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Research Paper

A decision tool for maize silage harvest operations

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In forage harvesting, self-propelled harvesters (SPFHs) are the component that most affects the cost of the process because of their high operating costs. Therefore efficient management of the SFPH is essential. There are basically two ways to improve the SPFH performance: to reduce the travelling distance between fields and to design an efficient planning for the transport vehicles. A decision support tool has been developed for silage harvest operations to help farm managers, consultants, and technicians decide which resources they should use to minimise the cost of harvesting operations. The focus is on searching the routes that provide reduced travelling distances for the SPFH by prioritising the harvesting starting date for each farmer, and matching the SPFH and number of trucks to minimise the total cost of the maize silage harvesting cycle. The developed decision support system is compared to a real scenario in a maize harvesting season. Results show that by using the decision support tool, savings of over 15% can be obtained in distances travelled when compared with manual scheduling. Savings over 20% could be made if the restriction of using the starting harvesting dates requested by the farmers was relaxed. Under the conditions tested, if tolerance levels are not considered, the harvesting system is more sensitive to selecting correct transport management approach than to the efficient management of SPFH routes.

1. Introduction

Tight profit margins and increasing of environmental constraints are making the strategic planning of farm production both more important and more difficult (Rotz, 2004). In the last years, dairy farms in north Spain have increased forage production to reduce the use of concentrates and to increase net profit margins. A key factor in cost reduction is the selection of appropriate farm machinery together with a good machinery management, since efficient machinery use has been shown to provide significant cost saving for farmers (Yule, Kohnen, & Nowak, 1999).

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Nomenclature

C	cost of a truck, € h^{-1}
C'	cost of the SPFH, € h^{-1}
Ce	effective field capacity of the SPFH, ha h^{-1}
CT	cycle time for system
CTh	cycle time of a harvester without idle times, h $cycle^{-1}$
CTt	cycle time for a transporter discarding idle times, h $cycle^{-1}$
GIS	geographic information system
HSDT	harvest silage decision tool
K	ratio C′/C
Nd	number of unloads by field
Nt	number of trucks involved in the transport
NP-hard	non-deterministic polynomial-time hard
SPFH	self-propelled harvester $T_{si}(l)$ compliance degree with the requested harvest dates
Ta_{si}	total activity time spent by the SPFH to complete the solution *si*
Th	time to harvest a field, h
Tht,t	time for harvest/transport interaction and transfer, h $cycle^{-1}$
Tt	time for transport travelling, h $cycle^{-1}$
Ttu,a	alignment and unloading time of the transporter in the silo, h $cycle^{-1}$
Uh	SPFH utilisation, busy h h^{-1}
VRP	vehicle routing problem
w_{21}	arbitrary weight

Harvesting forage crops constitutes an activity that demands huge planning effort from agricultural technicians, especially in regions with a large land fragmentation (understood as being large numbers of small fields exploited by each farmer). The harvest operation should be considered as a system where several processes interact (harvesting, displacement between fields, forage transport to the silo, and packing), each of which is also composed of different activities, such as harvesting, alignment with trucks, transport waiting, transport itself, unloading at the silo etc.

In northern Spain farmers typically have a large number of small sized plots (about 1 ha on average), scattered over a wide geographic area. This is also a feature common to several other European regions (Bentley, 1990; Keeler & Skuras, 1990; Thomas, 2006; Van Dijk, 2004). In this setting, the appropriate management of the SPFH routes is critically important to displacement times with regards to the total amount of SPFH activity time. Previous work byEscariz and Bueno (2007) estimated displacement times to be 21.3% of total SPFH activity time under local conditions. In addition, the large number of involved plots also contributes to make route management of SPFH a difficult problem. Identifying the routes which guarantee minimum costs is a vehicle routing problem (VRP). Under these conditions, heuristic algorithms provide good solutions with reasonable computational effort and they have been increasingly used agricultural tasks (Caramia & Guerriero, 2010; Dooley, Parker, & Blair, 2005; Ferrer, Mac Cawley, Maturana, Toloza, & Vera, 2008; Ravula, Grisso, & Cundiff, 2008).

Harvesting operations involve SPFH, trucks for transport, and machinery for silage packing. Use of all of this equipment has to be coordinated and individual components need to be suitably adjustment to field capacity; all in limited time, with a large number of fields to harvest. Bottlenecks within the transport or unloading operations may affect the capacity of harvest operations (Buckmaster, 2006).

In order to reduce costs and increase effective field capacity, optimal interaction between forage harvesters and transport vehicles is required. The processes of harvesting and transportation are intensively interlinked (Busato & Berruto, 2007). Several researchers have studied the importance of determining the right number of transport vehicles used in the harvesting operations. Sokhansanj and Turhollow (2002) stated that transport cost made up between 28% and 36% of the total cost for corn stover collection, depending on the baling system used. Sokhansanj, Mani, and Bi (2004) reported similar values in the harvesting operations of wheat and barley. Other studies have developed applications to help determine the optimum number of trucks (Crossley, 1987) and to reduce transport routes (Tan, Chew, & Lee, 2006). Usually the number of trucks involved in a harvesting cycle is determined by the component that most affects the profitability of the process, i.e. the one that has the highest operating cost (Ravula et al., 2008). With this assumption, other authors established the number of transport vehicles by keeping the forage harvester at full work capacity (Buckmaster & Hilton, 2005; Harrigan, 2003). However, this is not always the best way to minimise cost, as has been pointed by Gunnarsson, Vagström, and Per-Anders et al. (2008). It may be better to keep the harvester waiting for a while rather than adding an extra truck that could spend most of its time inactive.

Our study provides a decision support tool for silage harvesting operations that supplies the order of the fields to harvest that minimises SPFH travelling distances, with special attention given to respecting starting harvesting dates requested by farmers. In addition, once the scheduling has been generated, this tool provides the optimal number of transport vehicles involved in each field, with the aim of minimising the total costs of the silage harvesting cycle. This tool was particularised to the silage maize harvest, but it can be easily adapted to other forage crops (ryegrass, alfalfa …). The impact effect of the variation on the starting harvesting date (tolerance level) was analysed. Because the tool is not a simulation tool, particular emphasis was made on the quality of input data. In order to determine its usefulness a comparison was undertaken between the real situation and the scheduling provided by the decision support system tool.

2. Materials and methods

2.1. *Description of the harvesting process of maize silage*

In north Spain maize silage harvesting is usually contracted by farmers to specialised companies. This process involves the use of SPFH and several truck-mounted dump boxes for transport to bunker silos which may be several kilometres far from the location where the maize is harvested. The cycle includes three parallel machinery operations: harvesting,