evaluate drought-tolerant and short-duration rice varieties under farmers' field conditions, considering crop performance, production costs, profitability, and adoption constraints. Studies of agricultural land-use change should also distinguish climate-related losses from deliberate adjustments in cropping systems and land allocation, particularly in the Mekong Delta, where climatic and socioeconomic factors interact (Wang et al. 2025). Across these areas, future evaluations should report uncertainty, examine longer-term livelihood outcomes, and assess the accessibility of adaptation measures for smallholders. Such evidence would support a more comprehensive understanding of adaptation effectiveness and agricultural resilience under El Niño-related climatic risks.

Limitations

Several limitations should be considered when interpreting this review. The literature search was restricted to Crossref and DOAJ, with a single screening process and limited retrieval of relevance-ranked records. Most studies were assessed using abstracts, while three were available only as bibliographic records, and no formal risk-of-bias assessment was conducted. Consequently, relevant studies may have been missed, limiting the assessment of adaptation effectiveness. The production analysis relied on national calendar-year statistics that may obscure seasonal and regional differences in climatic exposure. Harvested area was derived from production and yield rather than independently observed, while discontinuities in Indonesia's production series remained unresolved. Therefore, the descriptive comparisons should not be interpreted as causal estimates of El Niño impacts. In addition, selected government responses were documented through news reports without independent verification, and the evidence classifications in Table 4 reflect the authors' qualitative judgements rather than a standardised assessment of study quality. These limitations warrant caution when interpreting the findings, particularly regarding the effectiveness of adaptation measures.

Conclusion

This review examined El Niño-related rice production variability and adaptation evidence in Indonesia, the Philippines, Viet Nam, and Thailand. Combined paddy production declined by 10.0% between 2014 and 2016, compared with 0.5% between 2022 and 2024, although these changes cannot be attributed solely to El Niño. Differences in yield and derived harvested area across countries and periods highlight the importance of assessing production outcomes beyond yield alone. The reviewed evidence supports the water-saving potential of alternate wetting and drying irrigation under experimental conditions, while irrigation access and management appear to influence production responses to climatic variability. However, evidence remains limited on whether planting calendars, drought-tolerant varieties, and supplementary pumping reduce El Niño-related production losses under farmers' field conditions. Future research should prioritise season-specific evaluations of production and economic outcomes using appropriate comparison groups.

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Stronger evidence on adaptation effectiveness, alongside coordinated agricultural planning, rice trade, and public stock management, could support more effective responses to future El Niño-related risks.

Declarations

Competing interests. [To be completed by the authors.]

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