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Research Article

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MACHoice: a Decision Support System for agricultural machinery management

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Abstract: Mechanisation is a key input in modern agriculture, while it accounts for a large part of crop production costs, it can bring considerable farm benefits if well managed. Models for simulated machinery costs, may not replace actual cost measurements but the information obtained through them can replace a farm's existing records, becoming more valuable to decision makers. MACHoice, a decision support system (DSS) presented in this paper, is a farm machinery cost estimator and break-even analyzer of alternatives for agricultural operations, developed using user-driven expectations and in close collaboration with agronomists and computer engineers. It integrates an innovative algorithm developed for projections of machinery costs under different rates of annual machine use and work capacity processing, which is crucial to decisions on break-even machinery alternatives. A case study based on the comparison of multiple alternatives for grape harvesting operations is presented to demonstrate the typical results that can be expected from MACHoice, and to identify its capabilities and limitations. This DSS offers an integrated and flexible analysis environment with a user-friendly graphical interface as well as a high level of automation of processing chains. The DSS-output consists of charts and tables, evidencing the differences related to costs and carbon emissions between the options inserted by the user for the different intensity of yearly work proceeded. MACHoice is an interactive web-based tool that can be accessed freely for non-commercial use by every known browser.

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1 Introduction

Agricultural practices and technological trends, settling requirements of agronomics, and ergonomics and environmental aspects, have resulted in specialized, more complex and expensive machines being made available (Bochtis et al. 2014; Fountas et al. 2015; Søgaard and Sørensen 2004). These points, coupled with the need for timeliness in cultural operations, have encouraged larger machines and have caused farm machinery and power costs to rise in recent years. Therefore, it is frequent to find farms with a level of mechanization above expected, as a result of disproportionate capacities of machinery relative to the annually work processed (Najafi and Torabi-Dastgerduei 2015; Søgaard and Sørensen 2004). This is frequent in small and medium-scale farms facing difficulties in meet the costs of up-to-date technology (Toro and Hansson 2004).

Although sometimes neglected, farm machinery operation and ownership costs often represent more than 30% of the total crop's production costs and substantially affect farm profitability (Anderson 1988; Bochtis et al. 2014; Buckmaster 2003; FAOstat 2015; Kasten 1997). Thus, in order to improve the contribution of any machinery system to farm profitability, it is essential to make smart decisions on purchasing, leasing, trading or renting machinery, and in how much work capacity to invest. In particular, the following 2 questions facing concerned farmers, contractors and machinery dealers need to be answered: i) On what crop area (or volume of work) could the machine ownership and operation be economically justified? ii) What difference in economic performance can be expected between machinery systems (or manual) alternatives to perform the same operation. Understanding the variety and genesis of machinery costs and how they are affected by the intensity of machine use is crucial to such decisions.

The best source of information to budget farm machinery costs is actual farm-level records; estimating costs is an alternative (Misener and McLeod 1987). However, the diversity of farming systems and the large number of alternatives to perform the same operation, make it difficult to define a generic cut-off point between profitable and unprofitable machine operation (Baio et al. 2013; Singh and Mehta 2015). A machinery or machine operation cost analysis takes place at a specific point in time. However, because it regularly involves capital investment (as in purchased machines), the economic evaluations are based on projections, generally for more than 5 years (ASAE, 2003b). Therefore, the feasible solution under such prospective circumstances is to analyse machinery costs of crop operations based on computer simulations. Using physical and financial information previously collected from in-field studies of the machinery performance, budgeting costs and break-even area (or work volume), formulations can be derived.

During the last two decades several software tools have been developed for agricultural machine cost estimates such as Mecacost (CRA-W, 2016), Machcost (Montana 2016), AMACA (Sopegno et al. 2016), Manitoba (PAMI, 2014), Estimating Farm Machinery Costs (Edwards 2009), Machinery Operating Costs Calculator (Metrics 2009), Machdata (Lazarus 2008), AgMach (Huhnke 2008), Farm Machinery Cost Calculator (Nibourg 2008), Equipment Life Cycle Cost (iSolutions 2007), Machinery Cost Calculator (Gamble 2001), Farmdoc (Schnitkey 2000), Idaho Machinery Cost Calculator (Smathers et al. 1994) and Maqcontrol (Piacentini et al. 2012). These tools are often based on formulas published by the American Society of Agricultural Engineers ASAE (2003a and 2003b) to calculate the machine costs, but they use different approaches to integrate this economic information at farm level, according the variation of the volume of work to be performed.

Table 1 summarises the main features of different programs available for farm machinery estimation. This table also contains appropriate references for full explanations of the abilities of each of the software tools. The authors reiterate that this analysis was not designed to determine the best and worst software and that each of the tested software tools has a role in machinery cost analysis. However, it is critical that users be aware of the differences in the software and select the one that best fits their economic needs.

The main insufficiencies of these software tools are, among others, not understanding how machinery costs are affected by the intensity of machine use, or comparing different alternatives (e.g. manual or mechanical) for the same operation (e.g. CRA-W, 2016; Montana 2016; Sopegno et al. 2016), lacking the ability to perform machinery break-even analysis and the dependence on a licensed software or operating system (e.g. Edwards 2009; Lazarus 2008; PAMI, 2014).

Moreover, since the development of those approaches does not link the users' expectations with tool performances, its application at farm level are very limited restricting it to scientific or technical documentation (Sopegno et al. 2016; Sørensen and Bochtis 2010).

Also, several tools available for costs estimation nowadays are based on Microsoft Excel spreadsheets which make them dependent on a licensed software: *Ag Decision Maker* (Edwards 2009), *MachData* (Lazarus, 2008), Manitoba (PAMI, 2014), Machcost (Montana 2016) and Ontario Government Agricultural Tool (Gamble 2001). The tools University of Idaho Machinery Cost Analysis (Smathers et al. 1994), AgMach (Huhnke 2008), Maqcontrol (Piacentini et al. 2012) and (Patel et al. 2012) are based on applications, which require the Windows

Table 1: Summary of the most relevant features of available tools for agricultural machine costs estimates

Feature	MAChoice	Mecacost	Machcost	AMA	Manitoba	Est. Farm Mach. Costs	Mach. Operating Cost	Machdata	*AgMach*	Farm Mach Costs	Life Cycle Cost Calculator	Mach. Cost Calculator	Farmdoc	Idaho Mach. Cost Analysis
	Cunha et al.	CRA-W	Montana	Singh et al.	PAMI	Edwards	FreightMetrics	Lazarus	Huhnke	Nibourg	iSolutions	Gamble	Schnitkey et al.	Smathers et al.
	2019	2016	2016	2015	2014	2009	2009	2008	2008	2008	2007	2001	2000	1994
Number of options allowed in comparison	Ilimited	3	1	1	3	2	2	2	3	1	1	1	1	3
Export/Save results	×		×		×	×		×	×		×	×		×
Change model input values	×		×								×			
Evolution of costs per work unit	×							×						
Costs chart	×	×												
Evolution and repair costs charts	×													
Summary table of costs	×			×	×	×	×	×		×	×	×	×	×
Allows the insertion of different units and currencies	×						×							
Cloud Based, responsive, compatible with all browsers	×	×		×			×			×			×	
No dependencies to programs or OS	×	×		×			×			×			×	

Operative System installed in a virtual machine or use an emulator (Table 1). A cloud-based tool is much more flexible than *.exe* applications or Excel spreadsheets, as it can be accessed everywhere by any operating system and can be compatible with several browsers. A few Web tools that calculate farm machinery costs are available, such as Farmdoc (Schnitkey 2000), Farm Machinery Cost Calculator (Nibourg 2008), Machinery Operating Costs Calculator (Metrics 2009), AMA (Singh and Mehta 2015) and Mecacost (CRA-W, 2016).

Mecacost (CRA-W, 2016) is the only tool that presents a costs chart, but it does not display the evolution of machinery' costs by units of work performed per year. Machdata (Lazarus 2008) includes the projection of costs feature but for only two options simultaneously. Recently Sopegno et al. (2016) presented the agricultural machine cost analysis app (AMACA), which was developed based on user-driven requirements. The main insufficiency of this tool is the estimates and graphical representation of machinery projections costs under different rates of annual machine use. It also does not allow the comparison between multiple alternatives for the agricultural operation.

The main goal of this paper is to present the functionalities of MACHoice, an interactive web-based tool for agricultural machinery management. MACHoice is a farm machinery cost estimator and break-even alternatives analysis tool for agricultural operations that was developed in close collaboration with agronomists and computer engineers following users-driven requirements, to provide farm machinery decision making processes with science-based information. The development of this decision support system (DSS) was encouraged by the importance of machinery costs on farm profitability and the inexistence of tools, with MACHoice's functionalities.

MACHoice, when contrasted with the available tools listed in Table 1, can compare an unlimited number of machines, includes a flexible machinery database, can use different currencies and work units (area, kg), is able to predict the evolution of repair and maintenance costs, and can estimate carbon emissions based on the engine specific consumption. MACHoice accepts an unlimited number of options (e.g. manual operation or rent machinery) which facilitates breakeven point determination. These features are particularly useful in farm cost planning, operation planning and when acquiring new machines. It can also be used to estimate machinery costs that may perform operations in several crops.

The next section presents MACHoice's main functionalities and the software structure used in the development. Section 3 illustrates how the main categories of machinery costs should be treated in an engineering economic analysis using the MACHoice tool. Section 4 covers the main parameters used to evaluate machinery performance and machinery cost function. Section 5 analyses the cost projection per unit of work and break-even point. A case study based on the economic comparison of different alternatives for grapevine harvesting is presented in section 6 to demonstrate MACHoice's performance on costs estimation and budgeting projections.

2 MACHoice tool

2.1 MACHoice: general aspects

This section briefly describes the main modules available in MACHoice. The case study presented in section 6 provides a complete overview and more-in-depth discussion on the operability of this Decision Support System (DSS).

MACHoice is a machinery costs estimator and budgeting alternatives analysis for agricultural operations. The calculations are based on a few specific parameters introduced by the user (e.g. purchase value, fuel price, machinery power) while others could be selected from embedded databases (e.g. machinery characteristics). MACHoice's output consists of charts and tables, evidencing the differences in costs between the options (machine and work characteristics) inserted by the user.

A number of user-driven requirements presented by Bochtis et al. (2014); Sørensen and Bochtis (2010) and Sopegno et al. (2016) for agricultural management systems were adopted in the MACHoice's development.

MACHoice provides an adapted graphical user interface (GUI) that allows users to enter the relevant parameters, assisted by tooltips and an interactive help system. Multiple machinery alternatives analysis for the same agricultural operation can be performed simultaneously.

Figure 1 presents a typical example of MACHoice GUI, with an example explaining the procedure of introducing machinery economical and technical characteristics. The structure of the main modules available in MACHoice is shown in figure 2. The layout of MACHoice is user-friendly in order to allow its operational use by a broad set of users, ranging from farmers to producers' associations, contractors and even machinery manufacturers.

The user starts by choosing different mechanization alternatives (Figure 1 – *frame* 1): machine purchasing, renting or a manual operation.

For the option *PURCHASE*, the machine's details should be inserted hierarchically: i) machinery type:

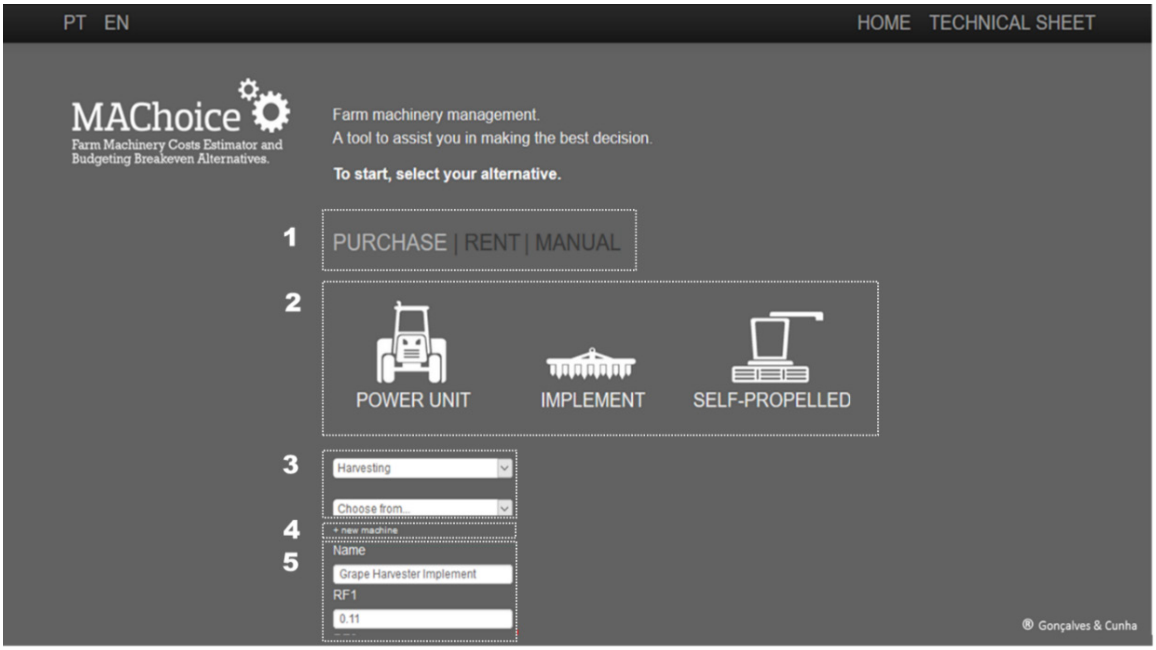

Figure 1: MACHoice's screen-shot of user interface with example explaining the path to add a new machine (e.g. Grape Harvester implement) for costs analysis

power unit, implement or self-propelled (Figure 1 – *frame 2*), ii) operation type (e.g. harvest, transport, sowing) and iii) machinery group (Figure 1 – *frame 3*), such as tractor, tillage or sprayers. After this procedure several fields are displayed with the default values stored on machinery database (Figure 1 – *frame 5*). The user can change the default parameters adding specific or personalized information about insurances, sheltering, and depreciation costs among others.

If the machine under study is not inserted into MACHoice's machinery database (see section 2.2), the user must click "+ new machine" link (Figure 1 – *frame 4 – new machine*) and the input fields related with the insertion of a new machine will be displayed.

The forms and data inputs are different according to the machine's specificity and operation type. In the case of the power unit, only one group is defined - traction and transport – so it, in this category the group list is not available. By contrast, the implements and self-propelled equipment have a wider range of operations, thus several operation-type groups are available. In the selected list of figure 2, $\mathit{GROUP\ LIST}_{I}$ and $\mathit{GROUP\ LIST}_{SP}$ represent the implements and self-propelled machines groups, respectively.

A previous step to decide the machinery type simplifies the insertion of values by the user once the forms and data inputs are displayed according to machinery specificity. Since implements and self-propelled machines can perform a wider range of operations compared to power units, an intermediate step with groups was created. This way, the machine will be organized in a group depending on the type of operations it will perform. For implements, the machinery was divided in the following groups: tillage, seeding and planting, fertilization and phytosanitary treatments, harvesting, and miscellaneous. This step can also facilitate the search for the machinery in the machine list. These groups are displayed in *select lists* (Figure 2 - $\mathit{GROUP\ LIST}_{I}$ or $\mathit{GROUP\ LIST}_{SP}$). After one group is selected, the following list will be filtered with the respective machinery (Figure 2 - $\mathit{MACH\ LIST}_{I}$ or $\mathit{MACH\ LIST}_{SP}$). For power units, one list contains all the machines (Figure 2 - *MACH LISTP*). When the user selects one machine from the list, the respective form is displayed (Figure 2 - *FORMP* for power units, *FORMI* for implements or *FORMSP* for self-propelled). This form requires the insertion of different data according to the type of machine preemptively filled with reference parameters such as RF1, RF2, work velocity, work width and field efficiency (see section 3). If the desired machine is not available in one of the *selected* lists (Figure 2 - *MACH LISTx*), the user can add a new machine by clicking "+ new machine" (Figure 1 – *frame 4 – new machine*) and insert its name, repair and maintenance coefficients and service life in the new frame displayed.

After selecting a machine or filling a *new machine* extra form, a new form will appear, in which the user must

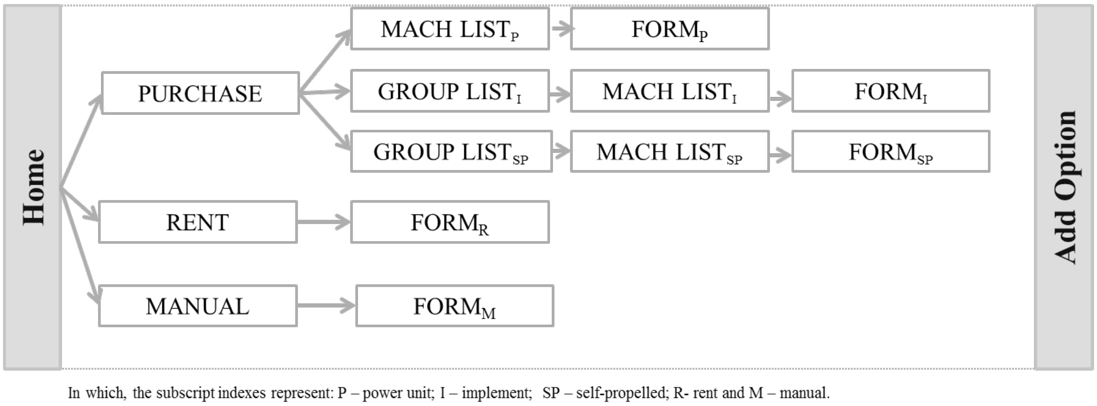

Figure 2: Flowchart of MACHoice's use, the user must select one of 3 options: *Purchase*, *Rent* and *Manual*. This selection triggers the display of different forms and selected lists

fill in the machine's specifications, such as purchasing price, predicted volume of work, fuel/oil price, velocity, and other parameters. These parameters depend on the type of machine.

If the user previously selected renting or manual operations, he will be redirected to a form (Figure 2 – *FORMR* and *FORMM*) where he needs to insert: machine renting/labor price per hour, number of machines/workers and their work capacity and efficiency (see section 2.2). After filling in the form, the user merely has to use the "add option" button to proceed.

2.2 MACHoice's machine databases

One of MACHoice's features is that the machinery *selected* lists (Figure 2 - *MACH LISTx*) are constructed from the database with every page load. This means if changes in the database are needed, e.g. insert or alter a machine data field; the website is updated with a page refresh. This allows flexibility for altering the content of the select lists without having to rewrite code.

The machinery data is stored in two internal tables (Figure 3). One of the tables stores the values of the parameters such as residual group (eq. 2, section 3.1.1), repair and maintenance costs coefficients (eq. 6¸ section 3.2.2), service life, velocity and work capacity, which will be (in)directly used in the estimation model (eq. 16, section 5.2). Estimates of the residual value were based on the ASAE (2003a) in which an equation for residual value percent and coefficients for several different types of equipment, or residual groups, is provided in Table 2.

The second database table stores the names, operation-type and type of machinery. The names are stored in two different languages (English and Portuguese, currently). MACHoice provides the parameters for a number of machines and the user can either change these machine default parameters or insert a new machine.

2.3 Internal structure and programming language

MACHoice tool was developed using several programming languages such as: Hypertext Preprocessor (PHP), Javascript (JS), MySQL, Hyper Text Markup Language (HTML) and Cascading Style Sheet (CSS). Other programming tools were also used: Bootstrap, Highstock, Asynchronous JS and XML (AJAX), jQuery and KnockoutJS.

Java Spript is an interpreted programming language with object oriented capabilities, distinguishing itself from other languages such as C and Java (Flanagan 2002; Richards et al. 2010). It is commonly used in web browsers, having core functions that allow interaction with the user, browser functionalities and browser's window. Another advantage in using this language when developing a website is that it makes it possible to run JS scripts embedded within HTML pages (Flanagan 2002; Richards et al. 2010).

One disadvantage in using *client-side* JavaScript is that the user has permission to explore all of the code written in JS, because the script runs in the users' browser instead of a server (Walker and Chapra 2014). This is not a problem for MACHoice, as JS is only used in pair with HTML in order to provide structure and dynamics to the website; it does not keep any relevant information about the costs model.

The PHP language, contrarily to JS, is a *server-side* scripting language but it can also be embedded within HTML and is open-source. As a *server-side* language,

id	type	res_group	rf1	rf2	hours	years	velocity	efficiency	name_en_US	group_en_US
1	Power	1	0.007	2	12000	10	NULL	NULL	Stationary motor	
2	Power	4	0.096	1.4	2500	NULL	NULL	NULL	Truck	
3	Power	4	0.96	1.4	2000	NULL	NULL	NULL	Van	
6	Power	4	0.127	1.4	2000	NULL	NULL	NULL	Off-road vehicle	
7	Power	4	0.19	1.3	3000	12	NULL	NULL	Farm trucks	
8	Power	1	0.007	2	12000	10	NULL	NULL	Tractor 2WD	
9	Power	1	0.003	2	16000	12	NULL	NULL	Tractor 4WD	
10	Power	1	0.003	2	16000	12	NULL	NULL	Catterpillar	
11	Implement	4	0.301	1.3	2000	12	4.5	80	Ridger	Tillage
12	Implement	4	0.301	1.3	2000	12	6.5	80	Subsoilers	Tillage
13	Implement	4	0.29	1.8	2000	12	7.5	80	Moldboard plows	Tillage
14	Implement	4	0.18	1.7	2000	12	7.75	80	Disk plow	Tillage
15	Implement	4	0.28	1.4	2000	12	8.5	80	Chisel	Tillage
16	Implement	4	0.27	1.4	2000	12	10.5	80	Cultivator danish	Tillage
17	Implement	4	0.27	1.4	2000	12	3.75	80	Cultivator	Tillage
18	Implement	4	0.36	2	1500	7	4.5	77.5	Rotary cultivator	Tillage
19	Implement	4	0.301	1.3	1500	7	12	80	Field cultivator	Tillage
20	Implement	4	0.18	1.7	2000	12	8.75	80	Disk harrow	Tillage

Figure 3: Screenshot of MACHoice's data bases showing the parameters for machine cost estimates (left) and translation database (right). The explanation of these machine parameters will be presented on the section 3

only those with permission to access the server can read the PHP code, thus, any code written in PHP is as secure as the server where it is being run. According to Welling et al. (2005), PHP is very efficient and was designed for use on the WEB or in the internet, as it has many built-in functions for performing useful web related tasks. Another important advantage is that it has native connections to different databases. For these reasons, PHP was used in MACHoice development.

In order to store the machinery data, MySQL databases were used. MySQL is a fast, free, portable and robust database; it allows the storing, sorting, searching and retrieving of data. The database uses Structured Query Language (SQL), the standard database query language. Another advantage common to these two languages, PHP and SQL, is their availability on many operating systems and any functional web server (Welling and Thomson 2005).

Additionally, one of the frameworks that was used, the Bootstrap, transforms MACHoice into a responsive website i.e. presents its content in the most accessible form to any viewport that accesses it (Frain 2012). Hence, it can adapt automatically to all screen resolutions, making MACHoice portable to mobiles and tablets (Xin et al., 2015).

3 Estimating machinery costs with MACHoice

Machinery costs are generally divided in two costs types: the ownership or fixed costs (FC) and operational or variable costs (VC); each one is subdivided in different shares (ASAE, 2003a; Fairbanks et al. 1971). The total annual running cost (CT) of a machine comprises both the fixed and variable costs.

In this section, we define the main categories of machinery costs and how they should be treated in an engineering economic analysis using the MACHoice tool.

3.1 Machinery fixed costs

The FC are those which remain unaffected, on a yearly basis, regardless of the amount of use of the machinery. The FC are not related to the operation itself and are usually determined on a yearly basis (e.g. Makeham and Malcolm 1986). Typical fixed costs include: machinery acquisition (Vi), depreciation (Dp), interest charges of capital, insurance and shelter. Some items, such as the price of the machine, whether new or used, the interest charges of capital and insurance, can be determined beforehand; others need to be estimated.

The next sections present how these FC are estimated by the MACHoice.

3.1.1 Machinery depreciation costs

Depreciation represents the reduction of the machine's commercial value during its service life and it is often the largest cost in terms of agricultural equipment (Calcante et al. 2013; Hunt 1995). The machinery's decrease in value over time is usually related to: the normal degradation of its irreparable parts, its obsolescence due to innovations that replace its work, or the alteration of farm production making it inadequate (Robb et al., 1998).

There are several methods that could be used to predict machinery depreciation, such as the declining-balance or sinking-fund method (Hunt 1995). In MACHoice, depreciation is obtained through a linear method presented in equation 1,

$$D_p\,(m.u./\,year) = \frac{V_i - V_f}{L} \qquad 1$$

in which D_p is the value of the depreciation expressed as monetary units (m.u.) per year; V_i (m.u.) is the purchase price; V_f (m.u.) refers to the value of the machine at the end of service life (L, years) or remaining value, generally measured in years. The remaining machinery value is generally not available; research has been conducted on the basis of equations to depend V_f on the list price. For a particular class of machinery, remaining value (V_f) is often assumed to be determined by its age and not its rate of use, using a constant rate of market value depreciation. MACHoice uses the following equation proposed by the ASAE (2003a),

$$V_f = V_i \times D_1 \times D_2^{Age_n} \;\; ; \;\; \text{if Age} < 1 \rightarrow V_f = V_i \times 0.85 \qquad 2$$

where V_f (m.u.) is the machine's remaining value expressed in function of purchase value (Vi) and D_1 and D_2 are depreciation factors (unitless). The conditional statement in equation 2, express that the factor D_1 and D_2 should be used with machinery that is at least one year old.

Depreciation factors (D1 and D2) for different machinery residual groups are in table 2 which represents an extract from ASAE (2003a).

In MACHoice, both the depreciation and V_f are estimated, by default, using the method proposed in ASAE (2003a) but the user could change the methodology to estimate these costs.

3.1.2 Annual interest charges of capital

Machinery is purchased with debt funds, equity funds, or some combination of the two. When debt funds are used there is an explicit interest charge. When equity funds are used there is an implicit charge referred to as opportunity cost (e.g. Kasten 1997).

In MACHoice, a percentual rate of annual interest charges of capital can be selected (as default is 10%) and it is considered invariable during the equipment service life (L; years).

3.1.3 Insurance and shelter

In MACHoice, insurance and shelter costs are estimated as a percentage of the machine's purchase value.

The insurance cost shall be estimated only when we do not have more stringent values. The rates for regional area and specific machine could be obtained from insurance agents and introduced directly in MACHoice.

The housing share is considered to be 0.75% (by default) of the purchase value (ASABE, 2003). However, this figure should serve as a guideline to be used when specific machinery housing values is unavailable on the farm.

Table 2: Depreciation factors for calculating remaining value percentages by machinery group

Depreciation Factor	Machinery residual groups (RG)					
	Tractors (RG 1)	Combines (RG 4)	Windrowers/ Mowers (RG 3)	Forage/ Harvesters (RG 2)	Balers (RG 3)	Planters/ Tillage (RG 4)
D1	0.67	0.65	0.67	0.56	0.66	0.66
D2	0.94	0.93	0.90	0.90	0.92	0.96

Source: Bowers (1994) and ASAE (2003a). RG are the residual groups of machines.

3.2 Machinery variable costs

Variable costs (VC) are those which are treated as proportional to the amount of machinery use. The most common machinery costs considered as operational costs are (e.g. Makeham and Malcolm 1986): fuel use, repair and maintenance, labor and additional or "supplementary charges". The next sections present how these VC costs are estimated in MACHoice.

3.2.1 Fuel and lubricants use

The fuel consumption figure is obtained by multiplying the engine power by the specific consumption and adjusting for the rate of use. In turn, the rate of fuel consumption varies according to the size of engine, kind of work performed (the engine load factor), type of fuel and the machine's operating mode. The rate of use of the engine power (e.g. tractor), is the average of their entire use throughout the year. This provides the consumption rate (L/h) and the respective costs are calculated by integrating the fuel price.

Annual average fuel requirements for tractors may be used to calculate overall machinery costs. In MACHoice, fuel consumption rates per hour for tractors are calculated using equation 3,

$$Q\ (L.h^{-1}) = SVFC \times Nm \times EPr \quad (3)$$

where, Q is the fuel consumption in litres per hour, SVFC ($L.kW.h^{-1}$) expresses the specific volumetric fuel consumption, Nm (kW) refers to the nominal power of the engine, and EPr (%) is the annual average ratio of equivalent power engine rated to power engine. Table 3 presents the typical values for EPr for different groups of machines.

The SVFC for Diesel engines was calculated with equation 4 (ASAE, 2003b; Grisso et al., 2004),

$$SVFC\ (L/kW/h) = 2.64 \times EPr + 3.91 - 0.203 \times (738 \times EPr + 173)^{0,5} \quad (4)$$

While the consumption of lubricants (L_D) for diesel engines is estimated by equation 5,

$$L_D\ (l/h) = 0.00059 \times Nm + 0.02487 \quad (5)$$

Equations 4 and 5 provide, respectively, the fuel and lubricants consumption (L/h) and the costs are calculated by integrating the respective prices per litre.

3.2.2 Repairs and maintenance costs

Maintenance (M) refers to all activities that should be performed on a regular basis to keep the machinery running in good conditions. *Repairs* (R) are more unpredictable, which makes them more difficult to budget. Repairs are executed by an expert, while maintenance tasks can be performed by a common driver, being simpler and more frequent. Maintenance costs are generally constant throughout machine life, while annual repairs costs for a given machine normally increases with the rate of its annual use. The repairs and maintenance costs (R&M) are influenced by several aspects such as machine characteristics and purchasing price, climate, soil and maintenance strategy (Calcante et al. 2013; Hunt 1995).

Many attempts have been made to relate R&M costs to the use of machinery by analyzing actual costs (Calcante et al. 2013; Robb et al. 1998).

ASAE (2003a) describes the accumulated charges for R&M for a particular machine as a function of the machine purchase price, accumulated use of machine in hours, and also two specific machine factors – RF1 and RF2. MACHoice estimates the R&M costs using the equation recommended by ASAE (2003a), presented here in equation 6),

$$CRM = \frac{V_i \times RF1 \left[\frac{AH}{1000}\right]^{RF2}}{AH} \quad (6)$$

Table 3: Values for the annual average ratio of equivalent power engine to rated power engine (EPr) for different group of agricultural machines

Machine Group	EPr (%)
Tractor with 2WD (multi-operational use)	35
Tractor with 4WD and caterpillars (multi-operational use)	40
Harvester of cereal (maize included), roots and tubers	75
Harvester of fodder	80

Source: ASAE, 2003a.

where, CRM is the average repair and maintenance costs (monetary units per hors; m.u./h), V_i is the purchase price of the machine (m.u.); RF1 and RF2 are the repair and maintenance factors (unitless) and AH (in hours) represents the accumulated use of the machine.

3.2.3 Machine operator costs

MACHoice includes the cost of the operator's labor as part of the variable costs of running a machine. These variable costs also include labor charges related to time wastes and machine maintenance tasks performed by the driver.

3.2.4 Additional or supplementary costs

Some operations, apart from the inherent costs of running the machine, also need additional or supplementary factors and, consequently, added costs.

The additional machinery costs are the ones that complement the activity of a machine and their value and depend directly on the rate of work performed by the machine. This is a case of tractor cost for implemented machines (e.g. sprayers, tillage) which is difficult to attribute or allocate to a specific work or farm activity.

The supplementary costs generally do not depend on the amount of time the machine is operating and can be reasonably measured and allocated to a specific operation such as herbicides or plastic for forage bags. The supplementary costs are important to compare machinery costs of different alternatives for the same agricultural operation such as: i) haymaking *vs.* plastic bags in forage conservation process, ii) herbicides *vs.* soil tillage, iii) self-propelled *vs.* trailed harvest machine selection.

MACHoice has specifics fields to accommodate both additional and supplementary cost and processing them according to the appropriate units.

3.2.5 Timeliness costs

Every crop operation is best done at a certain period/moment of the year outside of which the quantity and/or quality would be reduced (Fountas et al. 2015; Najafi and Torabi-Dastgerduei 2015). This lack of timeliness can be calculated as a cost resulting from a decrease in crop income. Timeliness cost becomes thus important to compare alternatives for the same operation such as machines of different work capacities. Therefore, the cost of owning a machine at the exact moment it is needed should be offset by the decreased risk of jeopardizing a crop production and or quality.

In MACHoice the expected timeliness costs could be introduced as a supplementary costs.

4 Field capacity and efficiency

Field capacity or work processing capacity, theoretical (WP) or effective (EWP), and work efficiency (WE) are the primary parameters used to evaluate machinery performance (Grisso et al. 2004; Renoll 1981). The WP represents the theoretical work units processed per unit-of-time for a particular field operation without any interruption (non-productive time) of the process, while the WE is defined as the ratio between the time that the machine is effectively operating under actual field conditions and the total amount of time dedicated to the operation (Hunt 1995). The effective work capacity (EWP) is always lower than the theoretical capacity and can be calculated by equation 7,

$$EWP_i = WP_i \times WE \Rightarrow EWP_i(w.u./h) = \frac{s_i(w.u)}{t_i(h)} \times WE \tag{7}$$

where EWP is the effective work capacity, *ti* represents the amount of time that the machine is operating by units of work processed (*si*) with the efficiency of the process WE (unitless).

The EWP is undoubtedly related to the crop system, the producers' technical knowledge, field shape and size, and crop and soil characteristics and might include: turning time, machine preparation in farmstead, time to load/unload machine's hoppers, maintenance time, and essential operator breaks, among others (Grisso et al., 2004; Hunt, 1995; Søgaard and Sørensen, 2004).

While calculating EWP through equation 7, the WE can be evaluated by using a reference table such as (ASAE, 2003b), or based on field process, by using machine operation parameters (equation 8),

$$EWP_i(w.u./h) = \frac{S_i(w.u)}{T_i(h)} \tag{8}$$

where S_i is the total work processed (*e.g.* worked area, kg harvested) by total time dedicated to the operation (T_i), which includes non-productive time of the operation.

The EWP is normally expressed in area per time, but it can be more precise if the units are adjusted to the type of work using MACHoice's features, for example, using kg per hour for harvesters or using bales per hour for balers.

5 Machinery costs projection and break-even analysis

The machinery costs projection is a model that allows the estimate of the total operation costs in structural situations different from there where the machinery was tested with actual farm records. This model is crucial for break-even alternatives (e.g. purchasing/renting, mechanical/manual) for the same agricultural operations.

5.1 Total and per-unit-of-work costs and their relationship to machine use

Because of the close relationship between machine use and costs, MACHoice estimates machinery projection costs for different rates of annual intensity of machine use (U, hours/year).

The total annual machinery costs (CT; m.u. year^{-1}) result from adding the fixed costs (CF) and the variable costs (CV) incurred per year, expressed in terms of intensity of annual use and is calculated from equation 9,

$$CT_{(m.u./year)} = CF_{(m.u./year)} + CVm_{(m.u./w.u.)} \times U_{(w.u./year)}, \quad 9$$

where CVm is the average variable costs and U is the intensity of annual use expressed in the units of work (w.u) performed (hectares, tons, etc.).

Dividing total annual costs by the units of work performed per year (U), yields the average annual cost per unit of work (CTm; m.u/wu; eq. 10),

$$CTm_{(m.u./wu)} = CT_{(m.u./year)}/U_{(w.u./year)} \quad 10$$

Combining both equations 9 and 10 provides us,

$$CTm_{(m.u./wu)} = CFm_{(m.u./wu)} + CVm_{(m.u./wu)} \quad 11$$

Where CFm is the average fixed costs (m.u.wu^{-1}).

Figure 4 presents how the fixed and variable machinery costs contribute to the total annual costs (CT) or the average total cost per unit of work processed (CTm). Both, total and per-unit-of-work costs, are closely related to machine use (U). Due to the direct relationship between operating costs and use, CT will increase directly with greater machine use (U). Conversely, CTm initially decreases and reaches a minimum (Figure 4).

Per-unit costs (CTm) initially decline sharply as machinery use increases because ownership costs are spread over more units of work per year. Eventually, however, a level of use is reached where dilution of ownership costs is offset by rising per-unit repair and dependability costs, resulting in very little change in overall per-unit costs. Stability in per-unit costs beyond a certain range of use also occurs due to a decline in the rate at which machine values drop with advancing age (eq.2).

With extremely high rates of annual use, CTm may increase as the rise in repair and dependability costs more than offsets the dilution of ownership costs.

5.2 Machinery costs projection

Although machine costs per unit of work such as hectare, number of bales, and tonnes, are desired, some cost

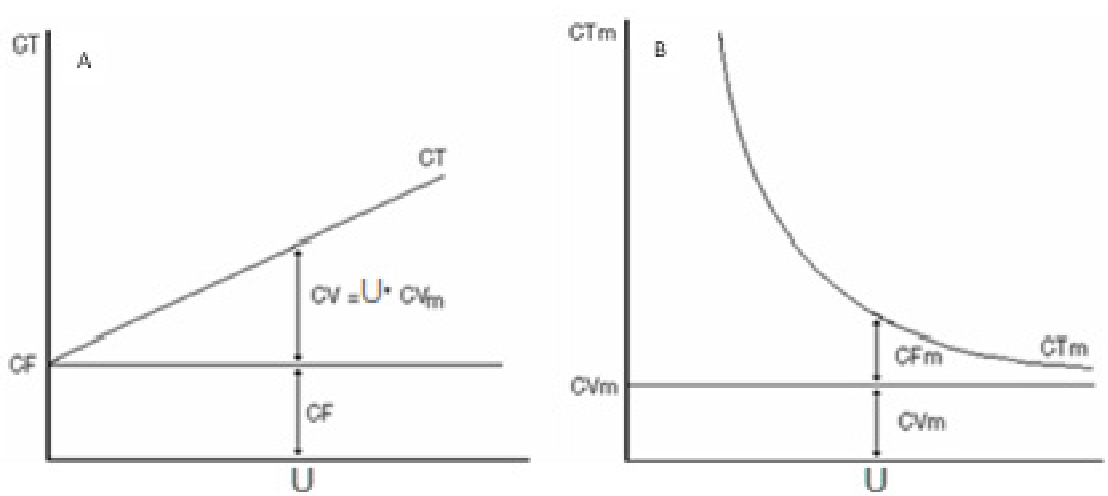

Figure 4: Representation of the impact of units of work processed per year (U) on the: total (CT), fixed (CF) and average variable (CVm) machinery costs per year (graph A), or average total (CTm), fixed (CFm) and variable (CVm) machine costs per units of work (right B)

components are determined by hours of operation. The concept of EWP is used to help make the transition from hours of use to units of work covered.

The EWP could be obtained by the relationship between the work volume i (Si; w.u./year) produced by the machine and its annual use (Ui), as presented in equation 12 (see also eq. 7 and 8).

Under no changes in the structural conditions related to machinery work efficiency (WE), such as field shape productivity or crop system, we can assume that the EWP does not alter when the machinery annual use Ui changes to Un, corresponding to the respective work volume of Si and Sn (eq. 12),

$$EWP_{i\_n}(w.u./h) = \frac{S_i}{U_i} = \frac{S_n}{U_n} \Rightarrow \frac{S_i}{S_n} = \frac{U_i}{U_n} \qquad 12$$

The total costs per unit of work, considering parameters related to the effective work capacity (EWP) and volume of work to be done (Si) by the machine, can be obtained using equation 13,

$$CT_{i\ (m.u./w.u)} = CTm_{\ (m.u./h)}/EWP_{\ (w.u./h)} \Rightarrow CT_{i\ (m.u./w.u.)} = CFmi/EWP + CVmi/EWP \qquad 13$$

Based on the cost equation 13 obtained for a given machine with an effective field capacity EWPi, working the volume of S_i and an annual use of U_i, we can generalize the cost projection model in order to obtain the costs of the same equipment according to the variation in the volume of work to be performed (U_n and S_n), assuming that the WE remains constant with the increase of annual use (U). Therefore, the average costs (CFm_n and CVm_n) for the annual use U_n can be expressed in terms of their average costs (CFm_i and CVm_i) calculated for the annual use U_i (eq. 14),

$$CFm_n(m.u./w.u.) = CFm_i \times \frac{S_i}{S_n} \qquad 14$$

In this generalization or cost projection model, the average fixed costs are calculated according to equation 14. However, contrarily to the average fixed and other variable costs, the average cost of maintenance and repairs (CMR) also depends on the annual machine's utilization (see eq. 6). Hence, in the estimation of the costs projection function the average cost of repairs (CMRn) for annual use U_n should be expressed in terms of average cost of repairs (CMR_i) for the annual use Ui according to equation 15,

$$CMR_n(m.u./h) = CMR_i \left[\frac{Sn}{Si}\right]^{RF2} \times \left[\frac{Si}{Sn}\right] \qquad 15$$

Thus, considering the machine's total cost per-work-unit (CTi) estimated for the workload S_i, the correspondent costs for different situations in terms of workload (S_n) could be estimated by the cost projection model presented in equation 16,

$$CT_n(m.u./w.u.) = \frac{CFm_i \times Si}{EWP \times Sn} + \frac{CVm_i - CMR_i\left[1 - \left[\frac{Sn}{Si}\right]^{RF2} \times \left[\frac{Si}{Sn}\right]\right]}{EWP} \qquad 16$$

where CT_n are the total cost for the work volume *Sn*, CFm_i are the average fixed costs for the work volume *Si*, CVm_i are the average variable costs for the work volume *Si*, *E*WP is the effective field capacity, and RF2 is a repair and maintenance coefficient (unitless). The CMR_i and CMR_n are repair and maintenance average costs for the work volume *Si* and *Sn* respectively.

The cost projection presented in equation 16 can be used to estimate the machinery operating costs in different work units.

5.3 Break-even analysis

The objective of the break-even analysis is to determine the number of units of work at which the costs of the proposed system to perform an agricultural operation equals those of the existing one (Hunt 1995; Singh and Mehta 2015). The breakeven point could be assessed by using equation 16.

It is a minimum beyond which machine costs could be justified due to the profitability of the operation. MACHoice machinery break-even point estimation is a simple technique that can be used for accurate assessment of the relative profitability of different alternative systems for the same operation that accomplishes the same result.

6 Case study, Vineyard harvesting alternatives

In order to present the MACHoice's performances, a case study based on a harvesting operation is presented. The purpose of this case study is to illustrate the typical results that can be expected from MACHoice, and to identify the capabilities and limitations of the developed application using a vineyard harvesting operation as an example.

This case study compares the cost of harvesting a vineyard with 30 hectares using three different alternatives: i) manual operation, ii) grape harvester implement (HI) – unpowered machine, and iii) self-propelled harvest (SP). The economic evaluations were extended based on MACHoice by hypothesizing costs projections change for grape harvest alternatives.

In this case study we assume that each harvest operation alternative (mechanical and manual) accomplishes the same results in terms of timeliness as well as grape damage and grape loss.

6.1 MACHoice inputs

The manual harvesting operation refers to 25 workers, with WE of 0.25 ha/h and a price of 5 €/h (occasional labour). Table 4 lists the main manual and machine's parameters required for estimating machinery costs, for a vineyard.

None of the machines considered in this case study were previously available in MACHoice's database (section 2.2). Thus, both SP and HI need to be introduced in the database before the economic evaluation. For this, the user must click the "+ new machine" link (Figure 1 – *frame 4*) and a different form appears. This form requires the insertion of the new machine's name, residual group value (Table 1), service life and reparation factors RF1, RF2 (eq. 6).

The self-propelled harvester (SP), when compared with the trailed (implement, HI) one, had a faster forward speed, required shorter times for unloading and manoeuvring at the end of the row and had higher WE. The WE and speed used in this case study were similar to the previous works developed in Itlay (Pezzi and Martelli 2015) and Spain (Fernandez-Alcázar 2009). Considering the 30 ha annually covered for each grape harvester tested and their WE, the annual use of the machines are 68.6 and 133.3 hours, respectively for SP and HI.

For the trailer harvester, the costs per hour for traction were previously calculated and introduced as a variable cost. The hourly cost for traction, which should be inserted on the MACHoice field as an additional or supplementary cost, was estimated based on the cost parameters from ASAE (2003a) assuming an annual use of 800 h for a tractor of 66 kW (Table 4).

In order to estimate the costs for the manual options, the user should select the *MANUAL* link (Figure 5 – *frame* 1), after which the respective form appears (Figure 5 – *frame 2*). As well as for the other mechanical alternatives, the manual option is added to the options list (Figure 5 – *frame* 4) which allows the cost comparison of the alternatives for grape harvesting under analysis.

6.2 MACHoice outputs

This section presents the main outputs of MACHoice for this case study.

MACHoice's results for repair costs, costs evolution, and carbon emissions are showed in three charts (Figure 6), while the detailed shares for the manual and machinery (HI and SP) harvesting alternatives are presented in table 5.

MACHoice presents the machinery costs in a dynamic and interactive way as represented in the figure 6. When

Table 4: Machinery data used for function cost estimation for each harvest machine tested in the case-study

Parameters	Units	Grape harvest implement (GHI)	Self-propelled (SPH)
Purchase price (Vi)	€	65 000	150 000
Repair factor, RF1[1]	[ ]	0.11	0.09
Repair factor, RF2[1]	[ ]	1.8	1.4
Service life (L)	Years	10	10
Residual group (RG)[1]	[ ]	3	2
Fuel price	€/L	-	1
Lubricants price	€/L	3	3
Work velocity[2]	km/h	1.5	2.5
Work width[2]	m	2.5	2.5
Work efficiency (WE)[2]	%	60	70
Annual use, U	ha	30	30
Traction power costs[3]	€/h	19.2	--
Ratio of power engine (EPr)[4]	%	-	75
Engine power	kW	-	73.5
Labor cost	€/h	6	6

1 The repairs factor (R1 and R2) for both SP and SHI were based on the values presented by Pezzi and Martelli (2015).

2 Optional in most of the implement cases

3 Estimated assuming an annual use of 800 h, 66 kW and a EPr of 40% for a tractor

4 Annual average ratio of equivalent power engine to rated power engine See table 3

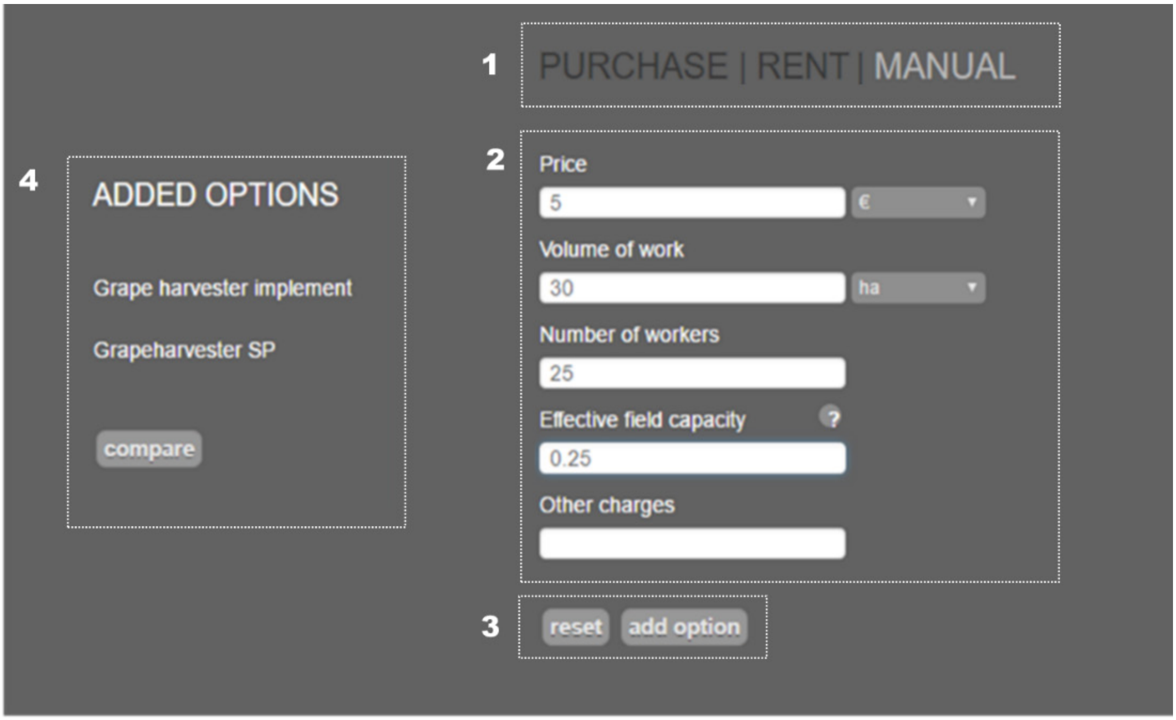

Figure 5: MACHoice's screen-shot explaining the path to insert manual option

the mouse cursor hovers over the middle chart (Figure 6), the tooltip identifies the options that were previously inserted by the user. The tooltip shows, for each option, the price per work unit (in the case study – euro/ha) and the hours of operating as a function of the amount of work per year. These values are calculated and are available in the tooltip for each point between the interval 1 w.u. and 10 times the volume of work inserted by the user. Since this case study has 30 ha, the costs will be calculated for a window of 1 and 300 ha (Figure 6 – costs evolution).

Figure 6 also graphically shows the CRM values computed from equation 6 for both HI and SP according to the work volume. The CRM chart presents the value zero for manual and rent options.

The *carbon emissions* (Figure 6) are calculated based on the machine engine's specific consumption and reference values provided in the conversion table of the annex II of the European Directive 2006/32/EC and Commission Decision 2007/589/EC.

Figure 7 represents the same chart (*costs per-*

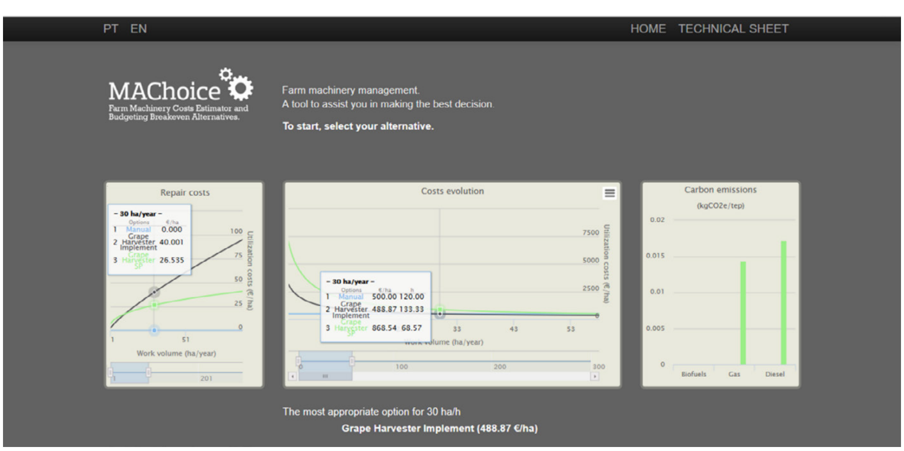

Figure 6: MACHoice's screen-shot of graphical user interface with the repair costs and costs per-unit-of-work for different alternatives of grape harvesting: manual and mechanical. The carbon emissions for the self-powered machines is presented in the graphic on the left side of the figure

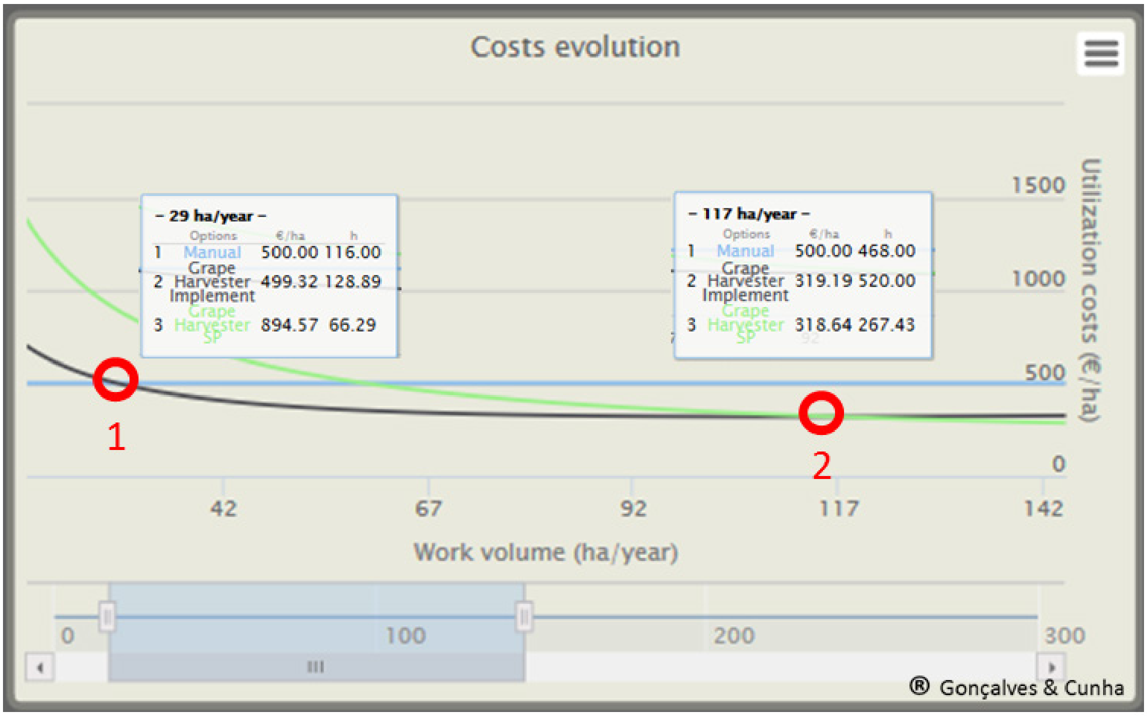

Figure 7: MACHoice's screen-shot (zoomed-in and altered) for the impact of work volume on the total costs. The blue series represents the manual option, the black expresses the grape harvest implement and the green exhibits the self-propelled harvest. Points 1 and 2 in red represent the break-even points for GHI and SP respectively

unit-of- work) presented in figure 6 but with a different visualization scale. The bar below the *x* axis, also called a navigator, is flexible and adjustable.

The cost of both machines are compared in figures 6 and 7. Likewise, the break-even analysis based on the minimum workable vineyard area to economically justify each grape harvest solution is presented. Since the case study deals with a vineyard with 30 ha, the best option is the HI with a cost of 488.87 €/ha and break-even point at 29 ha. For SH the costs in a vineyard size of 30 ha is close to 869 €/ha (table 5), and the break-even point is at 117ha, with a cost of 318.64 €/ha (Figure7).

This budgeting breakeven of manual and mechanical alternatives for grape harvesting in a vineyard size of 30 ha, are in line with the results presented by Fernandez-Alcázar (2009) for the vineyards in Spain and Demalè and Spezia (2009) in Italy.

Table 5 is an output of MACHoice displaying the costs per hour of work for the grape harvest options under analysis. The costs are divided into: depreciation, sheltering, fixed capital taxes, fuel, lubricants, repair and maintenance, labor and the total of fixed and variable costs. These can be exported to *.pdf* and *.xlsx* extension files using the MACHoice's features.

The costs for the manual option, in this cases, refers to 25 workers, with effective field capacity of 0.25 ha/h and a price of 5 €/h. The machinery costs were estimated for a vineyard size of 30 ha, using the data presented in table 4.

The machinery costs based on the MACHoice estimates, were also compared with the observed field costs for different alternatives of grape harvesting. The actual grape harvester costs used for this comparison were obtained from field measurements by Pezzi and Martelli (2015) in vineyard sizes of 84 ha and 125 ha, respectively, for HI and SP. Therefore, costs estimations for these areas and type of harvester machines (HI and SP) were also assessed by MACHoice. Figure 8 compares costs estimated by MACHoice against field measurements for HI and SP presented by Pezzi and Martelli (2015) for 84 ha and 125 ha, respectively for HI and SP. The FC represent around 40% and 60% of the total costs, respectively for HI and SP, which is in line with results from previous works (Demalè and Spezia 2009; Pezzi and Martelli 2015). The between-methods differences (MACHoice vs Field Measurements) for the FC and VC are always lower than 2%, with the highest differences being about 3% for the depreciation and RMC shares both associated with the HI (Figure 8). These differences could be related to the process of

Table 5: MACHoice output presenting the grape harvesting costs per hour for manual and mechanical alternatives of grape harvester for a vineyard size of 30 hectares

Machinery Costs	Units	Grape Harvester		Manual harvest
		Implement (HI)	Self-Propelled (SP)	
Depreciation	€/h	40.70	177.49	---
Sheltering	€/h	3.66	16.41	---
Fixed Capital taxes	€/h	28.40	130.01	---
Insurances	€/h	2.44	10.94	---
Fixed costs	*€/h*	*75.20*	*334.84*	---
Fuel	€/h	0.00	26.94	---
Lubricants	€/h	0.00	0.00	---
Repair & maintenance	€/h	9.00	11.61	---
Labour	€/h	6.60	6.60	---
Supplementary charges	€/h	0.00	0.00	---
Supplementary traction	€/h	19.20	---	---
Variable costs	*€/h*	*34.80*	*45.15*	---
Total costs 1	€/h	110.00	379.99	125.00
Effective Field Capacity	ha/h	0.225	0.437	0.250
Total costs 2	**€/ha**	**488.87**	**868.91**	**500.00**

estimating the traction costs associated with the HI.

The fuel and lubricants costs for the SP machine estimated by the MACHoice represent about 15% of the total costs (Figure 8), which is also in line with previous studies (Calcante et al. 2013; Pezzi and Martelli 2015). The RMC costs accounted for 15% and 29% for HI and SP, respectively, which are likewise similar to those found in other trials conducted in this area (Demalè and Spezia 2009).

The comparison of MACHoice's estimates with reference data collected in the fields showed consistent results, as demonstrated in figure 8, proving that the MACHoice approach is able to support decision-making process on the farm machinery costs.

7 Conclusion

MACHoice attempts to combine agronomic, engineering, and economics aspects as well as the user's requirements in a DSS to provide farm machinery management decision making processes with science-based information.

The added value of MACHoice is that it simplifies and significantly speeds up complex processes in a unique environment. It gives users without programing skills the opportunity to perform and automate advanced analyses to quickly process and plot important economic and environmental indicators of machinery management, such as costs estimates, carbon emissions and estimations of break-even alternatives for agricultural operations, managed in the built –in-database, to explore different approaches and to tune analyses on their needs.

The information provided by MACHoice may be helpful for a broad set of users, ranging from small farmers to farmers' associations, contractor or even machinery dealers in many situations such as: (i) prediction of the cash flows for different machinery costs mainly fuel and repair costs, (ii) performance of a sensitivity analysis for operation costs according to price variations (iii) predict the right time to replace machinery, (iv) selection between different machine models (v) estimation of break-even alternatives for agricultural operations, (vi) deciding between purchasing, leasing or renting equipment, in order to minimize costs of production, (vii) considering structural or technological changes, such as farm size changes or alternative crop systems, and viii) multi-farm usage of machinery in order to spread fixed costs over a larger area, as well as to reduce labour costs by using higher capacity machinery. This could be particularly important for small- and medium-scale farms where it is common to find a level of mechanization above expected, as a result of disproportionate machinery capacities.

Most of the functionalities proposed in the beginning of the project were accomplished, resulting in an open-access and efficient tool that can now help producers in decision planning. Further, the case study presented, points toward the feasibility of the proposed objectives. MACHoice, when compared with actual data, estimates plausible machine costs and breakeven alternatives for grape harvesting.

By evaluating the economic soundness of several

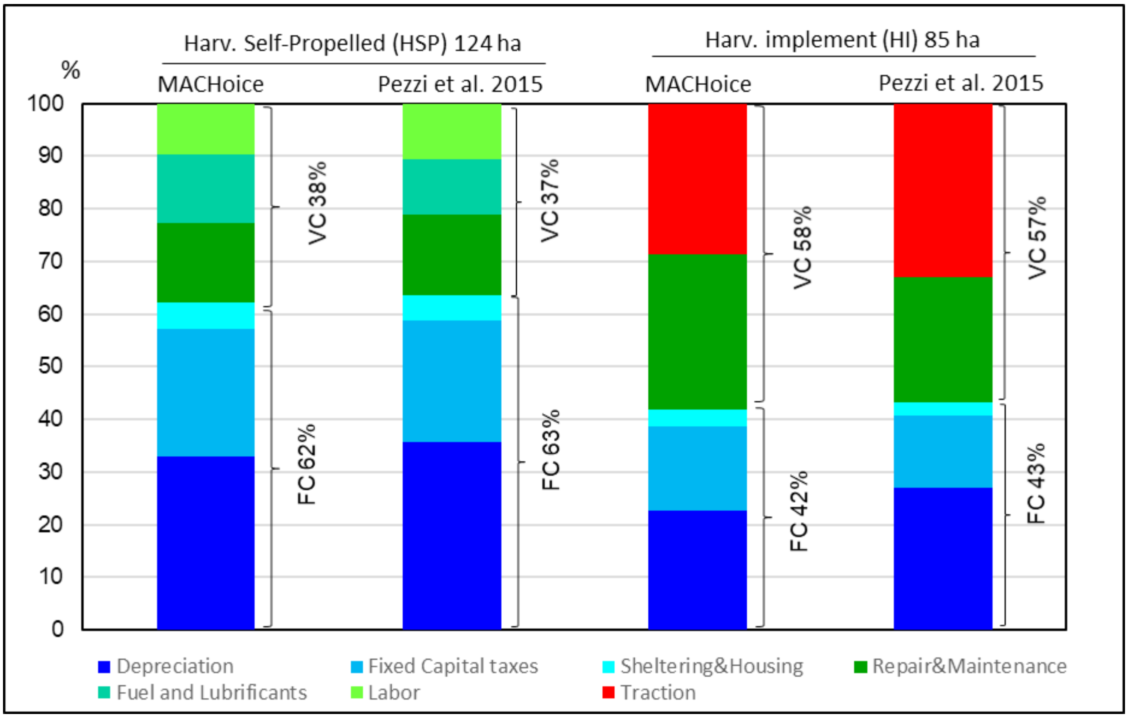

Figure 8: Comparison of fixed costs (FC) and variable costs (VC) estimated by MACHoice and field measurements presented in Pezzi and Martelli, (2015) used as a benchmark for self-propelled (HSP) and Harvest implement (HI) for 124 and 85 ha covered by year

alternative machinery systems, it is expected that MACHoice will provide the agriculture sector with a frame of reference in adjusting to evolving technology inherent to modern agriculture.

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