Factors affecting the amount of impurities when harvesting produced sugarcane with sugarcane harvester

K Kosum¹ and S Bun-art¹

¹School of Agricultural Engineering, Suranaree University of Technology, Muang, Nakhon Ratchasima, 30000, Thailand
E-mail: kk_changnoi@yahoo.com

Abstract. This study aimed to determine the amount of impurities adhering to sugarcane harvested from sugarcane harvesters. 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 impurities adhering to the sugarcane. The following types of impurities can be classified as tops at 54%, trash at 32%, and root and soil at 14%. The variance analysis was done at a significant level of 0.05, and it was found that the sugarcane type and the planting technique had an influence on the amount of tops impurities in both terms of the main factors and co-factors. The type of sugarcane was the main factor affecting the amount of trash impurities in terms of main factors; planting and soil type had an influence on the amount of trash impurities in terms of the co-factors.

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]. During the years from 2007 to 2008, major sugar importers, particularly Japan and South Korea, complained about the high starch content (300-800 ppm) in the raw sugar imported from Thailand. The starch can create some problems for further refinement processes. Furthermore, the starch sediment from these processes is insoluble so it can be harmful to the environment. The contamination of starch can occur from the harvesting process. It is found in the tops of sugarcane [3, 4]. It is not found in sugarcane trash, and varies according to the age of the sugarcane [5] or the sugarcane variety. Godshall et al. [6] reported that sugarcane varieties with a high sugar content also have a high starch content, and the sugarcane tops contained the maximum amount of starch. Green leaf and leaf sheath did not clearly affect the starch contamination in the sugarcane juice [7].

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 industry [8] because agricultural work is difficult and affords 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 replaces 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 [9].

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 [10]. 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 [9].

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 [11] 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.

Losses coming from impurities in the sugarcane impacts farmers by cutting sugarcane prices 0.63 $/ton. In addition to the increased cost of the sugarcane production process, the maintenance of production machinery has increased because processing plants need to remove impurities during processing. Also, stone and sand impurities shorten the lifespan of the boiler [12].

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

2. Materials and methods
The research method, established after a preliminary survey in Khonkhen and Chaiyaphum province, Thailand, was selected to allow for the analysis of the problem and to determine the value of the factors used in the experiment. Khon Kaen 3 sugarcane variety was 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 type of sugarcane, type of planting and soil type 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 impurities with sugarcane harvesting by sugarcane 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 [13].

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, planting will have 2 types: single-row and double-row. And 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 impurities found in sugarcane harvested by sugarcane 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 [14]. In preparation for sugarcane testing, the sugarcane was sampled on the trucks in the location where the sugarcane was harvested [12] 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 sugarcane and its impurities. After that, the impurities were removed from the tops, trash, roots and soil. Weighing the impurities and the sugarcane slices, the amount of impurity was calculated using the equation (1).

\[
\text{imp} = \left( \frac{W_{\text{imp}}}{W_{\text{total}}} \right) \times 100\% \tag{1}
\]

where imp is the impurity, \(W_{\text{imp}}\) is the impurity weight and \(W_{\text{total}}\) is the total weight

Table 1. Shows the factors and levels of each factor used in the experiment.

| Factor            | Level  |
|-------------------|--------|
| Sugarcane type    | Plant  |
|                   | Ratoon |
| Type of planting  | Single-row |
|                   | Double-row |
| Soil type         | Sand  |
|                   | Clay  |

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. Model adequacy checking. 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 impurities 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. The results are shown the type of the impurities attached to the sugarcane harvested by sugarcane harvesters are tops, trash and root and soil. And the percentage are as follows: 54% of the impurities found in the sugarcane tops were caused by operator settings in the high-level control of the topper. The operation of the topper is very much dependent on the evenness of the crop and operator setting. If operated at the correct height then sugarcane losses are minimised. 32% of the impurities found in the sugarcane trash were caused by the
primary extractor which was not able to completely remove the trash from the billets. These impurities were also caused by the wear and tear of the parts and systems, as well as the speed control of the primary extractor which was not able to suck the trash out of the billets. And 14% of the impurities found in the roots and soil were caused by crop dividers unable to gently raise and separate the sugarcane rows being harvested from adjacent rows. As a result, the stools in the adjacent rows were being pulled from the field, which is then transported up to the processor by feed rollers which is unable to clean roots and soil from the stools.

3.2. Statistical analysis

3.2.1. Model adequacy checking. When the residuals were analyzed, it was found 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.

Table 2. Shows results of analysis of variance of type impurities.

| Source               | P-Value   |
|----------------------|-----------|
|                      | Tops      | Trash  | Root& Soil |
| Model                | 0.002     | 0.059  |
| Linear               | 0.003     | 0.044  | 0.059      |
| sugarcane type       | 0.004     | 0.029  |
| Planting             | 0.034     | 0.586  | 0.059      |
| soil type            |           | 0.063  |
| 2-Way Interactions   | 0.035     | 0      |
| sugarcane type*planting | 0.035   |         |
| planting*soil type   |           | 0      |

3.2.2. Analysis of variance. Based on the comparisons of table 2 the statistical significance is as follows: Column 2 shows the analysis of variance of sugarcane impurity type tops. It was found that the sugarcane type and type of planting had a statistically significant influence on the amount of tops both in terms of the main factors and the co-factors. Column 3 shows the analysis of the variance of sugarcane impurity by type of trash. It was found that the type of sugarcane had a statistically significant influence on the amount of trash impurity in terms of the main factors. The planting and soil type had a statistically significant influence on the amount of trash impurity in terms of the co-factors. And column 4 shows the analysis of variance of sugarcane impurity type by roots and soil. It was found that the type of sugarcane, planting and soil type had no statistically significant influence on the amount of roots and soil impurities both in terms of the main factors and the co-factors.

3.2.3. Analysis of the impact of factors influencing the response. The main factors influencing the amount of the impurity are shown in figures 1. By (A) shows the effect of the main factors on the amount of top impurities. It was found that if the type of sugarcane harvested by the sugarcane harvester was ratoon-sugarcane, there will be more tops impurities than harvesting plant-sugarcane because the stalks of the sugarcane are highly uneven. Also if the sugarcane harvester is harvested on a single-row (planting), the tops impurity will be more than that those harvested on a double-row (planting) because the double rows are denser than the single row, causing the sugarcane's stalk to be more erect. Therefore, the sugarcane stalks are of a more equally height. So, easy to control the height of the topper. And (B) shows the effect of the main factors on the amount of trash impurities. Considering the type of sugarcane, it was found that in the operation of the sugarcane harvester that the plant-sugarcane will have more trash impurity than when harvesting ratoon-sugarcane. Furthermore, there will be more trash impurity if the harvester is being operated on sandy soils when compared with clay soils.
Figure 1. Shows the effect of the main factors influencing the amount of impurity of sugarcane type: A is tops, B is trash.

Figure 2. Shows the effect of the co-factors influencing the amount of impurity of sugarcane type: A is tops, B is trash.

The co-factors influencing the amount of impurity are shown in figures 2. By (A) shows the effect of the co-factors on the amount of tops impurities. When changing the operation of the sugarcane harvester from single-row planting to double-row, it was found that if the sugarcane is harvested in ratoon-sugarcane, then there was a wider range of tops impurity than in plant-sugarcane. And (B) shows the effect of the co-factors on the amount of trash impurities. When changing the operation of the sugarcane harvester from a sand soil to a clay soil, it was found that if the sugarcane harvested is in a single-row, then there was a wider range of trash impurities than in a double-row.

4. Conclusion
This research was designed using a 2k factorials design to determine the amount of impurities adhering to sugarcane harvested from a sugarcane harvester considering 3 factors: sugarcane type, planting and soil type. The study indicated that the impurities affixed to sugarcane can be classified into 3 types: tops at 54%, trash at 32% and roots and soil at 14%, respectively. For information on adjust, topper, roller and extractor. When the variance analysis was done at the significance level of 0.05, it was found that the sugarcane type and planting had an influence on the amount of tops impurities both in terms of the...
main factors and the co-factors. Sugarcane type was the main factor affecting the amount of trash impurities in terms of the main factor. Co-factors included the type of planting and the soil type which also influenced the amount of trash impurities.

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