**A web mobile application for agricultural machinery cost analysis**



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# A WEB MOBILE APPLICATION FOR AGRICULTURAL MACHINERY COST ANALYSIS

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**Abstract:**

It has been demonstrated that machinery and equipment are major cost items in farm businesses in different countries. Moreover, in the last years, high power machines, advanced technologies, higher prices for spare parts and repairing process, and fuel consumption contributed to an even more rising of the machinery costs. Many engineering and economic methods have been implemented to calculate machinery use and cost, but they are almost confined in scientific and technical documentations making it difficult for a farmer to apply these methodologies for deciding on buying, leasing, or sharing agricultural machinery.

Information and communications technology (ICT) has an increasingly important role on business processes and provides a powerful foundation to address many daily problems. Today users want to be connected to useful information in real time. To that effect, the aim of this work was to develop an easy-to-use mobile application, called “AMACA” (Agricultural Machine App Cost Analysis) for determining the machinery cost in different field operations and making it available via a web mobile application using a cross-platform approach. The customer-driven Quality Function Deployment [QFD] approach was implemented in order to link the user expectations with the design characteristics of the app. The AMACA app is free, readily available, and does not require

any installation on the end users' devices. It is a cross-platform application meaning that it operates on any device through a web interface and major browsers support it. The user can make subsequent calculations of the sensitivity of the results by varying the input parameters (fuel price, interest rate, field capacity, tractor power, etc.) and compare the results. AMACA app can support the decisions on whether to purchase a new equipment/tractor (strategic level), the use of own machinery or to hire a service, and also to select the economical appropriate cultivation system (tactical level).

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**Keywords**: Agricultural machinery cost, machinery management, agricultural operations

# 1 INTRODUCTION

Information and communications technology (ICT) has an increasingly important role on business processes and provides a powerful foundation to address many daily problems. Today users want to be connected to useful information in real time. For this reason the use of mobile technology has grown rapidly; in fact, for the year 2014 mobile technology and applications were identified in the top 10 strategic technology trends globally (Gartner, 2014).

Nevertheless, in the agricultural sector there is a slow adoption in the use of mobile technology, if it is compared to other business domains (Xin et al., 2015). This is in contrast with the huge potential for applied mobile technologies in the sector for a various number of decision making processes including tailored weather information, geo-referenced soil maps, natural disasters forecast, extension service advices, distance learning modules, plant diseases diagnosis, agri-products traceability, economic information, and agricultural machinery management (Xin et al., 2015).

It has been demonstrated that machinery and equipment are major cost items in farm businesses in different countries (Bochtis et al., 2014). Moreover, in the last years, high power machines, advanced technologies, higher prices for spare parts, repairing process and fuel consumption contributed to an even more rising of these costs. Actually, the cost of machinery remains a significant portion of the cost of production of a farm for many operations and continues to be one of the highest input costs for farmers (Buckmaster, 2003). Anderson (1988) showed that the machinery costs are about 35-50% of the farm cost. Many engineering and economic methods have been implemented to calculate machinery use and cost, but they are almost confined in scientific and technical documentations making it difficult for a farmer to apply these methodologies for deciding on buying, leasing, or sharing agricultural machinery.

Agricultural machinery cost regards two types of cost, namely the annual ownership (or fixed) cost, which occurred regardless of the machine use, and the operating (or variable) cost which is directly connected to the machine use intensity. The former cost derives from depreciation, interest, housing, and insurance cost, while the latter derives from maintenance, repair, fuel and lubricant consumption, labor cost and depends on various factors including hours of annual use, type of performed operation, field size and characteristic, operator's skills and experience, timeliness etc. (Schuler and Frank, 1991). There is not a unique process to determine machine costs and the most accurate method to evaluate them is the complete records of the actual costs incurred: unfortunately this method is not usable for prompt forecast purposes. The possibility to know in advance such costs is strategic for the farmers, but the agricultural machine cost determination available by internet applications e.g. (Busato and Berruto, 2014) are lacking of a mobile app.

The aim of this work was to develop an easy-to-use mobile application (app), namely Agricultural Machine App Cost Analysis (AMACA) for determining the machinery costs in different field operations and makes it available via a web mobile application using a cross-platform approach. Mobile apps in agriculture can be clustered in two broad categories (Brugger, 2011): m-learning (transfer of know-how on specific farming techniques and trends) and m-farming (decision support systems and services based on localized-specific data); for its characteristics AMACA can be considered an m-farming app.

# 2 Materials and methods

## 2.1 The design process

The design process for the AMACA development was focused on extracting the specific requirements for farm operations cost prediction including the steps of extracting the individual users' requirements, identifying the necessary system components, and identifying the need for supplemental development. The methodology of quality function deployment (QFD) has been followed in this process. QFD is one of the most common customer-driven tools of total quality management process linking the user expectations with the design characteristics of the product (Carnevalli and Miguel, 2008; Chan and Wu, 2002). Although QFD has been considered as a having a high potential for the design of new systems, especially in the case of ICT (Schiefer, 1999), there is a limited number of design process that have implemented such a methodology in the agricultural domain (Sørensen et al., 2010).

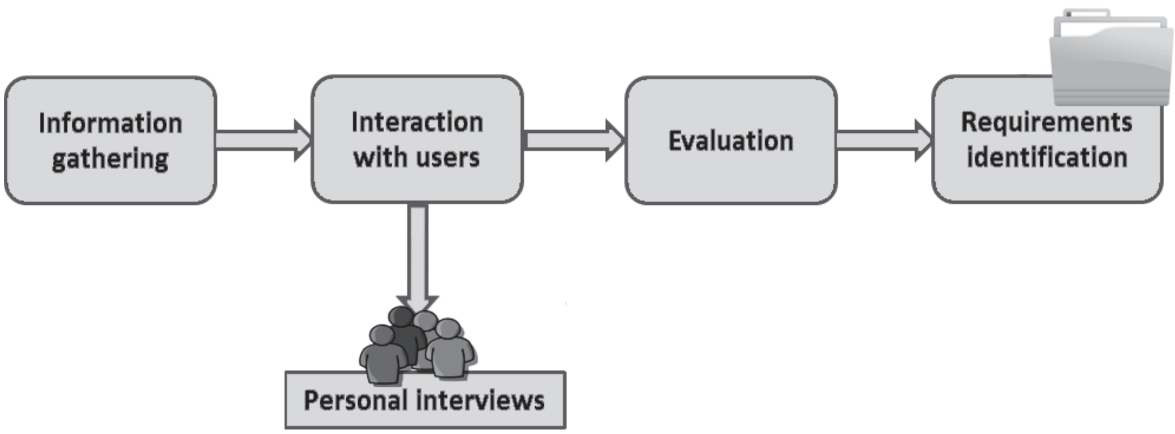


**Figure 1 - Identification of user needs**

The general steps of the QFD include the following:

- Users identification
- Users requirements extraction
- Users  requirements prioritization
- Design parameters identification
- Determination of relationships between users requirements and design parameters
- Correlation between design parameters

The above mentioned steps are described in detail in the following sections.

### 2.1.1 Users requirements

The identification of the users requirements includes four phases (Figure 1): the information gathering where the target groups of the users are identified and the questionnaires are defined, the interaction with the users where personal interviews take place, the evaluation phase where the user needs are addressed, and the requirements identification phase where the various requirements are prioritized according to the users preferences. The methodological approach involved a participatory approach and analysis, extracting current farm management challenges facing agricultural machinery users and owners.

Four target user groups were identified, including:

a. **Farmers.** As users the farmers have different roles. A farmer can use the application on a strategic level, e.g. to assess the cost for purchasing a new machinery (i.e. tractor, equipment, self-propelled machine), or in case of owing a machinery she/he can evaluate the cost for providing services to other farmers (i.e. to act as contractors), or for verifying the benefit of using a contractor service.

b. **Contractors.** Similarly to farmers, contractors can assess a number of decisions on strategic level (e.g. purchase more machines), on tactical level (to e.g. find the break-even point in the use of machinery), and on operation level (.e.g. to price the rates of servicing).

c. **Consultants**. Consultants might work for advisory services or private companies to support farmers in decision making for machinery purchase or contracting a service, and also to support farmers to evaluate the whole production cost for a crop.

d. **Machinery dealers**. Machinery dealers can use the application for providing farmers with an optimal solution for purchasing machinery based on their individual needs.

A number of user requirements for agricultural fleet management systems have been identified in Sørensen & Bochtis (2010). The majority of these user requirements have been adopted and/or modified while a number of them targeted to the application requirements were also identified. The voiced user requirements for the development of the AMACA app are listed in Table 1.

**Table 1 – Voiced user requirements for n agricultural management system**

| General category | ID | Specific requirement |
|---|---|---|
| Data aquisition | R1.1 | Improved general knowledge of the production process |
| | R1.2 | Effective documentation system |
| | R1.3 | Detailed work time specification |
| | R1.4 | Detailed cost elemets specification |
| | R1.5 | Information search availability (quick access to information) |
| | R1.6 | Easy and quick access to information |
| | R1.7 | Data exchange interfaces |
| | R1.8 | Available data bases |
| | R1.9 | Reduction of user inputted errors |
| Decision making | R2.1 | Resource optimization (e.g., labor, fuel) |
| | R2.2 | Generation of tasks orders |
| | R2.3 | Environmental benefits (e.g., soil compaction, resource usage) |
| | R2.4 | Preventive maintenance |
| | R2.5 | Benchmarking |
| Software / hardware / technology components | R3.1 | Dedicated user-interface |
| | R3.2 | Application roughness |
| | R3.3 | Communication with internal databases |

| | | |
|---|---|---|
| | R3.4 | Communication with external databases |
| | R3.5 | Availability in various devices |

A five-point scale measure was implemented for raking the requirements which was defined according to the following mapping:

1 → not at all important,

2 → not very important,

3 → fairly important,

4 → very important, and

5 → extremely important

For the extraction of the average relative importance ratings of the identified requirements the simple isobaric method was implemented.

### 2.1.2 Identification of design parameters

The process of design parameters identification for the AMACA app was based on the results from a workshop where various technical experts were involved. After the initial identification the design parameters were grouped in six representative categories. The selected design parameters are listed in Table 2.

**Table 2 - Selected design parameters grouped within six main categories.**

| Category | Description | ID | Design parameters |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Usability | The usability of the application regards the level of convenience that the user navigates and getting familiar with the app with a minimum amount of potential errors. It also refers to the level that the app enables user to read and internalize information. | F1.1 | Step-by-step functions |
| | | F1.2 | Tutorial |
| | | F1.3 | Low maximum number of steps (e.g. 3) |
| | | F1.4 | Self-explanatory navigation labels |
| | | F1.5 | Large site-wide buttons |
| | | F1.6 | Reduced pop-out menu |
| | | F1.7 | Use of input values ranges (thresholds) |
| | | F1.8 | Information button |
| | | F1.9 | Skimmable text presenting only the necessary information. |
| Presentation | Presentation refers to the visual appearance and organization of the user interface and of the provided information. | F2.1 | Simple and minimalistic design |
| | | F2.2 | Touch friedly interface (e.g. line spacing) |
| | | F2.3 | Text should be readable on any size of monitor (Fit screen resolution) |
| Visualization | Visualization regards the input and output processes | F3.1 | Pop-up menus for input selection |

| | | | |
|---|---|---|---|
| | and has to do with the analytical features that are used for inserting the information and presenting the results | F3.2 | Dashboards practices in the results presentation, such as tables and charts |
| Personalization | Personalization regards the customization for different user profiles in order to cover the needs of experienced and especially inexperienced users | F4.1 | Different user profiles (Farmers, Contractors, Administrator) |
| | | F4.2 | Multi-language menus |
| Interoperability | Interoperability with data sources and other applications | F5.1 | Software interoperability (e.g. Adroid, IOS, Windows) |
| | | F5.2 | Hardware interoperability: Wireless communication and Bluetooth |
| | | F5.3 | No instalation need |
| Scalability | Expandability for additional functions | F6.1 | Use of open scource encoding |

### 2.1.3 Correlation between the design parameters

Each design parameter has to be correlated with each one of the others as the latest step of the QFD approach, based on the measure of the correlation degree presented in Table 3:

**Table 3 – Measures of correlation degree for the design parameters**

| Symbol | Correlation degree |
|---|---|
| ‡ | strong positive |
| + | weak positive |
| ◊ | no correlation |
| ∨ | weak negative |
| ⍑ | strong negative |

## 2.2 Cost determination

Machinery fixed costs include depreciation, interest of investment, taxes, insurance and housing, while variable costs include repair and maintenance, wages, fuel and lubricants as initially suggested by Fairbanks et al. (1971) and now upgraded by ASABE (2009).

### 2.2.1 Fixed cost

For the estimation of the fixed cost it is assumed that the machines are used up to their maximum number of operating hours, called estimated life. The estimated life $h_{tot}$ used in the AMACA app was obtained by the (ASABE, 2009). Using afterward the machine annual use ($h$) as input value, the estimated life of the machine in years ($N$) is calculated.

The fixed cost is calculated both for tractors and equipment and concerned annual costs. The estimation of both depreciation and interest cost requires the machine remaining value which is provided by the ASABE (2009) formula:

$$V_r = 100(C_1 - C_2\sqrt{N} - C_3\sqrt{h})^2 \quad (1)$$

where $V_r$ is the machine remaining value (€), $C_i$ ($i$=1,2,3) are machine dependent coefficients (ASABE, 2009), $N$ are the estimated machine life (y), and $h$ is the annual use of the machine (h).

Depreciation is a cost that is the result of the age, the wear and the obsolescence of a machine. Also if the technology and design changes may accelerate the machine obsolescence, however the age and accumulated hours of use are the major factor in determining the remaining value of a machine (Poozesh et al., 2012).The following formula was implemented in AMACA:

$$Q_a = \frac{V_0 - V_r}{N} \quad (2)$$

where $V_0$ is the initial machine value (€)

Inflation reduces the real cost of investing capital in farm machinery. The formula which uses an average interest rate $i$ in the N years of the machine life was considered (Piccarolo et al., 1989):

$$Q_i = \frac{V_0 + V_r}{2} \cdot i \quad (3)$$

where $Q_i$ annual interest value and $I$ is the annual average interest rate.

The annual insurance and housing cost are case depended and provided as an input by the user.

### 2.2.2 Variable costs

Repair and maintenance cost usually represent about 10%-15% of the total mechanization costs (Calcante et al., 2013). For the estimation of the repair and maintenance cost the formula proposed by the ASABE Standards, (2006) was implemented:

$$RM_h = \frac{RF_1 \cdot P \cdot \left(\frac{h_{tot}}{1000}\right)^{RF_2}}{h_{tot}} \quad (4)$$

where $RM_h$ is the hourly repair and maintenance cost (€), $R_{F1}$ and $R_{F2}$ are repair and maintenance coefficients, machine dependent (ASABE, 2009, Table 3), and $P$ is the machine list price in (€).

Fuel and lubricant cost represent at least 16 - 45% of the total operation costs (Siemens and Bowers, 1999). Estimation models have been presented in various studies (ASAE, 2002; Grisso et al., 2004; Siemens and Bowers, 1999). The fuel consumption formula used by AMACA was obtained by Grisso et al. (2004):

$$Q = (2.64X + 3.91 - 0.203\sqrt{738X + 173}) \cdot X \cdot P_{pto} \quad (5)$$

where $Q$ is the fuel (diesel) consumption at partial load (l $h^{-1}$), $X$ is the ratio of equivalent PTO power to rated PTO power, and $P_{pto}$ is the rated PTO power (kW). Considering that this equation model fuel consumption is 15% higher than the field acquisition (Grisso et al., 2004), the same reduction was applied for the fuel consumption calculation in AMACA.

Lubricants consumption ($L$, in l $h^{-1}$) is calculated as indicated in ASAE Standard (2009):

$$L = 0.000566\, P_{pto} + 0.02487$$

For the estimation of the labor cost the hourly wage which is provided as an input is considered. Also as an input the consumables cost (€ $ha^{-1}$) is provided by the user.

Performance rates for agricultural equipment depend from achievable field speeds and the efficient use of time. Field speeds may be limited by heavy yields, rough ground, and adequacy of operator control. Small or irregularly shaped fields, heavy yields, and high capacity machines may cause a substantial reduction in field efficiency. Typical speeds and field efficiencies are given in Table 3 of ASAE Standards, (2009) and AMACA referred to it for parameters range. Both the working speed and the tools width were used to calculate the draft force required to the tractor by the equipment to accomplish the field operation and to evaluate the operation cost per hectare.

The equation of the ASAE Standard (2009) was used to calculate the draft force at the tractor drawbar required to pull a specific operating machines for tillage or seeding operations:

$$F = S_t \cdot \left[A + B \cdot S_f + C \cdot S_f^2\right] \cdot W_m T_d \tag{6}$$

where $F$ is the draft force required at the tractor drawbar (N), $A$, $B$ and $C$ are machine specific parameters (ASABE, 2009), $S_t$ is the soil texture (ASABE, 2009), $S_f$ is the machine field speed (km h$^{-1}$), $W_m$ is the machine width (m), and $T_d$ is the tillage depth (cm).

# 3 RESULTS AND DISCUSSION

## 3.1 Design process

### 3.1.1 Target groups

The study was carried out as an interview survey during the agricultural machinery fairs in February and October 2014 in Verona, Italy, and Cremona, Italy, respectively. The requirements gathering survey included targeted question through a one-to-one discussion administered by an experienced researcher on the agricultural management area.

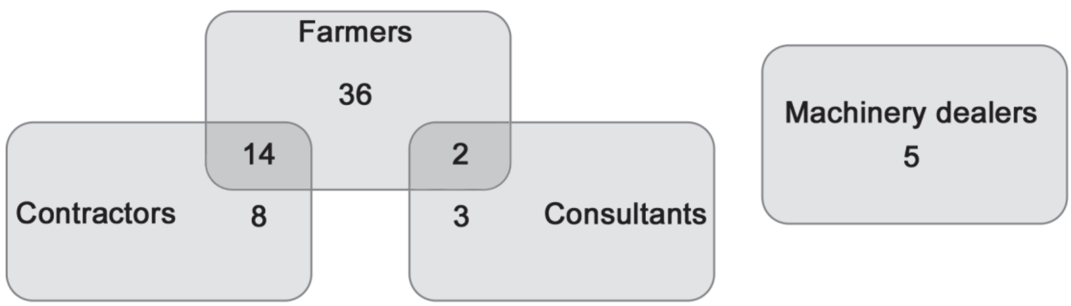


**Figure 2 - Distribution of different end user types**

In total 68 people were interviewed. Due to overlaps in some of the users types (Figure 2) the following categories eventually were considered:

Solely farmer: 36

Farmer-contractor: 14

Solely contractors: 8

Consultant-farmer: 2

Solely consultant: 3

Machinery dealers: 5

### 3.1.2 Prioritization of user requirements

The user requirements score is presented in Table 4. As a result, the 4 most important rakings are related to data acquisition and control. Farmers lack in knowledge of standard data on machinery use and they need some guidance on that. In fact the most important is the user requirement R1.6 – Easy and quick access to information. Connected to R1.6 there is R3.1 – dedicated user interface and R3.2 – application roughness. They need simple interface on a device (such as smartphone) that can be used also in the field or in open spaces. The less important requirement was R3.4 - the connection to external databases: this fact reflects the fear of the farmers to share their own data with some agencies database. However, from the scientific point of view external data bases are a prerequisite for efficient information systems in agriculture, and this will be considered in a next version of AMACA. Finally, users require to have detailed cost and work time specifications (R1.3, R1.4) other than to limit possible input errors (R1.9).

Figure 3 provides the prioritization of the user requirements.

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259 **Table 4 – Score on the selected requirements of different users groups**

| Requirement | Average score | Solely farmer | Farmer contractor | Farmer consultant | Solely contractor | Solely consultant | Machinery dealers |
|---|---|---|---|---|---|---|---|
| R1.1 | 3.12 | 3.11 | 3.00 | 4.50 | 2.13 | 5.00 | 1.00 |
| R1.2 | 2.05 | 1.22 | 1.43 | 2.50 | 1.75 | 3.00 | 2.40 |
| R1.3 | 4.52 | 4.19 | 4.50 | 4.50 | 4.88 | 4.67 | 4.40 |
| R1.4 | 4.48 | 4.33 | 4.64 | 4.50 | 5.00 | 5.00 | 3.40 |
| R1.5 | 3.05 | 2.11 | 2.79 | 3.50 | 3.25 | 3.67 | 3.00 |
| R1.6 | 4.74 | 4.75 | 4.57 | 4.50 | 4.63 | 5.00 | 5.00 |
| R1.7 | 1.83 | 1.11 | 1.43 | 1.50 | 1.63 | 2.33 | 3.00 |
| R1.8 | 1.72 | 1.14 | 1.64 | 1.50 | 2.00 | 1.67 | 2.40 |
| R1.9 | 4.45 | 4.42 | 4.21 | 4.50 | 4.50 | 4.67 | 4.40 |
| R2.1 | 2.63 | 3.94 | 4.07 | 2.50 | 2.63 | 1.67 | 1.00 |
| R2.2 | 1.98 | 3.17 | 3.14 | 2.00 | 1.38 | 1.00 | 1.20 |
| R2.3 | 1.68 | 1.50 | 1.07 | 2.50 | 1.00 | 3.00 | 1.00 |
| R2.4 | 3.75 | 4.53 | 4.71 | 4.00 | 4.88 | 3.00 | 1.40 |
| R2.5 | 2.57 | 2.00 | 2.57 | 3.00 | 2.88 | 4.00 | 1.00 |
| R3.1 | 3.81 | 3.50 | 4.00 | 3.50 | 3.88 | 4.00 | 4.00 |
| R3.2 | 3.90 | 4.89 | 4.86 | 3.50 | 4.75 | 3.00 | 2.40 |
| R3.3 | 3.25 | 2.31 | 2.79 | 3.50 | 3.25 | 3.67 | 4.00 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| R3.4 | 1.53 | 1.67 | 1.43 | 2.00 | 1.38 | 1.33 | 1.40 |
| R3.5 | 4.29 | 4.22 | 4.36 | 4.00 | 3.88 | 4.67 | 4.60 |

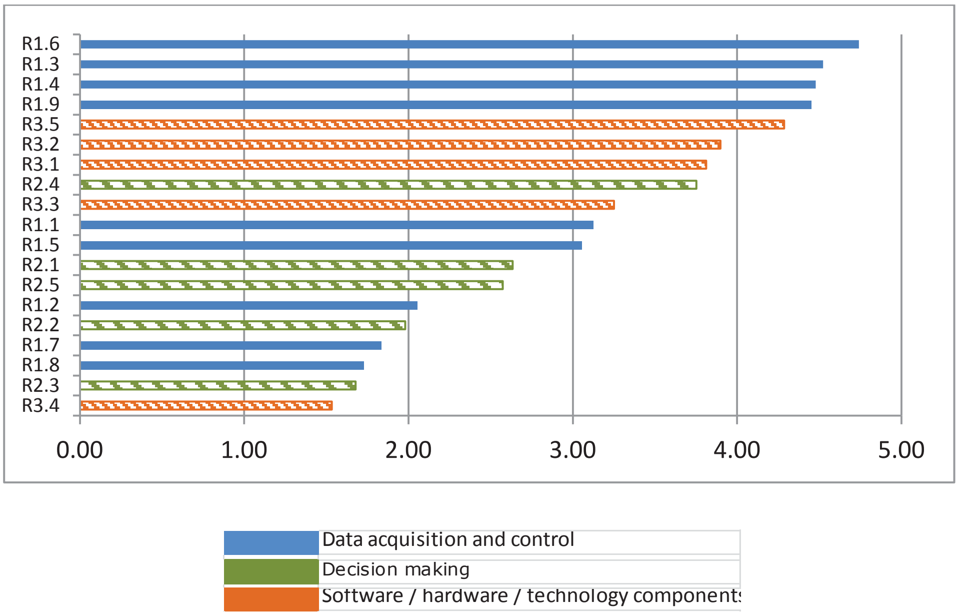



**Figure 3 - The average raking of the users requirements.**

### 3.1.3 Relationship raking

After the summation of the relationships between users requirements the highest values have been identified (Figure 4). Specifically, two interoperability design parameters (hardware interoperability, 120.97 and no installation need, 120.97), one visualisation (dashboard practices in results presentation, 158.08) and one usability (skimmable text for necessary information, 128.13) presented the highest values. The lowest values regarded personalisation (different users profile, 6.39) usability (reduced pop-out menu, 28.71, large site-wide buttons, 55.64 and step by step functions, 65.31).

| | | | Importance rating | Usability | | | | | | | | | Presentation | | | Visualisation | | Personalisation | | Interoperability | | | Scalability |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ` | | F1.1 | F1.2 | F1.3 | F1.4 | F1.5 | F1.6 | F1.7 | F1.8 | F1.9 | F2.1 | F2.2 | F2.3 | F3.1 | F3.2 | F4.1 | F4.2 | F5.1 | F5.2 | F5.3 | F6.1 |
| User requirements | Data acquisition and control | R1.1 | 3.12 | | 9 | | | | | | 9 | 9 | | | | | 1 | | 1 | | | | |
| | | R1.2 | 2.05 | 1 | 9 | | | | | | 9 | 9 | 1 | 1 | 1 | | 1 | | 3 | 1 | | | |
| | | R1.3 | 4.52 | | | | | | | 3 | | | | | | | 9 | | | | | | |
| | | R1.4 | 4.48 | | | | | | | | | | | | | | 9 | | | | | | |
| | | R1.5 | 3.05 | 3 | | 3 | 9 | 3 | 1 | 9 | 3 | 9 | | | | 3 | 3 | | 9 | 1 | | | |
| | | R1.6 | 4.74 | 9 | 9 | 9 | 9 | 9 | 3 | 9 | 3 | 9 | 9 | 9 | 9 | 3 | 1 | | 9 | 9 | 3 | 3 | |
| | | R1.7 | 1.83 | | | | | | | 9 | | | | | | | | | | | | | 9 |
| | | R1.8 | 1.72 | | | | | | | | 3 | | | | | | | | | | | | |
| | | R1.9 | 4.45 | 3 | | | 1 | 9 | 9 | 9 | | 1 | 3 | 9 | 3 | 1 | | | 3 | | | | |
| | Predictive planning and optimisation | R2.1 | 2.63 | | | | | | | 1 | | | | | | | 3 | | | 3 | | | |
| | | R2.2 | 1.98 | | | | | | | | | | | | | | 1 | | | | | | |
| | | R2.3 | 1.68 | | | | | | | | | | | | | | 1 | | | | | | |
| | | R2.4 | 3.75 | | | | | | | 3 | | | | | | | 3 | | | | | | |
| | | R2.5 | 2.57 | | | | | | | | 9 | | 3 | | | | 9 | 1 | | 1 | | | |
| | Software/harwar e/technology components | R3.1 | 3.81 | 3 | 1 | 9 | 3 | 1 | 3 | 1 | | 3 | 3 | 9 | 9 | 9 | 1 | 1 | 9 | 3 | 1 | 1 | 9 |
| | | R3.2 | 3.90 | | | | | | | | | | | | | | 1 | | | | 9 | 9 | 1 |
| | | R3.3 | 3.25 | | | | | | | | | | | | | | | | | 3 | 9 | 9 | 3 |
| | | R3.4 | 1.53 | | | | | | | | | | | | | | | 1 | | 3 | 9 | 9 | 3 |
| | | R3.5 | 4.29 | | | | | | | | | | 3 | 9 | 9 | 1 | 1 | | 1 | 9 | 9 | 9 | 9 |
| Raw score | | | | 65.31 | 93.04 | 86.14 | 81.58 | 55.64 | 28.71 | 117.91 | 98.28 | 128.13 | 76.74 | 117.61 | 117.61 | 61.98 | 158.08 | 6.39 | 118.01 | 118.02 | 120.97 | 120.97 | 103.04 |
| Relative score (%) | | | | 3.48% | 4.96% | 4.60% | 4.35% | 2.97% | 1.53% | 6.29% | 5.24% | 6.84% | 4.09% | 6.28% | 6.28% | 3.31% | 8.43% | 0.34% | 6.30% | 6.30% | 6.45% | 6.45% | 5.50% |
| Ranking | | | | 1 | 2 | 2 | 2 | 1 | 1 | 3 | 2 | 4 | 2 | 3 | 3 | 1 | 4 | 1 | 3 | 3 | 4 | 4 | 3 |

**Figure 4 - Scored relationships between user requirements and the selected design parameters**

Ranking analysis and hierarchical clustering analysis were applied to the relative scores for grouping the design parameters into *k* different groups in terms of the level of importance. Based on the approach presented in (Mardia et al., 1979) the grouping $k = \sqrt{n/2}$ was implemented, where *n* is the number of identified design parameters In this case the functional parameters (n=20) yield a number of groups of k=4, used as input values for the cluster analysis which produced the dendrogram in Figure 5.

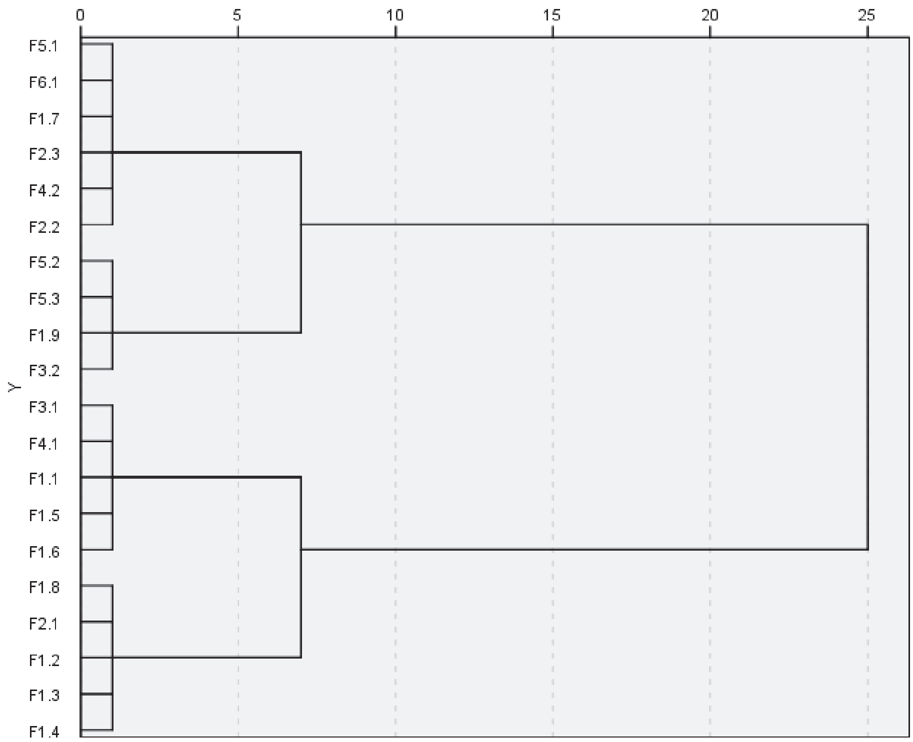



**Figure 5 – Clustered dendrogram**

The design parameters sorted in the 4 ranking classes evidenced the importance of some interoperability functions (F5.2 and F5.3) as well as of the dashboard practices in the result presentation (F3.2) and of the essential text presenting just the necessary information (F1.9).

### 3.1.4 Design parameter correlations

**Table 5 – Correlation between the design parameters**

| | F1.1 | F1.2 | F1.3 | F1.4 | F1.5 | F1.6 | F1.7 | F1.8 | F1.9 | F2.1 | F2.2 | F2.3 | F3.1 | F3.2 | F4.1 | F4.2 | F5.1 | F5.2 | F5.3 | F6.1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| F1.1 | | | | | | | | | | | | | | | | | | | | |
| F1.2 | ‡ | | | | | | | | | | | | | | | | | | | |
| F1.3 | ∨ | ◊ | | | | | | | | | | | | | | | | | | |
| F1.4 | + | + | ◊ | | | | | | | | | | | | | | | | | |
| F1.5 | ◊ | ◊ | ◊ | ‡ | | | | | | | | | | | | | | | | |
| F1.6 | ◊ | ◊ | + | ∨ | ∨ | | | | | | | | | | | | | | | |
| F1.7 | + | ◊ | ‡ | ◊ | ◊ | ‡ | | | | | | | | | | | | | | |
| F1.8 | ◊ | ‡ | ◊ | ‡ | ◊ | ◊ | ◊ | | | | | | | | | | | | | |
| F1.9 | + | ◊ | + | ‡ | ╤ | + | + | ◊ | | | | | | | | | | | | |
| F2.1 | ∨ | + | + | + | ╤ | ‡ | ◊ | + | ‡ | | | | | | | | | | | |
| F2.2 | + | ◊ | + | ‡ | + | ∨ | ‡ | + | + | + | | | | | | | | | | |
| F2.3 | ◊ | ◊ | + | ◊ | ◊ | + | + | ◊ | + | + | ◊ | | | | | | | | | |
| F3.1 | ◊ | ◊ | ◊ | ◊ | ◊ | + | ◊ | ◊ | ◊ | ◊ | + | + | | | | | | | | |
| F3.2 | + | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | + | + | ◊ | + | ◊ | | | | | | | |
| F4.1 | ◊ | + | ◊ | + | ◊ | ◊ | + | + | ◊ | ◊ | ◊ | ◊ | + | ‡ | | | | | | |
| F4.2 | ◊ | ‡ | ◊ | + | ◊ | ◊ | ◊ | + | + | ◊ | ◊ | ◊ | ◊ | + | + | | | | | |
| F5.1 | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | + | ◊ | | | | |
| F5.2 | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | + | ◊ | + | | | |
| F5.3 | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | + | ◊ | ‡ | + | | |
| F6.1 | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | + | ◊ | ‡ | + | ‡ | |

The correlation between the functional parameters is presented in Table 5. Higher variability is encountered in the categories of usability (F1.1-F1.9) and presentation (F2.1-F2.3), while no correlations are more present in the interoperability category (F5.1-F5.3). The results of QFD analysis conditioned both software development and GUI interface. The design parameters of the first two cluster groups were realized (use of input values range, skimmable text, touch friendly interface, text readable on any size of monitor, dashboards practices in the results, multi-language menus, software interoperability, hardware interoperability, no installation need and use of open source encoding), while only a few of the third group (self-explanatory navigation labels and information button) and none of the last were considered. Also the negative correlation of certain parameters influenced the choices: for example the large site-wide buttons (F1.5) was not realized because it had strong negative correlation with skimmable text presenting only the necessary information (F1.9, which belongs to the first cluster group).

### 3.2 Software development

Mobile web and native apps are technology challenges to deliver cross-platform (F5.1 and F5.2 of QFD analysis) apps. Mobile web apps reside on server without installation on devices (F5.3 of QFD analysis) and it is possible make changes during the real-time execution, while native apps are in the internal storage of the single device after the install procedure and it is not possible to make changes in real time (Mao and Xin, 2014). The main weakness of native apps is that they must be developed separately for each platform and this leads to an increase of development time and costs. The development of native apps for different mobile operating systems requires the use of different programming languages. Moreover, once it is modified, users are obliged to update their apps to receive upgraded services.

The more practical approach of the mobile web app was chosen, using HTML language for the content part, JavaScript for the logic, and CSS as a presentation style (F6.1 of QFD analysis). Also, all the recent browsers support HTML5, JavaScript and CSS languages. Xin et al. (2015) indicates that the cross-platform mobile development technology (JavaScript, HTML5 and CSS) used is a viable solution for mobile apps. Mobile app characteristics are imitated by modern web apps through rich user experiences. Even though the results may not be as attractive as native code, there are some advantages, such as the web portability, and the readiness to create cross-platform apps.

A lot of work is required to build a mobile web app that appears and performs like a native app, and also to fitting automatically various resolutions of devices (F2.3 of QFD analysis). To solve this question AMACA application used a touch-optimized (F2.2 of QFD analysis) JavaScript library: the jQuery Mobile (JQM). The JQM framework provides many features to support JavaScript basic library. HTML5 local storage feature was used to store some variables which can be modified by the user and are introduced as new parameters for calculations.

## 3.3 Data processing

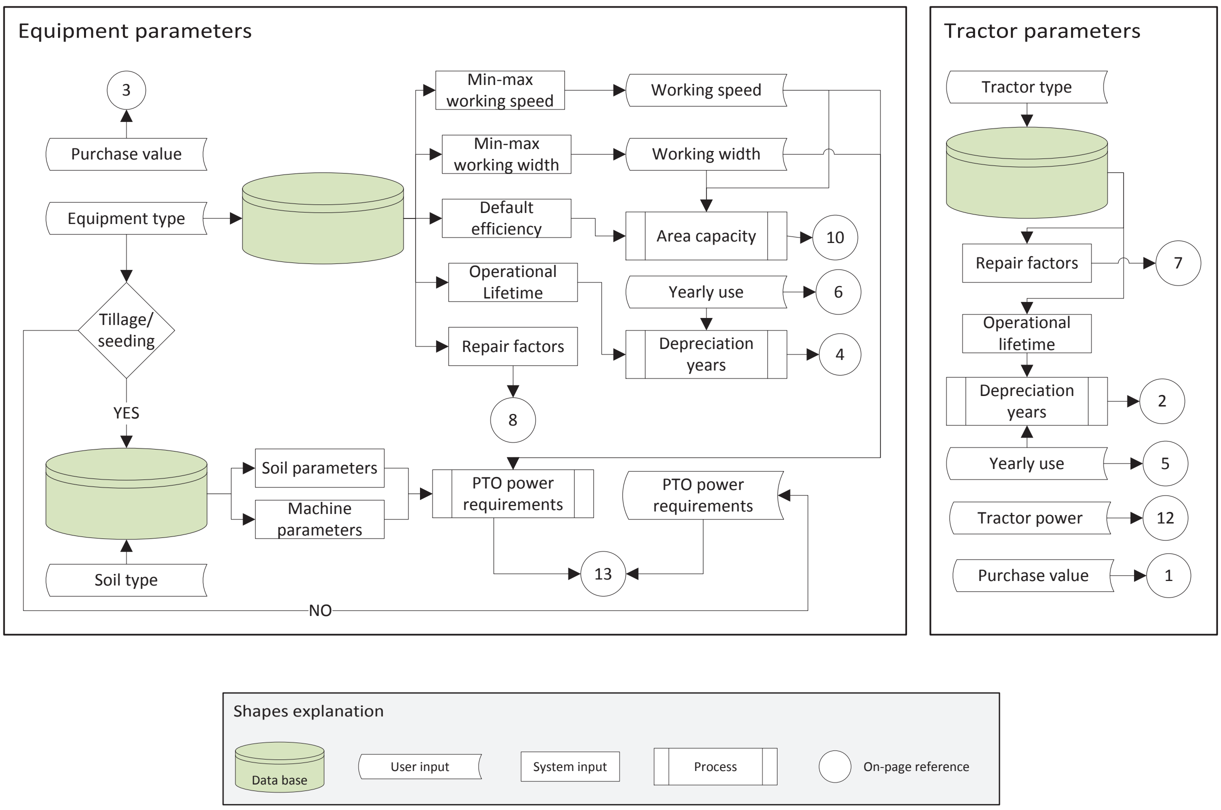



**Figure 6 – Flow diagram of data insertion of tractor and equipment parameters**

The data process follows the diagram of the Figure 6. Some parameters are entered by the operator, while others are selected from the targeted selection offered by the values in the database. For example the new value of the equipment or the tractor is entered by the user. The hours of work per year, the type of tractor are selected from values in the database. This allows the user to avoid large errors in data entry. Values  suggested are by default for the most common parameters, as a function of the type of machine chosen (average speed, working hours per year, etc.).

The processing of implement's data allows for the calculation of the field unitary capacity, the power demand, the lifetime of the machine (Figure 6). Processing data of the tractor allows to calculate in a first phase to the duration (year) of the same. The parameter of the duration of the tractor and equipment allows the user to calculate the hourly fixed costs of the operating machine and the tractor, while the power demands and the working capacity allows to calculate the variable costs (fuel consumption, maintenance) and the operation costs per unit of area, as can be seen see from the scheme of Figure 7.

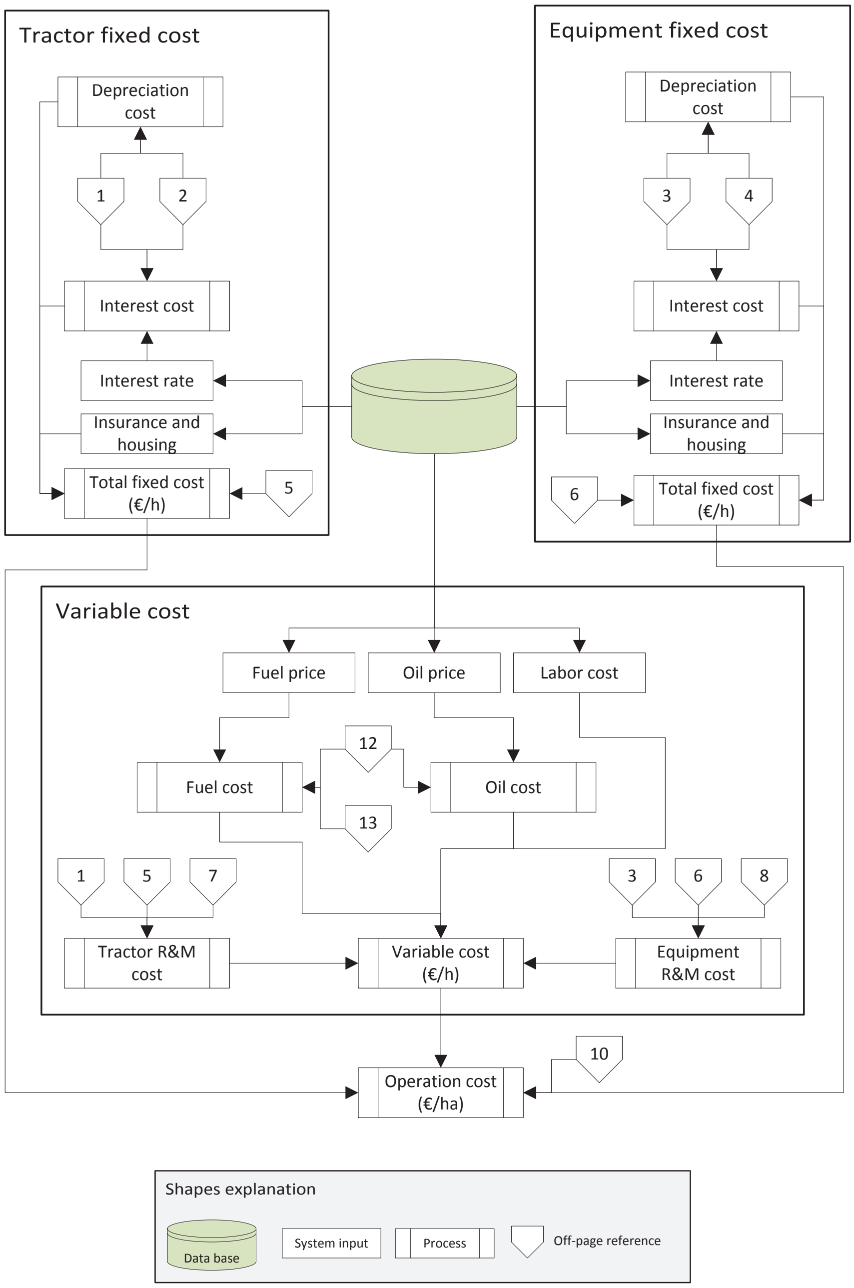



**Figure 7 - Flow diagram of computation of fixed and variable costs**

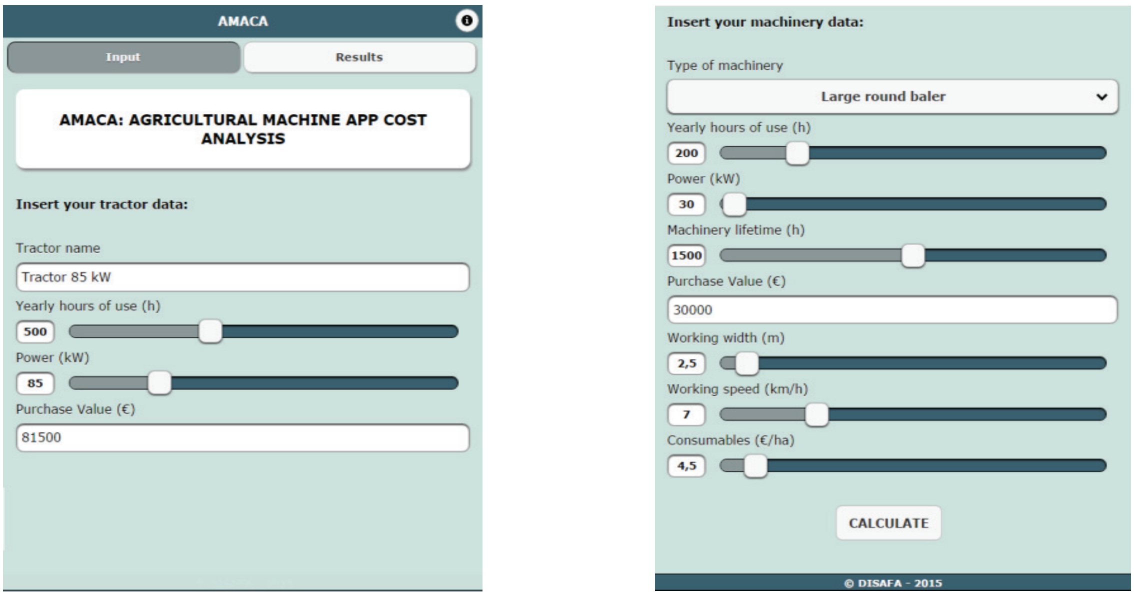
## 3.4 Application GUI

The app is composed by two main interface pages: Input and Results. Each page shares the same navigation header for a quick switching between the pages and the footer. History tracking and back button is also enabled on each page. A script for all the pages is implemented to automatically adjust the display size according to the browser/device's resolution (F2.3 of QFD analysis). The

Input page is designed to make the user input as easy as possible (F1.9 of QFD analysis). This page is divided into two sections: tractor data and machinery data.

The tractor data section allows the users to insert the required data of the examined tractor (Figure 8a). Input requirements are the yearly hours of use, the power (kW) and the purchase value of the tractor (€). For the yearly hours of use and the tractor power a range slider is available (F1.7 of QFD analysis).

Regarding the machinery data section, as illustrated in Figure 8b, after selecting the machine on a drop down menu, the user must input the yearly hours of use, the required power (kW), the machinery lifetime (h) and the purchase value (€). Then the operation working width (m), the working speed (km $h^{-1}$) and the consumables cost (€ $ha^{-1}$) must be inserted. Also in this case, all the above mentioned parameters may be chosen with the range slider (the range sliders vary in function of the machine type).




(a) (b)

**Figure 8 – Tractor input data (a) and machinery input data (b) interfaces**

The "info" button (F1.8 of QFD analysis) in the page header of the Input page lets the user to access the instruction page where it is possible to find detailed information about the application use.

HTML5 allows a local (on device) storage feature to store some variables. By tapping the "modify" button in the Instructions page it is therefore possible to change some parameters used for the calculations (Figure 9).

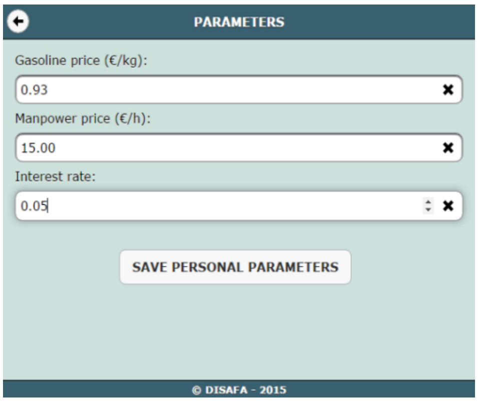



**Figure 9 – General parameters interface**

The Results page (Figure 10) can be accessed by tapping the "calculate" button on the Input page. It provides the cost analysis of the tractor and of the machinery inserted in the input page. In detail, users can find a first table (F3.2 of QFD analysis) with the amount of the fixed costs for the tractor and of the implement (depreciation, interest and insurance) expressed in € $y^{-1}$. For calculation purposes the total fixed costs and repair and maintenance costs are expressed as € $h^{-1}$.

In the second table users can find costs for both the tractor and the equipment as fuel consumption and labor. The hourly cost of the operation (total fixed costs plus proportional costs) is reported at the end of the page (machines costs), as the cost of the operation per hectare (machinery operation cost) and the total operation cost (€ $ha^{-1}$).

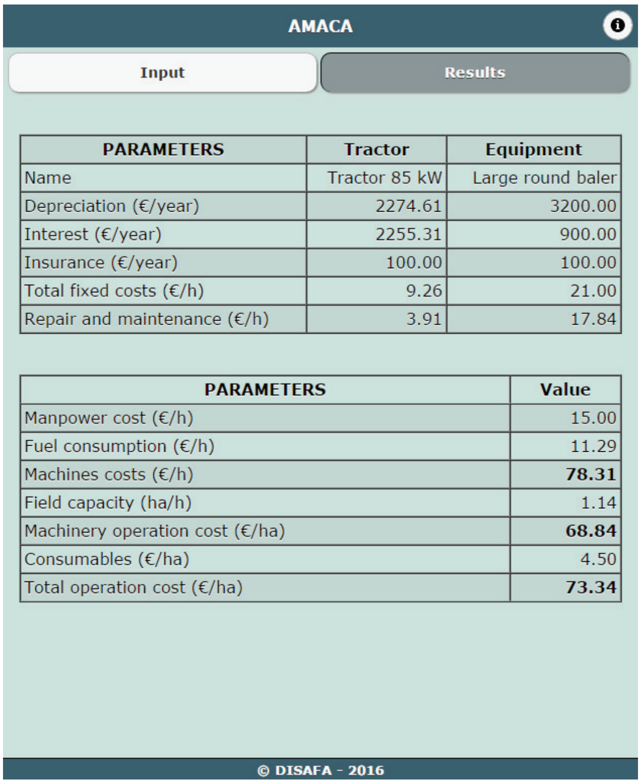



**Figure 10- Results page**

## 3.5 Results demonstration

### 3.5.1 Case study

In order to demonstrate the results provided by the app and its applicability, a case study was carried out. The case study was focused in the field operation of the forage harvesting. The input parameters are listed in Table 6.

**Table 6 - Input parameters and values of forage harvesting**

| Input | Value |
|---|---|
| Tractor yearly hours of use (h) | 500 |
| Tractor power (kW) | 85 |
| Tractor purchase value (€) | 56 500 |

| Type of machinery | Baler |
|---|---|
| Machinery yearly hours of use (h) | 200 |
| Machinery power requirement (kW) | 30 |
| Machinery lifetime (h) | 1 500 |
| Machinery purchase value (€) | 25 000 |
| Working with (m) | 6 |
| Working speed (km $h^{-1}$) | 5 |

In Table 7 are listed the outputs provided by the web mobile application AMACA for the case study mentioned before.

**Table 7 - Output values of the forage harvesting using AMACA**

| **Output** | **Tractor** | **Equipment** |
|---|---|---|
| Depreciation (€ $y^{-1}$) | 1 576.88 | 2 666.67 |
| Interest (€ $y^{-1}$) | 1 563.50 | 750.00 |
| Insurance (€ $y^{-1}$) | 100.00 | 100.00 |
| Total fixed costs (€ $h^{-1}$) | 6.48 | 17.58 |
| Repair and maintenance (€ $h^{-1}$) | 2.71 | 14.87 |
| Manpower cost | | 15.00 |
| Fuel consumption (€ $h^{-1}$) | - | 11.29 |
| Machines cost (€ $h^{-1}$) | - | 67.94 |
| Field capacity (ha $h^{-1}$) | - | 1.95 |
| Machinery operation cost (€ $ha^{-1}$) | - | 34.84 |
| Consumables (€ $ha^{-1}$) | | 8.00 |

| | | |
|---|---|---|
| Total operation cost (€ $ha^{-1}$) | - | 42.84 |

### 3.5.2 Sensitivity analysis

A sensitivity analysis was carried out to investigate the proper functioning of AMACA app. As it can be seen in Figure 11, operation cost varies linearly according to fuel price variations. The slight operation cost increase is reasonable since the fuel price directly affects only the fuel consumption cost, which is a minor part of the whole operation cost.

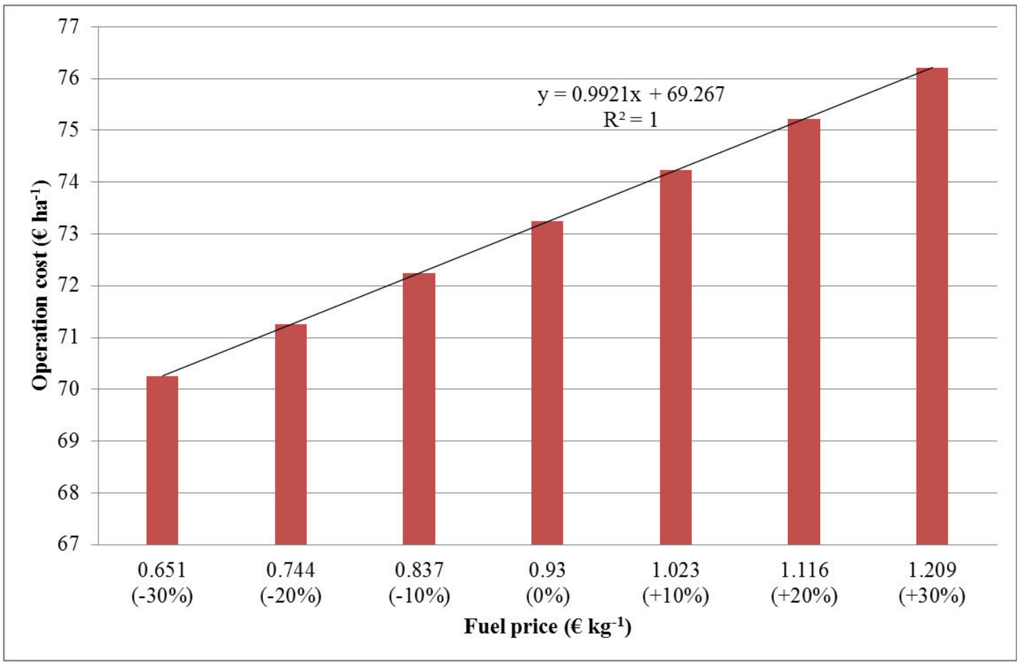



**Figure 11 – Operation cost changes due to fuel price variations**

### 3.5.3 Different tillage systems comparison

One of the potential uses of AMACA is the cost comparison among different field operations. An example is given concerning different tillage systems, whereas a traditional ploughing using a moldboard plow, a chisel plow and a harrowing with a tandem disk harrow were considered. Therefore the tractor power required to perform each operation was calculated. Being the tractor power requirements lower than 85 kW, the same tractor type in the example of the case study reported in chapter 3.5.1 was used.

Table 8 lists the rest of the input machine parameters used for the tillage comparison with the AMACA program.

**Table 8 - Operating machines characteristics**

| | Operating machine | | |
|---|---|---|---|
| | Moldboard plow | Chisel plow | Tandem disk harrow |
| Use (h $y^{-1}$) | 80 | 80 | 80 |
| Lifetime (h) | 2,000 | 2,000 | 2,000 |
| Purchase value (€) | 14,000 | 5,000 | 30,000 |
| Tractor power requirement (kW) | 60 | 35 | 50 |
| Working width (m) | 2 | 5 | 5 |
| Working speed (km $h^{-1}$) | 5 | 7 | 7 |

With these parameters AMACA produced the results shown in Figure 12.

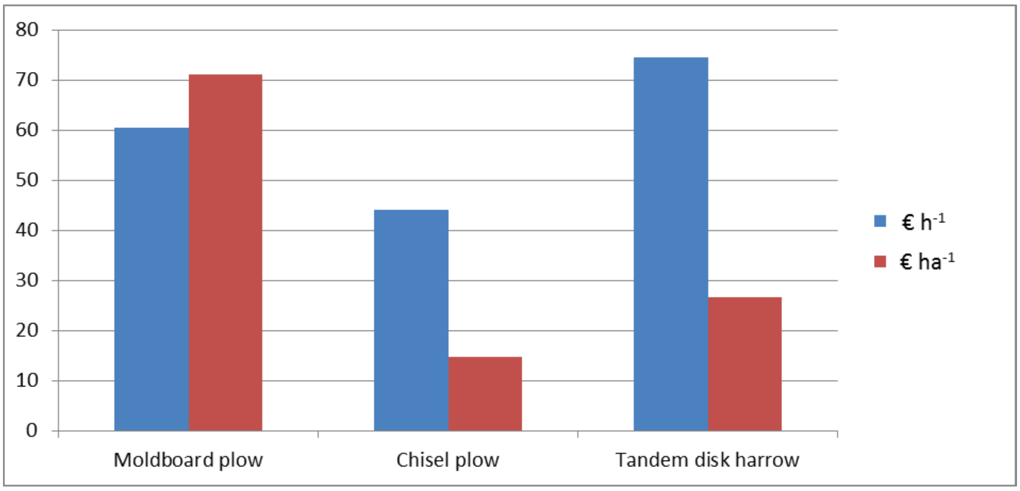



**Figure 12 - Unit cost of different tillage types**

While the traditional ploughing with the moldboard plow produces higher costs for unit of surface, the highest hourly costs are given with the tandem disk harrow: an easy example like this may address the user to choice the most economic operation in function of his operative conditions.

# 4 Conclusions

The process of the development of an easy-to-use web mobile app called "AMACA" (Agricultural Machine App Cost Analysis) for determining the machinery costs in different field operations was presented. The customer-driven QFD approach was implemented in order to link the user expectations with the design characteristics of the app.

The AMACA app is free[1], readily available, and does not require any installation on the end users' devices. It is a cross-platform application meaning that it operates on any device through a web interface and major browsers support it. The results can be sent via e-mail to the operator, who can make subsequent calculations of the sensitivity by varying some parameters (fuel price, interest rate, field capacity, the power of the tractor coupled to the machine) and compare the results. AMACA app can support the decisions on whether to purchase a new equipment/tractor (strategic level), the use of own machinery or to hire a service, and also to select the economical appropriate cultivation system (tactical level). However, it is necessary to have reliable input information, and thus detailed data may be obtained using telemetry devices and monitoring systems installed on tractors (Mazzetto et al., 2009; Sørensen and Bochtis, 2010), but only the active participation of farmers may really improve the tool capabilities. This is an issue of further research and development of the app.

[1] http://www.meccolt.unito.it/amaca/

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Table

**Table 1 – Voiced user requirements for n agricultural management system**

| General category | ID | Specific requirement |
|---|---|---|
| Data aquisition | R1.1 | Improved general knowledge of the production process |
| | R1.2 | Effective documentation system |
| | R1.3 | Detailed work time specification |
| | R1.4 | Detailed cost elemets specification |
| | R1.5 | Information search availability (quick access to information) |
| | R1.6 | Easy and quick access to information |
| | R1.7 | Data exchange interfaces |
| | R1.8 | Available data  bases |
| | R1.9 | Reduction of user inputted errors |
| Decision making | R2.1 | Resource optimization (e.g., labor, fuel) |
| | R2.2 | Generation of tasks orders |
| | R2.3 | Environmental benefits (e.g., soil compaction, resource usage) |
| | R2.4 | Preventive maintenance |
| | R2.5 | Benchmarking |
| Software / hardware / technology components | R3.1 | Dedicated user-interface |
| | R3.2 | Application roughness |
| | R3.3 | Communication with internal databases |
| | R3.4 | Communication with external databases |
| | R3.5 | Availability in various devices |

Table

**Table 1 - Selected design parameters grouped within six main categories.**

| Category | Description | ID | Design parameters |
|---|---|---|---|
| Usability | The usability of the application regards the level of convenience that the user navigates and getting familiar with the app with a minimum amount of potential errors. It also refers to the level that the app enables user to read and internalize information. | F1.1 | Step-by-step functions |
| | | F1.2 | Tutorial |
| | | F1.3 | Low maximum number of steps (e.g. 3) |
| | | F1.4 | Self-explanatory navigation labels |
| | | F1.5 | Large site-wide buttons |
| | | F1.6 | Reduced pop-out menu |
| | | F1.7 | Use of input values ranges (thresholds) |
| | | F1.8 | Information button |
| | | F1.9 | Skimmable text presenting only the necessary information. |
| Presentation | Presentation refers to the visual appearance and organization of the user interface and of the provided information. | F2.1 | Simple and minimalistic design |
| | | F2.2 | Touch friedly interface (e.g. line spacing) |
| | | F2.3 | Text should be readable on any size of monitor (Fit screen resolution) |
| Visualization | Visualization regards the input and output processes | F3.1 | Pop-up menus for input selection |

| | | | |
|---|---|---|---|
| | and has to do with the analytical features that are used for inserting the information and presenting the results | F3.2 | Dashboards practices in the results presentation, such as tables and charts |
| Personalization | Personalization regards the customization for different user profiles in order to cover the needs of experienced and especially inexperienced users | F4.1 | Different user profiles (Farmers, Contractors, Administrator) |
| | | F4.2 | Multi-language menus |
| Interoperability | Interoperability with data sources and other applications | F5.1 | Software interoperability (e.g. Adroid, IOS, Windows) |
| | | F5.2 | Hardware interoperability: Wireless communication and Bluetooth |
| | | F5.3 | No instalation need |
| Scalability | Expandability for additional functions | F6.1 | Use of open scource encoding |

Table

**Table 1 – Measures of correlation degree for the design parameters**

| Symbol | Correlation degree |
|---|---|
| ‡ | strong positive |
| + | weak positive |
| ◊ | no correlation |
| ∨ | weak negative |
| ⍑ | strong negative |

Table

**Table 1 – Score on the selected requirements of different users groups**

| Requirement | Average score | Solely farmer | Farmer contractor | Farmer consultant | Solely contractor | Solely consultant | Machinery dealers |
|---|---|---|---|---|---|---|---|
| R1.1 | 3.12 | 3.11 | 3.00 | 4.50 | 2.13 | 5.00 | 1.00 |
| R1.2 | 2.05 | 1.22 | 1.43 | 2.50 | 1.75 | 3.00 | 2.40 |
| R1.3 | 4.52 | 4.19 | 4.50 | 4.50 | 4.88 | 4.67 | 4.40 |
| R1.4 | 4.48 | 4.33 | 4.64 | 4.50 | 5.00 | 5.00 | 3.40 |
| R1.5 | 3.05 | 2.11 | 2.79 | 3.50 | 3.25 | 3.67 | 3.00 |
| R1.6 | 4.74 | 4.75 | 4.57 | 4.50 | 4.63 | 5.00 | 5.00 |
| R1.7 | 1.83 | 1.11 | 1.43 | 1.50 | 1.63 | 2.33 | 3.00 |
| R1.8 | 1.72 | 1.14 | 1.64 | 1.50 | 2.00 | 1.67 | 2.40 |
| R1.9 | 4.45 | 4.42 | 4.21 | 4.50 | 4.50 | 4.67 | 4.40 |
| R2.1 | 2.63 | 3.94 | 4.07 | 2.50 | 2.63 | 1.67 | 1.00 |
| R2.2 | 1.98 | 3.17 | 3.14 | 2.00 | 1.38 | 1.00 | 1.20 |
| R2.3 | 1.68 | 1.50 | 1.07 | 2.50 | 1.00 | 3.00 | 1.00 |
| R2.4 | 3.75 | 4.53 | 4.71 | 4.00 | 4.88 | 3.00 | 1.40 |
| R2.5 | 2.57 | 2.00 | 2.57 | 3.00 | 2.88 | 4.00 | 1.00 |
| R3.1 | 3.81 | 3.50 | 4.00 | 3.50 | 3.88 | 4.00 | 4.00 |
| R3.2 | 3.90 | 4.89 | 4.86 | 3.50 | 4.75 | 3.00 | 2.40 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| R3.3 | 3.25 | 2.31 | 2.79 | 3.50 | 3.25 | 3.67 | 4.00 |
| R3.4 | 1.53 | 1.67 | 1.43 | 2.00 | 1.38 | 1.33 | 1.40 |
| R3.5 | 4.29 | 4.22 | 4.36 | 4.00 | 3.88 | 4.67 | 4.60 |

Table

## Table 1 – Correlation between the design parameters

| | F1.1 | F1.2 | F1.3 | F1.4 | F1.5 | F1.6 | F1.7 | F1.8 | F1.9 | F2.1 | F2.2 | F2.3 | F3.1 | F3.2 | F4.1 | F4.2 | F5.1 | F5.2 | F5.3 | F6.1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| F1.1 | | | | | | | | | | | | | | | | | | | | |
| F1.2 | ‡ | | | | | | | | | | | | | | | | | | | |
| F1.3 | ∨ | ◊ | | | | | | | | | | | | | | | | | | |
| F1.4 | + | + | ◊ | | | | | | | | | | | | | | | | | |
| F1.5 | ◊ | ◊ | ◊ | ‡ | | | | | | | | | | | | | | | | |
| F1.6 | ◊ | ◊ | + | ∨ | ∨ | | | | | | | | | | | | | | | |
| F1.7 | + | ◊ | ‡ | ◊ | ◊ | ‡ | | | | | | | | | | | | | | |
| F1.8 | ◊ | ‡ | ◊ | ‡ | ◊ | ◊ | ◊ | | | | | | | | | | | | | |
| F1.9 | + | ◊ | + | ‡ | ₸ | + | + | ◊ | | | | | | | | | | | | |
| F2.1 | ∨ | + | + | + | ₸ | ‡ | ◊ | + | ‡ | | | | | | | | | | | |
| F2.2 | + | ◊ | + | ‡ | + | ∨ | ‡ | + | + | + | | | | | | | | | | |
| F2.3 | ◊ | ◊ | + | ◊ | ◊ | + | + | ◊ | + | + | ◊ | | | | | | | | | |
| F3.1 | ◊ | ◊ | ◊ | ◊ | ◊ | + | ◊ | ◊ | ◊ | ◊ | + | + | | | | | | | | |
| F3.2 | + | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | + | + | ◊ | + | ◊ | | | | | | | |
| F4.1 | ◊ | + | ◊ | + | ◊ | ◊ | + | + | ◊ | ◊ | ◊ | ◊ | + | ‡ | | | | | | |
| F4.2 | ◊ | ‡ | ◊ | + | ◊ | ◊ | ◊ | + | + | ◊ | ◊ | ◊ | ◊ | + | + | | | | | |
| F5.1 | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | + | ◊ | | | | |
| F5.2 | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | + | ◊ | + | | | |
| F5.3 | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | + | ◊ | ‡ | + | | |
| F6.1 | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | ◊ | + | ◊ | ‡ | + | ‡ | |

Table

**Table 1 - Input parameters and values of forage harvesting**

| Input | Value |
|---|---|
| Tractor yearly hours of use (h) | 500 |
| Tractor power (kW) | 85 |
| Tractor purchase value (€) | 81 500 |
| Type of machinery | Baler |
| Machinery yearly hours of use (h) | 200 |
| Machinery power requirement (kW) | 30 |
| Machinery lifetime (h) | 1 500 |
| Machinery purchase value (€) | 30 000 |
| Working with (m) | 2.5 |
| Working speed (km $h^{-1}$) | 7 |

Table

**Table 1 - Output values of the forage harvesting using AMACA**

| Output | Tractor | Equipment |
|---|---|---|
| Depreciation (€ $y^{-1}$) | 2 274.61 | 3 200.00 |
| Interest (€ $y^{-1}$) | 2 255.31 | 900.00 |
| Insurance (€ $y^{-1}$) | 100.00 | 100.00 |
| Total fixed costs (€ $h^{-1}$) | 9.26 | 21.00 |
| Repair and maintenance (€ $h^{-1}$) | 3.91 | 17.84 |
| Traction cost (€ $h^{-1}$) | 13.17 | 13.17 |
| Fuel consumption (€ $h^{-1}$) | - | 11.29 |
| Variable cost (€ $h^{-1}$) | - | 42.31 |
| Hourly costs (€ $h^{-1}$) | - | 83.31 |
| Operation cost (€ $ha^{-1}$) | - | 73.24 |

Table

**Table 1 - Operating machines characteristics**

| | Operating machine | | |
|---|---|---|---|
| | Moldboard plow | Chisel plow | Tandem disk harrow |
| Use (h $y^{-1}$) | 80 | 80 | 80 |
| Lifetime (h) | 2,000 | 2,000 | 2,000 |
| Purchase value (€) | 14,000 | 5,000 | 30,000 |
| Tractor power requirement (kW) | 60 | 35 | 50 |
| Working width (m) | 2 | 5 | 5 |
| Working speed (km $h^{-1}$) | 5 | 7 | 7 |

Figure

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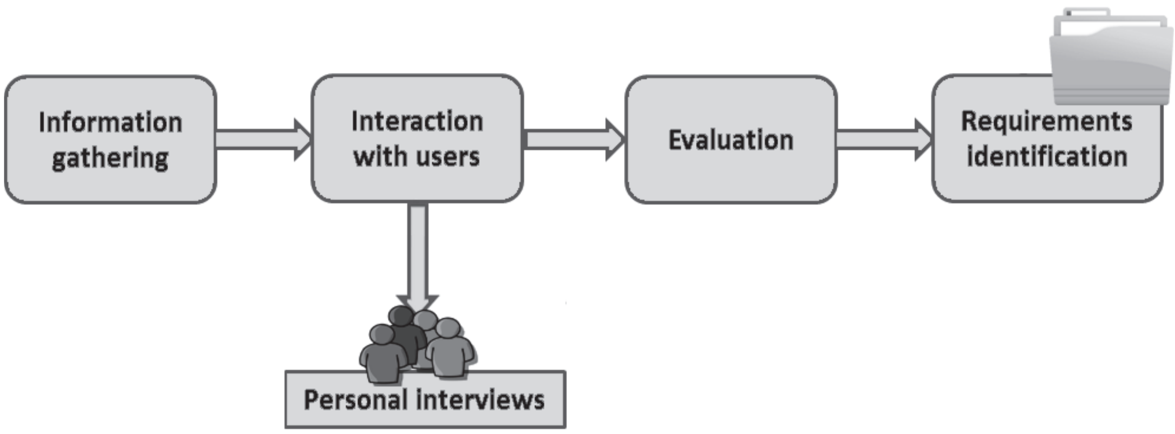


**Figure 1- Identification of user needs**

Figure
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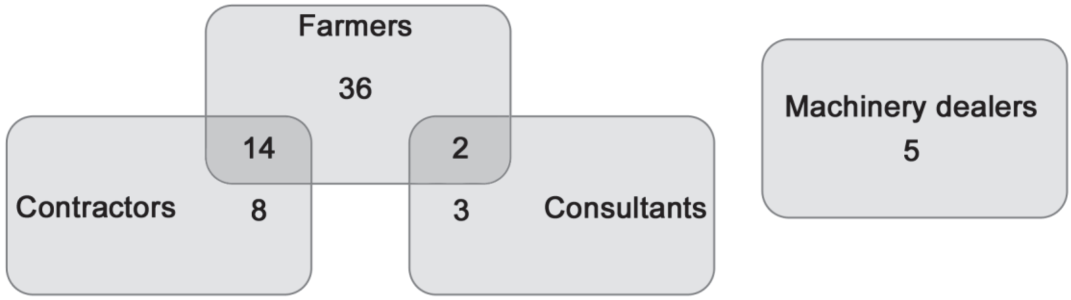


**Figure 1 - Distribution of different end user types**

Figure

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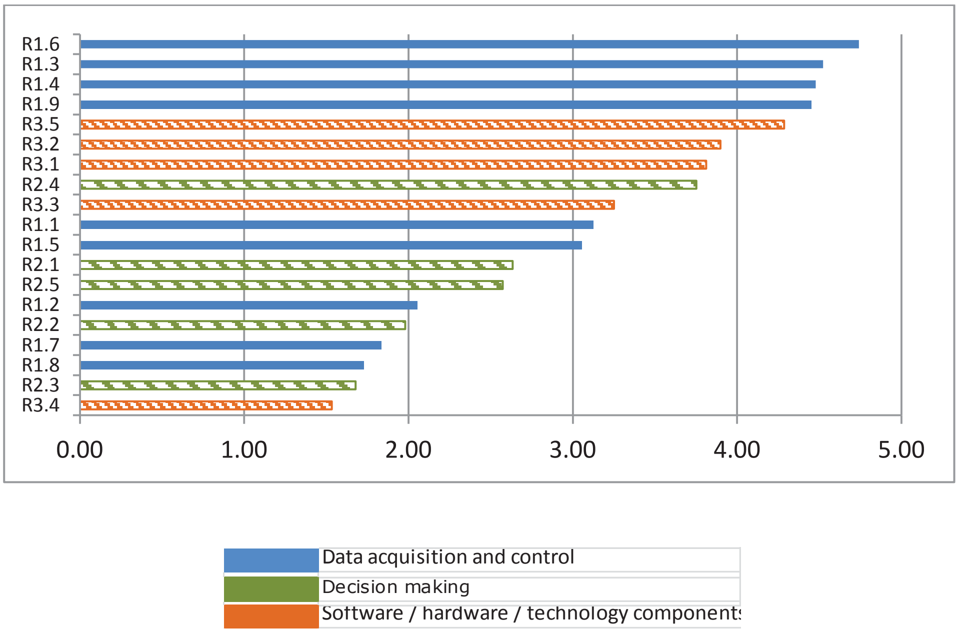


**Figure 1 - The average raking of the users requirements.**

Figure

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| | | | Importance rating | Usability | | | | | | | | | Presentation | | | Visualisation | | Personalisation | | Interoperability | | | Scalability |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| ` | | | | F1.1 | F1.2 | F1.3 | F1.4 | F1.5 | F1.6 | F1.7 | F1.8 | F1.9 | F2.1 | F2.2 | F2.3 | F3.1 | F3.2 | F4.1 | F4.2 | F5.1 | F5.2 | F5.3 | F6.1 |
| User requirements | Data acquisition and control | R1.1 | 3.12 | | 9 | | | | | | 9 | 9 | | | | | 1 | | 1 | | | | |
| | | R1.2 | 2.05 | 1 | 9 | | | | | | 9 | 9 | 1 | 1 | 1 | | 1 | | 3 | 1 | | | |
| | | R1.3 | 4.52 | | | | | | | 3 | | | | | | | 9 | | | | | | |
| | | R1.4 | 4.48 | | | | | | | | | | | | | | 9 | | | | | | |
| | | R1.5 | 3.05 | 3 | | 3 | 9 | 3 | 1 | 9 | 3 | 9 | | | | 3 | 3 | | 9 | 1 | | | |
| | | R1.6 | 4.74 | 9 | 9 | 9 | 9 | 9 | 3 | 9 | 3 | 9 | 9 | 9 | 9 | 3 | 1 | | 9 | 9 | 3 | 3 | |
| | | R1.7 | 1.83 | | | | | | | 9 | | | | | | | | | | | | | 9 |
| | | R1.8 | 1.72 | | | | | | | | 3 | | | | | | | | | | | | |
| | | R1.9 | 4.45 | 3 | | | 1 | 9 | 9 | 9 | | 1 | 3 | 9 | 3 | 1 | | | 3 | | | | |
| | Predictive planning and optimisation | R2.1 | 2.63 | | | | | | | 1 | | | | | | | 3 | | | 3 | | | |
| | | R2.2 | 1.98 | | | | | | | | | | | | | | 1 | | | | | | |
| | | R2.3 | 1.68 | | | | | | | | | | | | | | 1 | | | | | | |
| | | R2.4 | 3.75 | | | | | | | 3 | | | | | | | 3 | | | | | | |
| | | R2.5 | 2.57 | | | | | | | | 9 | | 3 | | | | 9 | 1 | | 1 | | | |
| | Software/harwar e/technology components | R3.1 | 3.81 | 3 | 1 | 9 | 3 | 1 | 3 | 1 | | 3 | 3 | 9 | 9 | 9 | 1 | 1 | 9 | 3 | 1 | 1 | 9 |
| | | R3.2 | 3.90 | | | | | | | | | | | | | | 1 | | | | 9 | 9 | 1 |
| | | R3.3 | 3.25 | | | | | | | | | | | | | | | | | 3 | 9 | 9 | 3 |
| | | R3.4 | 1.53 | | | | | | | | | | | | | | | 1 | | 3 | 9 | 9 | 3 |
| | | R3.5 | 4.29 | | | | | | | | | | 3 | 9 | 9 | 1 | 1 | | 1 | 9 | 9 | 9 | 9 |
| | | | Raw score | 65.31 | 93.04 | 86.14 | 81.58 | 55.64 | 28.71 | 117.91 | 98.28 | 128.13 | 76.74 | 117.61 | 117.61 | 61.98 | 158.08 | 6.39 | 118.01 | 118.02 | 120.97 | 120.97 | 103.04 |
| | | | Relative score (%) | 3.48% | 4.96% | 4.60% | 4.35% | 2.97% | 1.53% | 6.29% | 5.24% | 6.84% | 4.09% | 6.28% | 6.28% | 3.31% | 8.43% | 0.34% | 6.30% | 6.30% | 6.45% | 6.45% | 5.50% |
| | | | Ranking | 1 | 2 | 2 | 2 | 1 | 1 | 3 | 2 | 4 | 2 | 3 | 3 | 1 | 4 | 1 | 3 | 3 | 4 | 4 | 3 |

**Figure 1 - Scored relationships between user requirements and the selected design parameters**

Figure
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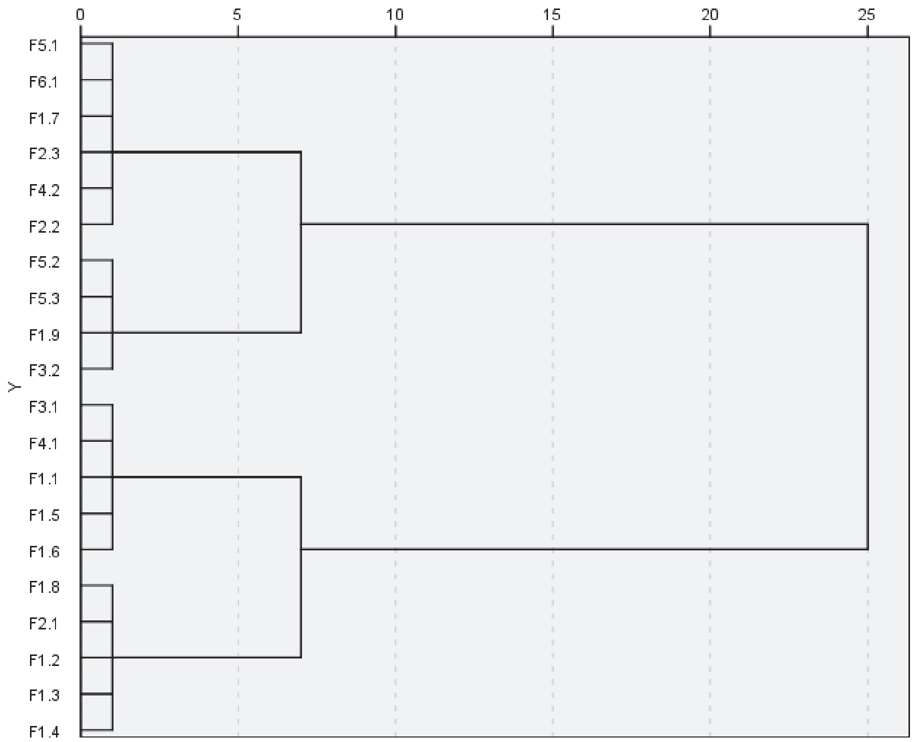


**Figure 1 – Clustered dendrogram**

Figure
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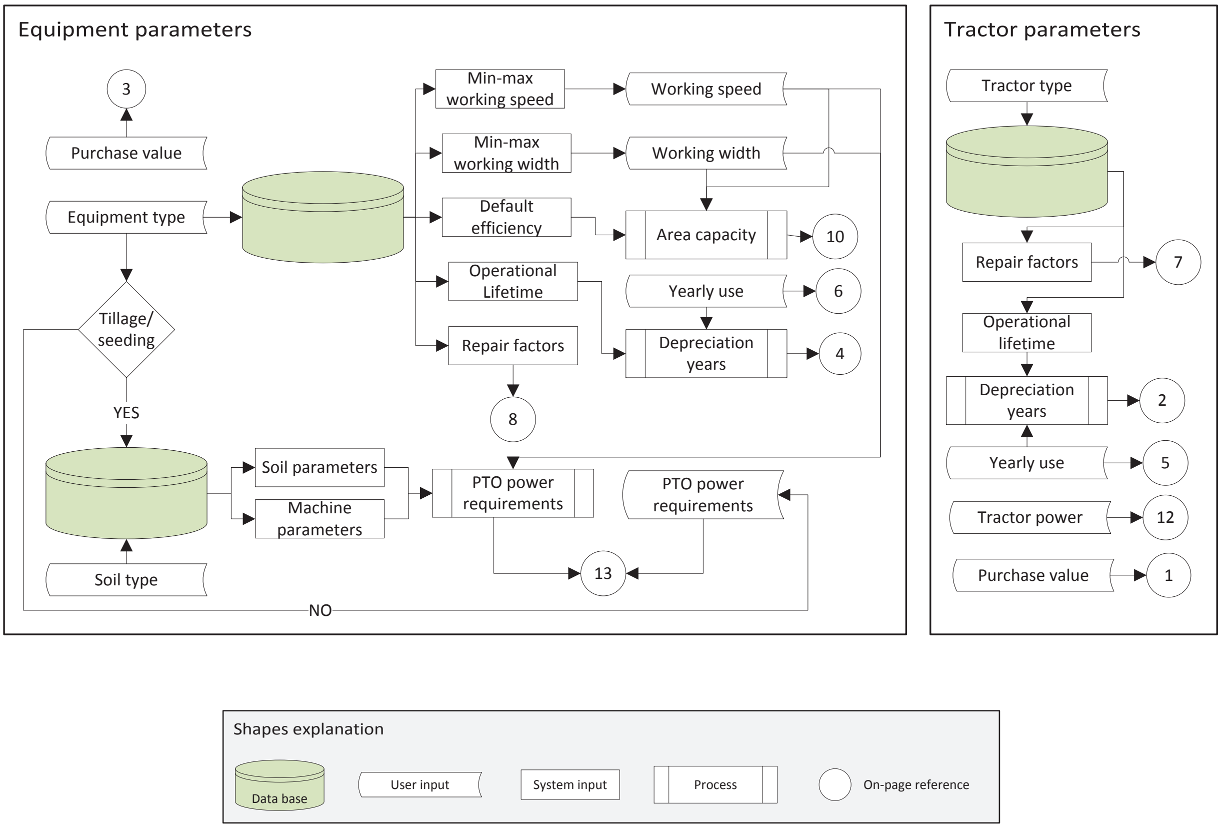


**Figure 1 – Flow diagram of data insertion of tractor and equipment parameters**

Figure

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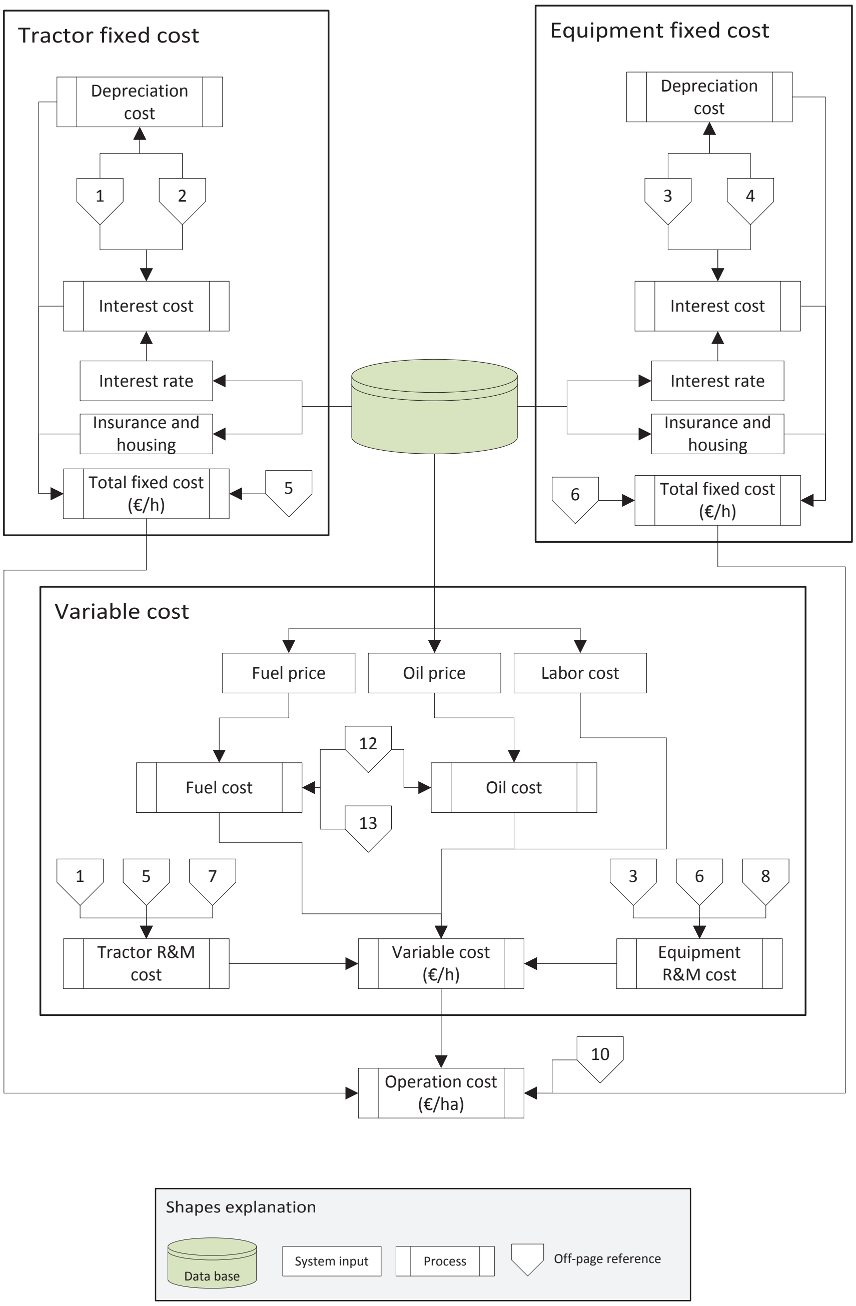


**Figure 1 - Flow diagram of computation of fixed and variable costs**

Figure
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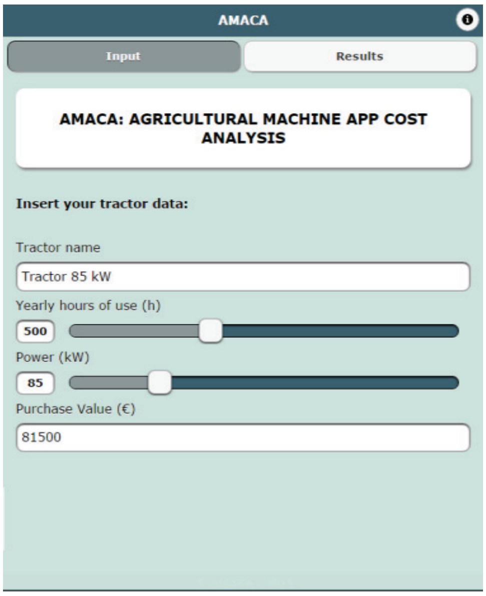
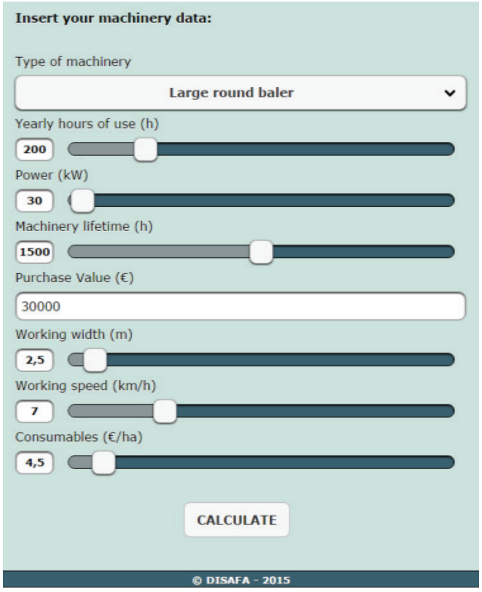



(a)




(b)

**Figure 1 – Tractor input data (a) and machinery input data (b) interfaces**

Figure
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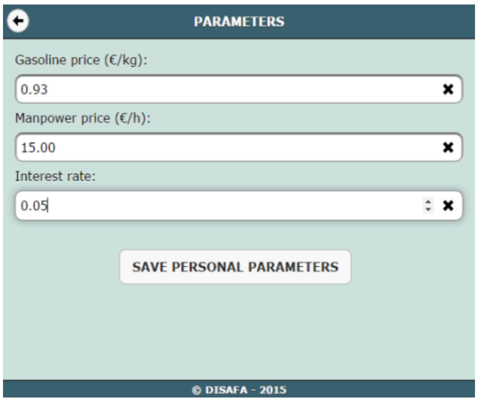


**Figure 1 – General parameters interface**

Figure
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**AMACA**

Input | Results

| PARAMETERS | Tractor | Equipment |
|---|---|---|
| Name | Tractor 85 kW | Large round baler |
| Depreciation (€/year) | 2274.61 | 3200.00 |
| Interest (€/year) | 2255.31 | 900.00 |
| Insurance (€/year) | 100.00 | 100.00 |
| Total fixed costs (€/h) | 9.26 | 21.00 |
| Repair and maintenance (€/h) | 3.91 | 17.84 |

| PARAMETERS | Value |
|---|---|
| Manpower cost (€/h) | 15.00 |
| Fuel consumption (€/h) | 11.29 |
| Machines costs (€/h) | **78.31** |
| Field capacity (ha/h) | 1.14 |
| Machinery operation cost (€/ha) | **68.84** |
| Consumables (€/ha) | 4.50 |
| Total operation cost (€/ha) | **73.34** |

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**Figure 1- Results page**

Figure

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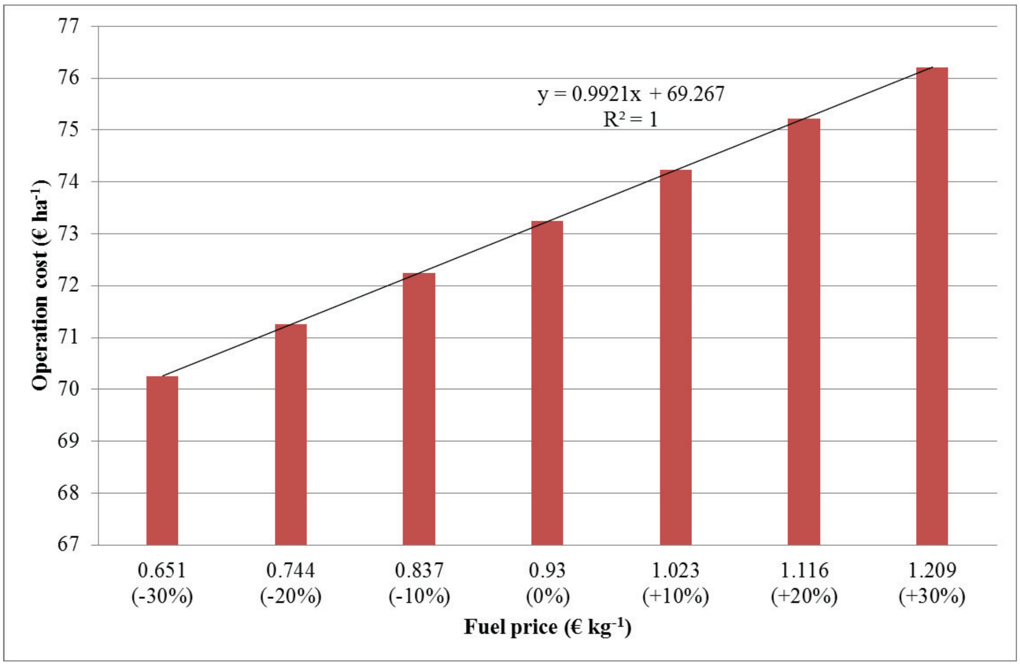


**Figure 1 – Operation cost changes due to fuel price variations**

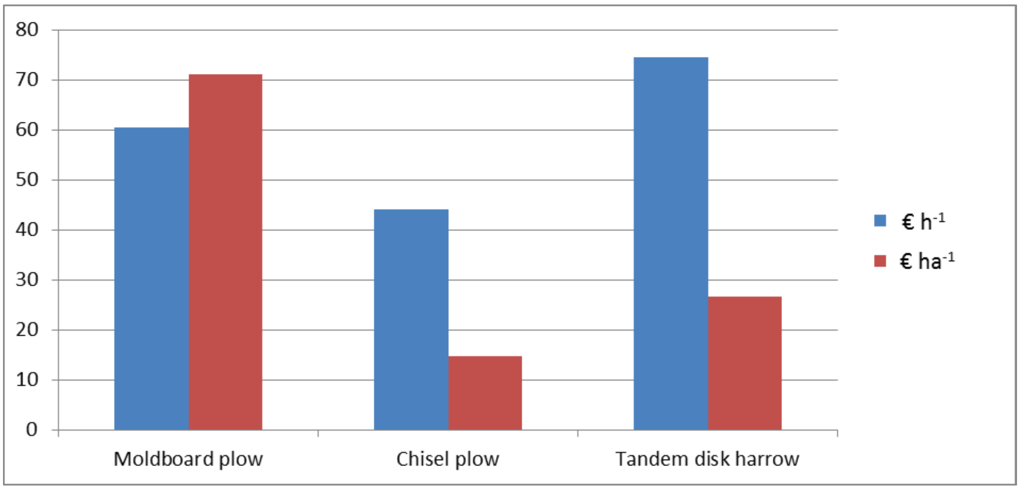


**Figure 1 - Unit cost of different tillage types**