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Precision agriculture and competitive advantage: Economic efficiency of the mechanized harvesting of Chardonnay and Nero d'Avola grapes

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ABSTRACT

In this work, the results of the research activity carried out on wineries are presented to demonstrate the economic convenience of carrying out mechanical harvesting. After determining the break-even point, for the introduction of the grape harvester in the company, the production costs and the relative profitability of two cultivars (Chardonnay and Nero d'Avola) were estimated. The research results highlight that the wine entrepreneur can improve profit margins with mechanical harvesting, operating with his machine on a minimum business area of 41.62 ha, otherwise resorting to renting the operation is always convenient as lowering production costs improves economic margins. The positive effects are therefore recorded both in the case of introducing the machine into the company and in the case that the entrepreneur rents the machine.

1. Introduction

The competitiveness of Italian viticulture must be achieved through effective marketing policies and by lowering production costs where possible. To achieve these objectives, both greater integration of the supply chain and an increase in the mechanization of cultivation operations are needed. All of this, especially in those rural contexts where the wine-growing activity is the fundamental part of the economic activity, represents the strategic variable of success on which to focus for the relaunch of the local economy [1]. The harvest operation, which has a decisive impact on the production costs of the vineyard due to the high and concentrated work requirements required, represents one of the cultivation operations on which to intervene to reduce production costs. The mechanical harvest makes it possible to overcome the drawbacks, especially of a technical-economic nature, of manual harvesting, such as timeliness of intervention and grapes harvested with homogeneous ripening. This aspect has positive effects on the quality of the grapes harvested and therefore on the wine produced. Therefore, the introduction of machines that allow the reduction of costs has positive effects both on the economic performance of the farm and on the quality of the product and this becomes strategic in the era of globalization where, with the ease of commerce and telecommunications, even products food products, and therefore also wine, is made available for consumption in parts of the world even very far from the place of production [2]. Process innovation has positive effects on a company's economic performance and allows wine entrepreneurs to carry out precise planning of harvesting operations according to the variety and seasonal climatic trends [3]. In recent times, especially in developed countries, the amount of workers willing to do the harvesting of agricultural products by hand has been increasingly reduced. This aspect has above all a social connotation for workers in developed countries as they are increasingly looking for less onerous jobs. In industrialized countries, the workforce for the countryside comes more and more from workers who come from developing countries and very often they are not brought into compliance with the labor standards. This aspect is socially relevant. However, we should ask ourselves why entrepreneurs do not bring workers into compliance with labor standards. In the case of small farms, as in the case of the vast majority of wine producers in Sicily, the company suffers the price as imposed by the wineries. This type of market is configured as an oligopoly made up of wineries. In this situation, the entrepreneur is led to save on the costs of the production process and therefore tries to achieve a competitive advantage by reducing costs where he can, i.e. by not bringing the workers into compliance. In this scenario, in economic terms given the rigidity of land supply, it is necessary to study competitive strategies to recover competitiveness margins [4]. To be competitive today, production costs must be reduced and the fruit and vine supply chains cannot reach levels of competitiveness without the introduction of machines to manage production in the field. In this work, after talking about innovation, we have analyzed how the introduction of the grape harvester in the winery (which represents a process innovation) allows to lower production costs and improve production margins.

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2. Innovation on farms

Innovation is the engine of growth. Competitive firms must always introduce innovations to gain a competitive advantage in the market. In agriculture, it is known that innovations take a long time to implement [5]. However, the implementation of innovation systems represents a variable successful strategy to create a competitive advantage. The sources of competitive advantage are the strategy of costs and that of differential advantage. In general, but especially in agriculture, one of the main effects of the introduction of innovations in businesses and territorial systems is the growth of productivity and competitiveness. Naturally, not all operating areas in which innovation can be used are replicable in every context, and above all, given a certain condition, not all innovations can generate an increase in productivity and competitiveness. Each company, given a territorial context, given the land factor with its orographic conformation as fixed, can only adopt certain innovations. On steep slopes, mechanization, for example, is difficult to implement. Therefore, one of the first fixed points when it comes to innovation in agriculture is the awareness of taking into account its complexity. Technological progress is one of the most important responses to increasing agricultural productivity and reducing costs by increasing the efficiency of the use of production factors [6]. Innovation does not spread rapidly but maintains its competitive potential for companies that invest in it. The gap between "innovative" and "prudent" entrepreneurs is spreading with a lengthening of the times for the diffusion of new products [7]. Innovation must always be linked to economic reasons (increase in revenues and/or reduction in costs). The entrepreneur is led to innovate according to a possible increase in the company's competitive capacity. But why do agricultural enterprises adopt innovation processes? To answer this question we need to refer to economic theory. Farms that innovate do so to reduce production costs as, for example, has occurred in the last ten years with the diffusion of mechanized grape harvesting. Furthermore, the company that innovates does so to improve the efficiency of the use of production factors [8]. And again, the innovation adopted by the entrepreneur can concern the growth of the quality of the products as occurs when one adheres to certain production regulations for products with the denomination of origin or typical indication. Finally, innovation can concern the diversification of company production to reduce both the technical risks of agricultural activity and those of the market. So innovation is the result that the entrepreneur finds as a function of a problem that he encounters during the business activity and the application phase of the business strategy. Innovation can have an incremental character, i.e. be an adjustment and actualization of an idea implemented in the past that still works in the basic structure, but needs to increase the possibilities of use or improve the efficiency of the process or be a solution completely new that exploits recently systematized knowledge or intuitions that go beyond the intervention processes usually used [9]. For production processes with low capital intensity, innovation spreads through imitation, i.e. the effect caused by the verification, by the reference entrepreneurial fabric, of the competitive advantages which the company that has it can enjoy adopted [10]. This effect occurs in those rural contexts where the "innovative" entrepreneur imitates the strategy of his neighbor. The first stimulus to innovate derives from the verification, by the entrepreneur, of the positive effect of the change on income, be it in terms of an increase in revenues at constant prices and/or a reduction in costs and/or an improvement in product quality and/or a change in the marketing process. The introduction of an innovation is generally an investment - of various kinds, but still a commitment of resources - and as such it is linked to a risk that the entrepreneur assumes in which the probability of failure should be minimized to speed up the transfer.

3. Materials and methods

The experimental activity was carried out on three wine-growing enterprises in the Trapani area (Sicilia – Italia), in a hilly area, with a production focus specialized in the cultivation of wine grapes, with a vineyard area varying between 80 and 85 ha. The farms are located in the Segesta area, an important area also from a historical point of view. Segesta was an ancient Elymian city located in the north-western part of Sicily. Inside the archaeological park, it houses a Doric-style temple and a theater from the Hellenistic age, partly dug into the rock of the hill. Other excavations have brought to light a Hellenistic-Roman town and a medieval village [18]. This archaeological site is among the best preserved in all of Sicily, despite the numerous transformations it has undergone, and is certainly one of the most evocative places of cultural interest thanks to the visible panorama and its position on the mountain. It is currently one of the major cultural and landscape tourism destinations in the province of Trapani. This analysis presents the data relating to two cultivars, one of which with white grapes (Chardonnay) and one with black grapes (Nero d'Avola), which will reflect the choices made, in recent times, by entrepreneurs during the process of renewal of viticulture. The density is equal to 4,000 plants/ha (sixth 2.50 × 1.00 m). The adjusted unitary productions were equal to 120 q/ha for Nero d'Avola and 80 q/ha for Chardonnay. The training system is the counter-espalier one with Guyot pruning. The technical-economic analysis was conducted assuming the mechanical harvest with a self-propelled grape harvester. For this study hypothesis, the minimum surface area, or break-even point, was estimated, which purchases the grape harvester conveniently [10]. After having defined the minimum convenience threshold (hectares of vineyard area) for the introduction of the grape harvester in the company, the production costs and the relative profitability were estimated for the two cultivars considered [11]. In particular, at first, the production cost was determined by considering the manual harvest (hypothesis A). Subsequently, two other hypotheses were considered which envisage mechanical harvesting; in particular one provides for the introduction of the grape harvester within the company (hypothesis B), and the other assumes the use of rental (hypothesis C). Furthermore, the break-even point was calculated. The analysis of the breakeven point is part of the choice between self-mechanization or rental [12]. Therefore, the judgment of economic convenience was determined by comparing the total operating cost of the grape harvester with the relative rental rate. Economic convenience exists when the total unit cost (per hectare of area) of the grape harvester to be introduced into the company with the purchase is lower than the cost incurred for the rental. In particular, the total unit cost of the grape harvester is defined as follows:

$$CTU = Cf/ha + Cv$$

Where:

CTU = total unit cost of the grape harvester (euro/ha);
Cf = fixed cost of the grape harvester (euro/year);
Cv = variable cost of the grape harvester (euro/ha);
ha = hectares of planted vineyard area.

Given a specific vineyard area, the total cost/ha of the harvest is given by the sum of a portion of the fixed cost/ha to harvest and the variable cost. The total unit cost, therefore, decreases as the number of hectares on which the harvest is carried out increases. The break-even point, to identify the number of hectares for which the cost of harvesting with your machine and with a rental machine are equal, occurs when:

$$Cf/ha + Cv = Cn$$

Where:

Cn = grape harvester rental cost (euro/ha).

To determine the costs, reference was made to the relevant literature [13–16]. Fixed costs are represented by those items of expense that do

not change as the hours of use of the machine vary and are: the reintegration portion (on the multi-year cost), interest on invested capital, expenses relating to insurance, and the cost of using the shelter of the grape harvester. The reinstatement quota was determined as the difference between the new value (net of the capital contribution, from the public aid of the agricultural economic policy, equal to 40% of the investment cost) and the residual value attributed at the end of the economic cycle of the machine, dividing the value by the economic life of the machine. Interest on invested capital is determined by applying a rate of 4% to the value of the average fixed asset. The insurance was charged considering the actual monetary outlay incurred during the agricultural year. As regards the price of use of the machine storage room, its determination was carried out by applying the rate of 3% to the reconstruction value of the warehouse considering the effective surface area. Variable costs also called marginal costs because they vary with the hours of use of the machine (or of the hectares harvested), are represented by: labor costs for running the machine, costs for repairs and maintenance, costs for purchasing fuel and lubricant, and interest on capital advanced for the use of the grape harvester. For labor costs, the trade union salary (including solid costs to be paid by the company) of the specialized tractor driver expected for the province covered by this study was considered. For the determination of the repair and maintenance costs, reference was made to the technical parameters of the operating costs of agricultural machinery of the CRPA [17]. For fuel and lubricant costs, once the consumption quantities (CRPA) have been determined, the tariffs set for the 2021–22 agricultural year have been applied. The interest on the advance capital is determined by applying a rate to the average advance expenses of 6 months. The estimate of the production cost of the vineyard is carried out by distinguishing between explicit and calculated costs. For explicit costs, these are all those items of expenditure inherent in the management of the vineyard during the agricultural year (labor, fertilizers, pesticides, fuels, lubricants, etc.). The determination of working hours for the various cultivation operations (fertilizing, pruning, soil tillage, weeding, treatments, etc.) refers to the average labor employed recorded in the companies examined. The monetary quantification, on the other hand, refers to the salary expected for the province subject of the trial for the year 2022; for the other production factors, the prices envisaged for the 2021–22 crop year were applied to the quantities recorded. Therefore, all explicit cost items include the cost of labor and the cost of materials used in the production process. The calculated costs include the shares (reintegration, maintenance, and insurance) on the land and agricultural capital, the interest on the agricultural capital, the costs of administration and supervision, taxes and consortium contributions, and the price of use of the land capital. In particular, the reintegration and the interest in the agricultural capital have been imputed according to their economic duration. The value of the vineyard reintegration quota was calculated by postponing (at a rate of 5%) all the expenses incurred for planting the same at the end of the planting station (2 nd year) and by reducing the non-repayable contribution used by the entrepreneurs – under the agricultural economic policy and equal to 57% of the total eligible cost (7,980.27 euros/ha), all about the economic life of the vineyard which, according to the principle of ordinariness, is considered equal to 16 years (the estimate of the years was made based on similar vineyard plantings by type of cultivar examined in the agricultural areas under study). The maintenance quotas were determined according to the effective use of the agricultural and land capital. The value of the insurance shares on the machines was calculated considering the actual monetary outlay incurred by the entrepreneurs. As far as taxes are concerned, Irap and IMU have been calculated and consortium contributions have also been considered; Irap was determined by applying the rate of 1.9% to the difference between the invoiced assets and the invoiced liabilities; for the IMU, the rate established by the Municipality in which the companies fall within the relative taxable base was applied. For the consortium contributions, the actual monetary outlays incurred by the entrepreneurs were considered. Management expenses are determined by applying a percentage of 5% to the gross production value to salable. The interest on the advance capital was determined by applying a rate of 4% to the average advance expenses of 6 months. The price of use of landed capital was determined by applying a rate of 2% on the average agricultural value in force for the year 2022 in the agricultural areas under study. The estimate of revenues, i.e. of gross salable production (GSP), was carried out considering, for the cultivars examined, an average of the quantities produced in the last 4 agricultural years (2019–2022). Its monetary quantification refers to the 2021–22 agricultural year.

4. Results and discussions

From the surveys, it was ascertained that to harvest 1 ha with the grape harvester examined, in hilly areas, it takes 1.5 h of work. The total operating cost of the grape harvester was 12,082.39 euros/ha of which 11,970.00 for fixed cost and 112.39 for variable cost. Reintegration, with 9,180.00 euros, absorbs 76% of the total fixed cost, and is, therefore, the item that weighs the most. In the context of variable costs, the most affected are repairs (73.44 euros), labor costs (18.75 euros), and fuel costs (14.25 euros); overall these items represent 94.7% of the variable cost per hectare. As already mentioned, the judgment of economic convenience must be expressed by comparing the operating cost of the grape harvester with that of the rental. For 2009, in the study area, the rental rate of contractors was 400 euro/ha. Therefore, the minimum area that justifies the purchase of the grape harvester from an economic point of view is 41.62 ha. Assuming manual harvesting, the production cost of Chardonnay was equal to 3,782.33 euros/ha, of which 2,693.00 explicit costs and 1,089.33 calculated costs (Table 1). The first item of expenditure is represented by harvesting which, with 1,063 euros/ha, absorbs 28.1% of the total cost of production. Following, in order of importance, are shares on capital (land and agricultural) which with 456.08 euros represent 12.1% of total costs. In particular, this cost item includes the reintegration portion of the cost of planting the vineyard which amounts to 383.58 euros/ha. For Nero d'Avola, the cost of carrying out cultivation operations amounts to 2,173.63 euros/ha. The calculated costs amount to 1,111.78 euros/ha, therefore the total production cost is equal to 3,285.41 euros/ha. The difference between the two cultivars can be ascribed to the high manpower required in Chardonnay compared to Nero d'Avola, especially for the harvest, for green pruning, and also for the number of anti-mildew and anti-downy mildew treatments. The average cost of production, considering a yield of 80 q/ha for Chardonnay and 120 q/ha for Nero d'Avola, amounts respectively to 47.28 euro/q in the first case and 27.38 euro/q in the second. To express an economic judgment on the cultivars examined, it is necessary to quantify the level of profit they can provide. Considering average prices of 40 euro/q for Chardonnay and 30 euro/q for Nero d'Avola, a business loss of 582.33 euro/ha is recorded in the case of Chardonnay while for Nero d'Avola there is a profit of 314.59 euros/ha. Therefore, according to the economic results achieved, there are two different economic scenarios. For Chardonnay, the production cost (euro/q) is far higher than what the market is currently able to offer for the product. For Nero d'Avola, on the other hand, the market price of the grape (euro/q) makes it possible to cover the production cost, which is lower than that of Chardonnay, and to make a small profit margin. In the case of the introduction of the grape harvester in the company, the production costs would decrease (Table 1).

In particular, in Chardonnay the total production costs would go from 3,782.33 euros/ha to 2,981.35 (−21.2%); in the case of the Nero d'Avola cultivar, the total cost would go from 3,285.41 euros/ha to 2,742.69 (−16.5%). In this hypothesis, the harvest is no longer the main expense item. The introduction of the grape harvester into the company decreases the cost of the cultivation operation by 75.4% for the Chardonnay and by 67.5% for the Nero d'Avola. This situation would change the company's profitability. In particular, in Chardonnay there would be a shift from a loss to a positive profit of 218.65 euros/ha; in Nero

Table 1
Production cost of wine grapes in western Sicily (euro/ha - values at 2022 prices).

Expense items	Cultivars					
	Chardonnay			Nero D'avola		
	Manual collection A	In-house mechanical harvesting B	Mechanical harvesting for hire C	Manual collection A	In-house mechanical harvesting B	Mechanical harvesting for hire C
Fertilization	223.50	223.50	223.50	191.75	191.75	191.75
Dry pruning	266.00	266.00	266.00	256.50	256.50	256.50
Prunings excerpt	228.00	228.00	228.00	190.00	190.00	190.00
Pruning shredding	23.50	23.50	23.50	17.63	17.63	17.63
Ligatures	142.50	142.50	142.50	161.50	161.50	161.50
Land works	94.00	94.00	94.00	117.50	117.50	117.50
Weeding	26.75	26.75	26.75	31.75	3175	31.75
Treatments against powdery mildew and downy mildew	282.25	282.25	282.25	177.00	177.00	177.00
Green pruning	256.50	256.50	256.50	152.00	152.00	152.00
Irrigation	87.00	87.00	87.00	71.00	71.00	71.00
Collection	1,063.00	262.02	400.00	807.00	262.02	400.00
Total explicit costs	**2,693.00**	**1,892.02**	**2,030.00**	**2,173.63**	**1,628.65**	**1,766.63**
Shares on land and agricultural capital	456.08	456.08	456.08	450.98	450.98	450.98
Interest in agricultural capital	11.70	11.70	19.70	9.44	11.70	14.43
Direction	160.00	160.00	160.00	180.00	180.00	180.00
Consortium taxes and contributions	110.55	110.55	102.96	120.36	120.36	112.76
Usage price of landed capital	351.00	351.00	351.00	351.00	351.00	351.00
Total costs calculated	**1,089.33**	**1,089.33**	**1,089.74**	**1,111.78**	**1,114.04**	**1,109.17**
Total Cost of Production	**3,782.33**	**2,981.35**	**3,119.74**	**3,285.41**	**2,742.69**	**2,875.80**

d'Avola the profit would instead increase, reaching 857.31 euro/ha. These results could undergo a further increase if the harvested hectares exceed 80 (minimum size of the companies surveyed); in this case, the cost per hectare of the harvest would decrease as the hectares harvested increased, considering that the fixed costs of the grape harvester would be spread over a greater number of hectares harvested. The results obtained show that there are very few wineries that could introduce the grape harvester into their production structure. In particular, in the province of Trapani, 3.3% of the total are wineries with vineyards of more than 30 ha. In light of this situation, the economic analysis was repeated assuming that firms resort to leasing. The results of the simulation show a decrease in total production costs of 17.5% (Chardonnay) and 12.4% (Nero d'Avola) respectively. Profitability, in this case, would be 80.26 euros/ha for Chardonnay and 724.20 euros/ha for Nero d'Avola. The results highlight a clear economic cost advantage for companies that adopt precision farming techniques. The grape cultivars examined are very widespread in the research area and therefore, the adoption of precision agriculture represents a strategy that could be adopted by many farms.

5. Conclusions

Within the various choices, the entrepreneur makes those that allow him to obtain the maximum profit. The analysis carried out highlighted how the wine entrepreneur could improve profit margins with mechanical harvesting. Considering the difficulties that companies have to be competitive (high production costs, low grape prices, difficulty in finding the workforce), the mechanization of the harvest represents a way to contain costs and improve profit margins. The minimum optimal size for introducing the grape harvester into the company is equal to 41.62 ha under the conditions taken into consideration in this trial. Therefore, the investment is justifiable in wineries with a rather large size. The results of the analysis also highlight that for small and medium-sized wineries it is convenient to carry out mechanical harvesting by renting and it is precisely in this direction that winegrowers seem to be orienting themselves in recent times. In fact, in recent years in western Sicily, according to the information collected in the area, the contractor companies that carry out mechanical harvesting have recorded a significant increase. This situation will most likely lead to a reduction in the rental rate, with positive effects on the economic performance of small and medium-sized enterprises that decide to carry out mechanical harvesting. The results of the research are very interesting both for the wineries and for the territory. In particular, in many rural areas in recent years there has been a shortage of manpower for grape harvesting as it represents a strenuous job and many young people are not willing to do it. Not only this aspect, but also the high labor cost represents a limitation. Therefore, in countries with high per capita incomes, in a period in which people who are willing to work in agriculture and in particular for grape harvesting are decreasing and considering the high cost of labor, precision agriculture represents a winning strategy for the company and for the territory in which the company insists. Therefore, the results of this research demonstrate the convenience at both the microeconomic and macroeconomic levels. The economic convenience demonstrated in the research highlights that at the company level production costs are reduced and therefore, without prejudice to the unit revenue, the profit margin increases. At a macroeconomic level, the research highlights that the conditions can be created for vitality and competitiveness for businesses and therefore for the territory. The results of the study also highlight that the application of precision farming methods requires large plots of land, where the machines can operate with savings in downtime. A limit to the research is given by the land structure in Sicily, especially for small farms where very large land bodies are difficult to find. This represents a limit to the innovation to be implemented. In the future, it should be investigated how a land recomposition would favor the overcoming of this limit.

Declaration of competing interest

I declare not to be in a conflict of interest Journal of agriculture and food research.

Data availability

Data will be made available on request.

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