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Research Article

Investigating Visible Cane Loss and Stump Damage Due to Sugarcane Chopper Harvester Usage in Thailand

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Sugarcane farmers face a primary concern regarding cane losses when employing mechanized harvesters. The present study aimed to investigate visible cane losses resulting from the use of large- and medium-sized chopper harvesters. Investigation of the cane losses by sugarcane harvesters was focused on the loss from remaining cane stumps, the extractors, and the elevators. The damage index of sugarcane stumps was investigated in the presented study. Large harvester usage led to cane losses of 2.19, 0.53, and 0.27 t/ha attributed to remaining sugarcane stumps, extractor-stage losses, and elevator-stage losses, respectively. The total cane loss from using large harvesters amounted to 2.99 t/ha (4.0% of total yield). Similarly, the use of medium-sized harvesters led to cane losses of 2.21, 0.44, and 0.20 t/ha attributed to remaining sugarcane stumps, extractor-stage losses, and elevator-stage losses, respectively. The total cane loss from using medium-sized harvesters was 2.85 t/ha (3.4% of total yield). Notably, the primary factor contributing to visible cane loss from sugarcane harvesters was the remaining stumps, which account for 71% and 76% of the total cane loss when using large- and medium-sized harvesters, respectively. The damage index for sugarcane stumps due to large- and medium-sized harvester usage was 0.04 and 0.12, respectively. Overall, these findings emphasize that resolving cane loss and stump damage caused by sugarcane harvesters is crucial for improving harvesting efficiency.

1. Introduction

Sugarcane, a major global industrial crop, relies heavily on human labor for production, especially during harvesting. To tackle labor shortages and improve efficiency, many countries have adopted mechanized sugarcane harvesting. Thailand, a major sugarcane producer, has plans to further increase mechanization in sugarcane harvesting [1]. During 2021-2022, the sugarcane cultivation area in Thailand was 1.6 million hectares, potentially yielding around 8.29 million tons of sugarcane. The central region of Thailand, known for its sugarcane production, plays a crucial role in the industry [2–4]. However, labor shortages are increasingly becoming a concern, particularly in sugarcane harvesting operations. Therefore, it is imperative for sugarcane harvesters to reduce harvesting time and address the labor shortage while maintaining crop yield.

Mechanical sugarcane harvesters have improved the quality of harvested cane through environmentally friendly methods [5]. However, the issue of cane loss attributed to these harvesters remains a key concern for farmers transitioning from labor-based to mechanized systems. Cane loss due to mechanized harvesters can occur at various stages and for various reasons, including the elevator and extractor stages, and owing to remaining stumps, stem lodging, and stump damage. Investigating and minimizing these losses are essential objectives [6, 7]. Although cane loss due to sugarcane harvester use may be a minor issue in developed countries where mechanized systems are commonplace, it poses major challenges for developing countries transitioning from manual labor to mechanized harvesters [8, 9].

Sugarcane harvesters face efficacy challenges associated with losses throughout the harvesting process [10, 11]. Cane losses can occur at four stages of harvesting. First, extractors may cause losses as stalks drain during harvesting. Second, elevators may contribute to losses when transporting stalks into baskets, especially under narrow-field conditions where the movement of harvesters is affected and some stalks may fall through the belt. Third, losses occur with remaining stumps after harvesting. Lastly, losses can result from harvested stems falling off the vehicle during transportation [12, 13].

Thailand serves as a compelling case study for transitioning from a labor-based system to mechanized sugarcane harvesters. In experimental plots in Thailand, cane losses due to harvesters have been estimated at 4.56 t/ha, with even higher losses in poorly managed areas [14]. Cane losses caused by sugarcane harvesters are categorized as low, medium, and high, with thresholds set at <2.5%, 2.5%–4.5%, and >4.5% of total yield, respectively [15]. In Thailand, average cane losses caused by sugarcane harvesters fall into the high category [14]. Reducing these losses would lead to increased production yield and higher incomes for sugarcane farmers. However, in Asian countries, limited information is available on cane losses caused by sugarcane harvesters at each stage of the harvesting process.

This study focuses on investigating cane losses during sugarcane harvesting caused by large- and medium-sized sugarcane harvesters, specifically at the extractor stage, elevator stage, and in remaining stumps. Additionally, a damage index for sugarcane stumps processed by these sugarcane harvesters was developed. The findings of this study will aid in managing sugarcane harvesting with harvesters, ultimately reducing cane losses throughout the process.

2. Materials and Methods

2.1. Planting Areas Used to Investigate Cane Losses. Data on sugarcane field preparation were collected through a questionnaire completed by 129 randomly selected sugarcane farmers in Central Thailand. The questionnaire mainly focuses on the shape and size of sugarcane fields and field preparation for mechanized sugarcane harvesters. Additionally, 24 sugarcane fields were observed and selected for the yield loss assessment. Characteristics of the selected plots to assess sugarcane production losses must be rectangular with a distance of 1.5 meters between the rows, and sugarcane was planted as a single row.

This study focused on areas planted with the Khon Kean 3 sugarcane variety in Kanchanaburi, Nakhon Pathom, Ratchaburi, and Suphan Buri provinces within the central region of Thailand. The planted areas had soil with a sandy clay loam texture, as well as topography ranging from flat to slightly undulating. Cane losses from large sugarcane harvesters (325 Hp) were recorded in Kanchanaburi (11 planting areas), Nakhon Pathom (1 planting area), and Suphan Buri (1 planting area). Cane losses from medium-sized sugarcane harvesters (200–250 Hp) were recorded in Kanchanaburi (7 planting areas), Ratchaburi (3 planting areas), and Nakhon Pathom (2 planting areas). A uniform row spacing of 1.6 m was employed in all sugarcane planting areas. The ground speed of the sugarcane harvesters was maintained at 4.0 km/h during harvesting.

2.2. Data Collection of Cane Losses Caused by Sugarcane Harvesters. Sugarcane cane loss data were collected during harvesting, with total visible cane losses calculated by summing the losses from remaining cane stumps, extractors, and elevators.

2.2.1. Remaining Cane Stumps. After sugarcane harvesting by the harvesters, data were gathered by cutting the remaining cane stumps at the base. A sample area measuring 15 m^2 (1.5 × 10 m) was randomly selected, and each stump in the sample area was cut at the base by a knife. A dusting brush cleaned the cut stumps before weighting by a digital scale. This process was repeated in six randomly located plots in each planting field, and the data from four plots were used to calculate the weight of the remaining stumps.

2.2.2. Loss at the Extractor. The loss of sugarcane from the cleaning fan was determined by collecting dropped cane billets and fragmented stalks on a 30 m^2 canvas (3 × 10 m). The canvas was positioned adjacent to the harvested row during harvesting. All collected components were weighed in six randomly chosen areas in each planting field.

2.2.3. Loss at the Elevator. To determine the loss of cane billets falling from the elevator system, the ground within a 150 m^2 area (1.5 × 100 m) along the harvesting row was considered. After harvesting, the billet loss samples were weighed. Six areas were randomly sampled in each planting field.

2.3. Sugarcane Stump Damage Due to Sugarcane Harvesters. Sugarcane stump damage was investigated in a 75 m^2 area (3 × 25 m), with four replications per planting field. The investigation areas in each plot were different locations from the collection data of the remaining cane stump's weight. Stump damage was categorized and scored as follows: (1) for no damage, (2) for peripheral damage, (3) for cracking, and (4) for fragmentation. The damage was visually evaluated following the methods reported by Kroes [16] and Reis [17] and by adapting the method of Manhães et al. [7]. To calculate the damage index, the following equation was used:

$$\mathrm{DI} = \frac{[(\mathrm{Uw} \times \mathrm{Un}) + (\mathrm{Pw} \times \mathrm{Pn}) + (\mathrm{Sw} \times \mathrm{Sn})]}{N}, \quad (1)$$

where DI represents the damage index, U_W denotes the weight assigned to undamaged stumps, U_n is the number of undamaged stumps, P_W represents the weight assigned to partially damaged stumps, P_n denotes the number of partially damaged stumps, S_W is the weight assigned to severely damaged stumps, S_n represents the number of severely damaged stumps, and N denotes the total number of stumps. Damage index weights of −1.00, −0.33, and 1.00 indicated no damage, moderate damage, and severe damage, respectively [18].

2.4. Data Analysis. The "pairs.panels" function from the "psych" package (Northwestern University, Evanston, IL, USA; https://cran.rproject.org/web/packages/psych/) in R [19] was used to analyze correlations among total cane losses due to sugarcane harvesters as well as the cane losses at the extractor fan, the elevator, and in the remaining stumps. Significance levels were set at $P < 0.05$ and $P < 0.01$. This correlation analysis aimed to identify the critical points of cane loss from the sugarcane harvesters. Moreover, analysis of variance was used to compare means of damage index. Significant differences among the damage index were compared using Fisher's protected least significant difference (LSD) at the 5% level of probability.

3. Results

3.1. Sugarcane Field Surveys. In total, 129 sugarcane planting fields in Central Thailand were randomly surveyed. The majority of sugarcane fields (76.74%) had a size smaller than 3.2 ha, whereas fields larger than 11.2 ha accounted for 12.4% of the total. The shapes of the sugarcane fields varied, with rectangular (69.33%), square (11.56%), trapezoid (17.78%), and triangular (1.33%) fields observed. Both double-row and single-row planting methods were used (57.59% and 42.41%, respectively). The sugarcane rows were rarely straight and had uneven heights. Regarding field operations, 51.77% and 48.23% of sugarcane plots were and were not subjected to earthing, respectively. In terms of topography, 71.43% of the sugarcane areas were flat, whereas the remaining 28.57% were slightly undulating.

3.2. Visible Cane Losses from Sugarcane Harvesters. The cane loss data for 13 plots, including losses from the remaining stumps, elevator, and extractor, are summarized in Table 1. The use of large harvesters resulted in cane losses of 2.19, 0.53, and 0.27 t/ha at the remaining stumps, elevator, and extractor, respectively. The total visible cane loss from large harvesters was 2.99 t/ha (4.0% of total yield), with a range of 1.18–4.98 t/ha. The predominant contributor to cane loss from large harvesters was the remaining stumps (2.19 t/ha), accounting for approximately 54.8% of the total cane loss.

Table 2 presents the total cane losses from the 11 plots harvested using medium-sized sugarcane harvesters. The total visible cane loss from these harvesters was 2.85 t/ha (3.4% of total yield). The cane losses at the remaining stumps, elevator, and extractor were 2.21, 0.44, and 0.20 t/ha, respectively. Notably, the majority of cane loss (65.0%) from medium-sized harvesters was attributed to the remaining stumps.

3.3. Effects of Cane Losses at the Remaining Stumps, Elevator, and Extractor on Total Cane Loss. The correlations between total cane loss and losses at the remaining stumps, elevator, and extractor following the use of large harvesters were examined (Figure 1). As shown in Figure 1(a), the highest correlation (0.92) was observed between total cane loss and loss from the remaining stumps. Considering total cane loss, the correlation with cane loss at the elevator was 0.26 (Figure 1(b)) and with cane loss at the extractor was 0.47 (Figure 1(c)). Therefore, cane loss at the remaining stumps had a highly significant effect on total cane loss, whereas cane losses at the elevator and extractor did not significantly affect the total loss of cane.

Regarding medium-sized sugarcane harvesters, a correlation of 0.98 was found between total cane loss and cane loss at the remaining stumps (Figure 2(a)). In contrast, the correlations between total cane loss and cane loss at the extractor and at the elevator were −0.19 (Figure 2(b)) and 0.67 (Figure 2(c)), respectively. Therefore, cane loss at the remaining stumps had a highly significant effect on total cane loss from medium-sized harvesters. Additionally, cane loss at the elevator showed a significant relationship with total cane loss. However, cane loss at the extractor did not significantly impact total cane loss (Figure 2).

3.4. Damage to Sugarcane Stumps Due to Mechanized Harvesting. The damage index of sugarcane stumps caused by large harvesters significantly differed among the 13 plots. The mean of the damage index was 0.04 and ranged from −0.38 to 0.45. The damage index of the plot numbers 3, 4, and 7 was higher than the damage index of the plot number 6 (Figure 3(a)). Only plot 6 exhibited a damage index value of −0.38. The plots 1, 2, 5, 7, 8, 9, 10, 11, 12, and 13 showed damage index values from −0.33 to 0.33. The plots 3 and 4 had damage index values higher than 0.33 (Figure 3(a)). The damage index of large harvesters from 13 locations was significantly different. The damage index from the plot numbers 3, 4, and 7 presented the highest level at 0.45, 0.36, and 0.31. The lowest damage index was found in the plot number 6 with the damage index at −0.38.

For medium-sized harvesters, the damage index of sugarcane stumps significantly differed among the 12 plots. The damage index ranged from −0.54 to 0.72. The average damage index value for the medium-size sugarcane harvesters was 0.12 (Figure 3(b)). The damage index of plots 23 and 24 was higher than that of plot numbers 14, 16, 17, 18, 19, 20, and 21. Plot 19 exhibited the damage index at −0.54, whereas plots 14, 16, 17, 18, 20, and 21 exhibited the damage index ranging from −0.33 to 0.33. The remaining plots (15,

Table 1: Total cane loss, including losses at the remaining stumps, elevator, and extractor, following the use of large sugarcane harvesters.

Location	Province	Horsepower (HP)	Plot number	Yield (t/ha)	Cane loss (t/ha)				
					Remaining stumps (t/ha)	Elevator (t/ha)	Extractor (t/ha)	Total cane loss (t/ha)	Total cane loss (%)
Tha Muang	Kanchanaburi	325	1	68.62	3.28	0.66	0.03	3.97	5.8
Tha Muang	Kanchanaburi	325	2	62.16	3.77	0.65	0.56	4.98	8.0
Bo Phloi	Kanchanaburi	325	3	77.49	3.83	0.62	0.50	4.94	6.4
Bo Phloi	Kanchanaburi	325	4	79.75	3.76	0.34	0.52	4.62	5.8
Tha Maka	Kanchanaburi	325	5	75.24	0.95	0.12	0.11	1.18	1.6
Tha Maka	Kanchanaburi	325	6	59.72	0.58	1.18	0.79	2.54	4.3
Mueang	Kanchanaburi	325	7	102.69	1.09	0.48	0.30	1.87	1.8
Mueang	Kanchanaburi	325	8	59.99	1.44	0.61	0.06	2.11	3.5
Song Phi Nong	Suphan Buri	325	9	105.10	2.32	0.50	0.00	2.82	2.7
Bo Phloi	Kanchanaburi	325	10	46.68	2.52	0.27	0.10	2.89	6.2
Bo Phloi	Kanchanaburi	325	11	54.56	1.82	0.47	0.16	2.45	4.5
Kamphaeng Saen	Nakhon Pathom	325	12	80.93	1.52	0.81	0.39	2.72	3.4
Bo Phloi	Kanchanaburi	325	13	71.00	1.54	0.17	0.00	1.71	2.4
	Mean ± SE			72.61 ± 8.64	2.19 ± 0.99	0.53 ± 0.30	0.27 ± 0.26	2.99 ± 1.06	4.0 ± 2.0

Table 2: Total cane loss, including losses at the remaining stumps, elevator, and extractor, following the use of medium-sized sugarcane harvesters.

Location	Province	Horsepower (HP)	Plot number	Yield (t/ha)	Cane loss (t/ha)				
					Remaining stumps (t/ha)	Elevator (t/ha)	Extractor (t/ha)	Total cane loss (t/ha)	Total cane loss (%)
Kamphaeng Saen	Nakhon Pathom	250	14	50.28	1.07	0.73	0.22	2.02	4.0
Lao Khwan	Kanchanaburi	200	15	75.46	1.65	0.21	0.11	1.96	2.6
Lao Khwan	Kanchanaburi	200	16	62.03	1.59	0.19	0.10	1.88	3.0
Mueang	Kanchanaburi	200	17	75.15	2.01	0.25	0.06	2.31	3.1
Tha Muang	Kanchanaburi	240	18	71.69	0.64	0.32	0.03	0.99	1.4
Photharam	Ratchaburi	240	19	83.51	2.25	0.61	0.79	3.65	4.4
Photharam	Ratchaburi	240	20	62.16	0.34	1.01	0.07	1.42	2.3
Mueang	Kanchanaburi	240	21	141.01	4.68	0.35	0.22	5.25	3.7
Chom Bueng	Ratchaburi	240	22	118.01	6.67	0.32	0.58	7.57	6.4
Huai Krachao	Kanchanaburi	240	23	63.03	1.85	0.44	0.02	2.32	3.7
Huai Krachao	Kanchanaburi	240	24	75.79	1.50	0.42	0.03	1.94	2.6
	Mean ± SE			79.85 ± 32.54	2.21 ± 1.86	0.44 ± 0.24	0.20 ± 0.24	2.85 ± 1.96	3.4 ± 1.3

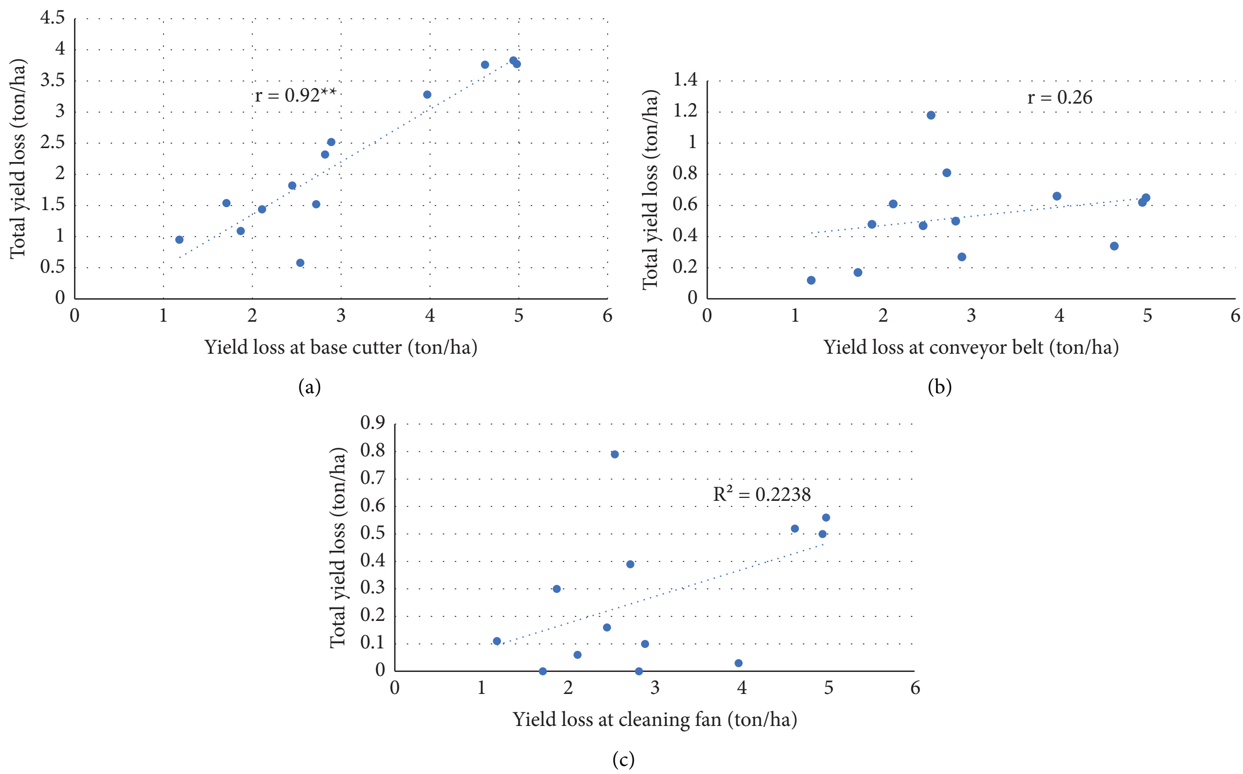


Figure 1: Correlations (*r*) between total cane loss and loss at the remaining stumps (a), loss at the elevator (b), and loss at the extractor (c) following harvesting with large sugarcane harvesters.

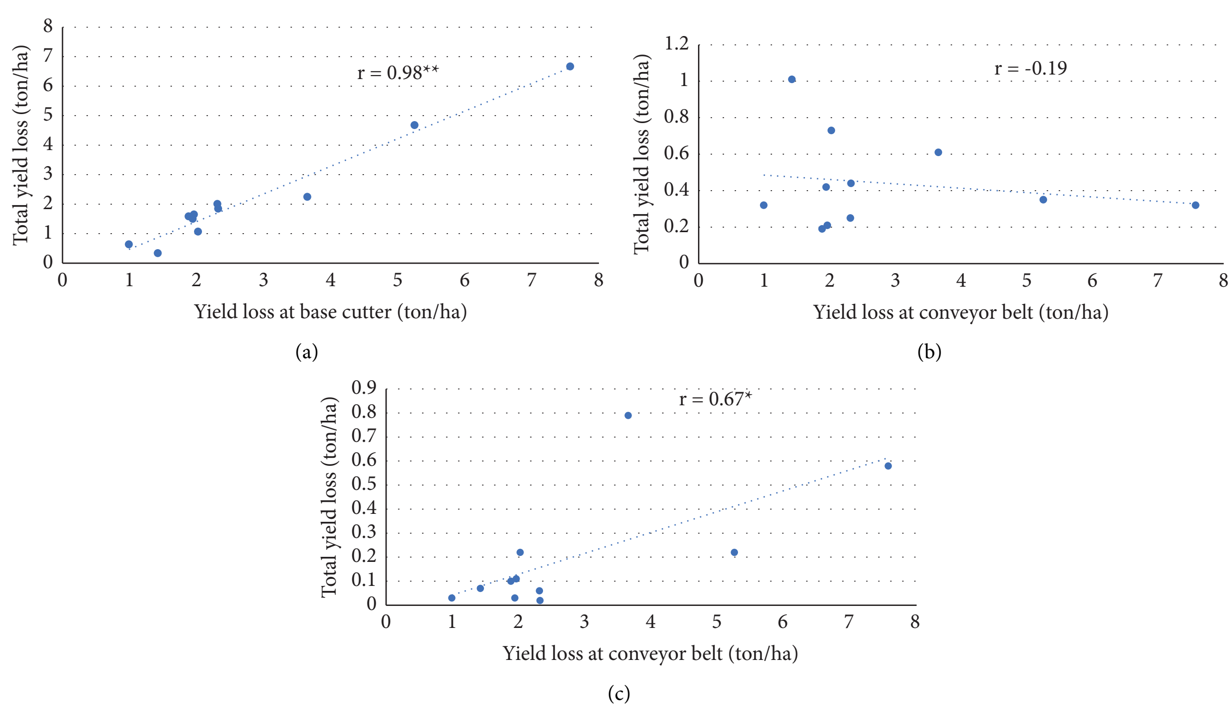
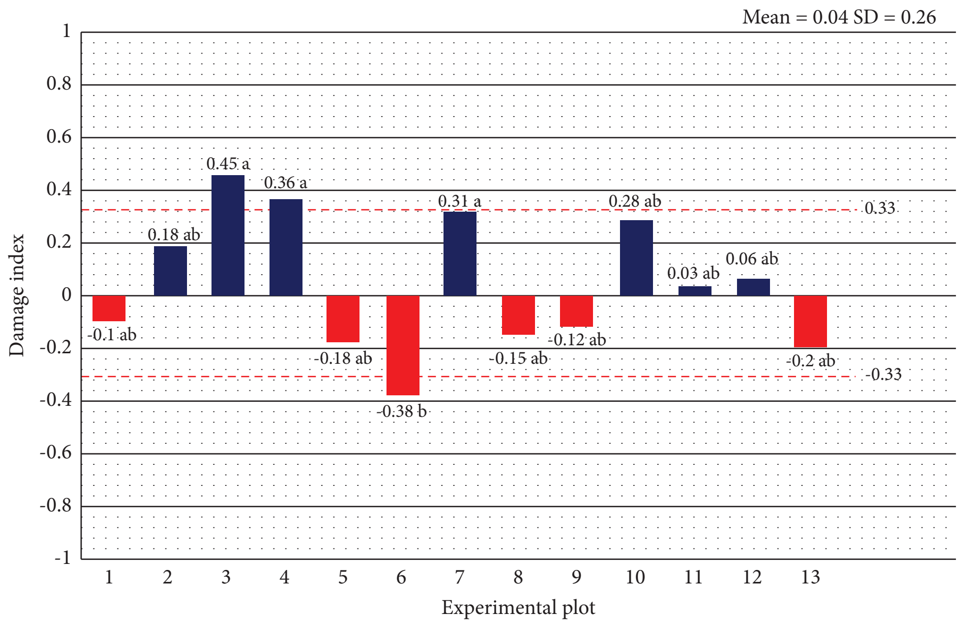
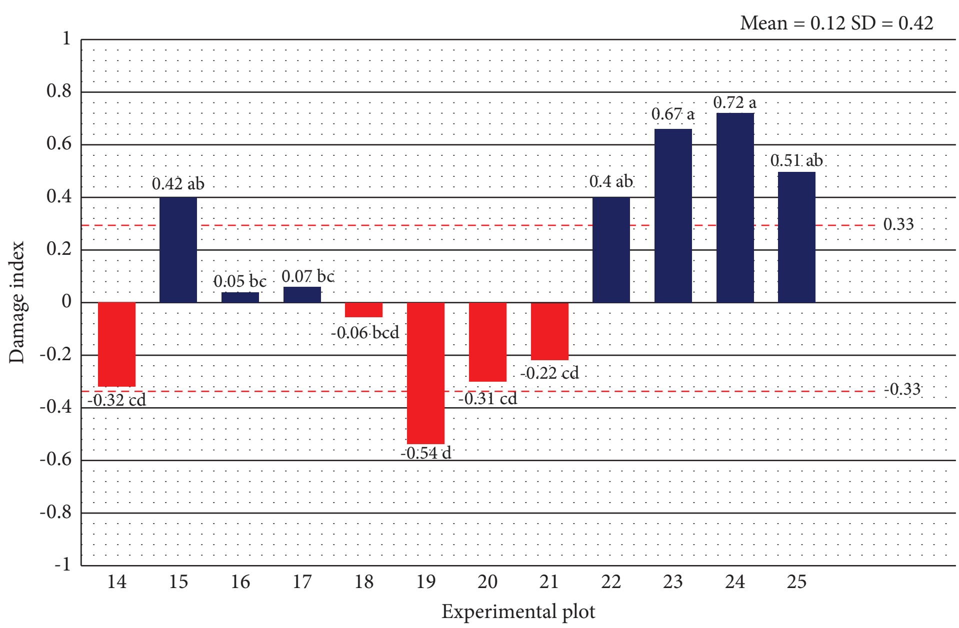


Figure 2: Correlations (*r*) between total cane loss and loss at the remaining stumps (a), loss at the elevator (b), and loss at the extractor (c) following harvesting with medium-sized sugarcane harvesters.



(a)



(b)

Figure 3: Sugarcane stump damage classification from harvesting by large-sized (a) and medium-sized (b) sugarcane harvesters.

21, 22, 24, and 25) showed the damage index exceeding 0.33 (Figure 3(b)). The damage index of large harvesters from 12 locations was significantly different. The damage index from Huai Krachao, Kanchanaburi (plot numbers 23 and 24) showed the highest values (0.67 and 0.72). The damage index from plot 19 at Photharam, Ratchaburi showed the lowest value at −0.54.

4. Discussion

The present survey of sugarcane planting fields in Thailand revealed that approximately 76% of sugarcane farmers were smallholders. The findings also indicated that many farmers did not adequately prepare their sugarcane farms for the use of harvesters, which can markedly affect harvesting efficiency. Insufficient farm preparation can lead to increased working time for harvesters in the field without a corresponding increase in the working area, resulting in decreased efficiency [20].

A major source of significant losses when using either large- or medium-sized sugarcane harvesters was the presence of remaining stumps caused by the base cutter, which was unable to cut close to the soil surface. The average total cane losses caused by the large- and medium-sized harvesters in the current study (4.0% and 3.4% of total yield, respectively) were lower than sugarcane harvesters in Brazil (8.1% of total yield) [21]. However, the average losses due to large harvesters in the current study were consistent with a previous study from Thailand, which reported yield losses of 3.27% [14]. Based on the classification by Reis [17], cane losses are categorized as low, medium, or high when they are <2.5%, 2.5%–4.5%, and >4.5%, respectively. Therefore, in the present study, the total visible cane losses caused by large- and medium-sized sugarcane harvesters can be classified as medium.

The current study revealed significant cane losses at the remaining stumps, with average losses of 2.19 and 2.21 t/ha for large- and medium-sized harvesters, respectively. In comparison, reported losses from remaining stumps in Brazil were around 0.05 t/ha, making the losses in Thailand approximately 44.2 times higher than those in Brazil [22]. Unlike Brazil and Australia, where sugarcane plots are well prepared for mechanized harvesting, leading to minimal losses from basal cutting, sugarcane cultural practices in Thailand need improvement, especially in areas such as earthing-up operations and rock clearing in sugarcane fields [20]. By adequately preparing sugarcane fields in Thailand, the basal cutting of harvesters could be performed closer to the bases of sugarcane stumps, resulting in reduced cane losses [22].

Damage index evaluation of this study was adapted from the report from Toledo et al. (2013) and Da Silva et al. [23]. In the presented study, damage index values of the large- and medium-sized were classified into three sections as partial damage (damage index <−0.33), moderate damage (damage index from −0.33 to 0.33), and high damage (damage index >0.33).

The predominant types of stump damage caused by large sugarcane harvesters were partial, moderate, and high damage at 7.7, 76.9, and 15.4%, respectively. The average damage index of the sugarcane harvesters was 0.04, which is indicated as moderate damage. The large-sized sugarcane harvesters were usually used for harvesting large-sized sugarcane farms. Most of the large-sized sugarcane farms in Thailand have farm contracts with sugar mills, and the management of the large-sized farms follows the guidelines of sugar mills. Then, the damage of sugarcane stumps was not serious.

For the medium-sized sugarcane harvesters, the predominant types of stump damage were partial, moderate, and high damage at 8.3, 50.0, and 42.7%, respectively. The averaged damage index of the medium-sized sugarcane harvesters was 0.12, which is indicated as moderate damage. However, the high stump damage from the middle-sized sugarcane harvesters was found in 42.7% of the total plots, which was higher than the investigation from the large-sized sugarcane harvesters. The middle-sized sugarcane harvesters were usually used for harvesting small-sized sugarcane farms. According to the information of farm management, small sugarcane farms were not managed well for sugarcane harvesters.

These findings indicate that sugarcane stump damage caused by sugarcane harvesters in Thailand was higher than that observed in Brazil [21]. Using sugarcane harvesters at different speeds, minimal direct ratoon damage was observed with the large harvester, with peripheral damage being the most common occurrence [7, 24]. Although the speed of the sugarcane harvesters in the present study was controlled at around 4 km/h, following the study conducted in Brazil [7], the stump damage observed in the current study was still high. Factors such as blade speed, blade angle, and blade sharpness may have contributed to the elevated stump damage [25]. Therefore, it is crucial for operators to possess the necessary knowledge and skills to use sugarcane harvesters efficiently and minimize damage.

The current findings highlight the need for improved management of sugarcane planting fields in Thailand, especially for small farms, to facilitate the efficient operation of mechanized harvesters. The study identified two major challenges faced by sugarcane harvesters: cane loss from remaining stalks after harvesting and stump damage. In response to labor shortages and environmental concerns, private sectors in Thailand have imported numerous sugarcane harvesters. However, field preparation and harvesting efficiency remain problematic in the country. Therefore, it is essential to provide farmers with training on field preparation techniques and drivers with training on maximizing the efficiency of sugarcane harvesters. These measures are crucial for minimizing cane losses, reducing stump damage, and improving overall harvesting efficiency.

5. Conclusions

The cane losses observed in this study following the use of large- and medium-sized sugarcane harvesters were 2.99 and 2.85 t/ha, respectively. Notably, the majority of cane losses for both harvester sizes occurred at the remaining stumps, accounting for approximately 71% and 76% of total cane loss. The damage indexes of large- and medium-sized harvesters were 0.04 and 0.12 (moderated damage). However, the frequency of plots with high stump damage from medium-sized sugarcane harvesters was higher than the frequency of plots harvested by large harvesters. Addressing these issues through farmer and driver training on field preparation and harvester operation, respectively, could effectively minimize the problem and enhance harvesting efficiency.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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