

Ageing Agriculture Vulnerability and Productivity Risk in ASEAN: Evidence from a Country-Level Index and Fixed-Effects Analysis, 2010–2024

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Abstract

This study examines ageing agriculture vulnerability in ASEAN by developing a country-level Ageing Agriculture Vulnerability Index (AAVI) and linking it with agricultural productivity outcomes. Drawing on secondary panel data for ten ASEAN countries during 2010–2024, compiled primarily from the World Bank World Development Indicators (WDI) and relevant international agricultural statistics, the index integrates ten indicators across five dimensions: demographic ageing, agricultural labour dependence, productivity risk, adaptive capacity, and food-system exposure. The results show substantial cross-country differences. Myanmar recorded the highest mean AAVI score during 2010–2024 (0.637), followed by Thailand (0.610), Cambodia (0.594), and Lao PDR (0.588), while Brunei Darussalam showed the lowest mean AAVI score (0.297). In the 2022 benchmark ranking, Myanmar ranked first (0.623) and Thailand second (0.597). Fixed-effects estimates indicate that agricultural employment share is negatively associated with agricultural value added per worker ($\beta = -0.0273$, $p < .001$), whereas population ageing alone shows only marginal evidence ($\beta = 0.0462$, $p = .051$). Moderation analysis further suggests that GDP per capita buffers ageing-related labour-productivity pressure ($\beta = 0.0236$, $p < .01$). Overall, ageing agriculture vulnerability in ASEAN is not simply a demographic outcome. It is a structural condition shaped by the interaction between ageing, labour-intensive agriculture, rural dependence, productivity constraints, and adaptive capacity. The findings offer policy implications for productivity upgrading, rural transformation, and food-system resilience.

1. Introduction

Population ageing is becoming an important structural issue for agricultural economies because it affects labour availability, farm succession, productivity, rural livelihoods, and food-system resilience. In ASEAN, this issue is particularly relevant because demographic transition and agricultural transformation are progressing unevenly across countries. Some countries, such as Thailand, Singapore, Viet Nam, and Malaysia, are moving toward older population structures, while others remain demographically younger but still rely heavily on agricultural employment and rural livelihoods. Recent studies show that ageing in ASEAN is linked with economic growth, inequality, social protection, and uneven development capacity (Taylor & Earl, 2024; Thanh Trong et al., 2024; Tiraphat et al., 2021).

The agricultural implications of ageing are not uniform. A country with a high share of older persons may have limited agricultural vulnerability if agriculture employs only a small proportion of workers, productivity is high, and adaptive capacity is strong. Conversely, a younger country may remain vulnerable if much of its workforce is concentrated in low-productivity agriculture. This distinction is consistent with comparative ageing research showing that ageing outcomes depend on institutional readiness and socio-economic capacity (Guan, 2008; Zaidi & Um, 2019). It also aligns with studies on Asian agrarian transformation, which show that farmer ageing is closely connected with labour restructuring, migration, farm succession, and rural livelihood change (Rigg et al., 2020; Yamaka & Klinlampu, 2024).

This study argues that ageing agriculture vulnerability should be understood as a multidimensional agricultural economics problem, not a purely demographic outcome. Vulnerability emerges when demographic ageing overlaps with agricultural labour dependence, rural exposure, productivity constraints, weak adaptive capacity, and food-system risk. ASEAN food security has improved, but the region continues to face structural challenges related to production resilience, policy coordination, and exposure to economic and environmental shocks (Sundram, 2023; Sundram & Brennan, 2024). An integrated framework is therefore needed to assess how ageing and agricultural structure jointly shape vulnerability across countries.

To address this gap, the study develops an Ageing Agriculture Vulnerability Index (AAVI) for ten ASEAN countries during 2010–2024. The index combines ten indicators across five dimensions: demographic ageing pressure, agricultural labour dependence, productivity risk, adaptive capacity, and food-system/economic exposure. This multidimensional approach follows vulnerability-index studies that emphasize exposure, sensitivity, adaptive capacity, transparent indicator selection, and clear aggregation rules (Crane et al., 2017; Hossain et al., 2023; Minh et al., 2023).

The study further links the AAVI with fixed-effects regression to examine whether population ageing and agricultural employment are associated with agricultural productivity, and whether adaptive capacity reduces ageing-related productivity risk. Agricultural value added per worker captures labour productivity, while cereal yield represents land or crop productivity. This distinction is important because labour productivity is closely related to employment structure and sectoral transformation, whereas crop productivity depends more on land, inputs, water, climate, and agronomic conditions (Raitzer & Maredia, 2012; Ma et al., 2023).

The article addresses four research questions: how ASEAN countries differ in ageing agriculture vulnerability; whether population ageing and agricultural employment are associated with productivity; whether fast-ageing countries face higher productivity risk than younger-structure countries; and which adaptive factors may reduce ageing-related vulnerability. The study contributes by proposing a country-level AAVI, providing comparative ASEAN evidence, and linking vulnerability indexing with panel regression analysis. The findings are intended to inform agricultural policy, rural transformation, and food-system resilience planning in ageing and labour-dependent agricultural economies.

2. Literature Review

2.1 Ageing, Agricultural Labour, and Rural Transformation

Population ageing affects agricultural economies through labour availability, farm succession, household production decisions, and rural livelihood security. In ageing societies, agriculture may experience a decline in younger workers, slower generational renewal, and increasing dependence on older farmers. These issues are especially important where agriculture remains labour-intensive and rural households still rely on farming as a major income source.

ASEAN is a useful setting because demographic ageing and agricultural dependence differ sharply across countries. Thailand, Singapore, Viet Nam, and Malaysia are moving toward older population structures, whereas Cambodia, Lao PDR, Myanmar, Indonesia, and the Philippines remain relatively younger but still retain sizeable agricultural and rural populations. Comparative ageing studies suggest that ageing outcomes vary according to institutional readiness, social protection, and socio-economic capacity (Guan, 2008; Zaidi & Um, 2019). In agriculture, Rigg et al. (2020) show that farmer ageing in Asia is embedded in migration, farm succession, agrarian transition, and rural livelihood change. Yamaka and Klinlampu (2024) similarly link ageing society with agricultural labour transformation in ASEAN.

Agricultural labour dependence is central to vulnerability. A high agricultural employment share often indicates limited capital intensity, weak mechanization, and slower structural transformation. ASEAN smallholders also face constraints in access to land, water, markets, and state support (Marks, 2019). These constraints may become more serious when demographic change reduces younger labour supply or increases reliance on older farmers. Ageing agriculture should therefore be understood as a structural condition, not simply as the rising number of older farmers.

2.2 Productivity Risk and Adaptive Capacity

Agricultural productivity is a key channel through which ageing agriculture vulnerability becomes economically significant. Labour productivity, measured by agricultural value added per worker, reflects the economic value generated by each agricultural worker and is closely linked with capital intensity, technology, skills, and sectoral transformation. Crop productivity, often represented by cereal yield, depends more on land quality, irrigation, inputs, climate, and agronomic practices. These two dimensions should be treated separately because a country may have high crop yield but low labour productivity if too many workers remain in agriculture.

Productivity upgrading is therefore essential for reducing vulnerability. Raitzer and Maredia (2012) emphasize the importance of agricultural research investment for productivity improvement and poverty reduction in Southeast Asia. Cahyadi and Waibel (2016) also show that agricultural livelihood arrangements shape smallholder vulnerability to poverty. In labour-intensive systems, vulnerability may increase further when labour costs rise and farming systems fail to adjust through mechanization, diversification, or productivity improvement (Jin et al., 2022).

Adaptive capacity determines whether ageing pressure becomes a serious productivity constraint. It includes income capacity, digital readiness, input availability, infrastructure, extension services, market connectivity, and institutional support. Peñalba and Elazegui (2013) show that small-scale rice farmers' adaptive capacity in Lao PDR and the Philippines depends on household resources, local production conditions, and institutional support. Landicho and Ramirez (2023) similarly argue that strengthening rural farming communities in Southeast Asia requires support mechanisms, knowledge sharing, and the scaling up of local best practices.

Digital access and input capacity are useful but imperfect proxies. National internet use may indicate broad digital readiness, but not actual farm-level digital adoption. Thi Hoa Sen et al. (2024) show that digital extension adoption among smallholders depends on specific barriers and enabling conditions. Fertilizer consumption may indicate production input capacity, but it can also reflect inefficient intensification or environmental pressure. Adaptive capacity should therefore be treated as a broader economic and institutional condition, rather than a single technology or input variable.

2.3 Food-System Exposure and Agricultural Vulnerability

Ageing agriculture is also linked to food-system exposure. Countries with high agricultural employment, large rural populations, and weak productivity may face greater difficulty maintaining resilient food systems when demographic and labour pressures intensify. ASEAN has made progress in food security, but structural challenges remain in production resilience, policy coordination, and exposure to shocks (Sundram, 2023; Sundram & Brennan, 2024). Climate change, market disruption, and uneven production capacity also shape food-system risk in the region (Islam & Kieu, 2021; Teng et al., 2021).

Agriculture's contribution to GDP can be interpreted as an economic exposure indicator. A high agricultural share may mean that shocks to the sector have broader consequences for employment, income, and rural welfare. However, a declining agricultural share does not automatically remove vulnerability if rural households remain dependent on farming. This is particularly relevant in ASEAN, where several countries have reduced agriculture's GDP share while still retaining large agricultural workforces or rural populations.

Vulnerability-index studies provide the methodological foundation for this analysis. Agricultural vulnerability is commonly understood as the interaction of exposure, sensitivity, and adaptive capacity (Crane et al., 2017; Hossain et al., 2023). Minh et al. (2023) show that livelihood vulnerability indexing is useful in Cambodia, Myanmar, and Viet Nam, while Hughes et al. (2012) demonstrate that national-level vulnerability assessment can support food-security analysis. Following this logic, the AAVI combines demographic ageing pressure, agricultural labour dependence, productivity risk, adaptive capacity, and food-system/economic exposure into one comparative measure.

2.4 Research Gap and Hypotheses

Existing research provides important insights into ageing, agricultural labour, productivity, adaptive capacity, and food-system vulnerability, but these strands are often examined separately. Ageing studies tend to focus on demographic change, welfare, and social protection. Agricultural economics research often emphasizes productivity, structural transformation, and farm-level adaptation. Food-system studies highlight resilience and exposure to shocks. What remains less developed is an integrated country-level framework that connects ageing, agricultural labour dependence, productivity risk, adaptive capacity, and food-system exposure in one comparative analysis.

This gap is important for ASEAN because demographic ageing and agricultural transformation do not move at the same speed across countries. Fast-ageing economies may not be highly vulnerable if

agriculture employs only a small share of workers and adaptive capacity is strong. Younger countries may remain highly vulnerable if agricultural employment is high, productivity is low, and rural dependence remains substantial. Based on this reasoning, the study proposes the following hypotheses:

H1

ASEAN countries differ significantly in their level of ageing agriculture vulnerability during 2010–2024.

H2

A higher share of agricultural employment is associated with lower agricultural labour productivity.

H3

Population ageing alone is not sufficient to explain agricultural productivity risk; its effect depends on agricultural labour dependence and adaptive capacity.

H4

Fast-ageing ASEAN countries do not necessarily have higher ageing agriculture vulnerability if they have stronger income capacity, lower agricultural employment dependence, and higher productivity.

H5

Adaptive capacity, particularly GDP per capita, technology readiness, and production input capacity, moderates the relationship between population ageing and agricultural productivity.

3. Methodology

3.1 Research Design and Data

This study applies a quantitative country-level panel design to examine ageing agriculture vulnerability and agricultural productivity risk in ASEAN. The analysis covers ten ASEAN member countries during 2010–2024: Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Malaysia, Myanmar, the Philippines, Singapore, Thailand, and Viet Nam.

The study uses secondary data from internationally comparable databases, mainly the World Development Indicators, supplemented by metadata-linked indicators from FAO/FAOSTAT, ILO modelled estimates, ITU indicators, and UN demographic sources. These sources provide comparable indicators on demographic ageing, agricultural employment, rural population, productivity, digital readiness, input capacity, food production, and macroeconomic structure. National-level vulnerability assessment is appropriate because the study aims to compare structural exposure across countries rather than explain household-level behaviour (Hughes et al., 2012; Hossain et al., 2023).

The unit of analysis is the country-year. The full panel contains a maximum of 150 observations. Because several agricultural and food-system indicators are incomplete for 2023–2024, the benchmark AAVI analysis focuses on 2010–2022, when the ten core indicators are more complete. The 2010–2024 results are treated as diagnostic and calculated using a missing-adjusted rule without imputation.

3.2 Variables and AAVI Construction

The study develops an **Ageing Agriculture Vulnerability Index (AAVI)** to capture the interaction between demographic ageing, agricultural labour dependence, productivity risk, adaptive capacity, and food-system/economic exposure. Table 1, the index includes ten indicators grouped into five dimensions. This structure follows vulnerability research that treats risk as the interaction of exposure, sensitivity, and adaptive capacity (Crane et al., 2017; Minh et al., 2023).

Table 1
Variables and operational definitions

Dimension	Indicator	Code	Expected direction
Demographic ageing pressure	Population aged 65+	SP.POP.65UP.TO.ZS	Higher = higher vulnerability
Demographic ageing pressure	Old-age dependency ratio	SP.POP.DPND.OL	Higher = higher vulnerability
Agricultural labour dependence	Agricultural employment share	SL.AGR.EMPL.ZS	Higher = higher vulnerability
Agricultural labour dependence	Rural population share	SP.RUR.TOTL.ZS	Higher = higher vulnerability
Productivity risk	Agricultural value added per worker	NV.AGR.EMPL.KD	Higher = lower vulnerability
Productivity risk	Cereal yield	AG.YLD.CREL.KG	Higher = lower vulnerability
Adaptive capacity	Internet users	IT.NET.USER.ZS	Higher = lower vulnerability
Adaptive capacity	Fertilizer consumption	AG.CON.FERT.ZS	Higher = lower vulnerability*
Food-system exposure	Food production index	AG.PRD.FOOD.XD	Higher = lower vulnerability
Economic exposure	Agriculture value added to GDP	NV.AGR.TOTL.ZS	Higher = higher vulnerability

*

Fertilizer consumption is treated as a production input-capacity indicator, although high use may also reflect environmental pressure or input inefficiency.

The regression analysis uses two dependent variables: log agricultural value added per worker and log cereal yield. Agricultural value added per worker captures labour productivity, while cereal yield represents land or crop productivity. These indicators are separated because labour productivity is more closely linked with employment structure and sectoral transformation, whereas crop productivity depends more on land, inputs, water, climate, and agronomic conditions (Raitzer & Maredia, 2012; Ma et al., 2023).

The AAVI is constructed using min–max normalization, which converts indicators with different units into a common 0–1 scale. This procedure is widely used in composite vulnerability assessment (Diouf & Gaye, 2015; Hossain et al., 2023). For indicators where higher values indicate higher vulnerability, the normalized score is calculated as:

$$V_{ijt} = \frac{X_{ijt} - X_j^{min}}{X_j^{max} - X_j^{min}}$$

For indicators where higher values indicate lower vulnerability, reverse normalization is applied:

$$V_{ijt} = \frac{X_j^{max} - X_{ijt}}{X_j^{max} - X_j^{min}}$$

where V_{ijt} is the normalized vulnerability score for country i , indicator j , and year t . X_{ijt} is the observed value, while X_j^{min} and X_j^{max} are the minimum and maximum values of indicator j in the sample.

The AAVI score is calculated as the arithmetic mean of the normalized indicators:

$$AAVI_{it} = \frac{1}{K} \sum_{j=1}^K V_{ijt}$$

where K is the number of indicators. Equal weighting is used for transparency and replicability when no strong theoretical basis exists for unequal weighting (Jose et al., 2017; Sahoo & Moharaj, 2024).

For the diagnostic 2010–2024 analysis, missing indicators are not imputed. Instead, the AAVI is calculated using available indicators only:

$$AAVI_{it}^{adj} = \frac{1}{K_{it}} \sum_{j=1}^{K_{it}} V_{ijt}$$

where K_{it} is the number of valid indicators for country i in year t . Thus, the 2024 values in Table 2 are interpreted as diagnostic because countries may have different numbers of valid indicators.

Table 2
AAVI interpretation criteria

AAVI score	Vulnerability level
0.000–0.333	Low vulnerability
0.334–0.666	Moderate vulnerability
0.667–1.000	High vulnerability

These thresholds are used only for descriptive classification. The main interpretation emphasizes relative differences across ASEAN countries and changes over time.

3.3 Empirical Strategy

The analysis proceeds in four steps. First, descriptive statistics compare ageing agriculture vulnerability across ASEAN countries and years. The 2022 AAVI ranking is treated as the benchmark because the ten core indicators are more complete in that year, while the 2024 ranking is reported as a diagnostic extension.

Second, Pearson and Spearman correlations are used to examine descriptive relationships between ageing-agriculture variables and productivity indicators. These correlations are not interpreted as causal effects.

Third, fixed-effects regression estimates the association between demographic ageing, agricultural labour dependence, adaptive capacity, and agricultural productivity. Country fixed effects control for time-invariant national characteristics, while year fixed effects control for common temporal shocks. The baseline model is specified as:

$$Y_{it} = \alpha + \beta_1 \text{Ageing}_{it} + \beta_2 \text{AgriEmp}_{it} + \beta_3 \text{Internet}_{it} + \beta_4 \text{Fertilizer}_{it} + \beta_5 \text{AgriGDP}_{it} + \beta_6 \text{GDPpc}_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

where Y_{it} is agricultural productivity, measured by either log agricultural value added per worker or log cereal yield. Ageing_{it} is the population aged 65 and above, AgriEmp_{it} is agricultural employment share, Internet_{it} is internet users, Fertilizer_{it} is fertilizer consumption, AgriGDP_{it} is agriculture value added to GDP, and GDPpc_{it} is log GDP per capita. μ_i and λ_t denote country and year fixed effects.

Fourth, moderation models test whether adaptive capacity changes the relationship between population ageing and agricultural productivity. The moderators are internet users, fertilizer consumption, and log GDP per capita. This follows vulnerability literature that treats adaptive capacity as a factor that can alter the effect of exposure on outcomes (Crane et al., 2017; Minh et al., 2023). The model is specified as:

$$Y_{it} = \alpha + \beta_1 \text{Ageing}_{it} + \beta_2 \text{Moderator}_{it} + \beta_3 (\text{Ageing}_{it} \times \text{Moderator}_{it})$$

$$+ \beta_4 \text{AgriEmp}_{it} + \beta_5 \text{AgriGDP}_{it} + \mu_i + \lambda_t + \varepsilon_{it}$$

The interaction term $\text{Ageing}_{it} \times \text{Moderator}_{it}$ indicates whether adaptive capacity strengthens or weakens the association between population ageing and productivity. Robust standard errors clustered by country are used to address heteroskedasticity and within-country serial correlation.

3.4 Missing Data, Limitations, and Ethics

The study does not use interpolation, extrapolation, or model-based imputation. For the benchmark AAVI analysis, the study emphasizes 2010–2022 because indicator availability is strongest. For the 2010–2024 diagnostic analysis, unavailable indicators are excluded from the denominator. For regression analysis, observations with missing values in required variables are excluded through listwise deletion.

Several methodological limitations should be noted. First, the AAVI measures country-level structural vulnerability and cannot capture individual farmer age, household labour allocation, farm succession, land tenure, gender differences, or local support systems. Second, some variables are proxies. Internet users indicate broad digital readiness rather than actual farm-level digital adoption, while fertilizer consumption reflects input intensity rather than sustainable production capacity (Thi Hoa Sen et al., 2024). Third, equal weighting improves transparency but assumes that all indicators contribute equally to vulnerability. Future studies could test alternative weighting methods such as principal component analysis, entropy weighting, expert scoring, or sensitivity analysis.

This study uses only publicly available country-level secondary data. No individual respondents are contacted, and no personal or identifiable information is collected. The analysis therefore does not involve human subjects in the conventional research ethics sense.

4. Results

4.1 Ageing Agriculture Vulnerability across ASEAN

The Ageing Agriculture Vulnerability Index (AAVI) shows substantial cross-country differences across ASEAN. Table 3, during 2010–2024, Myanmar recorded the highest mean AAVI score (0.637), followed by Thailand (0.610), Cambodia (0.594), and Lao PDR (0.588). These countries form the higher-vulnerability group, although their sources of vulnerability differ. Myanmar, Cambodia, and Lao PDR remain exposed mainly through agricultural employment, rural dependence, and productivity constraints, whereas Thailand combines rapid population ageing with a still-sizeable agricultural workforce.

At the lower end, Brunei Darussalam recorded the lowest mean AAVI score (0.297), followed by Singapore (0.332) and Malaysia (0.338). Their lower vulnerability reflects smaller agricultural employment shares and stronger income capacity. These results confirm that ageing agriculture vulnerability is not determined by population ageing alone. It becomes more serious when ageing overlaps with labour-intensive agriculture, rural dependence, and weak productivity.

Table 3
Country-level AAVI summary, 2010–2024

Country	Mean AAVI	AAVI 2022	AAVI 2024	65 + population 2024	Agricultural employment 2024
Myanmar	0.637	0.623	0.583	7.304	45.357
Thailand	0.610	0.597	0.689	15.363	28.986
Cambodia	0.594	0.522	0.518	6.164	34.165
Lao PDR	0.588	0.524	0.505	4.666	68.912
Viet Nam	0.510	0.468	0.499	9.047	25.874
Indonesia	0.485	0.427	0.442	7.289	27.960
Philippines	0.480	0.450	0.404	5.492	21.186
Malaysia	0.338	0.343	0.300	7.738	9.437
Singapore	0.332	0.323	0.306	13.656	0.098
Brunei Darussalam	0.297	0.279	0.163	6.868	1.237
Note:					

- AAVI ranges from 0 to 1, where higher values indicate higher vulnerability.
- The 2022 score is treated as the benchmark because the ten core indicators are more complete.
- The 2024 score is diagnostic because missing indicators were excluded from the denominator.

4.2 Benchmark and Diagnostic Rankings

Table 4, the 2022 benchmark ranking places Myanmar first, followed by Thailand, Lao PDR, and Cambodia. Viet Nam, the Philippines, and Indonesia form the middle group, while Malaysia, Singapore, and Brunei Darussalam show lower vulnerability. The 2024 diagnostic ranking places Thailand first, followed by Myanmar, Cambodia, and Lao PDR. However, the 2024 values should be interpreted cautiously because countries have different numbers of valid indicators. For example, Thailand’s 2024 AAVI was calculated from six valid indicators, while Lao PDR used eight. Therefore, the 2022 ranking is the more reliable cross-country benchmark.

Table 4
AAVI ranking in 2022 and 2024

Rank 2022	Country	AAVI 2022	Rank 2024	AAVI 2024	Valid indicators 2024
1	Myanmar	0.623	2	0.583	7
2	Thailand	0.597	1	0.689	6
3	Lao PDR	0.524	4	0.505	8
4	Cambodia	0.522	3	0.518	7
5	Viet Nam	0.468	5	0.499	7
6	Philippines	0.450	7	0.404	7
7	Indonesia	0.427	6	0.442	7
8	Malaysia	0.343	9	0.300	7
9	Singapore	0.323	8	0.306	7
10	Brunei Darussalam	0.279	10	0.163	6

4.3 Ageing, Agricultural Labour Dependence, and Productivity

The correlation results as shown in Table 5 indicate that agricultural labour dependence is more closely related to productivity than population ageing alone. Agricultural employment share has a strong negative association with agricultural value added per worker, with a Pearson correlation of -0.750 and a Spearman correlation of -0.960. By contrast, population aged 65 and above shows only a weak relationship with agricultural value added per worker. These results suggest that productivity risk becomes more serious when ageing occurs within labour-intensive agricultural systems.

Table 5
Correlation between ageing-agriculture variables and productivity indicators

Factor	Pearson with agricultural value added per worker	Spearman with agricultural value added per worker
Population aged 65+	0.078	0.285
Old-age dependency ratio	-0.018	0.214
Agricultural employment share	-0.750	-0.960
Note: Correlations are descriptive and should not be interpreted as causal effects.		

The fixed-effects regression as in Table 6 confirms this pattern. Agricultural employment share is negatively and significantly associated with log agricultural value added per worker ($\beta = -0.0273$, $p <$

.001). Population ageing shows only marginal evidence in the same model ($\beta = 0.0462$, $p = .0511$). For the cereal yield model, neither population ageing nor agricultural employment share is statistically significant at the 5% level. This suggests that labour productivity is more sensitive to employment structure, while cereal yield may depend more on agronomic, land, input, and climate-related factors.

Table 6
Fixed-effects regression results for agricultural productivity

Dependent variable	Predictor	Coefficient	Robust SE	t-statistic	p-value
In agricultural value added per worker	Population aged 65+	0.0462	0.0237	1.95	0.0511
	Agricultural employment share	-0.0273	0.0063	-4.33***	< 0.001
	Internet users	-0.0044	0.0017	-2.59*	0.0112
	Fertilizer consumption	-0.0000	0.0000	-1.39	0.1639
	Agriculture value added to GDP	0.0173	0.0108	1.60	0.1096
	In GDP per capita	0.2357	0.1694	1.39	0.1641
In cereal yield	Population aged 65+	-0.0412	0.0324	-1.27	0.2026
	Agricultural employment share	-0.0078	0.0064	-1.22	0.2291
	In GDP per capita	-0.8429	0.4842	-1.74	0.0817
Note:					

- Country and year fixed effects are included.
- Robust standard errors are clustered by country.
- Significance levels: * $p < .05$, ** $p < .01$, *** $p < .001$.

4.4 Fast-Ageing and Younger-Structure Countries

The group comparison in Table 7 shows that fast-ageing countries do not automatically have higher ageing agriculture vulnerability. The fast-ageing group, consisting of Thailand, Singapore, Viet Nam, and Malaysia, recorded a lower mean AAVI score (0.448) than the younger-structure group (0.514). This result is notable because the fast-ageing group has a higher average 65 + population share, but also lower agricultural employment dependence and higher agricultural value added per worker.

These findings support the argument that demographic ageing does not necessarily translate into agricultural vulnerability when countries have stronger income capacity, lower agricultural employment,

and higher productivity. Thailand remains an exception within the fast-ageing group because rapid ageing coincides with a still-significant agricultural and rural base.

Table 7
Group comparison between fast-ageing and younger-structure ASEAN countries

Group	Mean AAVI	Population aged 65 + mean	Agricultural employment mean	Agricultural value added per worker mean
Fast-ageing countries	0.448	8.737	21.017	12,101.352
Younger-structure countries	0.514	5.106	37.308	9,935.200
Note: Fast-ageing countries include Thailand, Singapore, Viet Nam, and Malaysia. Younger-structure countries include Brunei Darussalam, Cambodia, Indonesia, Lao PDR, Myanmar, and the Philippines.				

4.5 Moderating Role of Adaptive Capacity

The moderation results in Table 8 show that adaptive capacity can alter the relationship between ageing and productivity. In the model for log agricultural value added per worker, population ageing becomes negative and statistically significant ($\beta = -0.2819$, $p = .0268$), while agricultural employment share remains negative and highly significant ($\beta = -0.0321$, $p < .001$). This confirms that labour-intensive agriculture continues to weaken productivity outcomes after interaction effects are considered.

GDP per capita is the clearest buffering factor. Its interaction with population ageing is positive and significant in both the agricultural value added per worker model ($\beta = 0.0236$, $p = .0053$) and the cereal yield model ($\beta = 0.0728$, $p < .001$). This suggests that higher income capacity may reduce ageing-related productivity pressure through stronger infrastructure, technology, institutional readiness, and investment capacity. By contrast, internet access does not show a significant buffering effect, while fertilizer consumption provides mixed evidence.

Table 8
Moderation results: selected adaptive factors

Dependent variable	Predictor	Coefficient	Robust SE	t-statistic	p-value
In agricultural value added per worker	Population aged 65+	-0.2819	0.1273	-2.214*	0.0268
	Agricultural employment share	-0.0321	0.0062	-5.149***	< 0.001
	Internet users	-0.0071	0.0029	-2.438*	0.0148
	Population aged 65+ × Internet users	0.0006	0.0004	1.666	0.0958
	Fertilizer consumption	0.0001	0.0001	1.386	0.1658
	Population aged 65+ × Fertilizer consumption	-0.0000	0.0000	-2.082*	0.0374
	ln GDP per capita	-0.0210	0.1451	-0.144	0.8852
	Population aged 65+ × ln GDP per capita	0.0236	0.0085	2.787**	0.0053
	Agriculture value added to GDP	0.0089	0.0072	1.233	0.2174
In cereal yield	Population aged 65+	-0.5396	0.1705	-3.164**	0.0016
	Agricultural employment share	-0.0048	0.0033	-1.434	0.1517
	Internet users	0.0037	0.0053	0.705	0.4806
	Population aged 65+ × Internet users	-0.0009	0.0005	-1.620	0.1053
	Fertilizer consumption	0.0004	0.0002	2.477*	0.0133
	Population aged 65+ × Fertilizer consumption	-0.0001	0.0000	-3.638***	< 0.001
	ln GDP per capita	-0.6562	0.1609	-4.080***	< 0.001
	Population aged 65+ × ln GDP per capita	0.0728	0.0161	4.522***	< 0.001
	Agriculture value added to GDP	-0.0008	0.0059	-0.141	0.8882

Note:

- Country and year fixed effects are included.
- Robust standard errors are clustered by country.

- Significance levels: * $p < .05$, ** $p < .01$, *** $p < .001$.

4.6 Summary of Results

The results provide four main findings. First, ASEAN countries differ substantially in ageing agriculture vulnerability, with Myanmar, Thailand, Cambodia, and Lao PDR showing higher vulnerability. Second, agricultural labour dependence is more strongly associated with low agricultural labour productivity than population ageing alone. Third, fast-ageing countries do not automatically face higher vulnerability when agricultural employment is lower and income capacity is stronger. Fourth, GDP per capita appears to be the clearest buffering factor against ageing-related productivity pressure.

Overall, ageing agriculture vulnerability in ASEAN is not merely a demographic outcome. It is a structural condition shaped by the interaction between population ageing, labour-intensive agriculture, rural dependence, productivity constraints, and adaptive capacity.

5. Discussion

5.1 Ageing Agriculture Vulnerability as a Structural Agricultural Problem

The findings show that ageing agriculture vulnerability in ASEAN should not be viewed as a purely demographic issue. Population ageing matters, but its agricultural consequences depend on agricultural employment, rural dependence, productivity capacity, and institutional readiness. This supports Rigg et al. (2020), who argue that farmer ageing in Asia is embedded in broader agrarian transformation, migration, farm succession, and livelihood change. Yamaka and Klinlampu (2024) similarly link ageing society with agricultural labour transformation in ASEAN.

The cross-country patterns confirm this structural interpretation. Singapore and Malaysia show relatively low vulnerability despite population ageing because agriculture employs a smaller share of workers and broader income capacity is stronger. Myanmar, Cambodia, and Lao PDR show higher vulnerability because agriculture remains central to employment and rural livelihoods. Thailand is a critical case because rapid ageing overlaps with a still-significant agricultural and rural base. Evidence from Thai rice farmers also shows that older farmers adapt through behavioural and production adjustments, but their capacity to adapt depends on resources and support systems (Bunyasiri et al., 2024).

These findings shift the discussion from ageing as an age-structure problem to ageing as an agricultural economics problem. The key issue is not only how many people are old, but how ageing interacts with labour allocation, sectoral productivity, rural exposure, and adaptive capacity. Comparative ageing research also supports this view by showing that ageing outcomes differ according to socio-economic capacity and institutional readiness (Guan, 2008; Zaidi & Um, 2019).

5.2 Agricultural Labour Dependence and Productivity Risk

The strongest empirical result is the negative association between agricultural employment share and agricultural value added per worker. This suggests that agricultural labour dependence is a more direct source of productivity risk than population ageing alone. In countries where many workers remain in agriculture, the sector may continue to operate as a low-productivity labour absorber rather than a source of income growth.

This result is consistent with the agricultural transformation literature. Raitzer and Maredia (2012) emphasize the importance of agricultural research investment for productivity upgrading and poverty reduction in Southeast Asia. Jin et al. (2022) also show that labour-intensive systems become vulnerable when rising labour costs are not matched by mechanization, diversification, or productivity improvement. Therefore, reducing ageing agriculture vulnerability requires productivity-oriented transformation, not only demographic or welfare policy.

The distinction between labour productivity and crop productivity is also important. Labour productivity is closely linked with employment structure, capital intensity, technology, and sectoral transformation. Cereal yield depends more on land quality, irrigation, climate, input use, and agronomic practices. This explains why agricultural employment share is strongly associated with agricultural value added per worker, but not with cereal yield. Policy responses should therefore distinguish between labour-productivity upgrading and yield improvement.

5.3 Adaptive Capacity and the Role of Income

The moderation results show that adaptive capacity can reduce ageing-related productivity pressure. GDP per capita is the clearest buffering factor, suggesting that higher-income economies may better absorb ageing pressure through infrastructure, mechanization, technology adoption, credit systems, logistics, extension services, and institutional support. This finding aligns with studies showing that adaptive capacity depends on both household resources and wider institutional support (Peñalba & Elazegui, 2013; Landicho & Ramirez, 2023).

Internet users and fertilizer consumption provide more mixed evidence. National internet penetration does not necessarily translate into farm-level digital adoption. Thi Hoa Sen et al. (2024) show that digital extension adoption among smallholders depends on specific barriers and enabling conditions. Fertilizer consumption may indicate input capacity, but it may also reflect inefficient intensification or environmental pressure. Thus, adaptive capacity should not be reduced to a single technology or input variable. It should be understood as a broader combination of income capacity, infrastructure, institutions, knowledge systems, and farmer support.

5.4 Policy Implications

The findings suggest that ageing agriculture policy should move beyond elderly support alone. Social protection for older farmers remains important, but it is insufficient if agricultural systems remain labour-intensive and low-productivity. Countries with high AAVI scores should prioritize labour-saving

innovation, mechanization services, farmer cooperatives, shared machinery systems, rural extension, and productivity-enhancing investment.

Digital agriculture policy should also focus on actual farm-level usability. National internet access is not enough if older farmers and smallholders cannot use digital extension, weather information, online markets, or farm-management tools. Digital systems should therefore combine infrastructure with training, trust-building, local extension support, and user-friendly design.

Agricultural transformation should also be linked with rural income diversification. A declining agricultural employment share reduces vulnerability only when rural households can access better non-farm income opportunities, skills development, and market connections. Without these alternatives, structural transformation may produce rural insecurity rather than resilience.

At the regional level, ASEAN cooperation can support high-vulnerability countries through shared databases, technology transfer, food-system monitoring, and rural ageing policy exchange. This is important because ASEAN food security continues to face structural challenges and future shocks despite recent progress (Sundram, 2023; Sundram & Brennan, 2024). Thailand deserves particular attention because rapid ageing coincides with a still-meaningful agricultural workforce and rural livelihood base.

5.5 Contributions, Limitations, and Future Research

This study contributes by framing ageing agriculture vulnerability as a multidimensional structural condition. Rather than treating population ageing as a direct cause of agricultural decline, it shows that vulnerability emerges from the interaction between demographic ageing, agricultural labour dependence, productivity risk, food-system exposure, and adaptive capacity. This view is consistent with agricultural vulnerability studies that emphasize exposure, sensitivity, and adaptive capacity (Crane et al., 2017; Hossain et al., 2023).

The AAVI framework also provides a practical contribution. It converts a complex concept into a measurable country-level index that can be compared across countries and over time. Methodologically, the study links a composite vulnerability index with fixed-effects regression and moderation analysis, allowing both country patterns and productivity-related mechanisms to be examined.

Several limitations remain. The study uses country-level secondary data and cannot capture individual farmer age, household labour allocation, farm succession, land tenure, gender differences, health status, or local support systems. Some variables are also proxies. Internet users do not measure actual agricultural digital adoption, fertilizer consumption does not fully represent sustainable adaptive capacity, and agriculture value added to GDP does not capture full household dependence on farming. Future research should extend the AAVI to subnational levels, integrate farm-level survey data, and develop better indicators of mechanization, digital agriculture adoption, farm succession, and sustainable input use.

6. Conclusion

This study examined ageing agriculture vulnerability in ASEAN using country-level secondary data from 2010 to 2024. It developed the Ageing Agriculture Vulnerability Index (AAVI) from ten indicators covering demographic ageing, agricultural labour dependence, productivity risk, adaptive capacity, and food-system exposure. The study also linked the index with correlation analysis, fixed-effects regression, and moderation analysis to examine how ageing, agricultural employment, and adaptive capacity relate to productivity.

The findings show substantial differences across ASEAN countries. Myanmar, Thailand, Cambodia, and Lao PDR recorded higher vulnerability, while Brunei Darussalam, Singapore, and Malaysia showed lower vulnerability. The 2022 benchmark ranking placed Myanmar first and Thailand second. The 2024 diagnostic ranking placed Thailand first, but this result should be interpreted cautiously because several indicators were unavailable and excluded from the denominator.

Agricultural labour dependence was more strongly associated with productivity risk than population ageing alone. Agricultural employment share had a negative and statistically significant relationship with agricultural value added per worker, while population ageing showed weaker evidence. This indicates that vulnerability is driven less by ageing itself and more by the overlap between ageing and labour-intensive agricultural structures.

The comparison between fast-ageing and younger-structure countries reinforces this point. Fast-ageing countries do not automatically face higher vulnerability when agricultural employment is lower, productivity is higher, and income capacity is stronger. Thailand remains a critical case because rapid ageing occurs alongside a still-significant agricultural and rural base.

The moderation results suggest that GDP per capita is the clearest buffering factor. Higher income capacity may reduce ageing-related productivity pressure by supporting infrastructure, technology adoption, institutional capacity, and productivity-enhancing investment. Internet users and fertilizer consumption provide mixed evidence, indicating that broad digital access and input intensity are incomplete measures of agricultural adaptation.

Overall, ageing agriculture vulnerability in ASEAN should be understood as a structural agricultural economics issue rather than a purely demographic outcome. Risk is highest where population ageing overlaps with labour-intensive agriculture, rural dependence, low productivity, and limited adaptive capacity. Policy responses should therefore combine older-farmer support with productivity upgrading, labour-saving innovation, rural digital inclusion, agricultural restructuring, income diversification, and stronger food-system resilience planning.

Declarations

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Author Contribution

T.K. conceptualized the study, designed the research framework, developed the Ageing Agriculture Vulnerability Index (AAVI), collected and organized the secondary panel data, conducted the statistical analysis, interpreted the results, and wrote the main manuscript text. T.K. also prepared the tables, reviewed the literature, revised the manuscript, and approved the final version for submission.

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Data Availability

The data used in this study were obtained from publicly available international databases, primarily the World Bank World Development Indicators (WDI), supplemented by relevant indicators from FAO/FAOSTAT, ILO modelled estimates, ITU statistics, and United Nations demographic sources. The processed country-year dataset and analytical files used to construct the Ageing Agriculture Vulnerability Index (AAVI) and conduct the regression analyses are available from the author upon reasonable request.

Ethics Approval

Not applicable. This study was based exclusively on publicly available, aggregated country-level secondary data and did not involve human participants, animal subjects, personal data, interviews, surveys, experiments, or identifiable private information. Therefore, ethics approval from an ethics committee or institutional review board was not required.

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