The optimization for decreasing ruptured billets when harvesting sugarcane with chopper harvester

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Abstract. The purpose of this study was to analyze the level of factors that are optimized for the amount of ruptured billets when harvesting sugarcane with the sugarcane harvester. A factorial experimental design was used to study the effect of three factors: sugarcane type, planting and soil type. The experiments showed that the three factors affected the quantity of ruptures billets. Also, the variance analysis was done at a significant level of 0.05, and it was found that the sugarcane type, soil type and the planting technique had an influence on the amount of ruptures billets. And ratoon-sugarcane double-row and sand is the level of suitable factors that can reduce the amount of ruptures billets by 25%.

1. Introduction

Sugarcane is an economic crop that the Thai government encourages farmers to plant in order to expand the area planted as articulated under the Agricultural Crops Strategy [1]. In 2014, Thailand produced 103.7 million tons of sugarcane, and up to 11.3 million tons of sugar. About 65 percent of the output was exported to major customer countries including Indonesia, Japan, China and South Korea. The revenue brought into the country by sugar and sugarcane exports was 102,103 million baht [2].

In the present day, agricultural machinery is widely used to facilitate all steps of sugarcane production, especially in harvesting which takes place during November and May of each year. During these harvest times, farmers require a lot of labor to cut sugarcane so that it can reach the sugar mill before the closure of the season. But, at the present time, agricultural laborers have moved away from the industry [3] because agricultural work is difficult and produces a low income. As a result, the newest generation of workers have moved away from working in agriculture. In addition, the increase in the minimum wage increased the cost of production for farmers. One solution to the labor shortage was to use sugarcane harvesters which could replace the workers who once harvested sugarcane during the harvest season.

Various harvesting practices are used in sugarcane production, each requiring different harvesting technologies to ensure effective and efficient field operations. Based on how the sugarcane is presented to the harvester, harvesting practices are classified into two groups: 1) harvesting sugarcane with pre-harvest burning (burnt sugarcane harvesting) and 2) harvesting sugarcane without burning (green sugarcane harvesting). Based on the form of the harvested materials, two classes of harvesters have been developed, whole stalk harvesters and chopper harvesters [4].

A typical whole stalk harvester system consists of a topper, a base cutter, a feeding mechanism, and a discharging mechanism. The topper is designed to sever sugarcane tops and then discharge the severed tops to the side of the harvesting rows. Topped sugarcane stalks are then cut by the base cutters at about
30 mm above the ground level [5]. The feeding mechanism includes a set of rollers to convey the sugarcane stalks to the discharging mechanism. The discharging mechanism then delivers harvested stalks to either a wagon or onto the field.

Chopper harvesters include the components of whole stalk harvesters but have extra components including choppers and extractors. The functionality of the chopper and extractor are to chop whole stalk into billets and to separate leafy materials. During the harvesting process of the chopper harvester, the discharging mechanism is used to deliver the billets to a wagon or a truck [4].

Sugarcane harvesters used for sugarcane harvesting are both imported from overseas and produced by local manufacturers. In the operation of both the domestic and imported sugarcane harvesters, there are problems that cause a loss of productivity. Linedale [6] identified four major types of harvesting loss which includes: 1) extractor loss; sugarcane thrown from the harvester during the cleaning processes, 2) boot and elevator loss; billets falling from the harvester during its operation, 3) pick-up loss; sugarcane broken off or run-over and not taken into the harvester, and 4) spillage loss; billets spilt during transfer to the haul out equipment and en route to, or at, the tram siding or road transport systems.

Loss caused by the work process of chopper harvester can be divided into 1) Quantitative losses (weight), when the sugarcane is cut into billets, there will be an open surface on both ends of the sugarcane. Some billets have a rupture which increases the surface area without peeling when exposed to the dry weather of winter in Thailand. This makes the water in the sugarcane billets to evaporate into the atmosphere more easily. 2) Quality losses, when the sugarcane has an open surface area that is exposed to the environment, microorganisms can enter inside the sugarcane. These microorganisms can multiply rapidly until the sugarcane is spoiled. Consequently, the sugarcane will be rejected for purchase due to its condition because it will negatively affect the quality of sugar and machinery in the production process.

From the problems discussed above, the cost of using a sugarcane harvester has increased every year. Therefore, this study aims at determining the amount of ruptured billets and the factors affecting the amount of ruptured billets to provide information for decision making in controlling the operation of sugarcane harvester and to reduce such losses. The hypothesis of this research is that harvesting with sugarcane harvester affects the amount of ruptured billets.

2. Materials and methods
The research method established after a preliminary survey in Khonkhen and Chaiyaphum province in Thailand was selected for the analysis of the problem and to determine the value of the factors used in the experiment. In Khon Kaen, 3 sugarcane varieties were selected for analysis. The control factors included sugarcane without burning and the use of a chopper harvester (Austoft 8000 sugarcane harvester series, FPT Cursor 9 engine 4 valves 9 liters - 353hp (260kW) @ 2100 rpm). The sugarcane type, soil type and planting technique were the initial factors used to determine the amount of impurities and the statistical analysis from sugarcane harvested with sugarcane harvesters.

2.1. Experiment to find factors affecting the amount of ruptured billets with sugarcane harvesting by chopper harvesters.

The research was conducted using the 2k factorial experiment design because this experimental method leads to a high performance while monitoring the influence of many factors [7].

| Table 1. Shows the factors and levels of each factor used in the experiment. |
|-----------------------------|---------------------|
| Factor                     | Level               |
| Plant                      | Ratoon              |
| Single-row                 | Double-row          |
| Sand                       | Clay                |
2.1.1. **Determining the level of factors used in the experiment.** The experiment used two levels of factors: low (-1) and high (1) as shown in Table 1 with the three factors: sugarcane type, type of planting, and soil type. Usually, sugarcane is a plant that can be harvested many times. There are 2 types of planting: single-row and double-row. The soil type is in accordance with the soil conditions in the study area.

2.1.2. **Experimental design.** In this experiment, we used a statistical program (Minitab V. 18) to determine the order of experiments and the experimental design (DOE). For the study of three replicates, there are 24 units in the experiment.

2.1.3. **Experiment conducted to determine the amount of ruptured billets found in sugarcane harvested by chopper harvester.** The operator adjusted the speed of the harvester within the limits of the machine under the given working conditions in order to achieve the requirements for raw material quality and process productivity [8]. In preparation for sugarcane testing, the sugarcane was sampled on the trucks in the location where the sugarcane was harvested [9] by placing sample containers over the sugarcane on the front, center and rear of the truck being used with the sugarcane harvester. Then, the sugarcane from all 3 sample containers were collected to determine the total weight of the ruptured billets.

2.2. **Statistical analysis of results**

The results were interpreted using a statistical analysis to determine the relationship between the initial factors and the response factors. The statistical analysis was divided into 2 parts as follows:

2.2.1. **Residual analysis.** Using the residuals derived from the model chosen in Section 2.1, the residuals were normalized by distributing the variance of the residuals of various factors. The constant variance and decay needs to be random.

2.2.2. **Analysis of variance.** The variability source of the model was examined by considering the P-values of the various terms in the table for the analysis of variance compared with the statistical significance. (p = 0.05)

3. **Results and discussion**

3.1. **The amount of ruptured billets found in sugarcane harvesting trial**

Minitab V.18 was used to help plan the experiments using a 2k factorial design with three factors: sugarcane type, type of planting and soil type. There were 24 experimental units. It was found out that the average of the ruptured billets is 0.48 kg per 1 experiment.

3.2. **Statistical analysis**

3.2.1. **Residual analysis.** When the residuals were analyzed, it was found out that the model of each response was not abnormal because the distribution of residual is normal. The variance of the factors is uniform and there were no out-of-control signals for the data in the control charts. The results show that the responses are normal.

3.2.2. **Analysis of Variance.** Based on the comparisons of table 2, the statistical analysis shows that the sugarcane type, soil type and planting technique had a statistically significant influence on the amount of ruptured billets.

3.2.3. **Analysis of the impact of factors influencing the response.** The co-factors influencing the amount of ruptured billets are shown in figures 1. It was found out that the ruptured billets of the sugarcane is caused by the influence of sugarcane type and soil type. There are intersections on the line that connects the average of the results of both factors. Therefore, the increase or decrease of the ruptured billets will be changed by both factors accordingly. The ratoon-sugarcane has a wider period of ruptured billets.
between the sand and clay than plant-sugarcane. This implies that the ratoon-sugarcane planted in clay soil has the most ruptured billets.

**Table 2.** Shows results of analysis of variance of ruptured billets.

| Source                          | P-Value |
|---------------------------------|---------|
| Model                           | 0.005   |
| Linear                          | 0.616   |
| sugarcane type                  | 0.919   |
| Planting                        | 0.368   |
| soil type                       | 0.339   |
| 2-Way Interactions              | 0.001   |
| sugarcane type*planting         | 0.806   |
| sugarcane type*soil type        | 0.049   |
| planting*soil type              | 0.229   |
| 3-Way Interactions              | 0.049   |
| sugarcane type*planting*soil type| 0.049  |

The double-row planting technique has a period of ruptured billets between the sand and clay that is wider than single-row. This implies that the most ruptured billets are planted in clay soil using the double-row planting technique.

![Interaction Plot for Ruptured billets](image)

**Figure 1.** shows the effect of the co-factors influencing the amount of ruptured billets

3.2.4. **Determination of optimum values of factors affecting the ruptured billets when harvesting sugarcane of chopper harvester.** The result of the analysis of the most optimal value of factors affecting the ruptured billets from the operations process of chopper harvester is shown in table 3.
Table 3. Shows the optimal value of factors affecting the ruptured billets when harvested sugarcane with chopper harvester.

1. Parameters

| Response          | Goal   | Lower | Target | Upper | Weight | Importance |
|-------------------|--------|-------|--------|-------|--------|------------|
| weight losses     | Minimum| 0.14  | 0.93   | 1     | 1      | 1          |

2. Solution

| Solution          | sugarcane type | Planting | soil type | weight losses | composite desirability |
|-------------------|----------------|----------|-----------|---------------|------------------------|
| 1                 | ratoon sugarcane| double-row| sand      | 0.23          | 0.88607                |

3. Multiple Response Prediction

| Variable | Setting          |
|----------|------------------|
| sugarcane type | ratoon sugarcane |
| Planting     | double rows      |
| soil type    | sand             |

The prediction response of the rupture of the billets equals to 0.230, and the overall composite desirability level is equal to 0.8861. It can be concluded that ratoon-sugarcane, sandy soil and double-row planting technique are the appropriate factors that have led to the 25 percent decrease of ruptured billets harvested by chopper harvester as compared to the average ruptured billets from the past tests.

4. Conclusion

This research was designed using a 2k factorials to determine the amount of ruptured billets when sugarcane is harvested using the chopper harvester considering 3 factors: sugarcane type, soil type and planting technique. Based on the analysis of variance at the level of significance 0.05, it was found out that the sugarcane type, soil type and planting technique had an influence on the amount of ruptured billets. And from the optimal level of factors analysis, it was also found out that the type of sugarcane is ratoon-sugarcane, the soil type is sand and the planting technique is double-row. These are the suitable factors that reduce the amount of ruptured billets when harvesting sugarcane using the chopper harvester.

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Acknowledgement
The researcher would like to thank Khun Anupong Niamcharoen, Khun Songsak Phachada and Khun Yothin Kaewsriprom for their advice and assistance. I would also like to thank Suranaree University of Technology for providing financial support for this research.