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Productivity Degradation in Aging Smallholder Oil Palm Plantations: Policy Implications for Replanting Programs in Subulussalam City

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A B S T R A C T

This study analyzes the dynamics of productivity and farm income degradation resulting from oil palm crop aging and formulates policy implications for the Smallholder Oil Palm Replanting Program (PSR) in Subulussalam City. Using a quantitative-descriptive socio-economic survey of 98 independent smallholders, empirical findings reveal that oil palm stands in the old phase (≥ 21 years) experience a productivity decline to 15.04 tons/ha/year (24.5% lower than the intermediate phase), resulting in an annual revenue opportunity loss of IDR 12.61 million/ha. This degradation is driven by biological tree senescence, fertilizer capital constraints, and uncertified planting materials. Accelerating the integrated PSR scheme, facilitating land legality, and strengthening cooperative institutions are critical to restoring smallholder income and rural welfare.

INTRODUCTION

Oil palm (Elaeis guineensis Jacq.) serves as the primary catalyst for rural economies and the largest employment absorber across smallholder plantation centers in Indonesia. At the rural level, independent oil palm plantations function as a cornerstone of household economic resilience, where the majority of farm revenues are allocated to fulfill basic food needs, children's education, and family living expenditures (Handayani et al., 2024; Siregar et al., 2021). This high economic reliance on oil palm is also evident in the former transmigration settlement areas of Subulussalam City, where smallholder farming represents the primary source of community livelihoods (Bagio et al, 2020).

Nevertheless, the development of smallholder plantations in Subulussalam City currently faces a structural socio-economic anomaly that threatens smallholders' income stability. Based on data from the Central Statistics Agency (BPS) of Aceh Province and the Department of Agriculture and Plantation of Subulussalam City, the total smallholder plantation area expanded from 19,014 hectares to 19,304 hectares, yet total Fresh Fruit Bunch (FFB) production degraded from 29,120 tons to 28,800 tons (Badan Pusat Statistik Provinsi Aceh, 2023; Dinas Pertanian dan Perkebunan Kota Subulussalam, 2023). The sharpest contraction in yield was recorded in Simpang Kiri District, where annual production plummeted from 9,210 tons to 7,460 tons despite managing an area of 4,894 hectares (Dinas Pertanian dan Perkebunan Kota Subulussalam, 2023).

The socio-economic root of this production decline lies in the crop age cycle. Most smallholder plantations in Simpang Kiri District were established during the transmigration settlement wave several decades ago (Bagio et al, 2020). Consequently, smallholders' palm stands have simultaneously entered a biological senescence phase exceeding 20 to 25 years. In aging stands, physical yield degradation per hectare directly triggers a decline in farm revenue and constrains household purchasing power (Ningsih et al., 2021; Siregar et al., 2021). This situation is compounded by smallholders' liquidity limitations in purchasing fertilizers at recommended rates, historical reliance on uncertified local seeds, and limited technical maintenance skills (Mahsyuri & Ginting, 2021; Siswanto et al., 2020).

To overcome the aging plantation trap, the government established the Smallholder Oil Palm Replanting Program (PSR) funded by the Palm Oil Plantation Fund Management Agency (BPDPKS). However, the implementation of PSR among independent smallholders is frequently impeded by weak farmer group institutions, land certification administrative barriers, and limited cooperative managerial skills in preparing technical replanting proposals (Nasution et al., 2023). In light of these issues, this study aims to comprehensively analyze crop aging dynamics and their implications for productivity degradation in Simpang Kiri District, identify socio-economic and agronomic management bottlenecks, and formulate strategic policy directions for accelerating the PSR program in Subulussalam City.

LITERATURE REVIEW

Crop Life Cycle, Productivity, and Farm Income

In the perspective of agricultural socio-economics, smallholder oil palm farming represents a multi-year long-term capital investment. Resource allocation theory posits that farm revenue capacity is governed by the biological yield curve of the crop (Mustari et al., 2020). The Indonesian Oil Palm Research Institute (PPKS, 2017) categorizes oil palm age into distinct phases: Immature Phase (TBM, 0–3 years), Young Mature Phase (TM, 3–4 years), Intermediate Mature Phase (5–12 years), Prime Mature Phase (12–20 years as the peak productivity stage), Old Mature Phase (21–25 years declining stage), and Senescent Phase (> 26 years with marginal yields).

As smallholder plantations transition into the old phase, physiological deterioration decreases the average bunch weight and elevates harvesting labor costs due to extreme tree height (Inderiati, 2023; Lestari, 2024). This reduction in physical FFB volume directly compresses gross and net farm income allocated for household consumption (Koesriwulandari et al., 2023; Siregar et al., 2021).

H_1: *Crop age advancement during the old phase is significantly associated with the degradation of smallholder oil palm productivity and farm revenue.*

Production Input Allocation and Smallholder Plantation Governance

The achievement of farm productivity and revenue is determined by the efficient allocation of production inputs (land scale, agrochemicals, and labor) as well as farm management practices (Koesriwulandari et al., 2023; Mustari et al., 2020). Landholding size reflects economies of scale that expand physical output capacity and smallholder operational efficiency (Yamani et al., 2024). Balanced nutrient supply through fertilization and weed control via herbicides/pesticides maintain vegetative-generative metabolic continuity (Ferdiansyah, 2023; Romadhoni et al., 2022).

However, empirical studies on independent smallholders reveal widespread gaps in the adoption of Good Agricultural Practices (GAP) due to working capital constraints (Nasution et al., 2024; Mahsyuri & Ginting, 2021). The historical use of uncertified planting materials and irregular frond pruning practices represent persistent barriers to yield optimization (Alhafiz et al., 2020; Rosnina et al., 2019; Siswanto et al., 2020).

H_2: *The intensity of fertilizer allocation, crop protection, and labor allocation contributes significantly to smallholder oil palm revenue performance.*

H_3: *The low adoption of standard GAP guidelines (seed quality and systematic canopy sanitation) acts as a structural limiting factor on smallholder plantations.*

Conceptual Framework

The conceptual linkage between plantation aging dynamics, farm economic performance, and replanting policy directions is illustrated in Figure 1*:*

Figure 1. Conceptual Framework of Crop Aging Dynamics, Farm Economic Performance, and PSR Policy Formulation

METHODOLOGY

This research was conducted in Simpang Kiri District, Subulussalam City, Aceh Province. The study site was purposively selected because it represents the oldest and largest smallholder plantation hub originating from transmigration settlements in Subulussalam City experiencing yield contraction (Dinas Pertanian dan Perkebunan Kota Subulussalam, 2023; Bagio et al, 2020). The study covered five central villages with the largest smallholder oil palm areas: Mukti Makmur, Makmur Jaya, Pasar Panjang, Tangga Besi, and Pegayo.The population comprises all 4,106 independent smallholder households in Simpang Kiri District. The sample size was determined using the Slovin formula at a 10% margin of error (e = 0.10):

$$\boldsymbol{n} = \frac{\boldsymbol{N}}{\mathbf{1}+\boldsymbol{N}\,(\boldsymbol{e})^{\mathbf{2}}} = \frac{\mathbf{4{,}106}}{\mathbf{1}+\mathbf{4{,}106}\,(\mathbf{0{,}10})^{\mathbf{2}}} \approx 98 \text{ smallholder respondents}$$

Sample units were drawn using simple random sampling. Primary data were gathered through structured interviews using pre-tested questionnaires alongside direct on-field observations. Collected parameters encompassed socio-demographic characteristics (age, formal education, family dependents, farming experience), agronomic attributes (landholding size, stand age, fertilizer quantum, pesticide volume, harvest labor days, seed origin, pruning frequency), and economic metrics (annual FFB production volume, harvest frequency, farmgate FFB prices). Secondary data were compiled from official statistical reports published by BPS Aceh Province and the Department of Agriculture and Plantation of Subulussalam City.

Data analysis was carried out using quantitative-descriptive agricultural socio-economic methods:

1. Cross-Tabulation Analysis of Age Dynamics and Financial Performance: Examining physical productivity (tons/ha/year), total gross revenue (TR = Y x P_{FFB}), revenue per hectare, and opportunity loss across crop age phases.
2. Behavioral Analysis of Input Allocation: Evaluating fertilizer application patterns, crop protection routines, seedling certification, and canopy pruning discipline against standard GAP norms.
3. Policy Implication Synthesis: Formulating an operational smallholder replanting framework based on local cooperative institutions.

RESEARCH RESULT

Smallholder Socio-Economic Profile and Plantation Structure

The socio-demographic profile indicates that smallholders in Simpang Kiri District predominantly belong to the productive working age groups (41–50 years at 31% and 51–60 years at 27%), with formal education dominated by primary school graduates (57%). Landholding distribution shows that 80% of smallholders manage small-scale plots of 1–3 hectares, 12% manage <1 hectare, and only 8% own >4 hectares. Notably, 34% of respondents have operated their plantations for over 20 to 40 years. The complete socio-economic profile and stand age distribution are presented in Table 1.

Table 1. Smallholder Socio-Economic Profile and Plantation Stand Age Structure (n = 98)

Characteristic Parameter	Category / Classification	Frequency (Persons)	Percentage (%)
Formal Education Level	Primary School (SD)	56	57%
	Junior High School (SMP)	6	6%
	Senior High School (SMA/SMK)	25	26%
	Bachelor's Degree (S1)	11	11%
Farming Experience	5 – 10 Years	25	26%
	11 – 20 Years	40	41%
	21 – 30 Years	26	27%
	31 – 40 Years	7	7%
Landholding Scale	< 1 Hectare	12	12%
	1 – 3 Hectares	78	80%
	> 4 Hectares	8	8%
Crop Age Phase	Intermediate Mature Phase (5 – 12 Years)	30	31%
	Prime Mature Phase (13 – 20 Years)	52	53%
	Old & Senescent Phase (≥ 21 Years)	16	16%

Source: Processed Primary Data (2026)

Physical Productivity and Revenue Performance Across Crop Age Phases

Empirical data from the 98 smallholders reveal substantial disparities in both physical yield and financial returns across different stand age groups. The comparative performance across age phases is summarized in Table 2.

Table 2. Physical Productivity and Farm Revenue Breakdown by Crop Age Phase

Crop Age Phase	Sample Size (n)	Average Age (Years)	Average Land Area (Ha)	Physical Yield (Tons / Ha/Y)	Average FFB Price (IDR/ Kg)	Total Farm Revenue (Million IDR/ Yr)	Revenue per Hectare (Million IDR/ Ha)
Intermediate (5–12 Yrs)	30	8.43	1.40	19.91	2,465.67	65.29	49.17
Prime Mature (13–20 Yrs)	52	17.48	1.72	18.57	2,468.27	75.24	45.70
Old/Senescent (≥21 Yrs)	16	24.00	2.28	15.04	2,442.50	77.73	36.56

Source: Processed Primary Data (2026)

As shown in Table 2, the highest physical yield per hectare occurs during the intermediate mature phase (19.91 tons/ha/year) and prime mature phase (18.57 tons/ha/year). In contrast, plantations in the old/senescent phase (≥ 21 years) drop sharply to 15.04 tons/ha/year a 24.5% physical yield contraction. Economically, smallholders managing aging stands incur an annual opportunity loss of IDR 12.61 million per hectare compared to intermediate mature plantations (IDR 49.17 M - IDR 36.56 M = IDR 12.61 million/ha/year).

Input Allocation Behavior and Crop Maintenance Practices

Field evaluations indicate several distinct smallholder input management behaviors:

1. Fertilization Regime: Average inorganic fertilizer application ranges from 4 to 8 sacks (200–400 kg) per hectare per year, primarily consisting of Urea and NPK compounds. Applications of KCl and Dolomite remain irregular due to working capital limitations.
2. Weed Control and Crop Protection: Smallholders consistently apply chemical herbicides (Gramoxone, Marxone, Roundup) at 4–12 liters/ha/year to clear harvesting paths and circles.
3. Harvesting Labor: Operations rely on 2 to 4 workers per harvest cycle across an average of 24 harvesting rounds per year.
4. Seed Stock and Canopy Sanitation: Approximately 44.9% of stands originated from uncertified local sources, and routine frond pruning is largely performed only during fruit harvesting rather than as systematic maintenance.

DISCUSSION

Biological Aging and Socio-Economic Consequences of Productivity Degradation

The empirical findings confirm that biological tree senescence represents the primary driver of production decline across smallholder plantations in Simpang Kiri District. Smallholders cultivating old stands (≥ 21 years) achieve an average yield of only 15.04 tons/ha/year, far below the standard genetic potential of modern certified varieties which yield 22–25 tons/ha/year (Inderiati, 2023; PPKS, 2017).

Biologically and morphologically, palm trees older than two decades develop trunk heights exceeding 12 meters, which impairs net photosynthetic assimilation and nutrient translocation efficiency (Inderiati, 2023; Ningsih et al., 2021). Furthermore, harvesting excessively tall palms demands greater physical exertion and longer handling times, heightening the incidence of overripe fruit and uncollected loose fruits trapped within dense fronds (Lestari, 2024). This structural deterioration explains why aggregate regional production contracted in Simpang Kiri District despite net increases in planted acreage (Badan Pusat Statistik Provinsi Aceh, 2023; Dinas Pertanian dan Perkebunan Kota Subulussalam, 2023).

From a socio-economic viewpoint, yield degradation in aging stands triggers a direct gross revenue loss of IDR 12.61 million per hectare annually. Because oil palm farming constitutes the primary livelihood pillar for rural families in Subulussalam (Bagio et al, 2020; Siregar et al., 2021), this revenue compression constrains household expenditure allocations for nutrition, children's secondary and tertiary schooling, healthcare, and farm reinvestment (Handayani et al., 2024).

Agronomic Practice Gaps Among Independent Smallholders

The performance of smallholder plantations is further constrained by gaps in the adoption of Good Agricultural Practices (GAP) (Nasution et al., 2024):

1. Working Capital and Fertilizer Deficits: While fertilization directly improves yield, volatile FFB farmgate prices and high non-subsidized fertilizer costs force smallholders to apply sub-optimal dosages (Mahsyuri & Ginting, 2021; Romadhoni et al., 2022). In older stands, inadequate nutrient replenishment accelerates soil nutrient depletion.
2. Legacy of Uncertified Planting Materials: The historical use of uncertified seeds sets a low ceiling on maximum attainable yields (yield ceiling). Uncertified plantings exhibit high genetic heterogeneity, excessive male inflorescence rates, and thick shell proportions (dura), resulting in low oil extraction rates (Rosnina et al., 2019; Siswanto et al., 2020).
3. Non-Standard Frond Sanitation: The absence of scheduled maintenance pruning leads to under-pruning on tall, difficult-to-reach palms, creating dense canopies that restrict sunlight penetration and impede natural pollination (Alhafiz et al., 2020; Mahsyuri & Ginting, 2021).

Policy Implications for the Smallholder Oil Palm Replanting Program (PSR)

Empirical evidence indicates that increasing operational chemical inputs alone cannot restore senescent plantations to peak productivity without comprehensive tree replacement through replanting (Koesriwulandari et al., 2023; Mustari et al., 2020). Consequently, the Smallholder Oil Palm Replanting Program (PSR) supported by BPDPKS represents an indispensable policy intervention to ensure long-term rural economic sustainability in Subulussalam City.

To optimize PSR implementation, three strategic policy measures are recommended:

1. Facilitating Land Titling and Spatial Regularization: A major bottleneck for smallholders in accessing BPDPKS grant funds is land title formalization. The City Government of Subulussalam and the National Land Agency (BPN) should deploy accelerated Complete Systematic Land Registration (PTSL) schemes dedicated to smallholder plantation parcels to satisfy statutory grant criteria.
2. Institutional Capacity Building and Proposal Training: Most independent smallholders operate unorganized. Intensive socializations and proposal drafting training must be provided to smallholder cooperatives and farmer group leaders, replicating successful institutional mentoring models deployed in other oil palm clusters (Nasution et al., 2023).
3. Certified Seed Supply Chains and GAP/ISPO Institutionalization: The PSR initiative must guarantee access to certified high-yielding hybrid seedlings (e.g., PPKS, Socfindo, or Dami Mas varieties) adapted to local agro-climatic conditions (Nasution et al., 2024; Rosnina et al., 2019). Replanting must be paired with continuous extension on Good Agricultural Practices (GAP) and Good Handling Practices (GHP) starting from the immature stage to prepare smallholder plantations for mandatory Indonesian Sustainable Palm Oil (ISPO) certification (Nasution et al., 2024).

CONCLUSIONS AND RECOMMENDATIONS

Biological crop aging in transmigration-era plantations (≥ 21 years) is the primary determinant of productivity and revenue decline in Simpang Kiri District, Subulussalam City. Old stands suffer a 24.5% yield reduction relative to intermediate mature stands, generating an annual gross revenue opportunity loss of IDR 12.61 million per hectare. Compounding agronomic deficiencies such as sub-optimal fertilizer application, uncertified seedling heritage, and irregular canopy pruning accelerate yield degradation. Comprehensive crop replanting represents the only viable structural solution to restore smallholder economic viability.

Designating Simpang Kiri as a Priority PSR Zone:

1. The Subulussalam City Government and BPDPKS should prioritize Simpang Kiri District for targeted, phased replanting grant allocations.
2. Revitalizing Smallholder Producer Cooperatives: Strengthening cooperative governance is vital to establish credible legal entities capable of submitting collective PSR grant proposals and managing certified input supply chains.
3. Intensifying Sustainable Good Agricultural Practices: Agricultural extension services must deliver structured field training on 5T fertilization, canopy sanitation, and integrated pest management to ensure replanted stands achieve maximum productivity.

ADVANCED RESEARCH

This study was limited to cross-sectional farm-level data within a single production cycle. Future research should:

1. Conduct comprehensive financial feasibility and livelihood transition modeling (e.g., intercropping food crops or cattle-palm integration) during the immature phase (TBM) to support household cash flow during replanting.
2. Evaluate the organizational readiness of local smallholder cooperatives in fulfilling ISPO supply chain traceability standards post-replanting.

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