Mechanization for the Improvement of the Sugarcane Harvesting and Transportation System in Thailand*

——A Case Study in Udon Thani Province——

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Abstract

In Thailand, the cost of sugarcane harvesting and transportation constitutes a significant portion of the total sugarcane production cost. In order to reduce the total cost, it is necessary to clarify the current shortcomings of the harvesting and transportation processes. A field study was conducted in Udon Thani province, in northeastern Thailand, to accumulate information for analyzing the system's current shortcomings. The accumulated information showed that mechanical harvesting is key for reducing harvesting cost by around 8 to 57 US$ per ha, when compared with manual harvesting in the case of burned and green cutting, respectively. In addition, analyses performed through the use of a simple sugarcane harvesting and transportation simulation based on data obtained by time studies of the harvesting and transportation operations indicated that the field capacity of a chopper-type mechanical sugarcane harvester depends on the condition of the field in which it works, and the number of accompanying trucks it requires. Though the sizes of the fields in this area are relatively small, the accumulated area of fields having row lengths of longer than 160 m which allows the effective usage of a chopper was 316 ha or 51% of the total field area in this region. This fact shows that chopper can work at high capacity in half of the sugarcane fields in this region. However, the limited availability of trucks significantly influences the efficiency of mechanical sugarcane harvesting and transportation. In addition, since truck allocation affects the profit distribution among the various groups engaged in sugarcane production (i.e., sugarcane factories, machinery owners, and farmers) a truck allocation plan should be devised based on input from these groups.

Keywords] sugarcane, harvesting, transportation, mechanization, simulation, Thailand

I Introduction

Sugarcane is a crucial economic crop of Thailand. It is a perennial crop grown mainly as a source of sugar. The procedure for processing sugar involves harvesting the sugarcane stalks, then shredding them and extracting the sugarcane juice. Raw sugar is produced from the juice and is later refined into white sugar. Thailand produces sugar as an export commodity, the income from which is a source of foreign currency for Thailand and has supported its industrial development. Thailand is the second largest sugar exporter in the world. In 2004, the total export of white and raw sugar was 4.55 million tons, and the total value of exported sugar was 844.48 million US$, or 32.09 billion baht (1 US$ equals 38 baht).

It should be noted that the cost of sugarcane harvesting and transportation constitutes a large portion of Thai sugarcane's total production cost, with the average cost of sugarcane harvesting in Thailand accounting for 66% of the total labor cost, or equivalent to 35% of the total cost. The average cost for sugarcane transportation was 2.79 US$/ton, or 106 baht/ton in 2003 (Office of Agricultural Economics, 2003). Nearly half of the total cost is devoted to harvesting and transportation. Ultimately, both harvesting and trans-
portation costs are determinant factors of sugar’s domestic consumer price and international export value.

The high cost of sugarcane harvesting and transportation is one of the reasons for the reduction in the total amount of Thailand’s sugarcane cultivation. Farmers who have small fields and/or whose fields are located far from a sugar factory tend to abandon sugarcane cultivation. Such farmers have changed their cultivation into other crops that have lower production costs, such as cassava.

The Thai government has made an attempt to reduce this high cost of sugarcane harvesting and transportation. For this purpose, the Office of Agricultural Economics (OAE) established a loading station in Khon Kaen province to facilitate the supply of sugarcane to the sugar factory for all sugarcane farmers, particularly farmers with small acreages. Because most sugarcane farmers do not possess a truck and normally have only a small vehicle, it is difficult for them to transport their products from their farms to the sugar factory by using their own vehicles, instead having to rent a truck and pay the hiring cost for cutting, loading, and transporting. In the operation of the loading station, sugarcane farmers are required to transport their products from their fields to the station by themselves. Since the loading station is located in the neighborhood of sugarcane fields, sugarcane farmers with small acreages could transport their products from their farms to the station by using their own vehicles instead of hiring a truck, thus reducing transportation costs. The sugar factory collects the sugarcane from the loading station and transports it to the processing plant, this process being managed and operated by the sugar factory. The sugarcane farmers have to pay the standard cost of 2.24 US$ (or 85 baht) per ton for the transport of their products from the station to the sugar factory. Supplying sugarcane to the sugar factory via the loading station could reduce the harvesting and transportation costs of sugarcane farmers by around 20% when compared with the traditional system in which the costs include direct delivery from the field to the sugar factory (Paitoon et al., 2001). However, investment in the loading station to cover all regions in the country is expensive, the initial investment in one loading station being approximately 289,474 US$, or 11 million baht. Thus we see that the problem of the decrease in sugarcane cultivation cannot be solved through the use of loading stations alone. The decline in the amount of sugarcane cultivation persists, and has resulted in a reduction of sugarcane volume; approximately 16,668,269 tons were reduced in 2005, while approximately 1,126,370 tons were reduced in 2006 (Office of the Cane and Sugar Board, 2006).

Improper harvesting and/or delay in transportation will result in the crop’s deterioration. When harvested sugarcane has to be left in the field due to a lack of transportation vehicles, the sugarcane’s quality deteriorates significantly, resulting in a decrease in the sugarcane farmer’s income. Deterioration caused by sugarcane being left in the field also leads to a reduction in the amount of sugar produced, thus reducing the income of the sugar factory. This shows that harvesting and transportation efficiency directly influences the income of sugarcane farmers and the owners of sugar factories.

To determine the shortcomings in the harvesting and transportation processes, a field survey and interviews were conducted from March to December 2005 in northeastern Thailand. Data such as field size, distance to a sugar factory, and geographical location of sugarcane plots were measured and collected. Time studies on harvesting and transportation operations were also carried out in December 2005. Analyses using a simple sugarcane harvesting and transportation simulation were performed in order to examine how the proper introduction of chopper-type mechanical sugarcane harvesters could improve the efficiency of the harvesting and transportation system.

II Study site and methodology

1. Study site

The survey was conducted in Udon Thani province in northeastern Thailand. The topography in this region is hilly with steep slopes. Precipitation is about 1200 mm/year and is thus sufficient for rain-fed farming. The temperature ranges from 20 to 38 degrees Celsius year-round. The major crops cultivated on gently sloping fields are sugarcane and cassava, whereas farmers have grown rice for private use in lower areas.

Due to the abundance of sugarcane cultivation in this area, there are 15 sugar factories in the nine provinces of the northeast region, and 3 sugar factories in Udon Thani province. In the crop-year 2005-2006, 3.20 million tons of sugarcane were processed in the 3 factories, representing 21 percent of the northeast region’s total production (Office of the Cane and Sugar Board, 2006).

The study site is located within 102°50’36.0"E-102°56’4.2"E and 16°59’57.6"N-17°5’24.5"N, which corresponds to an area of 10 km by 10 km.

2. Survey methods

General data regarding sugarcane production in Thailand were collected from the Office of Agricultural Economics (OAE) under the Ministry of Agriculture and Co-operatives, and the Office of the Cane and Sugar Board (OCSB) under the Ministry of Industry. The data are useful for examining the general tendencies concerning the amount of annual sugarcane harvested, the amount of sugar produced, and produc-
tion costs as mentioned in the previous section. However, the shortcomings in the local sugarcane supply process cannot be clarified based directly on this information.

The first interview from sugarcane specialists and farmers was performed in March 2005; along with the survey, the fields were examined after the harvesting season.

In July 2005, sugarcane farmers and workers were interviewed. Interview items included the farmer's personal history, crop type, sugarcane variety, acreage under cultivation, history of cropping patterns, agricultural machinery owned, and operating cost and hours of farming operations. Additional information regarding the sugarcane plot was collected via questionnaire. The items used in the interview section of the survey are listed in Table 1.

The field investigation was performed from August through December 2005. Two topographic map sheets on a 1:50,000 scale published by the Royal Thai Survey Department (Sheet numbers: 55421 and 554311) and twelve aerial photos on a 1:25,000 scale were used to locate fields in the surveyed region. Since the characteristics of the field and the distance of the field from the factory affect the costs of harvesting and transportation, a GPS receiver and laser distance meters were utilized to further determine the fields' locations and to measure the plots' dimensions. We conducted our field investigation in collaboration with the staff of the K sugar factory, one of the factories located in the study site. The daily milling capacity of the K sugar factory that had been registered with the OCSB was around 10,211 tons of sugarcane (Office of the Cane and Sugar Board, 2006).

In December 2005, time studies regarding the harvesting and transportation operations were also carried out. The cutting speed of the chopper and the time required for mechanical harvesting operations (consisting of the turn around time of the chopper and truck at the head land and time for truck changing), as well as the time required for the truck's trip to the factory and time spent at the factory were measured.

The total number of farmers who responded to the questionnaire was 117. All of them usually supplied sugarcane to the K sugar factory. The dimensions of 248 sugarcane plots were measured. The total area of these fields was 617.76 ha or 3,861 rai (rai is an area unit of Thai, and 1 rai equals 0.16 ha or 1,600 m²).

### III Results of interview and field investigation

1. **The present state of sugarcane harvesting and transportation in Thailand**

This section discusses the present state of sugarcane harvesting and transportation based on the results of the field investigation which was conducted in the sub-district (Tambol in Thai) of 3 districts (Amphoe in Thai): Kumphawapi, Nong Saeng, and Non Sa-At. Since the surveyed areas were located near the sugarcane processing plant, sugarcane was site's the main product. The study measured the distance of the road connecting the investigated field and the K sugar factory. The investigated sugarcane fields were distributed in a range of 0.1 to 22 km from a sugar factory.

1. **Cultivation data**

Five varieties of sugarcane were cultivated in this region. K88-92, a main sugarcane variety of northeastern Thailand, had the largest cultivation acreage, occupying 67% of the total surveyed area. This variety was found in every village surveyed.

The area of newly planted sugarcane occupied 62% of the total sugarcane production area in the site. Meanwhile, the percentages of the areas cultivating first stubble, second stubble, and third stubble were 33%, 4%, and 1%, respectively.

2. **Supply of sugarcane**

Table 2 shows the amount of sugarcane unloaded daily at the K sugar factory. This table shows the four types of truck operating within the area. The average loading capacity of small 6-wheeled trucks (110 hp or 82 in kW) was 10 tons, while average loading capacity of larger 6-wheeled trucks (135 hp or 101 in kW) was 15 tons. These two types of 6-wheeled trucks usually transport whole stalk sugarcane. Meanwhile, the average loading capacity of 10-wheeled trucks was 24 and 15 tons when delivering whole stalk sugarcane and chopped sugarcane, respectively. In the case of a 10-wheeled truck with a trailer, the average loading capacity was 42 and 28 tons when delivering whole stalks and chopped sugarcane, respectively. Approximately 60% of the sugarcane processed daily at the K sugar factory was transported by 10-wheeled trucks.

Manual harvesting is still the primary harvesting mode in Thailand, and is also predominant in the present study site. Field survey results showed that approximately 89% of the sugarcane processed daily at the K sugar factory was manually harvested, while the remaining 11% was mechanically harvested.

Since burnt sugarcane can be more easily cut by

<table>
<thead>
<tr>
<th>Item asked the farmers</th>
<th>Measured data of each plot</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farmer name</td>
<td>Field size</td>
</tr>
<tr>
<td>Home address</td>
<td>Variety name</td>
</tr>
<tr>
<td>Number of plot</td>
<td>Crop type</td>
</tr>
<tr>
<td>Type of irrigation</td>
<td>Planting date</td>
</tr>
<tr>
<td>Rate of fertilizer</td>
<td>Field address</td>
</tr>
<tr>
<td></td>
<td>Distance to a sugar factory</td>
</tr>
<tr>
<td></td>
<td>Geographic information location; such as latitude, longitude, and altitude</td>
</tr>
</tbody>
</table>
workers, it is easier to find workers to cut burnt fields; 53% of the total harvested sugarcane of Thailand was burned in 2005 (Office of the Cane and Sugar Board, 2006). The same tendency was found in the study area; the percentage of harvested sugarcane burned prior to manual cutting was approximately 50% as shown in Table 2.

The K sugar factory processes both whole stalks and chopped sugarcane and has 10 unloading lines. There is one priority line specially provided for trucks unloading chopped sugarcane. In this unloading line, the waiting time was shorter than those in other lines. Since unloading chopped sugarcane can be finished relatively quickly, those trucks carrying chopped sugarcane can more quickly return to the fields to be reloaded. Trucks operating in conjunction with a chopper received the highest unloading priority in order to reduce the chopper's pause time. This indicates that the sugar factory seeks to support mechanical harvesting.

(3) Mechanization of harvesting and transportation

When the mechanization levels of the farmers were compared, large-scale farmers were found to possess mechanical harvesters, four-wheeled tractors, trucks, and other machinery (Fig. 1 (a)), while the small-scale farmer's owned a relatively minimal number of machinery.

Though few data exist regarding the number of harvesting machines operating in Thailand, we found that in our survey area, 6 mechanical sugarcane harvesters, the chopper type, were working, and that they were owned by 3 large-scale sugarcane farmers. The chopper-type mechanical sugarcane harvester usually operates in concert with trucks. Sugarcane stalks are cut into 12-14-inch billets and loaded, by using a loading elevator mounted on the chopper, into a truck that keeps its orientation parallel with the chopper (Fig. 1 (b)). When sufficient numbers of trucks are available, the chopper can harvest the field continuously. Our survey found that there were 38 units of 10-wheeled trucks, and 8 units of 10-wheeled truck paired with trailers, which were owned by the 3 large-scale sugarcane farmers.

Approximately 97% of the farmers in the study site do not own harvesting machines, with most not having adequate numbers of manual workers and trucks. Thus, they usually outsource the harvesting and transportation processes by hiring middlemen who provide labor and machinery. Two of three large-scale sugarcane farmers would work as middleman when they had finished harvesting their own fields. The field survey found that it was difficult for farmers to find

### Table 2 Daily amount of unloaded sugarcane at the K sugar factory classified by truck type

<table>
<thead>
<tr>
<th>Type of truck</th>
<th>Type of harvesting method</th>
<th>Number of unloading times Green</th>
<th>Burned</th>
<th>Daily amount of sugarcane, ton Green</th>
<th>Burned</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small 8-wheeled truck (110 HP)</td>
<td>Manual</td>
<td>28</td>
<td>20</td>
<td>287.28</td>
<td>208.24</td>
</tr>
<tr>
<td>10-wheeled truck</td>
<td>Manual</td>
<td>117</td>
<td>166</td>
<td>2,849.76</td>
<td>3,873.70</td>
</tr>
<tr>
<td>10-wheeled truck with trailer</td>
<td>Manual</td>
<td>36</td>
<td>50</td>
<td>1,506.93</td>
<td>2,104.40</td>
</tr>
<tr>
<td>10-wheeled truck</td>
<td>Mechanical</td>
<td>87</td>
<td>1</td>
<td>1,333.79</td>
<td>4.26</td>
</tr>
<tr>
<td>Big 6-wheeled truck (133 HP)</td>
<td>Manual</td>
<td>14</td>
<td>7</td>
<td>206.67</td>
<td>96.21</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>282</td>
<td>244</td>
<td>6,184.43</td>
<td>6,286.81</td>
</tr>
</tbody>
</table>

Fig. 1 Mechanization status in the study site
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Table 3 Number of plots at various field size and distance to the K sugar factory

<table>
<thead>
<tr>
<th>Field size, ha</th>
<th>Distance(^1) to sugar factory, km</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5&lt;Distance(\leq 10)</td>
<td>&gt;10</td>
</tr>
<tr>
<td>(\leq 1.6)</td>
<td>16 (3(\textsuperscript{m}))</td>
<td>57 (9)</td>
</tr>
<tr>
<td>1.6&lt;Field size(\leq 3.2)</td>
<td>26 (12)</td>
<td>32 (14)</td>
</tr>
<tr>
<td>&gt;3.2</td>
<td>12 (11)</td>
<td>25 (23)</td>
</tr>
<tr>
<td>Total</td>
<td>54 (26)</td>
<td>114 (46)</td>
</tr>
</tbody>
</table>

\(^1\) Distance to sugar factory measured in this study is distance of road connected between investigated field and the K sugar factory
\(^m\) Figures given in parentheses are the percentage of area corresponding to accumulated plots.

Cutting workers, particularly for green sugarcane harvesting, while it is not difficult to hire mechanical sugarcane harvesters and trucks from middlemen. The hiring of mechanized resources for the harvesting and transportation processes is becoming a common practice.

The data regarding workers actually engaged in harvesting showed that the hiring cost of mechanical harvesting was less than that of manual harvesting. The data obtained from the sugarcane workers showed that the cost of manual harvesting and loading burned sugarcane was around 148 US$/ha, or 900 baht/rai, while in the case of green sugarcane, the hire cost was around 197 US$/ha, or 1,200 baht/rai. Meanwhile, the hiring cost of mechanical harvesting was about 140 US$/ha, or 850 baht/rai for both burned and green sugarcane.

In addition, the survey revealed the sugarcane harvesting field capacity of the study area. The results confirmed that when using a mechanical harvester, harvesting can be completed within a much shorter time than would be required by manual harvesting. An average field capacity for mechanical harvesting was 45 tons per hour. Meanwhile, the manual harvesting, cutting the sugarcane at the bottom of stalks and removing some of the tops, carried out by one cutting worker was 1 ton and 2.5 tons per day in an unburned field and a burned field, respectively. In the case that only the bottoms of the stalks are cut, the cutting rate performed by one worker was 5 tons per day.

2. Local constraints of mechanical harvesting in Thailand

A cost comparison clearly indicates that mechanical harvesting is likely to be a key in reducing sugarcane production costs, since the survey discovered that the hiring cost of a mechanical sugarcane harvester was lower than the hiring cost involved in manual harvesting. Also, mechanical harvesting was encouraged by the sugar factory by giving priority to the line for unloading chopped sugarcane. However, local constraints such as field characteristics and transportation distance are usually considered in order to determine whether or not mechanization is worthwhile. Thus, field characteristics and the distance to the K sugar factory are discussed in the following.

All investigated fields were classified into nine datasets depending on their field size (3 levels) and their distance to the K sugar factory (3 levels). In regard to field size, since “rai” is a common Thai area unit (1 rai equals 0.16 ha) very familiar to Thai farmers and the Thai people, this unit of area was used in our field surveys in order to avoid confusion on the part of the sugarcane farmers and workers. The criteria of field size given in Table 3 was then classified into less than or equal 10 rai (or 1.6 ha), more than 10 rai but lesser than or equal 20 rai (or 3.2 ha), and more than 20 rai.

The field investigation results showed that 46% of the investigated plots were located at distance of 5 km to 10 km from the K sugar factory. The percentage of plots located at a distance of less than 5 km from the K sugar factory was 22%, while the percentage of the investigated plots located at a distance more than 10 km from the K sugar factory was 32%. The average distance to the factory was around 10 km, with a standard deviation of around 5 km.

In addition, the greatest percentage of field size was less than or equal to 1.6 ha (or 10 rai), comprising 128 plots or 52% of all plots in the study site (Table 3). The average in field size was around 2.5 ha (or 16 rai), with a standard deviation of around 2.3 ha (or 14 rai). It could be concluded that the sugarcane fields in the study site are generally small. This is an exceptional characteristic of sugarcane cultivation in Thailand when compared with other sugar exporting countries such as Brazil, South Africa, and Australia, where very large fields are cultivated. Accordingly, the difficulty involved in working and in managing the harvesting and transportation resources in many small fields might lead to Thailand’s high cost of sugarcane harvesting and transportation.

However, it is possible that the use of mechanical harvesters be expanded in the study site, since the percentage of the area in which the field size is greater than 3.2 ha (or 20 rai) was 47%, while the percentage of...
the area in which the field size is less than 1.6 ha (or 10 rai) was around 22%, as shown in Table 3.

In addition, the interview data showed that the sugarcane farmers having relatively small fields usually contracted the delivery of their products to the sugar factory located near their fields. Meanwhile, the sugarcane farmers owning larger fields produce a sufficient amount of product to support delivery to more than one sugar factory. They usually deliver their products according to the contract that they sign with each sugar factory. The allocation of their products to each sugar factory depends on the support given to them by each factory.

3. Incentives for mechanical harvesting

The use of mechanical sugarcane harvesters in green sugarcane harvesting presents obvious environmental benefits. Green sugarcane harvesting will avoid air pollution, and will assist in moisture retention as well as help preserve soil fertility (Braunbeck et al., 1999). As well, green harvesting will also help to decrease the sugarcane's loss of quality because burning the sugarcane prior to its harvest, as is usually found in manual cutting, results in the loss of sucrose content (Rungrat et al., 2000). Thus, the OCSB in cooperation with sugar factories seeks to promote green harvesting in Thailand by the development of a pricing system in which a lower price is paid for the burned harvested sugarcane than for the green harvested sugarcane. Around 0.53 US$ (or 20 baht) will be deducted from each ton of burned sugarcane.

In addition, the price of green harvested sugarcane in the study site will be increased 1.05 US$ (or 40 baht) per ton from the basic price announced at beginning of each harvesting season. The difference in price between green and burned harvested sugarcane, around 1.58 US$ (or 60 baht) per ton, is intended to stimulate the use of mechanical sugarcane harvesters in the study site. This combined with the lower hiring cost of mechanical sugarcane harvesters and the relatively higher price of green-harvested sugarcane could encourage investment in mechanical sugarcane harvesters and/or the expansion of their use.

4. Expectation of an efficient sugarcane delivery

Harvesting and transportation processes are associated with 3 groups: the sugarcane farmer, the machinery owner, and the sugar factory. Based on interviews with farmers, all the sugarcane farmers in our study site want to deliver their harvested sugarcane to a reception area at a sugar factory in a timely way. They do not want their harvested products to remain in the fields while awaiting transportation, or to be left in front of the sugar factory before unloading, because the sugarcane will be priced after it has been unloaded at the process line.

In addition, effective management planning of the many small sugarcane fields is also in the best interests of the sugar factory and the machinery owner. Based on interview data, decisions regarding regional planning are not easy for them to make alone, because they have to decide which fields are ready to harvest, how much and which mechanized resource are available, and when the operation should be completed. Thus, the sugar factory and the machinery owner need information and tools that assist in the decision-making process.

IV Analytical results of the simulation

1. Simulation of mechanical sugarcane harvesting and transportation

To confirm the possibility of further mechanization and its effect on the profitability of sugarcane harvesting and transportation, models simulating the mechanical sugarcane harvesting and transportation system in Thailand were developed based on Singh and Abeygoonawardana (1982). For this simulation, the results obtained from our time studies and survey of trucks were used, which are listed in Tables 4 (a) and 4 (b). The primary purpose of the simulation was to determine the most effective way to introduce mechanical sugarcane harvesters for improving the efficiency of the harvesting and transportation system.

Field characteristics such as field size, row length, amount of sugarcane, and distance to the sugar factory were used as inputs of the mechanical sugarcane harvesting and transportation simulation introduced below.

This simple simulation calculates the truck loading time, and the time necessary for the truck to arrive at the field, as explained below. Calculations concerning the deterioration time of the harvested sugarcane will be reported in a forthcoming paper.

The truck loading time \( TL_T \) is the time in minutes required to fill one truck. It can be given by

\[
TL_T = \left( \frac{COT}{AOS} \right) \left( \frac{RL \times 10000}{RS \times CSP} \right) \left( \frac{RL}{CSP + TTT} \right) + \frac{TTC}{60}
\]

where \( COT \) is the capacity of the truck in tons, \( RL \) is the row length of the field in m, \( RS \) is the row spacing of the crop which is set equal to 1.5 m, \( AOS \) is the total amount of sugarcane in the field in tons, \( FS \) is the field size in ha, \( CSP \) is the average cutting speed of the chopper in m/min, \( TTT \) is the turn around time of the chopper and truck at the head land in min, and \( TTC \) is the time required for truck changing in seconds.

Prior to transport, it was found that delays occurred when loaded sugarcane had to be adjusted in the truck. Therefore, the time for adjustment of the harvested sugarcane in the truck was also taken into consideration. The sugarcane adjustment consumed
approximately 5 and 10 minutes for a 10-wheeled truck and a trailer, respectively.

A round trip time involves the travel time from the field to the factory and the return time, as well as the amount of time the truck waits in a queue at the factory, and the time for reception and unloading of sugarcane at the factory. Thus, the cumulative time for a truck to return to the field in minutes, $TRTR$, is given by

$$TRTR = \left(\frac{DMF}{ASF} + \frac{DMF}{ASE}\right) \times 60 + DPT + BDT + (WTM + TRO), \tag{2}$$

where $DMF$ is the distance from the field to the sugar factory, km; $ASF$ is the average speed of a loaded truck in km/h, $ASE$ is the average speed of an empty truck in km/h, $DPT$ is the driver's personal time per truck per round trip in min, $BDT$ is the time spent on refueling of the truck per round trip in min, $WTM$ is the time the truck spends waiting in a queue at a sugar factory in min, and $TRO$ is the time for reception and unloading operations at a sugar factory in minutes. The latter term includes the waiting time required to weigh a truck loaded with delivered sugarcane, the time of the sampling test to determine the quality of the delivered sugarcane, the unloading time, and the time required to weigh an empty truck.

Based on these derived equations, further analyses were carried out in order to indicate that the field capacity of the chopper depends on the condition of the field where it is performed, and the number of trucks required for working with it. The details and results of these analyses are reported in the following sections.

2. Influence of row length on the field capacity of the chopper

In order to understand the chopper’s field capacity underlying the variation in the sugarcane field’s row lengths, the truck loading time, varying the values in row length from 20 m to 250 m, were calculated for given field sizes (1.6, 3.2, 4.8, 6.4 ha). The results showed that shorter truck loading times could usually be obtained when the chopper operated on fields having longer row lengths (Fig. 2) since fields with shorter row lengths required the truck and chopper to turn more frequently at the ends of the rows.

In Fig. 2, the results obtained from each given field sizes show the same tendencies. The truck loading time tended to decrease with the increase of row length from 20 m to 100 m. A slight decrease in the truck loading time was observed when the row length was longer than 100 m. When the chopper operated on a row length longer than 160 m, the truck loading time became lower than 30 minutes. A further increase in row length done longer than 160 m did not result in a significant reduction in truck loading time. Hence, in order to allow the effective operation of the chopper, row length should be equal to or longer than 160 m. This result was consistent with our interview results obtained from the large-scale sugarcane farmers who had much practical experience in sugarcane mechanization at the study site since 1981.

Therefore, high capacity operation of choppers in the study site is feasible, even though plots whose row length is between 40 m and 80 m are common (Fig. 3). The survey results showed that the accumulated area of fields whose row length is longer than 160 m was approximately 316 ha (or 1,975 rai) or 51% of the total area surveyed.

3. Influence of the number of trucks on the field capacity of the chopper

In order to examine the influence of the number of trucks on field capacity of the chopper, the number of trucks required for working with the chopper was determined based on the following assumptions:

1. The amount of working time during a single day is generally assumed to be 12 hours.
On a particular day, one chopper is allocated to one field. It could not be moved to operate on other fields during that day. This reflects the customs of this region.

The truck loading time (TLT) and the cumulative time for the truck to return to the field (RTR) were calculated for each investigated field based on the data acquired by the field investigation. The number of trucks (NTRUCK) required for working with a chopper waiting for a truck could be determined by the following expression:

\[ N_{TRUCK} = \frac{TLT + TR}{TLT}, \quad (3) \]

where the value of \( N_{TRUCK} \) should be rounded to the highest integer.

The chopper's cutting time in one day (CT) in minutes could be determined by using the following expression:

\[ CT = N_{TRUCK} \times TLT \times RTRIP, \quad (4) \]

where \( RTRIP \) is the number of round trips per day that a truck makes. In this calculation, number of round trips was set at twice a day. This assumption is made based on interviews with truck operators at the study site.

The results showed that when the chopper operated on the investigated fields, the average number of trucks (NTRUCK) required for working with the chopper was 6 units of 10-wheeled trucks per plot. Plots of between 0.16 and 3.2 ha and having an average transport distance of 10 km to the K factory
could be harvested and transported completely in one day by using 6 units of 10-wheeled trucks per plot. The number of plots in this size range was 160.

On the other hand, fields of 1.6 and 14.4 ha in size and 7 km distant from the K factory on average could not be harvested in one day by using 6 trucks. The number of plots in this category was 88.

An average percentage of the chopper's cutting time in relation to the total working time was 50%, when 6 trucks made two round trips a day. The chopper's operation had to be stopped for half a day, though there were still some remaining sugarcane stalks. This shows that the cutting time of the chopper was restricted by the number of trucks and the number of possible round trips. Two possibilities exist for extending the chopper's cutting time per day: (1) increasing the number of trucks per plot and/or (2) increasing the number of round trips on such plots, as expressed in eqn. (4).

Figure 4 shows influence of the number of trucks on the chopper's field capacity. When a field having a yield of 400 t and having 127 m rows, located 7 km from the sugar factory, was considered, a minimum of 5 trucks (\(N_{\text{TRUCK}}\)) was needed to eliminate the pause time of the chopper waiting for a truck. The chopper's total cutting time was 326 minutes. This cutting time was 45% of the number of daily working hours. It was found that a greater numbers of trucks allowed the chopper to operate longer in the course of a single day. For example in Fig. 4, when the number of trucks were increased to 11, the cutting time of the chopper would increase to 717 minutes or nearly 100% of the number of working hours per day. This would decrease the amount of time required to complete the harvest of this plot from 3 to 2 days.

V Discussion

The results obtained in the previous subsection showed that the efficiency of the chopper could be improved by increasing the number of trucks used. However, when the total process is considered, an increase in the number of trucks will result in an increase in the number of trucks waiting to unload at the sugar factory, and therefore in an increase in waiting time. A longer waiting time will not only lead to a reduction of work efficiency but also to a decrease in the weight and quality of the delivered sugarcane. In addition, it will delay the return of the trucks to fields, and reduce their availability to transport sugarcane to the factory, as well as causing chopper downtime. Thus, an excessive number of trucks in the harvesting and transportation system will decrease the number of possible round trips per day that the trucks can make. The sugarcane purchasing database of the K factory showed that most trucks could transport loads only once a day. The percentage of days in which the trucks transported cane once a day was 72% of their total delivery days, while the percentage of delivery days in which the trucks transported the harvests twice and three times a day was 23%, and 5% respectively. These facts indicate that an increase in the number of trucks was not an effective solution when the improvement in the efficiency of the sugarcane harvesting and transportation system as a whole was considered. Accordingly, how to best utilize the existing availability of trucks within the surveyed region is of importance. Proper determination of the optimum truck number needed for the sugarcane fields is necessary to support the efficient use of the chopper. Thus, the effective allocation of trucks for improving the efficiency of the sugarcane harvesting
and transportation system should be considered a significant issue for further research.

However, truck allocation for sugarcane harvesting and transportation in Thailand is complicated by the facts that field size of sugarcane cultivation in Thailand is commonly small as well as by the ownership structure of the sugar industry. Large differences exist between the Thai sugar industry and those of other sugar exporting countries. As our field investigation found, the average size of the sugarcane plots in the study site was 2.5 ha. Also, there is separate ownership of each sector of the Thai sugar industry including growing, harvesting and transporting, and mill processing. Only 3% of the sugarcane farmers in the study site own their own farms and mechanical harvesters. In contrast, in Australia and South Africa, sugarcane farms and mechanical harvesters are privately owned and average between 20 and 200 ha in size. In Brazil and the United States, most land under sugarcane cultivation is owned or controlled by the sugar factory (Higgins et al., 2007). These facts make truck allocation for efficient sugarcane harvesting and transportation in Thailand more difficult to achieve than in other countries.

As described, in Thailand three groups are involved in the harvesting and transportation processes: sugarcane farmers, the owners of mechanized resources, and the sugar factories. Each has its own needs regarding these processes. Both the owners of mechanized resources and sugarcane farmers would like to minimize the number of days required to harvest the fields, and the truck owners would also like to minimize the trucks' total traveling distance in order to reduce fuel costs. The sugarcane farmers and sugar factories want to minimize the deterioration time of the harvests. These facts clearly indicate the individual needs of each participant in the chain concerning their quests for further efficiency. Therefore, truck allocation for improving the mechanical harvesting and transportation system in Thailand should be considered together with input from the groups involved. Any solution should consider the social dimensions in order to determine an appropriate profit distribution.

VI Conclusions

This study revealed the possibility of the use of mechanical harvesting to reduce the cost of sugarcane harvesting by around 8 US$ per ha when compared with manual harvesting using burned cutting, and 57 US$ per ha in the case of green cutting. As well, the mechanized operation of green sugarcane harvesting will result in an increase in sugarcane farmers' profits, because a higher price for green harvested sugarcane than for burned harvested sugarcane, around 1.58 US$ (or 60 baht) per ton, was provided by the OCSB in cooperation with the sugar factory in the study site. These benefits of mechanization could encourage investment in mechanical sugarcane harvesters and/or the expansion of their use in the study site.

It was indicated that the field capacity of the chopper depends on the condition of the field in which it performs. The simulation result (Fig. 2) was consistent with our interview results. In order to allow the chopper to operate effectively, row length must be equal to or longer than 160 m. Thus, high capacity operation of the chopper in the study site is feasible, because the survey results showed that the accumulated area of the fields whose row length is longer than 160 m was 316 ha or 51% of the total surveyed area.

The number of trucks on in relation to the chopper's field capacity can increase or decrease the number of operating days required to harvest a field. However, an excessive number of trucks used in the harvesting and transportation system will cause a decrease in the number of round trips per day that trucks can make.

In consideration of the current availability of trucks within the surveyed region, determining the optimum number of trucks needed for the sugarcane fields is vital to allow efficient use of the chopper. However, truck allocation aimed at improving the efficiency of the Thai mechanical sugarcane harvesting and transportation system should be considered together with input from the groups involved. The details of such a planning process will be proposed in a future study.

References


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研究論文
タイ国におけるサトウキビ収穫、運搬システムの改善のための機械化について
－ウドンタニ県におけるケーススタディー－
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要 旨
タイ国でのサトウキビ生産では、生産経費に対するサトウキビの収穫作業経費の占める割合が高い現状にある。よって、総経費の削減を図るには、収穫作業プロセスの分析から問題点を抽出する必要がある。この目的で、タイ国東北部ウドンタニ県において、問題点抽出に必要な情報収集を目的として調査研究を行った。調査結果の分析により、機械化収穫により、火入れしたサトウキビの手収穫に比べて8 $/ha、火入れしないサトウキビの手収穫に比べ57 $/haの経費削減が可能との結果を得た。さらに、サトウキビ収穫作業の簡易なシミュレータを開発し、実際の時間測定結果を利用して検討した結果、チョッパー型サトウキビ収穫機の性能は、圃場条件とその圃場に割り当てられた輸送用トラックの台数に依存することが判明した。この地域の圃場は比較的小規模であるが、収穫機を効率的に運用するために必要なサトウキビ列長を160 mとした場合、調査地帯のサトウキビ栽培面積の51%，316 haがこの条件を満たしており、機械化により効率向上が地域の約半分の面積で達成できる可能性を確認できた。しかし、利用できるトラックの制限は、機械収穫・運搬性能に大きく影響していた。また、トラックの圃場への割り当て計画は、サトウキビ生産に関係しているサトウキビ農家、製糖工場、トラック所有者の収益配分にも影響することが分かり、利益配分を考慮した配分計画法が必要であると結論した。

キーワード：サトウキビ、収穫、運搬、最適化、タイ国

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