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The assessment of hazelnut mechanical harvesting productivity

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Abstract. Hazelnut cultivation represents a new opportunity for Calabrian mountainous and sloping areas (Southern Italy), where no alternative fruit crops, except forestry, could be settled. In this Region, hazelnut production doubled during the last fifty years, inciting the farmers to introduce mechanization in cropping practices such as harvesting in order to increase productivity and decrease production costs. Indeed, harvesting is currently one of the most expensive processes of the productive cycle, moreover to be time consuming if carried out manually. Mechanization degree depends significantly on the terrain topography: in sloping areas, rakes are often associated to aspirating machines to harvest the fallen fruit, while the employment of harvesting machines from the ground prevails in flat areas. In this context, the present paper aims to assess technical and economic aspects of harvesting operation, using a harvester from the ground model 'Jolly 2800' (GF s.r.l., Italy). Particularly, for technical purposes data about operational working time as well as working productivity were collected according to CIOSTA requirements, in two harvesting sites, whereas, for mechanical harvesting economic evaluation, an estimation model was applied to calculate machinery cost per hour. Moreover, the cost per kg of hazelnut in shell and the average cost per hectare were estimated also. The obtained results show a working productivity of 0.065 ha h^{-1} op^{-1} in the first harvesting site, while it was equal to 0.022 ha h^{-1} op^{-1} in the second one. Concerning the average cost per hectare, the second harvesting site showed the worst economic performances, with 550.76 € ha^{-1} against 182.54 € ha^{-1} obtained in the first one.

Key words: hazelnut, mechanical harvesting, tractor-mounted harvester, work productivity, economic analysis, sloping terrain.

INTRODUCTION

Hazelnut (*Corylus avellana,* L.) that belongs to the family of *Betulaceae*, is extended on about 915,550 ha in the world in 2014, with a production of 713,451 tonnes of hazelnut in shell. With more than 75,000 tonnes, Italy is the second producer in the world after Turkey, which produces 450,000 tonnes (FAOSTAT, 2014). In Calabria, it has been introduced since 17th century and it is currently spread over an area of 325 hectares producing more than 761.5 tonnes of hazelnuts in shell according to the Italian National Institute for Statistics data (ISTAT, 2016). It represents a key cultivation for

Calabrian hilly territories, especially for those areas where there are no alternative crops, except forestry.

However, most of the orchards do not enable to reach high and regular yields. Indeed, they are mainly plants with irregular planting layout, situated in sloping terrain or terraces in mountainous area, where labour becomes ever scarcer. This determines high production costs and consequently the marginalization of this natural resource that could contribute significantly to the development of local territories (Abenavoli & Proto, 2015). Harvesting is currently one of the most expensive processes of the productive cycle; an operation that can engrave up to 40–60% on the production cost, moreover to be time consuming if carried out manually. According to the producers, mechanical harvesting is an essential factor for the subsistence of hazelnut cultivation (Blandini & Schillaci, 2007). It is therefore necessary for the relaunch of such a cultivation to introduce efficient and economically sustainable mechanized models adapting the orchard design as well (Tous et al., 1994). In Italy, hazelnut mechanical harvesting has been developed during the last years, in order to overcome labour scarcity and cost management of this practice (Blandini & Schillaci, 2007). Indeed, the necessity to reduce harvesting costs and the relative operating time, have pushed machines industries to realize diverse and ever more innovative models for harvesting from the ground such as self-propelled, trained, or mounted machines (Pagano, 2008). These machines permit with little labour a fast harvesting of hazelnuts from the ground. However, harvesting period has to be as brief as possible; in way to avoid that fallen hazelnuts could have alterations that compromise their marketing (Ascopiemonte, 2009).

In this context, experimental trials were carried out in two hazelnut orchards situated in Calabria, in view to assess technical and economic aspects of a tractor mounted harvest machine (Jolly 2800 model, GF s.r.l., Italy), which is commonly used for hazelnut harvesting from the ground.

MATERIALS AND METHODS

Orchard description

Experimental trials were carried out in two orchards situated in the municipality of Torre di Ruggiero (Province of Catanzaro, Southern Italy) that grow at 590 m above sea level. The orchards are mainly composed by shrubs of '*Tonda Gentile Romana*' main variety and some pollinators (as '*Tonda Giffoni*'), of 12 to 14 years old, with an almost regular planting distance of 4.6 x 4.6 m in a flat terrain for the first orchard having a yields about 2,372 kg ha^{-1} during trials, and somehow 4.5 x 4.5 m in a sloping terrain (up to 13%) for the second one which had an average yields of 2,083 kg ha^{-1}.

Operational working time

Hazelnut harvesting was carried out using the Jolly 2800 (GF s.r.l., Italy). It was mounted in the rear of a Lamborghini 660F Plus tractor (44 kW) with power take-off and three-points attachment (Fig. 1). Four people composed both of the harvesting sites, one specialized operator drived the tractor, two operators gathered the fallen nuts in windrows using backpack blowers (SA2062, Efco/Emak S.p.A., Italy) (Fig. 2), in order to facilitate the harvester work (Colorio & Pagano, 2011). The fourth operator was charged to handle the harvested product and replace the full bags by the empty ones in the machine.

In order to asses harvesting site working productivity referred to the operative time, working time of the machine was measured as reported by several authors (Monarca et al. 2009; Bernardi et al. 2013) according to CIOSTA (Commission Internationale de l'Organisation Scientifique du Travail en Agriculture) requirements (Bolli & Scotton, 1987). The operative time (OT) includes the effective time (ET) during which the activity is carried out as well as the accessory time (AT) needed for moving and discharging; and excludes the idle time. Time measurement started when the harvester was positioned at the beginning of the row, ready to start gathering.

Figure 1. Hazelnut mechanical harvesting from the ground using the Jolly 2800 machine.

Figure 2. Hazelnut gathering in windrows using backpack blowers.

Economic analysis

Furthermore, technical and economic data were recorded. An estimation model based on Miyata (1980), as described in Behjou et al. (2009), Bernardi et al. (2016), Cho et al. (2016) and Sánchez-García et al. (2016) was applied in order to calculate the machinery cost per hour (e.g., agricultural tractor cost) and the equipment cost (e.g., Jolly 2800, Efco-SA2062), taking into account also the operator-machine labour cost. The used model was however modified according to the experimental trials considering hazelnut harvesting (Table 1).

To compare the two working sites, the cost per kg of hazelnut in shell and the average cost per hectare were estimated also. Specifically, the cost per kg in shell was calculated dividing the total harvesting cost per hour by the harvesting yield per hour.

To evaluate the average cost per hectare, the harvesting cost per kg was multiplied by the harvesting yield per hectare. The harvesting cost analysis was performed by splitting the operating cost into its variable and fixed components.

Table 1. The considered parameters for the economic analysis in the Calabrian hazelnut orchards

Cost item	Symbol	Source
Fuel consumption cost € h^{-1})	FCC	Fuel consumption (l h^{-1})*fuel price (€ l^{-1})
Oil consumption cost (€ h^{-1})	OCC	Oil consumption (kg h^{-1})*oil price (€ kg^{-1})
Maintenance (€ h^{-1})	M	Field survey
Worker labour cost (€ h^{-1})	WLC	Worker (n)*average wage per hour (€ h^{-1})
Total variable costs per hour (€ h^{-1})	THVC	FCC+OCC+M+ WLC
Interests on capital goods (€ $year^{-1}$)	ICG	((Machinery value (€)+salvage value (€))/2)*interest rate (%)
Depreciation (€ $year^{-1}$)	D	(Machinery value (€)-salvage value (€))/ economic life of machinery (years)
Insurance (€ $year^{-1}$)	I	Field survey
Space cost (€ $year^{-1}$)	SC	Area occupied by the machine (m^2)* price per m^2 (€ m^2)*(0.01~0.03)
Total fixed costs per year (€ $year^{-1}$)	TYFC	ICG+D+I+SC
Total fixed costs per hour (€ h^{-1})	THFC	TYFC/average annual machine use (h $year^{-1}$)
Total harvesting work site cost per hour (€ h^{-1})	THC	THFC + THVC
Harvesting cost per kg in shell (€ kg^{-1})	HCkg	THC/ harvesting yield per hour (kg h^{-1})
Harvesting cost per hectare (€ ha^{-1})	HCha	HCkg* harvesting yield per hectare (kg ha^{-1})

Variable costs included fuel and oil consumption of the tractor and the backpack blowers, as well as maintenance and human labour cost. Within the fixed costs, depreciation, insurance, interest on capital goods and the occupied space cost of the machinery were taken into account. In particular, labour cost was estimated in terms of opportunity cost that corresponds to the employment of temporary workers for manual and mechanical operations considering the local current hourly wage (Stillitano et al., 2016). For this purpose, for qualified workers employed for mechanical operations, such as the tractor driver, a compensation of 9.46 € per hour was considered, while, for the generic workers 8.57 € per hour was considered. Interests on capital goods (machines) were determined by applying an interest rate of 2%. The machinery salvage value was estimated as demolition material selling (steel and iron), which is equal to 10% of the initial purchase cost. Input costs (e.g. fuel and oil consumption) were calculated according to the market pricing referred to 2016.

RESULTS AND DISCUSSION

Elaborated data revealed that the operative time OT (OT=ET+AT) was equal to 3.79 h ha^{-1} in the first harvesting site (flat) while it was equal to 11.34 h ha^{-1} in the second one (hilly orchard). Both values are higher than those found by ENAMA (2004), Monarca et al. (2009) and Zimbalatti et al. (2012), which correspond respectively to 2.61 h ha^{-1}, from 2.13 to 2.27 h ha^{-1} and 3.50 h ha^{-1}. The results of statistical analysis (Table 2) did not highlight any significant difference, between the two harvesting sites, for the operative time as well as for the effective time; however, it did for the accessory time. Indeed, it was necessary to spend more accessory time to move between the rows and to position correctly the harvester in the second harvesting site due to the slope as well as to the irregularity of planting layout.

Table 2. One-Way Analysis of Variance (ANOVA) results of related to the working times

	Df	Sum Sq	Mean Sq	F value	Pr(> F)
Effective Time (ET)					
HS	1	1,632	1,632	0.539	0.469
Residuals	30	90,848	3,028		
Accessory Time (AT)					
HS	1	2,868	2,867.5	9.029	0.00504 **
Residuals	33	10,480	317.6		
Operative Time (OT)					
HS	1	324,896	324,896	5.754	0.096
Residuals	3	169,391	56,464		

*α = 0.05 Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1,* HS: Harvesting site (Variation source).

Working capacity in the first harvesting site (flat orchard) was equal to 0.26 ha h^{-1} corresponding to 631 kg h^{-1}. While, working productivity was equal to 0.065 ha h^{-1} op^{-1} corresponding to 158 kg h^{-1} op^{-1}. Regarding the second harvesting site (hilly), working capacity was equal to 0.088 ha h^{-1} corresponding to 184 kg h^{-1}. While, working productivity was equal to 0.022 ha h^{-1} op^{-1} corresponding to 46 kg h^{-1} op^{-1}. Employing the same harvesting machine, ENAMA (2004) obtained a work rate of 0.38 ha h^{-1} corresponding to 263 kg h^{-1}. Monarca et al. (2009) obtained values of working capacity equal to 0.47 ha h^{-1} and 0.44 ha h^{-1} corresponding to a working productivity of 940 kg h^{-1} and 1,100 kg h^{-1} respectively, whereas, Zimbalatti et al. (2012) obtained a value of 13 kg h^{-1}.

Economic analysis shows a total hourly cost equal to 48.58 € h^{-1} for both harvesting sites, 89.4% among which represent the variable costs due to labour costs (80.97% of the variable costs). Machinery and equipment ownership costs (i.e., depreciations) account for a large share of the total fixed costs, corresponding to 77.3%. Moreover, the two analysed harvesting sites were compared considering the cost per kg of hazelnut in shell as well as the average cost per hectare (Table 3). The findings are clearly influenced by the obtained yields referred to the operative time (OT) in each orchard. Indeed, a higher cost per kg of hazelnut in shell, corresponding to 0.26 € kg^{-1}, was obtained in the second harvesting site (hilly), while in the first one, this cost was equal to 0.08 € kg^{-1}. Concerning the average cost per hectare, the second harvesting site showed the worst economic performances, with 550.76 € ha^{-1} against 182.54 € ha^{-1} obtained in the first one. This is mainly due to the greater amount of time dedicated to harvesting, which is linked to the terrain conditions. These results differ from those obtained by Tous et al. (1994) and Yildiz (2016), who obtained an average cost per hectare around 490 \$ ha^{-1} and 436.47 € ha^{-1} respectively, using a mechanical harvester from the ground and blowers, with different plant productivity and workers' number.

Table 3. Comparison between the two analysed hazelnut orchards

Parameter	Harvesting site 1 (flat)	Harvesting site 2 (hilly)
Operative time (hours ha^{-1})[1]	3.79	11.34
Working capacity (ha $hour^{-1}$)	0.26[2] (631 kg $hour^{-1}$)	0.09[3] (184 kg $hour^{-1}$)
Working productivity (ha $hour^{-1}$ op^{-1})	0.065 (≈ 158 kg $h^{-1}op^{-1}$)	0.022 (46 kg $h^{-1}op^{-1}$)
Machinery cost (€ $hour^{-1}$)	48.58	48.58
Cost per Kg in shell (€ kg^{-1})	0.08	0.26
Harvest cost per ha (€ ha^{-1})	182.54	550.76

[1]Operative time (OT) = ET+AT; [2] aprox. 1,5 ha day^{-1}, [3] aprox. 0.5 ha day^{-1}.

The achieved analyses clearly showed the low performances obtained in the studied harvesting sites, and particularly in the hilly orchard, from both technical and economic points of view. However, it is to be stated that this cultivation has been subject, during the considered campaign, to wild boar (*Sus scrofa*) damages. These latter concerned not only the production but impeded also usual agricultural practices prior harvesting.

CONCLUSIONS

The recovery and valorization of hazelnut cultivation that plays a multifunctional role is guaranteed only if a careful planning of machinery employment to accomplish the diverse agricultural practices, especially harvesting, is carried out. Indeed, in order to reduce accessory time and increase productivity using the above-described harvester, orchards should be well managed, and trees planted according to a regular layout. Further trials using other mechanical harvesting machines and devices as well as diverse site organization should be carried to compare the obtained results and look for more sustainable solutions.

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