Determination of field capacity and yield mapping in olive harvesting using remote data acquisition.

J. Agüera-Vega[1], G. L. Blanco[1], F. J. Castillo[1], S. Castro-Garcia[1], J. A. Gil-Ribes[1] and M. Perez-Ruiz[2]
[1] *Rural Engineering Department, University of Cordoba, Edificio Leonardo da Vinci. Campus de Rabanales, Ctra. Nacional IV, km. 396, 14014 Córdoba, Spain.*
[2]*Aeroespace Engineering and Fluids Mechanics Department. Agroforestry Engineering Area. University of Sevilla. Ctra. Sevilla-Utrera km 1, 41013 Sevilla, Spain.*
jaguera@uco.es

Abstract

Sensors, communication systems and geo-reference units are required to achieve an optimized management of agricultural inputs with respect to the economic and environmental aspects of olive groves. In this study, three commercial olive harvesters were tracked in Spain and Chile using remote and autonomous equipment to determine their time efficiency and field capacity. An experimental methodology for analyzing the data to determine the field capacity and efficiency is proposed, which, along with a conventional methodology, was used to analyze the data to determine field capacity and efficiency. The results of both methodologies are compared to validate the suitability of the experimental methodology. Furthermore, a yield monitor was developed and evaluated using one of the tested olive harvesters. The results show that yield monitoring of olives is possible, but further research is needed to achieve a more reliable methodology.

Key words: Yield mapping, harvester, field capacity, olive growing.

Introduction

Olives are the main woody crop in Spain. Olive orchards cover 2.5 Mha, of which 93% is dedicated to oil olive production (MAGRAMA, 2011). Most of the olive orchard area (~76%) is currently planted according to the traditional model: 2, 3 or 4 trunks per tree and wide spacing between trees. However, 24% of the area presents a major challenge to mechanized operations due to steep slopes. Only 56% of the area is considered suitable for mechanization under traditional orchards (AEMO, 2012). Cropping olives for oil has traditionally been performed in the Mediterranean basin. However, in the last decade, this practice has spread to other countries such as Chile, where it increased from 5000 ha in 2003 to 15000 ha in 2011 (MINAGRI, 2012).

Since the trunk shaker, no new harvesting systems have been developed for olives (Gil-Ribes et al, 2009). Thus far, canopy shaker systems have been tested in traditional olive oil orchards in Spain. This harvesting method is characterized by a high amplitude and low frequency applied directly to fruit-bearing branches (Gil-Ribes et al, 2011).

Optimum machinery management is considered one of the main factors in making olive orchards more profitable and environmentally sustainable. Overall, precision agriculture, particularly precise vehicle tracking systems, is considered essential to reach this objective. These systems can avoid travelling over long distances to be on-site during operations in olive tree fields.

The use of DGPS technology within an orchard with large trees can be a problem due to GPS outages under the tree canopy (Heidaman and Rosa, 2005). Furthermore, yield variabilities in herbaceous crops may arise due to soil characteristics. In olive groves, however, there is great variability among individual trees each year, although mainly in non-irrigated plants (Alamo et al, 2012). In addition, the practice of harvesting in alternate years makes it more difficult to interpret yield maps for fruit trees. A few studies have been conducted on yield mapping in woody crops. For hand-harvested citrus, yield maps (Schueller et al, 1999; Whitney et al, 2001) or canopy size maps (Schumann and Zaman, 2005) have been reported. The monitoring of agricultural field operation is now feasible and may be a useful tool for olive farmers, but as yet, it is not widely used in commercial olive groves.

The aim of this research was to determine olive harvester field performance (field capacity and efficiency) using a remote and autonomous device and to evaluate a yield-monitoring system for a mechanical olive harvester.

Materials and methods

Three commercial olive harvesters were tracked during the olive harvesting seasons of 2010/2011 and 2011/2012 in the southern region of Spain. The harvester models were the following: Colossus (MaqTec, Argentina, straddle harvester), Oxbo 3210 (USA, lateral canopy shaker) and VX7090 New Holland (CNH Global, Belgium, straddle harvester for hedgerows). In addition, a VX7090 harvester was used in Chile on a super high-density olive farm (more than 1000 trees/ha hedgerow trained). The self-propelled MaqTec Colossus straddle harvester was used on a high-density olive orchard (between 200 and 400 trees/ha single trunk trained), “Coto Bajo” located in Guadalcázar (Córdoba). The Oxbo 3210 harvester was used in two configurations: (i) in “Moratalla”, a high-density olive orchard (490 trees/ha hedgerow trained) without a catch frame, and (ii) in “La Mata”, a traditional olive orchard (65 trees/ha, several trunks trained) with a catch frame designed at the University of Córdoba. The catch frame was designed to intercept and manage harvested fruits. The aim was to perform integral harvesting without requiring on-foot operators. The olive harvester model VX7090 was also tracked in a few super high-density olive farms scattered throughout the provinces of Córdoba and Seville.

A modem MTX 65+G, which integrates a GSM (Global System for Mobile communications) GPRS radio system and a GPS receiver with 16 channels, including a range of I/Os and USB/SPI.12C/RS232 ports, was used to track the harvesters. This device sent data in real time every 4 s. Each record contained the machine latitude and longitude, date, time, speed, course, GSM coverage and the status of four digital inputs. One digital input signal was enabled to monitor the status of the hydraulic valve to determine when the shaking system of the machine was working.

In this study, two different methodologies were used to examine the time elements corresponding to labor associated with typical field operations (e.g., machine preparation time, travel time, time to load or unload). The first methodology (conventional) focused on the actions of the vehicle for each time interval. This methodology was designed for manual division and data analysis. The second methodology (experimental) did not take into account the actions of the harvester but instead divided time intervals depending on work parameters such as speed, turning angle, covered distance or status of the digital inputs. The experimental methodology was programmed on a computer using conditions on time elements to determine in which field operation the record would be included. The conditions were imposed on the records, separating the time elements into different groups (working time, turning and displacement and preparation) in the conventional methodology. The experimental methodology arranges the time elements into four groups (movement time, stoppage, parking, unknown time). The first group was split into two subgroups (working time and transport time).

Field capacity and field efficiency were calculated using both methods to test the appropriateness of the experimental methodology for tracking agricultural machinery. Travel times between fields and intervals with insufficient information regarding the harvester were omitted in the calculation process. Potential work parameters were obtained for each type of harvester to determine its appropriateness for each field operation.

A yield monitor was mounted on the Oxbo 3210 with a catch frame, which was operating in a traditional olive orchard. To measure the yield, a load cell was installed in the rear hopper support to measure its weight in each record of the tracking equipment. The load cell was calibrated by simulating the fruit distribution during actual operation. This device provided the accumulated weight of the harvested fruit in real time and when the hopper was unloaded. The load cell was wired to provide an analogical signal to the modem. Weight data were sent with each record and processed after the harvester operation to obtain each tree harvest.

Spatial distribution maps were created using the GIS software SStoolbox (SST Development Group, Inc., Stillwater, OK, USA) by interpolating the harvest of 33 trees using the inverse distance weighted method. To calculate each tree harvest, the transport time from the catch frame to the hopper was taking into account to read the weight from the record in which all of the fruits of each individual tree were inside the hopper. SPSS (IBM, Armonk, NY, USA) and Statistix 8 (Analytical Software, Tallahassee, FL, USA) were used for the statistical analyses.

Results and discussion

Experimental methodology validation

The validation of the experimental compared with the conventional time element methodology was statistically demonstrated using Student´s t-test. The means and standard deviations obtained by both methods were compared, with a field capacity of $\rho=0.82$ and a field efficiency of $\rho=1$ (Figure 1). According to these results, both the conventional and experimental methodologies can be considered appropriate for use in agricultural machinery tracking (Figure 1). Employment of the experimental methodology can improve the work efficiency of technicians by reducing their work time in the field. This methodology allows for satisfactory remote management of agricultural fields. Furthermore, the use of an automatic method to obtain the labor time enables a large amount of data to be processed, thus providing more consistent results. This research promotes many significant benefits as a result of the initial experimental methodology implementation, including the following: (i) reduced travel time because technicians can control the machinery from the management center, (ii) improvements in the immediate accessibility of machinery information because data are available on a web server and (iii) cost savings because these systems improve the work efficiency of technicians. Additionally, work organization can be improved using precision agricultural techniques such as agricultural fleet management to achieve acceptable farm management in economic and environmental terms.

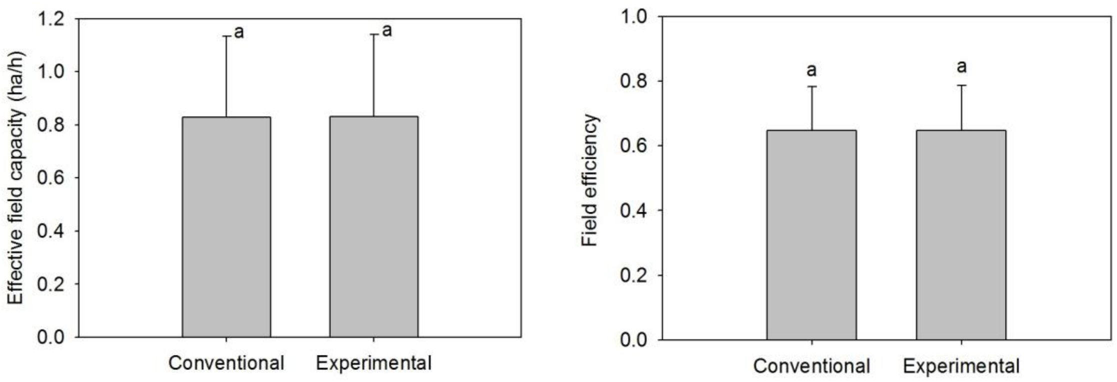

Figure 1. Effective field capacity and field efficiency calculated using the conventional and experimental methodologies. Different letters show significant differences between groups according to Student´s t-test ($\rho < 0.05$).

Data recorded in the 2011/2012 campaign by the New Holland model operating in Chile were used to validate the experimental method. More than 45 full days of work were utilized for the comparison.

Field capacity and efficiency

The New Holland straddle harvester stands out for its high effective field capacity. However, this harvester did not have the best field efficiency. The highest field capacity was achieved by the Oxbo 3210 harvester without a catch frame (Table 1). This high value arose because the Oxbo 3210 is a non-integral harvester, and does not suffer from time losses when unloading fruit. Furthermore, it is smaller in size and weight. The Colossus had low values of effective field capacity and field efficiency, most likely due to the dampness of the 2010/2011 harvesting season in Spain. Some Colossus characteristics had an influence on the low values of the parameters, such as high harvester weight and slow speed during working and traveling. The orchard topography, which was not completely flat, may also have influenced the low values shown by this harvester. In Australia, the Colossus was reported to have an effective field capacity of 0.30 ha/h (Ravetti & Robb, 2010).

Table 1: Effective field capacity and efficiency for tracked olive harvesters. Values are presented as the mean ± standard deviation unless there is only one working day.

Harvester	Harvesting season	Tracking time (h)	Effective field capacity (ha/h)	Field efficiency
Lateral canopy shaker[1]	2010/2011	11	0.36 ± 0.12	0.88 ± 0.12
Straddle harvester[2]	2010/2011	257	0.15 ± 0.05	0.63 ± 0.13
Hedge straddle harvester in Spain[3]	2010/2011	38	0.70 ± 0.1	0.60 ± 0.07
Hedge straddle harvester in Chile[3]	2010/2011	23	0.74 ± 0.2	0.75 ± 0.12
Hedge straddle harvester in Chile[3]	2011/2012	720	0.83 ± 0.3	0.65 ± 0.13
Lateral canopy shaker[4]	2011/2012	1.5	0.36	0.71

[1] Oxbo 3210 harvester without a catch frame operating in a high-density olive grove with a 7 x 3.5 m planting pattern. Fruits fell onto nets managed manually by workers aided with a tractor-pulled shovel.

[2] Maqtec Colossus harvester working in high-density olive groves with a 7 x 5 m to 6 x 2 m planting pattern.

[3] New Holland VX 7090 super high-density olive harvester operating in super high-density olive groves with a 7 x 1.5 m to 3.5 x 1.35 m planting pattern.

[4] Oxbo 3210 harvester with a catch frame operating in a traditional olive orchard with a 13-m quincunx planting pattern. Fruits fell on the catch frame and were then carried, cleaned and stored in a hopper.

Tracked canopy shakers improve the field capacity of traditional harvesting methods to 0.12-0.20 ha/h, as reported for tractor-hitched trunk shakers, or 0.25-0.30 ha/h, as measured for self-propelled trunk shakers. In Australia, a COE L2-E Receiver (3453, Riviera Rd., Live Oak, CA, USA) side-by-side harvester showed field capacities of approximately 0.39 ha/h (Ravetti and Robb, 2010), and in Italy, canopy shakers with a catch frame for high-density olive orchards can harvest 0.25 ha/h (Vieri and Sarri, 2010). A lateral canopy shaker without a catch frame was employed on traditional olive orchards; working around trees canopies, it harvested 0.39 ha/h. This shaker can make crossed rounds to harvest a square-spaced olive orchard, and its effective field capacity is 0.23 ha/h (Gil-Ribes et al, 2011).

Using the Oxbo 3210 with a catch frame, traditional Mediterranean orchards could improve their competitiveness, approaching high grove values. Currently, super high-density orchards are the best choice with respect to harvesting method. Nevertheless, they have agronomic problems and limiting factors that make this olive cropping system unsuitable for other areas. The results show that it is possible to mechanically harvest traditional olive groves and improve yield, which could represent an alternative cropping system for high- and super high-density olive orchards. Furthermore, super high-density groves are less profitable than high-density groves (Pastor and Humanes, 2006; Freixa, 2009; De Gennaro et al, 2012) due to the need for intensive pruning to keep the hedge small enough for the vineyard harvester to work (Pastor et al, 2006), although it currently seems to be the best choice for carrying out efficient mechanical olive harvesting.

Yield mapping

Thirty-three harvested trees from the traditional “La Mata” orchard provided an average yield of 41.24 kg per tree, and a standard deviation of 20.13 kg per tree was found in this study. This large deviation due to the significant variability among trees. The highest achievable yield monitor resolution was obtained because one yield value was assigned to each olive tree. Creating a yield map for traditional olive groves is fundamental in applying farming precision techniques such as variable rate application (VRA) to olive groves.

shows a yield map of olive trees in a traditional orchard. This map presents a gradient of decreasing production from north to south. Based on the author´s assumptions and an expert consultation, this decrease was due to fungal disease attacks, mainly by olive tree peacock leaf spot (Fusicladium oleagineum) and anthracnose in olive (Colletotrichum gloeosporioides). The yield map could be used to optimize the control of fungal disease.

Yield monitoring represents a significant advance in applying precision farming techniques to olive orchards. Results such as these indicate that such technologies could be used on commercial farms. However, further research is required to determine whether these techniques would be profitable for use in olive groves, even on small farms, where economic efficiency must be achieved (Álamo et al, 2012).

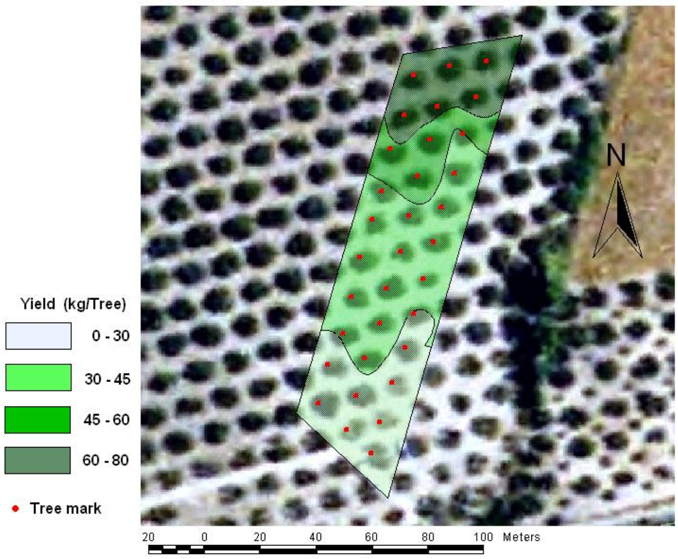

Figure 2. Olive yield map estimate in a traditional orchard system.

Conclusions

The experimental methodology presented herein, which allows for computer data processing, was validated. The methodology also reduced the work time and made fleet machinery management easier, increasing technician work efficiency and providing more reliable results.

The super high-density straddle harvester achieved higher field capacities than the other harvesting methods, but this machine only works in super high-density olive groves. Using a lateral canopy shaker with a catch frame, traditional olive orchard harvesting performance could improve up to high-density olive orchard performance.

Various factors may hinder yield-mapping quality. Differences between trees may mask the spatial variability of the soil and production input usage. Although each tree yield could be discerned in the presence of great variability, further studies are needed to obtain reliable results and to enable commercial yield mapping for olive groves.

Acknowledgments

The authors thank the Ministry of Economy, Innovation and Science of the Andalusian regional government for economic support. We appreciate Soluciones Agrícolas de Precisión S.L. for its collaboration in providing modems and a web server. We are grateful to Todolivo S.L. and DEA S.L., who allowed us to obtain data from their harvesters and to use it in writing this document.

References

AEMO – Asociación española de municipios del olivo, 2012. Aproximación a los costes del cultivo del olivo (Olive growing costs approachment). Report AEMO Seminar. Córdoba, May 2012.

Álamo, S.; Ramos, M. I.; Feito, F. R. y Cañas, J. A. 2012. Precision techniques for improving the management of the olive groves of southern Spain. Spanish Journal of agricultural research 10 (3), 583-595.

De Gennaro, B.; Notarnicola, B.; Rosielli, L. y Tassielli, G. 2012. Innovative olive-growing models: An environmental and economic assessment. Journal of cleaner production 28, 70-80.

Freixa, E. 2009. Estudio comparativo sobre la viabilidad económica de explotaciones de olivar intensivas y superintensivas en Cataluña (comparative research about intensive and superintensive olive farms viability in Catalonia). Last accessed 21/09/2012 in http://www.maqtec.com.

Gil-Ribes, J. A.; Blanco Roldán, G. L.; Castro García, S. 2009. Mecanización del cultivo y de la recolección en el olivar (Olive growing and harvesting mechanization). Andalusian regional goverment. Ministry of agriculture and fisheries. 195 pp.

Gil Ribes, J. A.; Blanco Roldán, G. L.; Castro García, S.; Agüera Vega J.; Muñoz Tejada, R.; Jiménez Jiménez, F.; Solá Guirado R. R.; Jiménez Herrera, B. y García Zamorano, F. 2011. Introducción de un sistema sacudidor de copa para la recolección mecanizada del olivar tradicional de almazara (Canopy shaker system employment for mechanized traditional oil olive orchards harvesting). Expoliva. XV simposio científico-técnico del aceite de oliva. Foro del olivar y el medio ambiente: OLI 37. Jaén May 2011, 7 pp.

Heidman, B.C. and Rosa, U.A. 2005. Integration of sensor data and orchard layout characteristics for real time tree detection. ASAE Paper number: 051071.ASAE, St Joseph, MI, USA

MAGRAMA – Ministry of agriculture, feeding and environment, 2011. Anuario de estadística agraria 2011 (Agricultural statistics report 2011). Last accessed 30/08/2012 in http://www.magrama.gob.es/es/estadistica/temas/default.aspx

MINAGRI – Ministerio de agricultura de Chile, 2012. Estadísticas de frutales (Fruit trees statistics). ODEPA. Last updating 03/02/2012. Last accessed 30/08/2012 in http://www.minagri.gob.cl

Pastor, M.; Hidalgo, J. C.; Vega, V. y Fereres, E. 2006. Viabilidad agronómica y económica de las plantaciones superintensivas en Andalucía (Agronomic and economic viability of superintensive orchards in Andalusia). Last downloaded 21/09/2012 in http://www.aemo.es.

Pastor, M. y Humanes, J. 2006. Poda del olivo (Olive pruning). Moderna olivicultura (5th ed.). Ed. Co-publication Andalusian regional government, Ministry of agriculture and fisheries and Spanish agricultural editorial.

Ravetti, L. y Robb, S. 2010. Continuous mechanical harvesting in modern Australian olive growing systems. Advanced horticultural science 24 (1), 71-77.

Schueller, J. K.; Whitney, J. D.; Wheaton, T. A.; Miller, W. M. y Turner, A. E. 1999. Low cost automatic yield mapping in hand-harvested citrus. Computers and electronics in agriculture 23, 145-153.

Schumann, A. W.; Zaman, Q. U. 2005. Software development for real-time ultrasonic mapping of tree canopy size. Computers and Electronics in Agriculture 47 (1), 25-40.

Vieri, M. y Sarri, D. 2010. Criteria for introducing mechanical harvesting for oil olives: Results of a five-year project in central Italy. Advanced horticultural science 24 (1), 78-90.

Whitney, J. D.; Ling, Q.; Wheaton, T. A. y Miller, W. M. 2001. A citrus harvesting labor tracking and yield mapping 5systems. Applied Engineering in Agriculture 17 (2), 121-125.