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Land consolidation of small-scale farms in preparation for a cane harvester

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ABSTRACT

The cane cultivation areas of certain countries are primarily composed of small-scale farms. To adopt harvesting machinery efficiently, consolidating these small plots is essential. However, the decision to plough out cane ratoon to synchronize the cultivation process in consolidated land area is complicated because the plots have different cane ages and different ownerships. To address this problem, we develop a mathematical model and a heuristic method based on the greedy algorithm to create a consolidation and plough-out plan. The solution obtained using the heuristic method differs from the optimal solution less than 1.5% for small cases of 5, 10, and 15 cane plots and requires less computational time. The proposed heuristics, when used to solve large-sized problems, suggest a plan with benefits that are approximately 49.39% higher than those of the conventional unsynchronized method. This approach is likely to facilitate consolidation planning for sugar mills and cane growers, resulting in more efficient harvester utilization.

1. Introduction

The cultivation areas for cane and other crops in certain countries in Asia and Africa belong to small-scale farmers (Piewthongngam et al., 2009). As indicated in Fig. 1, most of the cane growers are small-scale farmers who own less than 1.6 ha. Hence, the decision to cultivate is made in dependently by individuals.

In Thailand and other labour-intensive countries, due to labour shortage, the use of harvesting machinery is becoming more economically attractive. Moreover, adopting the harvester is even more inviting because the machineries are supported by the millers (Kaewtrakulpong et al., 2008). The obstacles in adopting the harvester are the machine cost and the small-scale farm. For the cost of the harvester, millers resolve the problem by encouraging contractors to invest in the machine and provide affordable service to small-scale growers. There seems to be a threshold land area under which it is not economically feasible to utilize the harvester. Making frequent turns and allocating U-turn area to the harvester result in inefficiency (Vorasayan and Pathumnakul, 2014).

Hence, combing connected land plots into a sizable land area makes economic sense. This operation requires preparation of the sugar cane field areas in order to support the harvester. During the tillage operations, the land should be cleared of rocks. It is necessary to prepare a fine tilth before planting in order to obtain the desired row and inter-row profiles. Fields should be laid out in block form to produce longer cane rows and reduce the time lost in turning. Adequately wide headlands for the safe and speedy turning of the harvester and haul out equipment must be provided. Entry and exit from every row must be unhindered. This means that rows must not terminate in a bank or ditch, or in another row. In most instances, this would mean a row spacing of 1.4–1.6 m. Wider row spacing also assists crop lifters fitted to harvesting machines in lifting lodged cane. Row length should suit both the harvester and transport equipment. Row lengths of 200–600 m will result in acceptable performance from most types of mechanical harvesting and loading systems. Ideally, rows in adjacent blocks should be aligned so that the harvester can travel from one block to another without stopping. These land preparations and required operations imply that, for small-scale farms, growers in a connected land area have to synchronize their cultivation processes to efficiently share the harvester.

However, the decision to plough out cane ratoon to synchronize the cultivation process and consolidate land area is complicated because the plots have different cane ages and different

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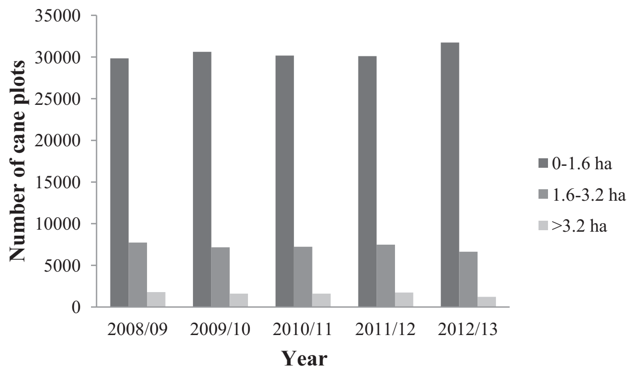

Fig. 1. Number of sugarcane plots by farming scale, for 2008/09–2012/13, in a sugar mill area.

ownerships. Ploughing out cane of different ages results in different opportunity costs for each plot. Most of the time, growers prefer to keep ratoon until it reaches its highest possible economic yield. Hence, an immediate land consolidation is not likely to occur without compensation. If the average cost per ton of cane is USD 22.88, and the average cane production of ratoon 1st–4th are as shown in Table 1, then the opportunity cost of ploughing out cane for harvester prior ratoon 4th will occur (Table 1). Another obstacle is that a decision to consolidate land area is easier with growers who have worked in the same group. Land consolidation has a number of benefits. The consolidation of plots results in the reduction of harvest expenses. Harvesting a large land plot results in a higher harvester utilization rate. This approach reduces the loss of fuel and reduces non-value added activities such as turning, waiting, and machinery adjustment.

This complex decision requires an effective tool to assist decision makers in order to effectively consolidate the land. In this study, we develop a mathematical model and a proposed modified greedy algorithm to address the land consolidation issue of cane growers. The details of the model are presented in the next sections.

2. Literature review

Many previous research works have used a geographic information system (GIS) for zoning in order to partition areas. For example, Pilehforooshha et al. (2014) used the mapping system to appropriately organize cultivation areas according to the requirements for growing each type of plant. Wang et al. (2004) divided groups of areas along watersheds, according to environmental resource, economical, and social factors. Effat and Hegazy (2013) specified groups and chose community locations in desert areas, in order for the development of a new city to be appropriate and sustainable, economically and socially.

In forestry, rigorous research works utilize GIS data to assign land plots to groups. The grouping of adjacent areas is used for planning woodcutting, such as in Nelson (2001); Könnyű et al. (2014) and Könnyű and Tóth (2013). In forestry, adjacent land plots, represented as polygons in GIS, are assigned into blocks of different areas and ages of trees for woodcutting and growing. GIS field data and attributes are converted into input data for the mathematical models to obtain the maximum amount of wood that causes the least amount of damage or effects on the environment. To maximize profits in forestry, the properties of trees that are old enough to be cut, the size of each area, and the area limitations that are acceptable for the environmental concerns or the maximum area as specified by law, are considered (Könnyű et al., 2014). Adjacent areas can be converted from the GIS map into mathematical principles using adjacency constraints as conditions by considering the boundaries between adjacent areas. From the aforementioned, the principles of the adjacency matrix can be applied to grouping adjacent sugar cane fields in the same fashion as planning woodcutting and organizing a factory layout: Combining adjacent plots for sugar cane fields is similar to organizing a layout that requires selecting adjacent departments. However, it differs from woodcutting in that cutting will not be performed in adjacent blocks to satisfy environmental constraints.

When applying graph theory principles to create a network of sugar cane fields from the adjacency matrix, the network has edges between adjacent plots. Each connecting edge has a weight, which is the plough-out cost of the plot. A network that is connected with such a minimum total weighting is called a Minimum Spanning Tree, or MST, which is defined as a subset of the weighted graph without directions specified for the edges (undirected graph), spanning all nodes, with minimum total weight (Rai and Sharma, 2015). It is a widely known method, developed in 1926, to determine a format for connecting electrical wiring using the least amount of wire (Jayawant and Glavin, 2009). The minimum spanning tree method has been widely applied, such as in the energy distribution system problem, to find a spanning tree that causes the energy distribution to be at a minimum in order to reduce loss (Ahmadi and Martí, 2015), and in determining the form of spanning tree with the least weight, for telecommunications network design (Shangin and Pardalos, 2014). MST is also an effective and widely used data-grouping tool (Wang et al., 2014). Examples include grouping information on germs in each given geological area using a graphical method based on MST (Zhou et al., 2015), and grouping complex biological data (Pirim et al., 2015). Grouping using MST assigns weights or edges representing the distances between pairs of points, and removal of edges leads to a clustering of adjacent data (Päivinen, 2005). Combining groups of sugar cane fields for the use of harvesters is similar to the aforementioned maximum/minimum spanning tree problem, with the extra condition that the combined plots must not exceed the capacity of the harvester. This can considered as a Knapsack problem (KP), in which there are a number of objects with different values and weights, and objects must be chosen to maximize the total value, under the constraint that the total weight does not exceed a specified capacity (Jukna and Schnitger, 2011; Wedashwara et al., 2016).

In previous research, both of these problems have been combined as a Knapsack constrained maximum spanning tree problem (KCMST), which was developed by Yamada et al. (2005). There have been research works that use the KCMST concept for

Table 1
The cost of ploughing out for cane ratoon (USD per ha).

Cane ratoon (year)	Yield (ton per ha)	Income (USD per ha)[a]	Ploughing out cost (USD per ha)	5% of ploughing out cost (USD per ha)
1	81.25	1859	3289 = 1430 + 1144 + 715	164
2	62.5	1430	1859 = 1144 + 715	93
3	50	1144	715	36
4	31.25	715	0	0

[a] Obtained from cane cost of USD22.88 per ton.