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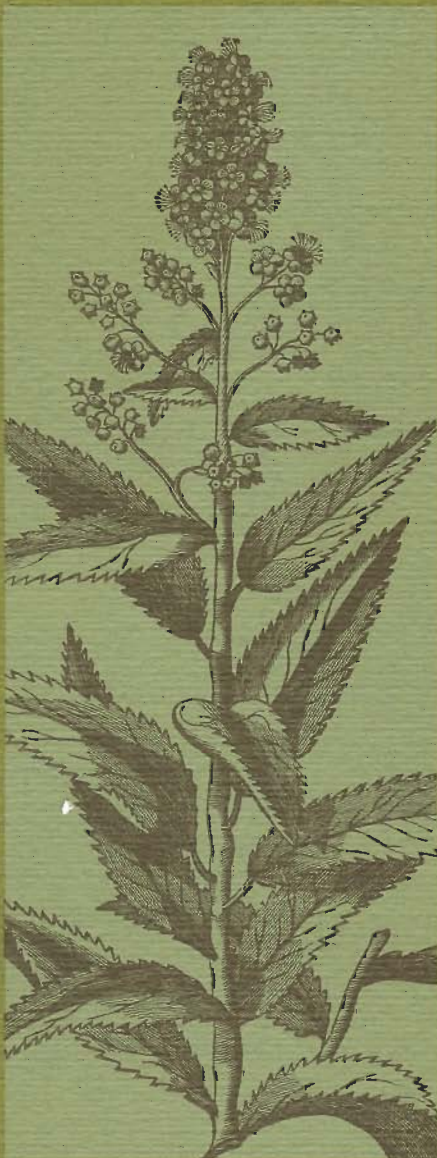

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Traditional olive crop mechanization in areas with a high landscape value. Results of tests with new olive picking equipment

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Key words: harvesters, landscape preservation, olive crops.

Abstract: The research is based on the increasing problem of preservation of high value areas. Traditional olive growing systems have in fact a fundamental role in the landscape and environmental safety. A special Olive Picking Module has been developed with picking equipment: the "rotating comb" driven by a common digger. Harvest productivity reached an average time of 14-17 min/plant, that is almost 50% of that obtained with similar combing equipment. Results have been referred to specific "Olive Tree Indexes" to better compare productivity in plants of different dimensions.

1. Introduction

Olive growing in Italy occupies approximately 1,010,000 ha, 73% of which is on hillside and mountain areas; in particular regions like Tuscany, this proportion increases to 94% (ISTAT, 1992). Almost all the hillside plantations are traditional in type with a prevalence of goblet-trained trees. The maintenance of these "typical" training systems is in some cases absolutely necessary because of their high landscape, environmental and economic value (Distaso, 1998). It is therefore necessary to find solutions to make olive growing sustainable especially in the harvest phase which produces more than 50% variation in production costs in many cases (Tombesi *et al.*, 1998); all of this while respecting the quality of the operators' working conditions, and an adequate income from an economic and productive point of view (Sequi, 1997).

The problem has been raised for the "typical" olive groves in Tuscany where in many cases, owing to the size and shape of the trunk and boughs, it does not seem possible to efficiently use shakers. Therefore a combing system has been chosen, although it presents several problems with the technologies available at the moment. The harvesting activity is totally or partially discontinuous. The positioning systems are often slow and inaccurate. The working postures are not ergonomic because the operator has to move between the tractor driver's seat and the place from which he manoeuvres the harvesting arm. The working time is long: 20-40 min/plant (Bolli and Barcaglia, 1992; Bolli, 1996).

In cooperation with a manufacturing group[1] and with the sponsorship of ARSIA[2], a module was created, consisting of a revolving platform excavator, on which a prototype of a rotating comb was mounted instead of the digger. This prototype met the requirements of speed, precision and operative ergonomics as far as the machine is concerned and of continuity of the picking action through the use of the vibrating, revolving, freely rotating comb. The combs available on the market at present have a "paintbrush" shape (Picchio) or are circular combs connected to a rod that prevents them from freely rotating (Olivary).

2. Materials and Methods

The module for detaching the olives from the tree is a machine consisting of a rotating platform excavator. A toolbar has been mounted on its mechanical arm, using the bolt of the digger bucket. The stan-

[1]Fiat Kobelco, Pasquali Macchine Agricole.

[2]ARSIA - Tuscan regional agency for agricultural development and innovation. "Project to test a mechanisation process for the continuation of olive growing in areas with a high landscape value".

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dard hydrostatic circuit provided on the excavator arm enables the hydraulic motors of the implement on the end of the arm to work.

The advantages of using this machine lie in its extreme manageability and agility of movement, both of the whole machine and above all of the working arm, with evident productive advantages and especially for the operator's safety and comfort.

The agricultural machines that use utensil positioning arms do not, at present, have such levels of quality or operating speed and constitute a large part of the cost of the whole machine. The cost of the excavator can be absorbed by a wide range of agricultural operations, as well as digging: pruning, cleaning borders, shifting material.

Olive picking equipment: the "rotating comb"

To detach the olives, a prototype of the comb unit with spokes arranged radially, passing through a coaxial cable cylinder was designed and realized (Fig. 1).

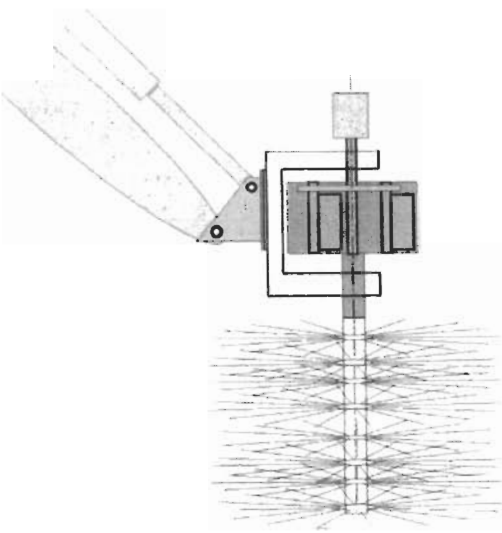

Fig. 1 - Olive picking equipment: "the rotating comb".

The principle of interaction with the plant and the tree, that can be defined as "oscillating" and "combing" of the canopy from the outside, substantially recalls manual picking and canopy vibrating action.

The cylindrical comb is 1 m height and 1 m in diameter. The penetration capacity of the rods into the canopy is thus approximately 0.5 m. The axial oscillation of the rotating comb is obtained by means of a system of eccentric masses that rotate in phase and make the axis rotate in alternate directions. The eccentric masses are moved by a hydraulic motor in an axial position. This particular solution allows the oscillating group with the comb to rotate freely, thus enabling the comb to roll easily over the canopy.

The four eccentric masses have a total mass of 36 kg. Each eccentric mass has been created with a 20 mm rotating axis incorporating a cylindrical mass of 80 mm in diameter and 100 mm in length. The axis of the eccentric masses rotates at a distance of 120 mm from the main rotating axis.

The hydraulic motor with gears of 0.025 dm^3 (and a maximum allowable capacity of 12 dm^3/min), according to the capacity provided by the machine, provides a variable rotation of 20-40 rad/s.

The rods were made using rods which pass through the cylinder to exploit their elasticity throughout their length, thus decreasing the risk of breaking through fatigue. Cylindrical rods of various diameters were tested, using different materials; polyzene, nylon, rubber coated glass fibre.

With a free rod, without interference from the vegetation, and with a rotation of the hydraulic motor of approximately 20-25 rad/s corresponding to an oscillation frequency of 6-8 Hz, the distal part of the rods travels approximately 100-120 mm/sec.

The olive catching module

The olives are caught and collected using a special caterpillar tractor consisting of a mechanised frame equipped with power points and a standard hoist, managed principally from the ground (Fig. 2). The implement consists of a temporary olive storage tank, with a bucket scoop mounted on the front, to facilitate the unloading of the olives into the bin. The scoop incorporates a canvas of variable dimensions that is laid on the ground. The bin and scoop are mounted on the tool bar by means of a pin that allows a lateral inclination in order to adapt to the gradient and to facilitate lateral unloading.

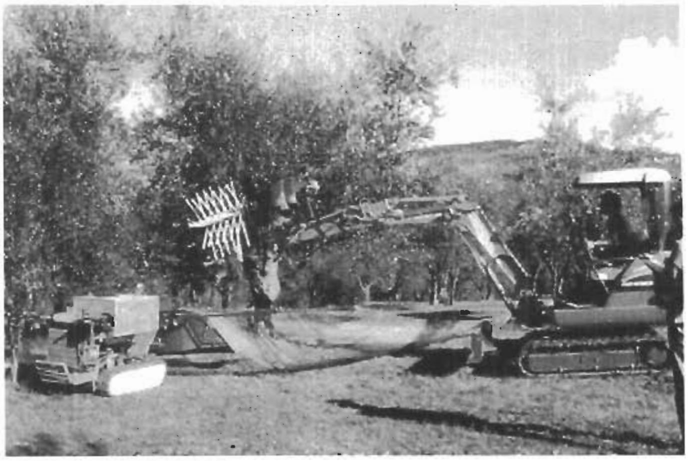

Fig. 2 - Realized olive harvest equipment.

Test methodology

The tests were carried out in the 1997-2000 harvest seasons on plantations at the Montepaldi Farm (Chianti area), Monnagiovanella Farm (hills near Florence) and on the Rispescia Farm (hills in the

Grosseto area - Uccellina Park). The machines worked on plants typical of "areas with a high landscape value", i.e. plants trained into the traditional goblet shape, following the traditional geometry of the older trees. In the old olive grove on the Rispescia Farm we worked on century-old trees with trunks of 1 m or more in diameter.

In the trials, general reference data (climatic conditions, the farm, soil conditions and lay of the land) were collected, as well as characterisations of the plant and of the type of vegetation present (analysis of the cube). This would seem necessary since the utensil works by brushing the entire canopy, and its relative productivity depends on the volume of the vegetation and also on the particular characteristics of the canopy and on the olive/vegetation mass ratio.

The following data were collected:

[1] plant characteristics

a) cultivar, planting density, type of training, age;
b) trunk parameters [number, height (m), diameter (m)];
c) branch parameters [number, length (m), diameter (m)];
d) canopy dimensions [height (m), diameter of the horizontal involution circle (m)];
e) volume contained (m^3), that considers the cylinder contained within the canopy and is calculated from the dimensions of the canopy;
f) empty/full (%) defined by making a visual estimate of the quota of the involution cylinder of the canopy where vegetation is not present;
g) real canopy volume (m^3) calculated with the product of the two previous parameters.

[2] analysis of the cube. This type of measurement considers a cube with 0.5 m sides, made of steel rods, which is put into the vegetation where there is the greatest quantity of olives. The "cube" provides data on a volume of 1/8 m^3. The "cube" is inserted in the productive areas of the vegetation. All the branches inside the cube are removed and collected and the following measurements are taken:

a) the mass of the vegetation (kg) (branches and leaves);
b) the mass of 10 productive twigs (kg);
c) average length of the same twigs (cm);
d) their ramification on the basis of reference indexes 0 - 1 - 2;
e) the mass of the olives (kg) present in the cube.

[3] canopy indexes. Calculated on the basis of the plant's characteristic parameters, the measurements of the cube and the harvest data:

a) total mass of the canopy (kg);
b) twig density (no./m^3);
c) canopy unit mass (kg/m^3);
d) potential production (kg/m^3), using the production in the cube as a reference;
e) real production (kg/m^3) taking the actual quantity of olives on the tree as a reference;
f) productive efficiency (%) is the ratio between the tree's actual production and its potential production from the product of the net volume of the entire vegetation and the production in the "cube". This reference index was adopted to highlight the plant's potential and the uniformity of production; production in the foliage is very discontinuous with many zones heavily loaded and others almost totally lacking in olives. Thus, even if the utensil's working capacity is proportional to the volume of the vegetation explored, the efficiency of olive picking also depends on the uniformity of production on the plant.

[4] characteristics of the olives (considering samples of 100 olives):

a) mass of 100 olives (g);
b) diameter (mm); average and standard deviation;
c) length (mm); average and standard deviation;
d) detachment resistance (N); average and standard deviation. Measured with dynanometers with a suitable scale for the measurement (max 2.5, 5, 10 N). To this are added "characteristic indexes" measured with a picnometer;
e) average mass of the olives (g);
f) average volume of the olives (cm^3); thus calculating:
g) average density (g/cm^3);
h) resistance/mass index (N/g).

[5] analysis of harvesting time (min/plant):

a) combing: phases in which the comb is moved tangentially to the vegetation with alternating movements in order to comb the volume of vegetation;
b) movement of the arm; phase in which the mechanical arm holding the comb is positioned in other portions of the canopy;
c) change of place: phases in which the excavator is moved to other positions around the tree;
d) time per plant: the sum of the previous measurements. The extra time for movement from one tree to another has not been taken into consideration because this depends on the different conditions of the olive grove in terms of the distance between plants, gradient, working space and conformation.

[6] analysis of the harvested product:

a) quantity harvested (kg);
b) olives left on the plant (kg);
c) pending production (kg): the sum of the two previous measurements;
d) harvest efficiency (%): the product of the quantity harvested per pending production;
e) bruised olives (%) (considering samples of 100 olives harvested);
f) fallen leaves and branches (%): mass of material picked together with the olives/total mass of the canopy.

[7] working capacity and productivity indexes

a) estimated working capacity (plants/hr);
b) estimated harvesting capacity (kg olives/hr) calcul-

tated for the same type of plant;

c) PVR index (hr/m^3); the volumetric productivity of the harvest of the rotating comb indicates the harvesting time per plant in relation to the vegetation volume present and is obtained by calculating the regression between the two parameters in all the tests.

3. Results

Table 1 shows the average data of the measurements taken according to the methodology illustrated for the different testing stations. The values refer to the averages of the readings for typical plants identified during the seasons 1997-2000 and for the same plants (14 plants - Monna Giovannella; 16 plants - Montepaldi and Ripescia). Table 2 shows the results and picking indexes. In the tests carried out at Montepaldi (Florentine hills) we worked with canopy volumes of 20 m^3, a productive efficiency of 25.7%, a detachment strength of 4.9 N, pending production of 17.5 kg/plant; the average working capacity was 4.3 plants/hr with 72.2 kg/hr harvested olives.

In the tests carried out in the Chianti area (Monna Giovanella farm) we worked with canopy volumes of 32 m^3, a productive efficiency of 25%, detachment strength of 4.9 N, pending production of 20 kg/ plant; the average working capacity was 4.3 plants/hr with 76 kg/hr harvested olives.

Table 1 - Average data of the tests conducted in the different areas

		Montepaldi Fiorentine hills		Monna Giovannella Chianti		Rispescia Uccellina park (gr)	
		average	SD	average	SD	average	SD
General data	temperature (°C)	15	*3*	16	*3*	14	*1*
	UR%	66	*11*	70	*0*	39	9
	soil conditions	grassed-wet		grassed-wet		grassed-wet	
	declivity	7%	*3%*	7%	*3%*	5%	*4%*
Tree data	cultivars	Frantoio		Frantoio-Moraiolo		Frantoio-Moraiolo-Leccino	
	planting geometry	4x6		5x6		10x10	
	planting density	417		333		85	
	type of training	policone		pot		pot	
	age	10		40		20 + years-old trees	
trunk	n°	1		2	*1*	1	
	height (m)	0.57	*0.23*	1.06	*0.70*	0.96	*0.21*
	diameter (m)	0.24	*0.20*	0.30	*0.23*	0.24	*0.70*
branches	n°	3	*1*	3	*1*	3	*1*
	height (m)	3.56	*0.11*	3.50	*1.04*	3.10	*0.54*
	diameter (m)	0.08	*0.01*	0.20	*0.05*	0.13	*0.05*
canopy	height (m)	4.2	*0.3*	4.3	*0.7*	4.8	*0.4*
	diameter (m)	3.4	*0.2*	4	*0.6*	4.5	*0.4*
	apparent volume (m^3)	38	*4*	51	*11*	76	*12*
	empty/full (%)	48%	*11%*	40.4%	*9%*	33.7%	*12.8%*
	real canopy volume (m^3)	20	*2*	32	*7*	49	*6*
"cube" analysis (0,125 m^3)	canopy mass (kg)	0.430	*0.151*	349	*121*	330	*84*
	mass of 10 prod. twigs (kg)	0.111	*0.26*	119	*40*	142	*32*
	average length of the twigs (m)	0.38	*0.06*	0.31	*0.04*	0.46	*0.11*
	ramification index (0-1-2)	2		1		2	
	mass of the olives on cube (kg)	0.439	*0.139*	363	*127*	278	*82*
canopy indexes	total mass of the canopy (kg)	68	*32*	81	*29*	129	*31*
	twig density (n°/m^3)	318	*125*	261	*123*	189	*40*
	canopy mass (kg/m^3)	3.4	*1.2*	2.9	*1.1*	2.8	*0.7*
	potential production (kg/m^3)	3.5	*1.1*	2.8	*1*	2.2	*0.6*
	real production (kg/m^3)	0.9	*0.2*	0.7	*0.1*	0.7	*0.2*
	productive efficiency (%)	25.7%	*18%*	25%	*10%*	31.8%	*33%*
olive characteristics	mass of 100 olives (g)	120.6	*25.2*	130.6	*34.1*	227.9	*36.5*
	diameter (mm)	10.4	*0.6*	10.8	*0.8*	13.9	*1.1*
	lenght (mm)	15.8	*1.1*	15.9	*1.7*	19.6	*0.7*
	detachment resistence (N)	4.9	*0.5*	4.9	*0.9*	5.2	*0.9*
	average mass of the olive (g)	1.2	*0.3*	1.3	*0.3*	2.3	*0.4*
	average volume (cm^3)	1.4	*0.2*	1.4	*0.2*	2.2	*0.2*
	average density (g/cm^3)	0.9	*0.1*	0.9	*0.2*	1.0	*0.1*
	resistance/mass index (N/g)	4.3	*1.2*	3.9	*1.1*	2.4	*0.6*

Table 2 - Tests results and indexes

		Montepaldi Fiorentine hills		Monna Giovannella Chianti		Rispescia Uccellina park (gr)	
		average	SD	average	SD	average	SD
analysis of harvesting times	combing (min)	9.9	*2.1*	8.8	*2.5*	10.5	*2.4*
	arm movement (min)	2.0	*0.9*	3.8	*0.9*	3.1	*1.3*
	change of place (min)	2.1	*0.7*	2.1	*0.6*	3.4	*0.5*
	time per plant (min)	14.1	*1.8*	14.7	*3.0*	17.0	*2.0*
analysis of the harvested product	quantity harvested (kg)	16.4	*5.7*	19.1	*6.9*	28.5	*12.1*
	olive left on plant (kg)	1.1	*0.3*	1.0	*0.3*	1.7	*0.8*
	pending production (kg)	17.5	*5.8*	20.0	*7.2*	30.1	*12.7*
indexes	harvest efficiency (%)	93.5%	*2.2%*	94.8%	*1.43%*	94.4%	*1.5%*
	bruised olives (%)	1.7%	*0.4%*	2.0%	*0.6%*	2.5%	*0.2%*
	fallen leaves and branches (%)	0.9%	*0.1%*	0.6%	*0.2%*	0.4%	*0.05%*
	working capacity (plants/hr)	4.3	*0.6*	4.3	*1.1*	3.6	*0.4*
	harvest capacity (kg olive/hr)	72.2	*31.1*	76.0	*15.5*	101.3	*44.1*
	PVR index (hr/m^3)	*Y=0.10x+11.8 (per plants > 20 m^3)*					

In the tests carried out in Maremma (Uccellina Park - Rispescia farm) we worked with canopy volumes of 49 m^3, a productive efficiency of 31.8%, detachment strength of 5.2 N, pending production of 30.1 kg/plant; the average working capacity was 3.6 plants/hr with 101.3 kg/hr harvested olives.

The PVR index, obtained from the regression for all the tests, between the actual vegetation volume and the picking time per plant, is y=0, 10x+11.8 with R^2=0.84 (Fig. 3). It should be taken into consideration that the plants were all harvested singly and that for plant canopies > 20 m^3, three positions are necessary.

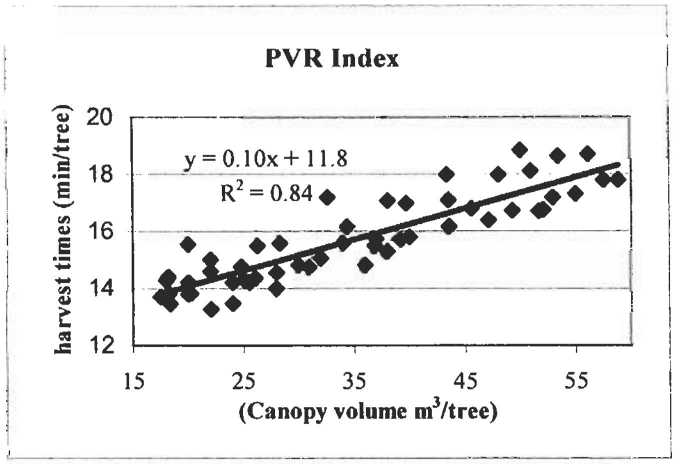

Fig. 3 - PVR index.

4. Discussion and Conclusions

The research has highlighted the possibility, for particular agricultural tasks such as olive picking in hillside areas and for widely spaced training systems, of adopting unconventional machines coupled to the operating implements. In this sense, modern diggers seem suited to carry out the task with multifunctional machinery, capable of carrying out a wide range of operations apart from normal excavating.

The rotating comb prototype has also produced positive results. The possibility of rotating freely enables the comb to avoid damaging the boughs and branches, and the slight spiralling of the productive branches over the axis of the comb helps drupe detachment by combing.

The working capacity, that under different test conditions varies on average between 14 and 17 min/plant, is much lower than the values of 20-40 min/plant (Bolli, 1996) measured in tests using other combing machines available on the market.

Ackwnoledgements

Particular thanks to Giancarlo Cosi and Marino Piva for their precious cooperation.

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Olive picking tests with a shaker module and a harvesting umbrella, mounted on a rotating platform excavator

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Key words: farm machinery, olive harvest, shaker and new implement.

Abstract: Results of tests on new olive harvest equipment: a rotating excavator equipped with shaker on the mechanical arm and gather umbrella on the blade grader are presented. The research is motivated by the increasing problem of maintenance of olive production in central Italian hillside areas. An innovative olive harvester has been developed with an excavator that controls the olive shaker and the gathering umbrella. The fitted equipment does not compromise the original functionality of the excavator. The implements have a sustainable cost and are quickly joined to the machine. Field tests were conducted in the olive harvest season 2001 at the Montepaldi farm belonging to the University of Florence. The module achieved a productivity of 27 olive trees per hour with a harvest efficiency of 90.5%. The field test is a terraced area with olive trees having these features: 22 m^3 canopy volume, about 15 kg/plant production, 1.3 g drupe mean weight, 5 N detachment resistance. Continuous use of the module during the harvest season produced an average productivity of 180 plants/day.

1. Introduction

The olive harvest is still today the critical moment in olive oil and olive production; harvesting costs make up more than 50% of the total production cost (Tombesi, 2001). The impossibility of picking all the olives in the optimal period and the often long period that passes after the product has been detached from the tree and before it is processed are cause for the fall in product quality (Montedoro, 1991); the technologies used are still inadequate for working efficiently and quickly and often they are not suited to training systems and growing conditions typical of hillside olive growing, especially in central Italy.

Moreover, much research has been undertaken in this sector since the 1960s (Vitali, 1967). Technological solutions have followed two main lines: beaters and combs, and branch shaking (Vieri *et al.*, 2001). The former produce a higher yield and can work on free forms and with very thick vegetation. However they have the disadvantage of having to pass the utensil (comb) throughout the canopy, and thus require long operating times which average 15 min. per plant (on plants with an average vegetation volume of 30 m^3) (Vieri *et al.*, 2001). The machines that use pincers or shaker heads, on the other hand, are faster since the shaking action ends within 15 s (beyond this time the plant suffers damage from abrasion, bark peeling or bough break); in this case the harvest yield is greatly affected by the shape of the tree (which determines the vibration transmission module) and by the characteristics of the drupe (mass and detachment resistance), typical of each cultivar and variable according to ripeness and seasonal trend (Tombesi, 1998).

Unfortunately, the high cost of existing harvesting equipment is not matched by adequate productivity due to the time required to shift the machine and implement group, and to position the plant-holding implement (shaker) and the interceptor (olive catching umbrella). A recent example is provided by the redesigning of a new machine, the SR 12, developed in the 1960s (Stefanelli, 1971). Despite the marked improvements made on the positioning arm and umbrella, the harvesting time is still long and the cost of mounting the machine on a caterpillar tractor is high (about 35,000.00 euro).

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An interesting innovation developed by Giametta (2001) attains remarkable productivity of about 1 min per plant (excluding the unloading phase); it is a prototype that works on regular plantations on the plains, and shakes the tree trunk. However, the machine is not suited to hillside land or to irregular plants, and it cannot shake branches.

The present technological scenery leads to the consideration that harvesting equipment has reached a good level of development but that operations as a whole have not yet reached adequate efficiency. It should be noted that manufacturers dedicate much effort to designing mechanical arms and positioning units that often make up the largest percentage of the design cost but do not achieve the necessary performance level in terms of simplicity, agility, manoeuvring and positioning speed.

Thus, the functional component that limits efficiency is the machine itself and the unit that positions the harvesting implements. Looking beyond the agricultural sector alone, earth-moving equipment consists of a machine - the rotating platform excavator - that fully meets the mechanical needs of the harvesting implements (weight, dimensions, possibility of producing hydraulic energy to work the implements) and possesses a system for moving and positioning the utensil (scoop or hydraulic breaker, etc.) that is extremely efficient, agile, fast, with very ergonomic management, the result of over 50 years of experience and research.

It therefore seemed obvious to attempt to develop equipment using this machine and joining it to the harvesting implements. A first experiment was made some years ago (Vieri, 2000) adopting a combing head. In that case, the picking times did not decrease beyond the values for the same type of equipment available on the market, since it is however necessary to pass the comb through the whole canopy, which takes approximately 15 min per plant, and this is not acceptable.

A system using a rotating platform excavator was therefore developed. It was coupled with the shaker head instead of the scoop and an olive catching umbrella that opens hydraulically, equipped with a small storage hopper, mounted on the small front blade with which this type of medium-small machine is normally equipped (Fig. 1).

This arrangement was developed by making simple modifications to the excavator structure, so as not to interfere with the machine's original function, which can be quickly restored.

In practice, the aim was to develop an efficient module at a sustainable cost. In this case the cost of harvesting equipment to be mounted on the excavator, is less than 10,000.00 euro.

Fig. 1 - The olive harvest equipment developed.

2. Materials and Methods

The machine consists of a caterpillar excavator with a rotating platform; the dimensions and characteristics are shown in Table 1.

Table 1 - Features of the machine used to drive olive harvester

Features		
main characteristics		
power (cee 80/1269)	kW	25
operating weight	kg	4.300
producer/model	Fiat/Hitachi	EX40u
oil hydraulic plant for services		
hydraulic pumps	n°	2
pump volume		variabile
total flow rate	dm³/min	max 82
maximum operating pressure	MPa	24
max. weight for the applied tool	kg	240
main features with steel tracks		
speed	m/s	0-1,2
maximum slope can be overcome	%	58
maximum track length	mm	2.245
total classis width	mm	1.950
shoe width	mm	400
specific pressure on ground	kPa	25
arm structure lenghts		
maximum rotating radius	mm	5.550
minimum rotating radius	mm	2.485
maximum reachable height	mm	4.490

The advantages of using this machine are that it is extremely manageable and agile to move, both the whole machine and, above all, the working arm. The considerable technological experience that has contributed to the construction of this type of equipment produces a remarkable working capacity combined with extremely easy management. Precision and ergonomic management are the most typical features in favour of a possible use in agriculture. The agricultural machines that use utensil-positioning arms do not have the same levels of operativeness and contribute heavily to the cost of the whole implement. This is why it appears convenient to use the mechanical arm, for various operations, as well as the possibility of digging and lifting light materials. In this sense, the cost of the excavator can be distributed over a wide range of mechanized operations (picking, pruning, cleaning banks, shifting materials) with evident advantages in terms of productivity and especially for the safety and comfort of the operator.

Using the two bolts that join the scoop to the arm, a plate attachment has been made so that hydraulically-powered machines weighing less than 200 kg can be easily coupled to it.

A standard hydrostatic circuit, serving the excavator arm, activates the hydraulic engines of the shaker positioned on the end of the arm, and the pistons that control the clamp holding the trunk or the branches.

Olive picking equipment: "the shaker"

To detach the olives, a shaker with a modified coupling system, as shown in figure 2, and with the following characteristics was used:

- overall size	mm	700x600x18
- equipment weight	kg	45
- maximum opening of the pliers	mm	250
- weight of eccentric masses	kg	18
- eccentricity	mm	28
- hydraulic motor size	cm^3	22
- maximum oil flow rate	dm^3/min	52
- maximum oil pressure	MPa	20
- oscillating frequency	H_z	up to 40

Olive catching umbrella

The interceptor group consists of a temporary olive storage container with support rods for the fabric that forms the olive catching umbrella. The group is attached with a coupling "suspended" from the digger blade and is fixed with pins or bolts that prevent it from becoming detached (Fig. 3).

The umbrella height is determined by the position of the digger blade, to which it is locked. The umbrella is opened and shut using the same controls as for the digger blade, first activating an electric switch that controls a flow deviation electro-valve on the rotating pistons of the umbrella shafts.

The capacity of the container in this first prototype is a volume equal to approximately 250 kg of olives. Unloading is done manually and makes use of an opening in the proximal part of the excavator; by raising the container, the floor is tilted, making the olives slide to the bottom. Although it has not been included in this initial experiment, the design phase also contemplated an aspirator and leaf-stripping unit positioned behind the excavator with the aim of emptying the

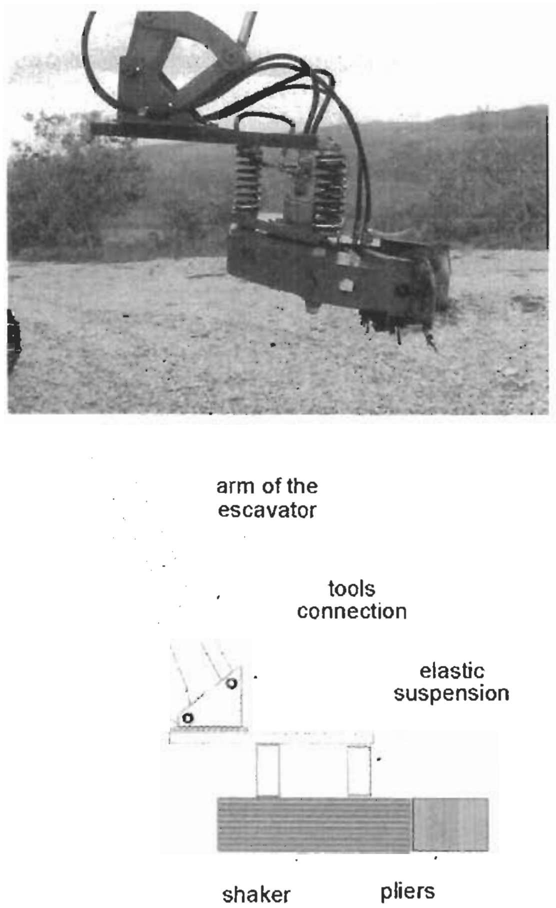

Fig. 2 - The olive tree shaker applied to the escavator arm.


Fig. 3 - The olive catching umbrella.

harvest from the umbrella out of the container and bagging the olives directly.

The machine operates as follows:

1) Coupling phase: the machine is positioned in front of the trunk; the hopper is brought up close to the tree trunk and the umbrella (divided into two portions) is opened so as to cover the entire ground area beneath the tree; the arm brings the shaker close to the trunk or boughs and it is fixed to them by means of the pincer.

2) Shaking phase: all the eccentric masses are activated for a few seconds and then the positioning and shaking may be repeated from a different position.

3) Recovery and shifting to the next plant: The umbrella is closed again and the machine moves on. When plants are arranged in rows, as in the case of the tests we conducted, the best path to follow is that shown in figure 4 with alternate working on two adjacent rows.

4) Emptying the hopper when it is full (in the tests, every 8-10 trees).

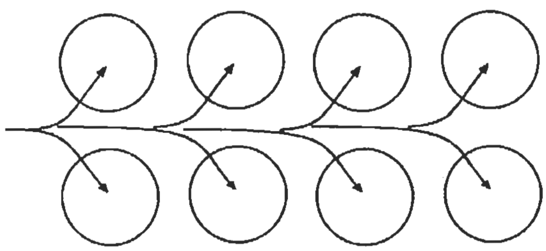

Fig. 4 - Operative scheme.

Test methodology

The tests were carried out during the 2001 harvest season on plantations on the Montepaldi Farm (S. Casciano V.P., FI), belonging to the University of Florence.

As well as the general reference data (climate conditions, farm, soil conditions and gradient), the tests included the following types of measurements:

1) characteristics of the plant:
  a) cultivar, planting density, type of training, age;
  b) trunk parameters [number, height (cm), diameter (cm)];
  c) bough parameters [number, height (cm), diameter (cm)];
  d) canopy dimensions [height (m), diameter of the horizontal involution circle (m)];
  e) volume contained (m^3), which considers the cylinder contained within the canopy and is calculated from the canopy dimensions;
  f) empty/full (%) defined by making a visual estimate of the quota of the involution cylinder of the canopy where vegetation is not present;
  g) real canopy volume (m^3) calculated with the product of the two previous parameters.

2) analysis of the cube: this type of measurement considers a cube with 0.5 m sides, made of steel rods, which is put into the vegetation where there is the greatest quantity of olives. The "cube" provides data on a volume of 1/8 m^3. The "cube" is inserted in the *productive areas* of the vegetation. All the branches inside the cube are removed and collected and the following measurements are taken:
  a) the weight of the vegetation (g) (branches and leaves);
  b) the weight of 10 productive branches (g);
  c) average length of the same branches (cm);
  d) their ramification on the basis of reference indexes 0-1-2;
  e) the weight of the olives (g) present in the cube.

3) canopy indexes: calculated on the basis of the plant's characteristic parameters, the measurements of the cube and the harvest data;
  a) total weight of the canopy (kg);
  b) branch density (number/m^3);
  c) canopy unit weight (kg/m^3);
  d) potential production (kg/m^3), using the production in the cube as a reference;
  e) real production (kg/m^3) taking the actual quantity of olives on the tree as a reference;
  f) productive efficiency (%) is the ratio between the tree's actual production and its potential production derived from the product of the net volume of the entire vegetation and the production in the "cube". This reference index was adopted to highlight the plant's potential and the uniformity of production.

4) characteristics of the olives (considering samples of 100 olives).
  a) weight of 100 olives (g);
  b) diameter (mm); average and standard deviation;
  c) length (mm); average and standard deviation;
  d) detachment coefficient (N); average and standard deviation. Measured with dynanometers with a suitable scale for the measurement (top scale 250, 500, 1000 g). To this are added *"characteristic indexes":*
  a) average mass of the olives (g);
  b) average volume of the olives (cm^3);
  c) average density (g/cm^3);
  d) resistance/weight index (N/g);

5) analysis of harvesting time (minutes per plant)
  a) coupling phase (min);
  b) shaking phase (min);
  c) recovery and change of place (min);
  d) emptying the hopper (min);
  e) total time per plant (min);

6) analysis of the harvested product
  a) quantity harvested (kg);
  b) olives left on the plant (kg);
  c) pending production (kg): the sum of the two previous measurements;
  d) harvest efficiency (%): the product of the quantity

harvested per pending production;
e) bruised olives (%) (considering samples of 100 olives harvested);
f) fallen leaves and branches (%): weight of material picked together with the olives/total weight of the canopy.

7) working capacity index
a) estimated working capacity (plants/hr);
b) estimated harvesting capacity (kg olives/hr) calculated for the same type of plant.

Analysis of the working times and the quantity harvested was considered for 92 trees; analysis of the plant indexes for 10 plants. The same plants were used to measure the harvest yield, picking the olives left on the tree. Loss of olives on the ground are to be considered nil because none fall outside the umbrella.

3. Results

Table 2 shows the average data from the tests conducted according to the described methodology. The values refer to the averages of the tests conducted.

Figure 5 shows the working phases of the harvest and the relative times as a percentage. The analysis was made on 92 plants for a total measured time of 3.4 hr and a harvest of 1,250 kg. The test involved two operators who alternated driving and unloading olives. The results show that for a reference plant (indicator plant) with:

- A productive vegetation of 22 m^3;
- Prevalently goblet trained;
- Average production 15 kg;
- Drupes with a weight of 1.3 g;
- Detachment resistance 5 N.

the estimated production is approximately 27 plants/hr, with a harvest yield of 90.5%, equal to 365 kg of olives/hr, with 1.2% of bruised olives and 0.6% of leaves and twigs removed.

4. Discussion and Conclusions

In the reference scenario for the experimentation, or that of preserving hillside olive growing in central Italy, this first experiment has shown that available technologies are now ready to provide specific high performance mechanized solutions.

The prototype developed has shown that it is possible to build unconventional productive models with highly productive, inexpensive solutions. The excavator is by now a more widespread tool on farms and only a small investment is needed to assemble the olive picking module. Moreover, this machine's manoeuvrability enables it to work on terraces and on difficult ground.

The tests presented have been confirmed by using the module developed on the farm during the whole

Table 2 - Average data of the tests conducted

Data	average	*dev.st.*
General data		
temperature (°C)	17	3.5
UR%	70	8
ground conditions	grassed wet	
slope	7%	3%
Trees data		
cultivar	Frantoio	
planting geometry (m)	4x6	
plant density (number/ha)	417	
type of training	policone	
age (years)	12	
Trunk dimensions		
number	1.0	
height (cm)	55	22
diameter (cm)	26	15
Branches dimensions		
number	3	1
height (cm)	405	10
diameter (cm)	9	2.5
Canopy dimensions		
height (cm)	4.3	0.2
diameter (cm)	3.2	0.5
involution cylinder volume (m^3)	36	3
empty/full (%)	52%	12%
effective volume (m^3)	22	2
"cube" analysis		
canopy mass (kg)	410	130
mass of 10 prod. twigs (kg)	105	22
average lenght of the twigs (m)	37	4.5
branching index (0-1-2)	2	
mass of the olive on cube (kg)	285	102
Canopy indexes		
total mass of the canopy (kg)	72	29
twig density (number/m)	318	125
canopy mass (kg/m^3)	3.3	1.1
potential production (kg/m^3)	2.3	0.9
real production (kg/m^3)	0.7	0.3
productive efficiency (%)	30%	
Olive characteristics		
mass of 100 olives (g)	122.2	23.0
diameter (mm)	10.0	0.8
lenght (mm)	16.4	1.0
detachment resistence (N)	4.9	0.5
Olive characteristics indexes		
average mass of the olive (g)	1.25	0.25
average volume (cm^3)	1.35	0.25
average density (g/cm^3)	0.9	
resistance/mass index (N/g)	5.82	
average mass of the olive (g)	4.65	
Analysis of harvesting times		
coupling up phase (s/tree)	21.6	12
shaking phase (s/tree)	11.5	9
closing umbrella and repositioning phase (s/tree)	42.8	21
unloading phase (s/tree)	58.7	1.4
total time (min/tree)	2.24	0.7
Harvested product analysis		
quantity harvested (kg)	13.5	4.3
olives left on plant (kg)	1.4	2.4
pending production (kg)	14.9	5.2
harvest efficiency (%)	90.5%	3.8%
bruised olives (%)	1.2%	0.5%
fallen leaves and braches (%)	0.1%	0.1%
Indexes		
working capacity (plants/hr)	27	2
harvest capacity (kg olive/hr)	365	27

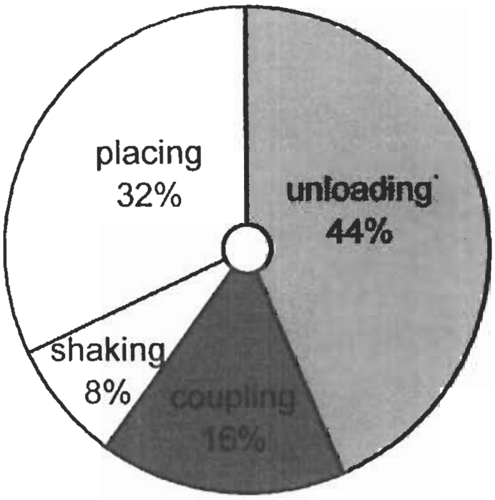

Fig. 5 - Steps and related weight of operative times.

olive picking season with an average productivity of 180 plants per day. This aroused the interest of medium to large farming estates and sub-contractors who serve the small farms. Working times can be further reduced by equipping the module with an aspirator and bagging unit, mounted on the rear of the excavator.

Acknowledgements

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