https://doi.org/10.17221/168/2025-RAE

Harvester service life impact on sugarcane field losses and product contamination

*Kanya Kosum**

Department of Mechanical Engineering, Faculty of Engineering and Technology, Rajamangala University of Technology Isan, Nakhon Ratchasima, Thailand

**Corresponding author: kanya.ko@rmuti.ac.th*

Citation: Kosum K. (2026): Harvester service life impact on sugarcane field losses and product contamination. Res. Agr. Eng., 72: 109–120.

Abstract: Mechanical sugarcane harvesting generates substantial material losses that are associated with the equipment age. This study evaluated the relationship between the harvester service life and the operational efficiency by analysing field losses and product contamination across machines with varying operational histories (1, 14, 16, and 17 years) in Chaiyaphum Province, Thailand, using a randomised complete block design. The results indicate that the 17-year-old machines exhibited 54% higher total losses (241.93 kg·ha^{-1}) compared to the newer equipment (156.90 kg·ha^{-1}). The field losses were attributed primarily to base cutting operations (36%) and roller mechanisms (34%), collectively accounting for 70% of the total losses. The contamination analysis revealed sugarcane tops as the predominant impurity source (57% The revenue loss analysis indicates excessive field losses from ageing equipment reducing the farm profitability by 12–18%. The non-linear relationship between the equipment age and performance demonstrates that maintenance practices significantly influence degradation patterns, providing critical insights for optimising mechanical harvesting systems.

Keywords: agricultural machinery; harvesting efficiency; equipment maintenance; sugarcane; mechanical degradation; revenue losses

Sugarcane (*Saccharum officinarum*) represents a critical agricultural commodity in Thailand's economic landscape, with cultivation spanning 1.78 million ha during the 2023–2024 production season. The mechanisation of harvesting operations has emerged as a crucial technological advancement, yet significant material losses occur during the harvesting processes (Kosum and Bun-Art 2020).

Contemporary sugarcane harvesting systems are classified into whole stalk and chopper harvesters (Ma et al. 2014). Chopper harvesters process the sugarcane into billets while removing the extraneous vegetative matter through integrated chopping and extraction systems. Despite technological advancements, mechanical harvesting systems continue generating substantial material losses, particularly under green cane harvesting conditions where fields are not pre-burned (Manhães et al. 2014).

The material losses in mechanical harvesting are categorised as visible and invisible losses. Visible losses encompass the industrially recoverable sugar content remaining in the field, including the whole stalks, billets, and stumps resulting from improper basal cutting operations (Ripoli and Ripoli 2004). Additionally, mechanical harvesting introduces increased debris incorporation and microbial contamination risks, particularly from bacteria, such as *Leuconostoc*, which accelerates the sugar degradation and reduces the factory yields (Egan and Rehbein 1963; Larrahondo et al. 2006).

The economic implications of sugarcane harvester ownership present significant challenges for agricultural operations. Substantial capital requirements associated with new harvesting equipment has led many farmers to acquire used harvesters with extended service histories (Salassi et al. 2002). While these machines may maintain acceptable operational status with proper maintenance, ageing equipment often exhibits declining mechanical efficiency that may compromise harvesting performance (Sharma et al. 2011).

Equipment degradation in agricultural machinery follows complex patterns influenced by operational conditions, maintenance practices, and environmental factors. Predictive maintenance approaches using condition monitoring and data analytics have demonstrated potential for extending equipment service life by 20–30% (Arnaiz-González et al. 2016), though implementation in developing regions remains limited. Previous research on combine harvesters and cotton pickers has documented non-linear performance degradation with the age (Miu and Kutzbach 2008), yet limited studies have quantified these relationships for sugarcane harvesting systems. Understanding degradation patterns is essential for lifecycle cost analyses and optimal replacement timing. Strategic maintenance management frameworks emphasise the importance of balancing preventive and corrective maintenance interventions based on equipment condition assessment (Murthy et al. 2002).

International benchmarks have demonstrated significant optimisation potential. Brazilian mechanical harvesters achieve total losses of 3–5% of the harvested material under optimal conditions, whilst Australia's Queensland industry achieves 2–4% total losses through using precision agriculture technologies (Garside et al. 2005). Real-time yield monitoring systems enable quantitative assessment of harvester performance variability across field conditions (Magalhães and Cerri 2007), providing foundations for data-driven equipment management strategies. Recent advances in precision agriculture and sensor-based monitoring systems offer the potential for real-time performance assessments (Maldaner et al. 2022), though implementation in developing countries remains limited.

Despite extensive research into the mechanical harvesting efficiency, a limited number of studies have specifically addressed the engineering relationship between the equipment service life and performance degradation patterns in tropical agricultural conditions. This knowledge gap represents a critical limitation for developing evidence-based equipment management strategies (Bochtis et al. 2014).

This investigation addresses how the harvester service life is associated with material loss patterns and product quality in mechanical sugarcane harvesting systems. While the chronological age (years) serves as the primary comparative variable due to the data availability, we acknowledge that the accumulated use (operating hours, harvested area) represents a more mechanistically appropriate indicator of equipment degradation from an engineering perspective. The hypothesis posits that the harvester service life is associated with both the magnitude and distribution of the material losses during mechanical harvesting operations, with specific mechanical subsystems exhibiting differential degradation patterns affecting the overall system performance. However, the relationship between the age and performance may be substantially moderated by maintenance practices and the operational history.

MATERIAL AND METHODS

Experimental design and site characteristics

Field locations and sampling dates. The experimental investigation was conducted at three commercial sugarcane farms in Chaiyaphum Province, Thailand, during January 2024 under dry soil surface conditions. The study location represents typical sugarcane production conditions in Thailand's north-eastern region, with sandy loam soils (62% sand, 24% silt, 14% clay) and an average annual rainfall of 1 200 mm.

Specific field locations and dates. Farm A (15°47'23''N, 102°01'15''E): January 12–14, 2024; Farm B (15°49'18''N, 102°03'42''E): January 18–20, 2024; Farm C (15°46'07''N, 102°02'58''E): January 25–27, 2024. All the sites were located within an 8 km radius to minimise the soil and climatic variation.

Harvester specifications. The study employed a randomised complete block design evaluating four sugarcane harvesters of an identical manufacturer and model specifications, differentiated by the operational service life: 1, 14, 16, and 17 years. All four harvesters were CASE IH Austoft 8000 (CNH Industrial, Brazil) series chopper-type machines manufactured in 2007 (17-y), 2008 (16-y), 2010 (14-y), and 2023 (1-y) with identical original specifications: rated engine power 250 kW (335 hp), theoretical harvesting capacity 60–80 t·h^{-1}, and cutting width 1.5 m (single row). All the machines underwent pre-season inspection by authorised CASE IH service centres to ensure basic operational functionality. However, detailed maintenance histories including the component replacement schedules, accumulated operating hours, and cumulative harvested area were not systematically recorded or available for the analysis. This represents a significant limitation, as accumulated use metrics are mechanistically superior indicators of equipment wear compared to the chronological age alone. Each harvester was evaluated across three replicate field blocks, providing 12 experimental units. The block randomisation controlled the field-to-field variability in the soil conditions and sugarcane stand characteristics.

Harvesting operations and standardisation

Harvesting operations were performed on sugarcane fields (cv. Khon Kaen 3) without prior burning (Figure 1A). Field conditions were standardised across the experimental plots ensuring consistent soil moisture content (18–22%), plant density (120 000–130 000 stalks·ha^{-1}), and topographical characteristics (slope < 3%). The sugarcane maturity was uniform with a total soluble solids content of 18–20 °Brix, measured using a digital refractometer.

The harvester operators maintained consistent operational parameters within the manufacturer-recommended ranges: forward speed (4.5 to 5.5 km·h^{-1}), cutting height (3–5 cm above ground level), and extractor fan speed (1 800–2 000 rpm). All the operators possessed a minimum 5 years harvesting experience ensuring consistent operational practices.

Field loss quantification methodology

Field losses were systematically quantified using established sampling protocols adapted from Peloia et al. (2010). Random sampling plots measuring 7.0 m in length spanning the full width of the planting furrows (1.5 m row spacing) were established within each harvested row (Figure 1B). Three plots were selected per row across three rows per field, yielding nine sampling locations per experimental unit, totalling 108 sampling plots. Figure 1B shows the representative post-harvest field conditions immediately following the harvester's passage. Sampling plots (7.0 × 1.5 m) were randomly established within each harvested row using systematic random sampling with GPS coordinates recorded for each plot (Trimble Geo7X, ± 0.5 m accuracy). All the field sampling was completed within 2 hours post-harvest to minimise material losses from wind dispersal. The sample size determination followed the power analysis ($\alpha = 0.05$, $\beta = 0.20$) based on the preliminary data indicating the expected effect size of $d = 0.8$ for the harvester age effects.

Figure 1. Mechanical harvesting operation: (A) chopper-type harvester performing green cane harvesting with simultaneous truck loading; (B) post-harvest field surface showing residual plant material distribution

The field-retained sugarcane material was classified according to the responsible harvester subsystem:

(1) Base cutter losses (L_1): complete sugarcane stalks remaining due to excessive cutting height;

(2) Roller losses (L_2): cut sugarcane stalks not successfully conveyed to processing stages;

(3) Elevator losses (L_3): processed billets failing to reach truck loading systems;

(4) Primary extractor losses (L_4): fragmented billets inadvertently removed by extraction systems.

All the collected material was cleaned of soil contamination and weighed using calibrated digital scales. The results were expressed in kg·ha^{-1} for a comparative analysis.

Impurity analysis protocol

The contamination levels in the harvested billets were evaluated through systematic truck sampling procedures following the ISO 3963:1977 guidelines. Sampling containers (10 L capacity) were positioned at three locations within each transport truck. Three replicate samples were collected from each section during the loading operations, providing nine samples per truck.

The collected samples were manually sorted within 2 h of collection separating the contamination categories:

(1) Sugarcane tops (I_1): terminal growing points inadvertently incorporated during harvesting;

(2) Sugarcane trash (I_2): leaf material, stems, and extraneous plant matter;

(3) Root material (I_3): root systems incorporated due to excessive cutting depth.

Each contamination category was individually weighed and expressed as kg·ha^{-1}.

Direct loss valuation

Revenue losses from field losses and contamination were quantified using farm-gate pricing for the 2024 harvest season in Chaiyaphum Province. This analysis explicitly excludes: maintenance costs (component replacement, repairs, service labour), fixed ownership costs (depreciation, insurance, storage, taxes), capital costs (equipment purchase price, financing costs, opportunity costs). These exclusions reflect data unavailability rather than irrelevance. Comprehensive financial records were not systematically maintained by the harvesting contractors participating in this study, which is typical of small-scale agricultural machinery operations in Thailand's sugarcane sector. Therefore, the results represent the partial economic impact from field losses only and should not be interpreted as a complete farm-level profitability analysis or equipment replacement decision criteria. Revenue loss components were quantified as:

(1) The unharvested material: material remaining in the field valued at 30 EUR·t^{-1} (2024 farm-gate price);

(2) Quality penalties: contamination-based price reductions (1.25–2.50 EUR·t^{-1} depending on the impurity levels);

(3) Processing penalties: additional factory cleaning charges (0.63 EUR·t^{-1}).

These values reflect the 2024 market conditions and represent conservative estimates based on the contracts between the harvesting contractors and the sugarcane producers in the study region.

Statistical analysis

The data analysis employed analysis of variance (ANOVA) techniques evaluating the significant differences between the harvester service life categories and the loss type classifications. Normality was assessed using Shapiro-Wilk tests, and homogeneity of variance was confirmed through Levene's test. The post-hoc analysis utilised Tukey's honestly significant difference (HSD) test for multiple comparisons when the ANOVA indicated significant effects.

The correlation analysis examined the relationships between the harvester age and loss patterns using Pearson correlation coefficients with 95% confidence intervals. Linear and non-linear regression models were fitted quantifying the relationships between the service life and the performance parameters. The effect sizes were calculated using partial eta squared (η^2). Statistical significance was established at $\alpha = 0.05$, with the results presented as means ± standard error.

A regression analysis was performed to model the relationship between the harvester service life and the total material losses. Both linear and non-linear (exponential, logarithmic, and power function) models were fitted to the data. The model selection was based on the coefficient of determination (R^2), the Akaike information criterion (AIC), and a visual assessment of the residual plots. The power function model was selected as the best fit based on these criteria. Given the limited number of machines evaluated (n = 4) and the absence of intermediate age categories (5–10 years), all the regression modelling should be considered exploratory and descriptive rather than confirmatory or predictive. The models provide frameworks for understanding the observed patterns in this specific dataset, but have limited capability for prediction beyond the studied age ranges or generalisation to other equipment populations. The statistical relationships identified should be interpreted as associations rather than definitive causal mechanisms, particularly given the absence of maintenance history data. All the regression analyses were conducted using IBM SPSS Statistics 28.0 with a significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

Service life impact on the harvesting performance

The experimental investigation revealed substantial variations in material losses across the harvesters with different service histories (Table 1). The statistical analysis using a one-way ANOVA indicated significant differences in the total losses among the harvester age groups ($F_{3,32} = 18.74$, $P < 0.001$, $\eta^2 = 0.64$).

The 17-year-old harvester exhibited the highest total losses (241.93 ± 17.86 kg·ha^{-1}), representing a 54% increase compared to the newest equipment (156.90 ± 12.48 kg·ha^{-1}). However, the relationship between the service life and loss magnitude was non-linear ($R^2 = 0.73$, $P < 0.001$), with the 16-year harvester displaying total losses (153.37 ± 13.21 kg·ha^{-1}) statistically equivalent to the newest machine ($P = 0.89$) and substantially lower than the 14-year unit (203.92 ± 15.92 kg·ha^{-1}). This anomalous pattern – where the oldest well-maintained machine significantly outperforms a younger machine – provides compelling evidence that the maintenance history, operational practices, and operator skill influence the performance more strongly than the chronological age alone. Without detailed maintenance and usage records (operating hours, component replacement history, service intervals), we cannot definitively attribute the performance differences to the specific mechanical conditions. However, this finding suggests that equipment degradation does not follow a simple age-based trajectory, but reflects the complex interaction of temporal factors, usage intensity, maintenance quality, and operational management. This finding aligns with observations on combine harvesters, where the maintenance quality influenced the degradation trajectories more strongly than the chronological age alone.

Mechanical system performance evaluation

The analysis of the harvester subsystem contributions to field losses provides critical insights for mechanical engineering optimisation (Table 2).

Table 1. Material losses by harvester service life (mean ± SE, n = 9)

Service life (years)	Field losses	Impurities	Total losses
		(kg·ha^{-1})	
1	74.97 ± 8.32^{a}	81.93 ± 9.15^{b}	156.90 ± 12.48^{a}
14	126.98 ± 11.76^{b}	76.94 ± 7.83^{b}	203.92 ± 15.92^{b}
16	91.75 ± 9.94^{a}	61.62 ± 6.47^{a}	153.37 ± 13.21^{a}
17	173.46 ± 14.25^{c}	68.47 ± 8.92^{ab}	241.93 ± 17.86^{c}

SE – standard error; different superscript letters within the columns indicate significant differences ($P < 0.05$) according to Tukey's HSD test

Table 2. Sugarcane losses by harvester working process (mean ± SE, n = 108)

Source of loss	Average loss (kg·ha^{-1})	Percentage (%)	F-value	P-value
Base cutter	42.24 ± 4.76^{c}	36	12.85	< 0.001
Rollers	41.49 ± 4.12^{c}	34	12.85	< 0.001
Elevator	22.51 ± 2.89^{b}	19	12.85	< 0.05
Primary extractor	13.18 ± 1.95^{a}	11	12.85	< 0.05

SE – standard error; different superscript letters indicate significant differences ($P < 0.05$) according to Tukey's HSD test

The one-way ANOVA revealed statistically significant differences among the harvester components ($F_{3,32} = 12.85$, $P < 0.001$, $\eta^2 = 0.55$).

Systematic analysis of mechanised harvesting losses requires classification by causal subsystem and operational stage (Benedini and Conde 2008), enabling targeted engineering interventions for performance optimisation.

Base cutting systems and roller mechanisms collectively account for 70% of the field losses, identifying these subsystems as priority targets for condition monitoring and predictive maintenance interventions as shown in Figure 2.

Engineering analysis of the performance degradation

The base cutting system represents the primary source of field losses, accounting for over one-third of the total material loss. The regression analysis revealed a significant relationship between the harvester age and the base cutter losses ($R^2 = 0.52$, $P < 0.01$), indicating that the equipment age explains 52% of the variability in the base cutter losses. This degradation is attributed to the blade geometry deterioration reducing the cutting efficiency by 15–25% over extended service periods, hydraulic system wear causing cutting height variations, and suspension system deterioration affecting the ground following capability. Similar degradation patterns have been documented in cotton harvesters, where the blade wear accounts for 40–50% of the performance decline.

The roller mechanisms contribute substantially to field losses, with the performance degradation following similar pattern to base cutters ($R^2 = 0.46$, $P < 0.01$). The primary degradation factors include bush roller wear reducing the stalk gripping capability by 20–30% (Ma et al. 2014), conveyor roller misalignment preventing effective material transfer, and drive system inefficiencies affecting roller synchronisation. These findings support predictive maintenance approaches based on wear

Figure 2. Field losses by subsystem: (A) base cutter losses – complete stalks with inadequate cutting; (B) roller losses – stalks failing conveyance; (C) primary extractor losses – fragmented billet material; (D) elevator losses – billets failing to reach loading system

https://doi.org/10.17221/168/2025-RAE

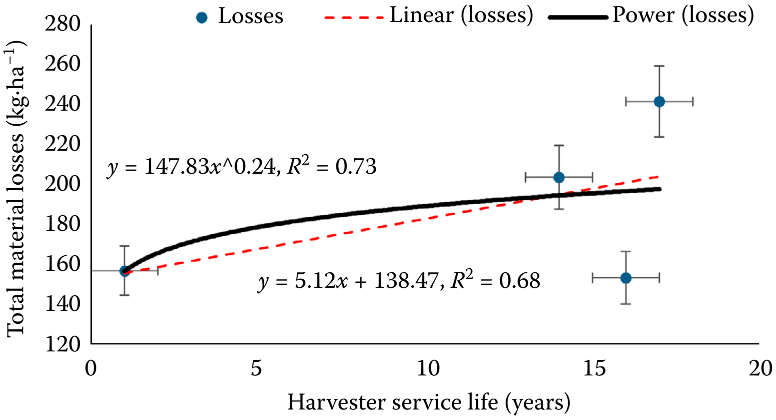

Figure 3. Relationship between the harvester service life and total material losses

Experimental data (●) with fitted regression models: linear (dashed line, $y = 5.12x + 138.47$, $R^2 = 0.68$) and power function (solid line, $y = 147.83x$^0.24, $R^2 = 0.73$). The power function model provides a superior fit, particularly capturing the non-monotonic relationship observed with the 16-year-old harvester; error bars represent standard error ($n = 9$)

monitoring rather than fixed-interval replacement schedules (Bochtis et al. 2014).

Figure 3 illustrates the mathematical relationships between the harvester service life and total material losses. The linear regression analysis yielded the equation:

$$y = 5.12x + 138.47 \ (R^2 = 0.68, P < 0.01)$$

where: y – the total losses (kg·ha^{-1}); x – the harvester age (years).

However, this linear model inadequately captures the observed performance variability, particularly the superior performance of the 16-year-old harvester.

The non-linear regression using a power function provided a superior model fit:

$$y = 147.83x\text{^}0.24 \ (R^2 = 0.73, P < 0.001)$$

The power function model better accommodates the non-monotonic relationship between the age and losses, reflecting the complex interaction between the chronological age and maintenance quality. The model indicates that losses increase with the age following a decelerating power relationship, with maintenance interventions creating significant deviations from predicted trajectories.

Alternative non-linear models were evaluated, including exponential ($y = 156.4e$^$0.03x$, $R^2 = 0.69$) and logarithmic ($y = 157.2 + 31.5\ln(x)$, $R^2 = 0.65$) functions. The power function demonstrated superior predictive capability based on the Akaike information criterion (AIC = 128.4 vs. 131.7 for the exponential and 134.2 for the logarithmic models).

These mathematical relationships provide quantitative foundations for predicting equipment performance degradation and establishing economically optimal replacement intervals. The power function suggests that maintenance investments yield diminishing returns beyond 15 years of service life, supporting replacement strategies in the 13–17 year range for tropical operating conditions.

Contamination analysis and product quality

The contamination levels in the harvested billets represent the critical quality parameter affecting the downstream processing efficiency (Table 3). The ANOVA analysis confirmed significant differences among impurity categories ($F_{2,24} = 28.94$, $P < 0.001$, $\eta^2 = 0.71$).

The sugarcane tops constitute the predominant contamination source (57%), indicating specific mechanical limitations in the extraction and separation systems. Extractor fan performance directly

Table 3. Composition of impurities in the sugarcane billets (mean ± SE, $n = 36$)

Type of impurity	Average amount (kg·ha^{-1})	Proportion (%)	Statistical significance (P)
Tops	40.0 ± 3.2^c	57	< 0.001
Trash	19.0 ± 2.1^b	26	< 0.01
Roots	12.0 ± 1.8^a	17	< 0.05

SE – standard error; different superscript letters indicate significant differences ($P < 0.05$) according to Tukey's HSD test

Figure 4. Contamination categories: (A) sugarcane tops with attached leaves; (B) sugarcane trash and extraneous matter; (C) root material from excessive cutting depth

influences both trash content and recoverable sucrose losses (Johnson et al. 2002), representing a critical optimisation parameter for mechanical harvesting systems.

This contamination profile indicates the mechanical limitations in the topping mechanisms and extraction systems, providing targeted opportunities for engineering improvements as shown in Figure 4. These results align with Brazilian studies reporting 50–60% top contamination in mechanical harvesting systems (Neves et al. 2004), though Australian operations achieve lower contamination (30–40%) through advanced sensor-based topping systems.

Revenue loss analysis

The revenue implications of the harvester performance variations extend beyond the direct material losses to encompass quality penalties and additional processing costs (Table 4). However, this analysis explicitly excludes the maintenance costs, fixed ownership costs, and capital costs, which

Table 4. Economic impact of the harvester service life on the farm profitability

Service life (years)	Direct loss cost	Quality penalty	Additional processing	Total economic impact	Profitability reduction (%)
	(EUR·ha^{-1})				
1	47.1	12.3	8.2	67.6	8.2
14	61.2	11.5	9.8	82.5	12.5
16	46.0	9.2	7.6	62.8	7.8
17	72.6	10.2	12.4	95.2	18.3

Economic calculations based on the average sugarcane price of 30 EUR·t^{-1} and typical farm profit margins of 15–20%

are critical components of a complete economic assessment.

The 17-year-old harvester generated revenue losses of 95.20 EUR·ha^{-1} from field losses and contamination, compared to 67.60 EUR·ha^{-1} for the newest equipment – a difference of 27.60 EUR·ha^{-1}. To contextualise these figures: a typical farm yields 80–100 t·ha^{-1} with farm-gate prices of 30 EUR·t^{-1}, this represents approximately 1.1–1.4% of the gross revenue per hectare from the field loss differentials. Critical caveat: these calculations explicitly exclude: maintenance cost differentials between newer and older equipment (typically increasing substantially with age), fixed ownership costs (depreciation, insurance, storage, taxes), capital costs (equipment purchase price ~ 400 000–500 000 EUR for a new Austoft 8000), opportunity costs of capital investment. Therefore, these partial revenue loss estimates cannot be directly interpreted as changes in farm profitability or used as standalone criteria for equipment replacement decisions. A complete economic analysis would require comprehensive cost accounting including maintenance expenditures, which typically increase exponentially with the equipment age (Sharma et al. 2011) and may exceed the revenue loss differentials. For perspective: Salassi et al. (2002) reported that maintenance costs for sugarcane harvesters in Louisiana increase from approximately 15 000 EUR annually for new equipment to 45 000–60 000 EUR annually for 15+ year old machines – cost increases that substantially exceed the revenue loss differentials observed in this study. The findings suggest equipment replacement decisions should consider the balance between direct machinery costs and operational efficiency impacts, with the maintenance quality potentially extending the productive equipment life beyond conventional replacement schedules while maintaining acceptable performance levels. These findings align with the lifecycle cost analyses by Salassi et al. (2002), who reported similar profitability thresholds for sugarcane harvesting equipment in Louisiana.

Performance degradation patterns and mechanical implications

The non-linear relationship between the harvester service life and performance degradation contrasts with simple linear deterioration models often assumed in agricultural machinery research. The superior performance of the 16-year-old harvester (153.37 kg·ha^{-1} total losses) compared to the 14-year-old unit (203.92 kg·ha^{-1}) and its statistical equivalence to the newest machine exemplifies this non-linearity and demonstrates that the chronological age alone is insufficient for predicting equipment performance.

Based on the limited data from four machines, we tentatively propose that the observed non-linear pattern may reflect a complex interaction of multiple mechanical deterioration processes: initial wear-in period (0–3 years), stable operation phase (4–12 years), accelerated degradation phase (13–15 years), and variable performance phase (16+ years) where performance becomes highly dependent on the maintenance history. However, this mechanistic interpretation remains speculative without intermediate age data (5–10 years) and detailed maintenance records. This mechanistic understanding aligns with Weibull reliability models commonly applied to agricultural machinery (Miu and Kutzbach 2008).

These observations suggest – though the limited sample size precludes definitive conclusions – that the performance degradation may follow a multi-phase pattern rather than continuous linear decline, with potential critical intervention points where proactive maintenance might restore the equipment to near-optimal performance levels. The case of the well-performing 16-year-old harvester provides anecdotal evidence for this possibility. Equipment replacement decisions require comprehensive evaluation of both direct operational costs and performance degradation patterns (Dhillon 2002), with optimal timing varying substantially across operational contexts. The economic implications suggest that strategic maintenance investments during transition phases could potentially extend the equipment productive life significantly beyond conventional replacement schedules, potentially reducing annualised ownership costs by 20–30% (Bochtis et al. 2014), though this requires validation through controlled longitudinal studies with comprehensive cost tracking.

International comparative analysis

Performance data provide valuable insights when compared with international mechanisation benchmarks. Thailand's mechanical harvesting performance (9.2–14.5% total losses) indicates a significant optimisation potential compared to international best practices (Brazil: 3–5%, Australia:

https://doi.org/10.17221/168/2025-RAE

2–4%), particularly in the field loss reduction and contamination control.

A comparison with Brazilian and Australian mechanisation experiences suggests systematic maintenance protocols and operator training programmes could reduce Thailand's harvesting losses by 50–70%, potentially improving the farm profitability by 8–12% annually. The integration of precision agriculture technologies, including real-time monitoring systems, has demonstrated substantial potential for optimising mechanical harvesting operations (Bramley 2009), though adoption rates vary significantly across agricultural sectors and geographic regions. Recent implementations of sensor-based monitoring systems in Australian operations (Maldaner et al. 2022) demonstrate potential pathways for performance optimisation in tropical conditions.

Study limitations

Several limitations should be acknowledged:

Chronological age vs. accumulated use. The most significant limitation is the use of chronological age (years) rather than accumulated use metrics (operating hours, harvested area) as the primary independent variable. From an engineering mechanics perspective, equipment degradation is fundamentally driven by usage cycles, load exposure, and operational stress rather than calendar time. Two harvesters of an identical chronological age may exhibit drastically different mechanical wear states depending on: annual utilisation intensity (hours per season), cumulative harvested area, field conditions (slope, soil abrasiveness, crop density), operational practices (speed, cutting height, loading patterns). Without the usage data, we cannot distinguish between age-related degradation (corrosion, seal deterioration, static component ageing) and use-related degradation (wear, fatigue, dynamic component failure). This conflation limits the mechanistic interpretation.

Limited sample size and missing intermediate ages. This study evaluated only four harvesters (n = 4) under specific soil and crop conditions in Thailand's north-eastern region. The dataset lacks machines in the 5–10 year age range, which prevents the identification of degradation trends during the main operational lifespan of harvesters. Consequently, the regression analyses should be considered exploratory and descriptive rather than confirmatory. The apparent non-linear relationship, while statistically significant ($R^2 = 0.73$), is based on effectively two age groups (new vs. old) rather than a continuous age spectrum. The performance degradation patterns may differ for other harvester models or under different environmental conditions.

Absence of maintenance records. Comprehensive maintenance and operational records including: component replacement schedules and dates, cumulative operating hours, cumulative harvested area, service intervention history, repair costs and downtime were not systematically recorded or available for any of the studied machines. This represents a critical gap that prevents: attribution of performance differences to specific maintenance practices, economic analysis of maintenance cost-performance trade-offs, validation of condition-based maintenance strategies, development of predictive degradation models. The superior performance of the 16-year-old harvester strongly suggests that the maintenance quality matters, but without maintenance records, this remains inferential rather than demonstrated.

Scope limitations. This study focused exclusively on visible losses; invisible losses including juice extraction efficiency and sugar recovery rates were not quantified. The 12-month study duration precluded an assessment of seasonal variations in degradation patterns or year-to-year performance trends for the individual machines.

Single manufacturer and model. All the evaluated harvesters were from the CASE IH Austoft 8000 series. Degradation patterns may differ substantially for other manufacturers (John Deere, Cameco, CNH) or harvester types (whole-stalk vs. chopper). Any generalisation beyond this specific model should be cautious.

Geographic and operational scope. The study was conducted in a single region (Chaiyaphum Province) during one harvest season (January 2024) under specific conditions (green cane harvesting, sandy loam soils, flat terrain). Performance patterns may differ under: burned vs. green cane harvesting, different soil types and moisture conditions, variable terrain (slopes, rock content), different crop varieties and stand characteristics.

Future research should address these limitations through multi-year longitudinal studies incorporating comprehensive maintenance and usage documentation across diverse harvester models, manufacturers, and operational conditions, with a particular emphasis placed on collecting machines spanning the complete age spectrum from new to end-of-life.

CONCLUSION

This investigation quantified the associations between the sugarcane harvester service life and the operational performance, establishing three key findings:

First, the harvester age is associated with material losses, with the 7-year-old equipment exhibiting 54% higher losses than the newer machines. The non-linear relationship ($R^2 = 0.73$) suggests that maintenance practices may override simple age-based predictions, though the limited sample size ($n = 4$ machines) and absence of intermediate ages (5–10 years) restricts any definitive interpretation. The superior performance of the 16-year-old harvester compared to the 14-year-old unit provides anecdotal evidence for the importance of maintenance quality, though validation would require comprehensive maintenance records that were unavailable.

Second, the base cutting systems (36%) and roller mechanisms (34%) represent priority maintenance targets, collectively accounting for 70% of the field losses. The performance degradation is correlated strongly with the age ($R^2 = 0.52$, $P < 0.01$), suggesting potential intervention points for condition-based maintenance programmes, pending validation through controlled studies.

Third, the revenue loss quantification from field losses and contamination indicates the 17-year-old harvester generated 27.60 EUR·ha^{-1} more in gross revenue losses compared to the newest equipment (95.20 EUR vs. 67.60 EUR·ha^{-1}). However, these partial revenue impacts exclude maintenance costs, depreciation, and capital costs – all critical components of equipment replacement decisions. A complete economic analysis would require comprehensive cost accounting unavailable in this study. Therefore, economic thresholds for equipment replacement cannot be established from the data alone.

These findings provide descriptive foundations for understanding maintenance protocols and equipment replacement trade-offs. The implementation of condition-based maintenance focused on base cutting and roller systems could potentially reduce losses by 30–40%, though this estimate requires validation through controlled intervention trials. The case of the well-performing 16-year-old harvester suggests that the maintenance quality can extend the equipment productive life substantially, potentially offsetting the capital costs of new equipment purchases. International benchmarking indicates Thailand's mechanical harvesting performance (9.2–14.5% losses) could potentially approach Brazilian standards (3–5%) through systematic maintenance improvements and operator training programmes, though a direct comparison should account for the differences in the field conditions, crop varieties, and operational contexts.

Future research should investigate: controlled maintenance intervention trials with randomised treatment assignments, longitudinal degradation studies tracking individual machines with comprehensive maintenance and usage documentation, economic modelling incorporating complete cost structures (maintenance, depreciation, capital, opportunity costs), evaluation across multiple harvester manufacturers, models, and geographic/operational contexts, development of predictive degradation models incorporating real-time sensor data and the assessment of precision agriculture integration effects on the equipment longevity. Critically, future studies should prioritise collecting machines spanning the complete age spectrum (1–20 years) with the intermediate ages (5–10 years) currently absent from this dataset. Farm management information systems incorporating equipment performance data enable evidence-based maintenance scheduling and replacement timing decisions (Fountas et al. 2015), representing a promising direction for improving mechanical harvesting efficiency. The integration of sensor-based monitoring systems with predictive maintenance algorithms represents a promising direction for enhancing the mechanical harvesting efficiency in tropical agricultural systems, though implementation barriers (cost, technical capacity, infrastructure) in developing country contexts require careful consideration.

Acknowledgement

The author gratefully acknowledges the invaluable technical assistance provided by the harvester operators and engineers: Mr Anupong Namcharoen, Mr Songsak Phachanda, and Mr Yothin Kaewsriprom. Their expertise and cooperation were instrumental in the successful completion of this investigation. Special appreciation is extended to the sugarcane farmers who provided field access and operational support during data collection. The author also acknowledges the support provided by Rajamangala University of Technology Isan.

REFERENCES

Arnaiz-González Á., Fernández-Valdivielso A., Bustillo A., de Lacalle L.N.L. (2016): Using artificial neural networks for the prediction of dimensional error on inclined surfaces manufactured by ball-end milling. International Journal of Advanced Manufacturing Technology, 83: 847–859.

Benedini M.S., Conde A.J. (2008): Systemic view of losses in mechanized sugarcane harvesting. In: Proc. 26th Int. Society of Sugar Cane Technologists Congress, Durban, 2008: 566–570.

Bochtis D.D., Sørensen C.G., Busato P. (2014): Advances in agricultural machinery management: A review. Biosystems Engineering, 126: 69–81.

Bramley R.G.V. (2009): Lessons from nearly 20 years of precision agriculture research, development, and adoption as a guide to its appropriate application. Crop and Pasture Science, 60: 197–217.

Dhillon B.S. (2002): Engineering Maintenance: A Modern Approach. Boca Raton, CRC Press.

Egan B.T., Rehbein C.A. (1963): Bacterial deterioration of mechanically harvested cut up sugarcane during storage over weekends. Proceedings of the Queensland Society of Sugarcane Technologists, 30: 167–172.

Fountas S., Carli G., Sørensen C.G., Tsiropoulos Z., Cavalaris C., Vatsanidou A., Liakos B., Canavari M., Wiebensohn J., Tisserye B. (2015): Farm management information systems: Current situation and future perspectives. Computers and Electronics in Agriculture, 115: 40–50.

Garside A.L., Bell M.J., Robotham B.G., Magarey R.C., Stirling G.R. (2005): Managing yield decline in sugarcane cropping systems. International Sugar Journal, 107: 16–26.

Johnson P.C., Clementson C.L., Richard E.P., Jr. (2002): Relationships between extractable and total stalk saccharose in sugarcane. Field Crops Research, 77: 219–232.

Kosum K., Bun-Art S. (2020): The losses of sugarcane harvested from a sugarcane harvester. Suranaree Journal of Science & Technology, 27: 010009.

Larrahondo J.E., Briceño C.O., Rojas M. (2006): An assessment of after harvest sucrose losses from sugarcane field to factory. Sugar Tech, 8: 233–238.

Ma S., Scharf P.A., Karkee M., Zhang Q. (2014): Sugarcane harvester technology: A critical overview. Applied Engineering in Agriculture, 30: 727–739.

Magalhães P.S.G., Cerri D.G.P. (2007): Yield monitoring of sugar cane. Biosystems Engineering, 96: 1–6.

Maldaner L.F., Molin J.P., Canata T.F. (2022): An approach to sugarcane yield estimation using sensors in harvester and ZigBee technology. Sugar Tech, 24: 813–821.

Manhães C.M.C., Garcia R.F., Correa Júnior D., Francelino F.M.A., Francelino H.O., Santos C.M.F.G. (2014): Evaluation of visible losses and damage to the ratoon cane in the mechanised harvesting of sugarcane for different displacement speeds. American Journal of Plant Sciences, 5: 2956–2964.

Miu P.I., Kutzbach H.D. (2008): Modeling and simulation of grain threshing and separation in threshing units – Part I. Computers and Electronics in Agriculture, 60: 96–104.

Murthy D.N.P., Atrens A., Eccleston J.A. (2002): Strategic maintenance management. Journal of Quality in Maintenance Engineering, 8: 287–305.

Neves J.L.M., Magalhães P.S.G., Moreira C.A. (2004): Evaluation of trash and losses in mechanical harvesting. Engenharia Agrícola, 24: 17–24.

Peloia P.R., Milan M., Romanelli T.L. (2010): Capacity of the mechanical harvesting process of sugar cane billets. Scientia Agricola, 67: 619–623.

Ripoli T.C.C., Ripoli M.L.C. (2004): Sugarcane Biomass: Harvesting, Energy and Environment. Piracicaba, Escola Superior de Agricultura Luiz de Queiroz. (in Portuguese)

Salassi M.E., Breaux J.B., Naquin C.J. (2002): Modeling within-season sugarcane growth for optimal harvest system selection. Agricultural Systems, 73: 261–278.

Sharma A., Yadava G.S., Deshmukh S.G. (2011): A literature review and future perspectives on maintenance optimisation. Journal of Quality in Maintenance Engineering, 17: 5–25.

Received: October 3, 2025
Accepted: February 5, 2026