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Olive grove equipment technology. Straddling trees: mechanized olive harvests

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Abstract: Today even countries with centuries-old olive growing traditions have to look at the latest, most dynamic, non labor-intensive olive growing systems to abate production costs (notably, harvesting operations) and remain competitive in a globalized market. In particular, the olive growing innovation process is based on a model referred to as "super intensive", whose main advantage lies in highly-efficient mechanized harvesting operations performed uninterruptedly by means of grape harvesters modified to handle olives. This paper reports the results of experimental mechanical harvesting tests in a super-intensive olive cultivation.

1. Introduction

The increased interest by olive growers all over the world in state-of-the-art olive growing systems is accounted for by the need to satisfy the demands of a more and more competitive global market. The shift from classical planting methods to methods calculated for greater mechanization, the main aim being to create modern planting and cultivation systems in which high efficiency translates into increased yields and reduced costs, is a decisive aspect of this scenario. The greatest prospects for development lie in mechanizing the harvest, provided some of the limitations in the sector are rationalized, not least by fitting the trees to the machines, and not simply the machines to the trees as has been done to date. The new challenge for innovation is so-called 'super-intensive' cultivation with a density of up to 2,000 trees per hectare.

The form of training generally thought to fit this new olive growing model best is made up of plants with a central axis slightly taller than 2 m, which can however reach up to 4 m of height, with the final 1.5 m portion flexible enough to avoid damage by the harvester. The length of the lateral branches, which usually depart from the central axis at a height of 0.50-0.70 m from the ground and are oriented in parallel with the row, gradually decreases from the base to the top of the crown (Iannotta and Perri, 2006; Rallo *et al*., 2006). Such form of monocone training must be then modified over time through appropriate pruning operations meant to reduce the size of tree crown and obtain flat surfaces which respond better to the requirements of grape harvesters modified to handle olives. This system normally uses a spacing of about 1.35-1.50 m between trees and about 3-4 m between rows. Within three years of planting, tree crowns literally close the spaces between trees forming a sort of uninterrupted hedge-like row. If appropriately fertilized and irrigated, plants start bearing fruit within two years, maximum three years of planting (Rallo *et al*., 2006). This model of cultivation, which could be conceived as a short-term investment (assuming a life span of 15-20 years for this kind of planting), is based on the assumption that only an integral mechanization of the harvesting operations is likely to guarantee olive growing maximum economic efficiency: the harvesting worksite is, in fact, made up of just two workers, one driving the harvester and the other in charge of the trailer destined to collect and handle harvested olives (Giametta, 2006).

The main advantage is the efficiency that can be achieved with mechanical harvesting using row-

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straddling machines which have long been used with excellent results in grape harvesting, but modified to handle olives. The present study is intended to explore both productivity and work capacity of two of the most commonly used grape harvesters in order to assess their harvesting performance in a series of tests conducted in Andalusia and Catalonia, Spain.

2. Materials and Methods

In Andalusia tests were conducted at experimental olive groves where comparative analyses were jointly carried out in terms of varieties (Thesis A) and density (Thesis B), by the University of Cordoba, IFAPA (Instituto Andaluz De Investigación y Formación Agraría, Pesquera y Alimentaria) and the company Todolivo (De la Rosa *et al.,* 2006 a, b). Thesis A was focused on a comparative analysis between the following varieties: 'Arbequina' (Agromillora selection), 'Arbequina IRTA-I 18', 'Arbosana', 'Koroneiki' and 'Fs-17' (Fontanazza *et al*., 1998; Barranco *et al.,* 2004); all these varieties had the same planting distance of 3.75 x 1.35 m (1975 plants/ha). Table 1 shows the main technical features of the areas tested. Thesis B focused on the comparison of 10 different planting densities (from 780 to 2,581 plants/ha with a spacing from 3.1 m to 5.7 m between rows and from 1.25 m to 2.25 m between trees) in 'Arbequina' (Agromillora selection) olive groves. Both the sizes and technical features of the planting densities under study are reported in Table 2. In Catalonia instead tests were conducted in a five-year old olive grove located in Reus (Tarragona), which had been planted with 'Arbequina' ("Agromillora" selection) olive trees (Tous *et al.,* 2006). The olive grove in question has a 1.50 x 3 m planting distance and a plant density of about 2,500 plants/ha. Table 3 provides the parameters of the plants present on the surface tested.

Grape harvesters and worksites used

The harvesters utilized during the tests, Grégoire G120 SW in Andalusia and New Holland Braud VX

Table 3 - Technical features of the surfaces tested

Treatment	Value
Plant height (m)	2.40
Crown height (m)	1.70
Crown diameter (m)	1.30
Crown volume (m^3)	2.10
Test rows (n)	5.00

Table 1 - Comparison of the average sizes of the five varieties studied

Cultivar	Plant height (m)	Crown height (m)	Crown diameter (m)	Crown volume (m^3)	Tested row (n)
Arbequina	4.00	3.30	2.00	10.16	3
FS-17	4.00	3.30	1.97	9.84	3
Arbosana	4.00	3.30	2.00	10.16	3
Arbequina I-18	4.00	3.30	1.97	9.84	3
Koroneiki	4.00	3.30	1.96	9.75	3

Table 2 - Comparison of the average sizes of the different planting distances studied (cv. Arbequina, Agromillora selection)

Density (p/ha)	Plant height (m)	Crown height (m)	Crown diameter (m)	Crown volume (m^3)	Rows distance (m)	Trees distance (m)	Tested row (n)
780	4.00	3.30	1.96	9.75	5.70	2.25	4
909	4.00	3.30	1.96	9.75	5.50	2.00	4
952	4.00	3.30	1.97	9.84	5.25	2.00	4
1143	4.00	3.30	1.97	9.84	5.00	1.75	4
1203	4.00	3.30	1.96	9.75	4.75	1.75	4
1481	4.00	3.30	1.96	9.75	4.50	1.50	4
1569	4.00	3.30	2.00	10.16	4.25	1.50	4
2000	4.00	3.30	1.83	8.51	4.00	1.25	4
2254	4.00	3.30	1.83	8.51	3.55	1.25	3
2580	4.00	3.30	1.96	9.75	3.10	1.25	3

680 in Catalonia (Fig. 1 and 2), both have a frame with 4WD and engines to work the four wheels, traction on them being controllable to guarantee a wheel lock of practically 90° so that the machine can return on its own tracks using a blocked back wheel as a pivot. Another interesting application is a hydraulic cylinder fitted to each wheel to permit work on slopes of up to 30°. The hydraulic transmission circuit, worked by a diesel engine, is composed of a set of variable flow, rotating piston pumps linked by pipes and auxiliary devices to the tools. The harvesting head is set into the frame so that it is hanging free and can seek its own alignment as required. The olive harvesting device as such consists of arms mounted on the inside near the machine and fitted with vibrating rods to comb and shake the outside of the foliage at between 450-480 strokes a minute (Barranco *et al*., 2004). The Grégoire shaking system has 28 curved beaters in a single block, and the new generation ARC harvesting system is equipped with guaranteed unbreakable, untwistable, moulded picking rods. The New Holland Braud with its unique SDC shaker system uses much the same concept as the Grégoire, but is fitted with 24 rods to work on each individual plant with variable intensity according to the harvesting head's area of contact, using a much more controlled and gradual shaking action (Arrivo *et al*., 2006). As the machines proceed down each row picking the olives continuously as they go, they also intercept the fruit and shift it to storage hoppers. In the Grégoire, the picked olives finish on two sets of plastic scales slightly titled towards the external conveyors, which open up as the tree goes by. The conveyor consists of rubber with crosswise palettes. The Braud, on the other hand, collects the picked olives in soft, food quality polyurethane baskets fitted to two conveyor belts. The conveyors are slightly out of synch with each other so that there is a perfect mutual fit, and the system runs at a rate inversely proportional to the machine's travel speed

Fig. 1 - Grégoire G 129 SW and its shaking system.

Fig. 2 - New Holland Braud VX 680 and olive harvesting device.

so that the baskets remain stationary in relation to the ground surface; perfect pick up without any spilling is ensured. Hoppers store the picked olives, and the crop is only off-loaded directly onto a truck or trailer when the rows are very long and the on-board hopper space insufficient. The back tilting hoppers can hold up to 3,500 kg. Just below the top, there are augurs to keep the hopper's load level and make emptying easier.

To avoid the most remote risk of pollution by mineral oil, the augurs are powered by electric motors. Crop quality is additionally ensured by two upper and two lower fans on the conveyors to clean out leaves. The worksite is made up of two workers, one driving the harvester and the other in charge of the trailer from the rows to the oil mill; in the Andalusia trial the loading area was located at a certain distance from the area where the tests were performed to allow for weighing operations of the product harvested. Assessment of the time taken by the different operations envisaged by the tests under consideration was done under C.I.O.S.T.A. ranking requirements (Bolli and Scotton, 1987), i.e. tests were considered to start when the harvester was positioned opposite the row to begin harvesting operations, and to end when the product was fully unloaded.

3. Results and Discussion

Tables 4, 5 and 6 present distribution data in terms of operational times per surface units, productivity and work capacity for the mechanized harvesting tests in super intensive olive orchard cultivation.

Andalusia

Thesis A indicates that the lowest harvester operation time (TO) (4.1 hr/ha) was registered for the 'Arbequina I-18'; 'Arbosana' and 'Arbequina' (Agromillora selection) follow with slightly higher values (Table 4). Thesis B highlights instead that the lowest harvester operation time (2.6 hr/ha) was recorded for densities of 780 plants/ha and 909 plants/ha (Table 5). As far as Thesis A is concerned, the average speed of advancement of the machine along the rows was determined to be 0.74 km/hr. The total of accessory times (TA) was instead equal to 1.64 hr/ha; the average time taken to turn the machine accounted for 25% of the total of accessory

Table 4 - Average values of the parameters assessed and harvesting capacities. Thesis A

Cultivar	TE	TA	TO	Yield	Work capacity in terms of TO		Work productivity in terms of TO	
	(hr/ha)	(hr/ha)	(hr/ha)	(t/ha)	(ha/hr)	(t/hr)	(ha/hr/operataor)	(t/hr/operator)
Arbequina	3.5	1.7	5.2	9.1	0.19	1.76	0.10	0.88
FS-17	5.8	2.5	8.3	11.9	0.12	1.40	0.06	0.70
Arbosana	3.1	1.5	4.6	18.0	0.22	3.89	0.11	1.95
Arbequina I-18	3.0	1.1	4.1	8.3	0.24	2.03	0.12	1.02
Koroneiki	4.7	1.7	6.4	19.4	0.15	3.00	0.08	1.50

TE= actual working time.
TA= accessory time.
TO= operation time.

Table 5 - Average values of the parameters assessed and harvesting capacities. Thesis B

Density	TE	TA	TO	Yield	Work capacity in terms of TO		Work productivity in terms of TO	
	(hr/ha)	(hr/ha)	(hr/ha)	(t/ha)	(ha/hr)	(t/hr)	(ha/hr/operator)	(t/hr/operator)
780	1.9	0.7	2.6	6.3	0.38	2.34	0.19	1.17
909	1.7	0.9	2.6	6.0	0.39	2.54	0.20	1.27
952	1.9	0.8	2.7	7.4	0.36	2.70	0.18	1.35
1143	2.1	1.0	3.1	7.3	0.32	2.27	0.16	1.14
1203	2.2	1.0	3.2	7.6	0.31	2.33	0.16	1.17
1481	2.7	1.1	3.8	8.4	0.26	2.22	0.13	1.11
1569	2.8	1.0	3.8	8.7	0.26	2.30	0.13	1.15
2000	3.1	1.5	4.6	10.4	0.22	2.26	0.11	1.13
2254	3.4	2.2	5.6	11.6	0.18	2.09	0.09	1.04
2580	3.8	2.2	6.0	12.0	0.17	1.98	0.09	0.99

TE= actual working time.
TA= accessory time.
TO= operation time.

Table 6 - Average values of the parameters measured and harvesting capacities in Catalonia

TE (hr/ha)	TA (hr/ha)	TO (hr/ha)	Yield (t/ha)	Work capacity in terms of TO (ha/hr)	Work capacity in terms of TO (t/hr)	Work productivity in terms of TO (ha/hr/operator)	Work productivity in terms of TO (t/hr/operator)
2.1	0.2	2.3	8.4	0.45	3.80	0.22	1.90

TE= actual working time.
TA= accessory time.
TO= operation time.

times while the remaining 75% of TA was accounted for by unloading times. The total of the harvester operation time of the machine (TO) was 5.6 hr/ha whereas the work capacity of the machine (CO) was 0.18 ha/hr. As for Thesis B, the average speed of advancement was 0.93 km/hr. The total of accessory times (TA) was 0.57 hr/ha, with a 37% and a 62% incidence for turns and unloading, respectively.

The average operation time of the machine (TO) was 3.8 hr/ha, whereas the work capacity of the machine (CO) turned out to be 0.29 ha/hr.

Idle time was negligible compared to the hours of operation of the harvesters in both theses. The results obtained in terms of harvest efficiency indicate yields of 13.4 t/ha with a work productivity of 0.09 ha/hop for thesis A, whereas in thesis B the same parameters were 8.6 t/ha in terms of harvest yield and 0.14 ha/hop for work productivity. Production losses, i.e. the amount of drupes remaining on the branches and therefore not processed by the harvester, were in the order of 8%.

Catalonia

The results of the tests demonstrate that the time of operation (TO) per unit of surface was 2.3 hr/ha and the total accessory time (TA) was 0.2 hr/ha. The time taken to turn the machine accounted for 35% of total accessory times, whereas 65% of these latter were accounted for by unloading times. The actual hours of operation of the harvester (TE) amounted to 2.1 hr/ha, while idle time was 0.1 hr/ha. The speed of advancement of the harvester along the rows was 1.6 km/hr. In terms of harvest efficiency, the yield obtained was 8.4 t/ha. Hence, the work capacity of the harvester (CO) turned out to be 0.45 ha/hr, while the work productivity (PO) was 0.22 ha/hop. Drupe loss was in the order of 6%.

The analyses carried out within the present study do highlight that 'Arbequina I-18' seems to be the variety best suited to super intensive cultivation as the work times assessed for this variety during the tests performed turned out to be the lowest. The results obtained for Thesis B (Fig. 3) highlight that for higher densities a better yield corresponds to an increase in the time required to accomplish harvesting operations. In addition, as olive groves age, decreases in yield occur for higher densities which are ascribable to a decreased level of illumination. This phenomenon does occur especially in the presence of favorable growth conditions and of disproportionate relations between the height and the width of the hedge-like row. Therefore the ideal number of plants per hectare remains to be established together with the minimum investment required to obtain the best of productivities.

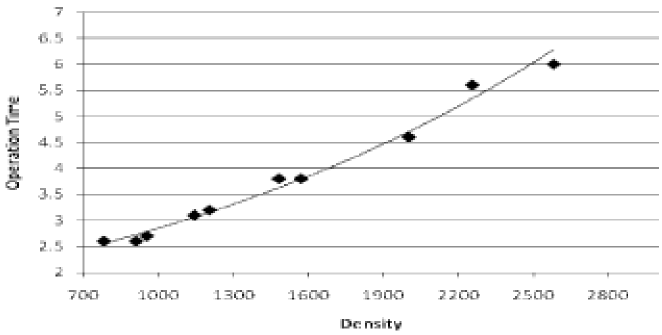

Fig. 3 - Comparison of operational working times per planting density (Thesis B).

Another interesting factor is the impact that the length of the individual rows is likely to have on the operation of the harvesters in question. In Andalucía the presence of rows of contained length (42 m on average) has had a negative impact on the harvester work capacity due to the resulting increase in accessory times. Other negative impacts were also observed which were ascribable to the small size of the dirt lanes used to turn the harvester as well as to location of the unloading area far from the area being tested to favor weighing operations of the olives harvested. As a result a significant increase in terms of harvester operation efficiency can be obtained (as confirmed by the higher levels of productivity observed in Catalonia compared to those of Andalusia) by designing the systems in question in a view to predisposing them to an integrated harvesting system, i.e. increasing the length of rows and containing logistic problems (narrow dirt lanes, poor road system, elevated slopes).

4. Conclusions

The super intensive model, which responds to issues linked to chronic labor shortage and the need to contain production costs, is likely to revamp that portion of obsolete and non cost-effective practices which are no longer competitive in the olive growing sector, and is however resulting in a "global revolution in olive tree cultivation techniques" (Loreti, 2007).

The notion of subsistence olive growing, on which traditional olive growing relies, has to come to terms with the new notion of income olive growing which is meant to contain costs and reach appropriate levels of productivity while safeguarding olive quality (Fontanazza, 1996). Integrated mechanical harvesting allows maximum exploitation of the ideal time of plant maturity, avoids olive manipulation and speeds up olive transportation to the olive mill.

Performance of the two grape harvesters (Braud and Grégoire) tested was highly positive, as they succeeded in detaching almost all the drupes (more than 90%), with one only passage, and this independently of both size and location of drupes on the tree crown and of their maturity stage. These same factors have repeatedly been observed to have a negative impact on the work efficiency of harvesting machines relying on tree shakers (Tous *et al.*, 2006). As to the technical problems observed, with the exception of little drawbacks linked to the need to make stopovers to remove leaves from beaters, no significant problem (in terms of machine reliability) was observed. Quite the contrary, both harvesters turned out to be highly performing in terms of work productivity and quality. It should be emphasized, in fact, that damage to both harvested olives and plants, (wounds, tearings, branch breaks) was neglectable and confined to the most vigorous branches protruding from the row. This kind of drawback could be overcome with an appropriate pruning technique (Loreti, 2007). It should be additionally emphasized that these machines have been remarkably upgraded over time in terms of both design and technology. Experimental studies aimed to establish several fundamental parameters of super intensive cultivation are presently being conducted to express a final judgment on the model in question also in terms of ideal varieties and planting densities. One such parameter has to do with the economic (in addition to "biologic") duration of the crops and the best form of management of the hedge-like row in the different phases of vegetative development. Plant breeding studies are presently underway to select reduced vigor genotypes specifically adapted to super intensive cultivation (Mallen *et al.*, 2006). Indeed, variety diversity is likely to become an interesting factor in view of the different adaptation levels of the different cultivars to specific environmental conditions, as well as different degrees of their susceptibility to pathogen attacks, not to mention the possibility to get a diversified production over the time also in terms of quality, a factor likely to make a difference to respond to the needs of a global market (De la Rosa *et al.*, 2006 a, b). The possibility of introducing this system in Italy remains to be assessed, especially in terms of the choice of the cultivar to be used as well as in terms of the logistic problems linked to the orography of the Italian territory and, last but not least, in terms of adaptation of the entire chain of production (oil mills, packhouses) to the super intensive model which is characterized by a workload concentrated in only 30-40 days and no longer spread over the traditional three to four-month period.

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