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Article

A Mobile App for Supporting Citrus Fruit Growers in Greece

Sotirios Karetsos *, Constantina Costopoulou, Nefeli Gourdomichali and Maria Ntaliani

Informatics Laboratory, Department of Agricultural Economics and Rural Development, Agricultural University of Athens, Iera Odos 75, 11855 Athens, Greece
* Correspondence: karetsos@aua.gr

Abstract: Crop management is a challenging and time-consuming task that involves many different data and farming activities. Data regarding the plots, the crop, and seasonal farming activities, are important for improving crop management for different cultivations. Specifically, citrus fruits are significant cultivations for Greece. Citrus cultivation is mainly practiced in small-sized, dispersed, family-owned plots and requires cumulative knowledge and experience regarding various activities. Such knowledge has to be easily registered and be made accessible ubiquitously, and should cover various activities for each plot, such as plowing, planting, pruning, spraying, irrigating, harvesting, and the purchase of agricultural supplies. Usually, farmers keep an archive of farming activities on paper, in a non-structured form, from which it is difficult and time consuming to retrieve and use information. The objective of this article is the deployment of a mobile app for citrus management that supports the recording and retrieving of farming data. The app design was based on the requirements of two hundred farmers and its implementation was based on the Android platform. The usability test evaluation shows that the app meets citrus farmers' requirements. Limitations of this study include the small evaluation sample and the exclusive use of the Greek language. Future work focuses on the development of localized apps for specific crops, combined with other functionalities, such as location-based services, alerts, and cloud data storage, to help farmers with their specific needs in practice.

Keywords: mobile apps; smart mobile devices; citrus growers; farming activities; Greece

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1. Introduction

Emerging challenges related to energy and the environment are expected to significantly affect production costs, while at the same time the need to shift to more sustainable production methods becomes more imperative. The motivation of this study lies in the fact that crop management should be carried out in a way that excludes errors or omissions to control costs, mitigate climate change and improve productivity. Crop management is a challenging and time-consuming task that involves many different data and farming activities. Data should cover various activities for each plot, such as plowing, planting, pruning, spraying, irrigating, harvesting, and the purchase of agricultural supplies. A farmer has to maintain a personal calendar for registering and monitoring these data for distinguishing time periods of cultivation, rescheduling farming activities and improving resource management, planning and decision making [1,2]. However, farmers with ubiquitous access to reliable and precise data, easily registered from their own field, have the advantage of being able to adapt crop management more effectively [3–5].

Citrus cultivation is significant for Greece, which holds third place in production in Europe, after Spain and Italy [6]. It is mainly practiced in small-sized, dispersed, family-owned plots, and requires cumulative knowledge and experience regarding various activities. Usually, farmers keep an archive of farming activities on paper, in a non-structured form, from which it is difficult and time consuming to retrieve and use information.

Mobile devices offer powerful computing and communication capabilities. They contain a variety of chips and sensors, such as global positioning system (GPS), gyroscope, microphone, camera, and accelerometer. They are used as a medium for relaying and accessing information, as well as digital services [7] using mobile applications (also known as mobile apps or simply apps). Such apps are software applications designed to run on a smart mobile device [8]. Initially, apps were intended for productivity support, for example, email, calendar, and contact databases, but public demand caused the rapid expansion of apps into other areas, such as mobile games, factory automation, GPS and other location-based services, order-tracking, and ticket purchases, so that there are now millions of apps available on the market [8].

Mobile apps for agriculture aim at improving the management and decision making involved in farming activities, and consequently farmers' lives. Today, they are considered substantial enablers for providing a variety of services (real-time and non-real-time) for responding to the challenges faced by stakeholders in the agri-food value chain and rural areas [9], implemented in a specific context of focus, regarding rural area, type of cultivation and stakeholders' profile [10].

The objective of this article is to describe the development process of a mobile app for citrus management that supports the recording and retrieving of farming data (aimed at produce cost reduction), including the app functionalities and its evaluation. The app design was based on the requirements of two hundred Greek citrus growers; its implementation was based on the Android platform; and its evaluation was undertaken by ten citrus growers. Therefore, the structure of this study is as follows: Section 2 regards the usage of smartphones and, particularly, agricultural mobile apps, in agriculture, and investigates existing mobile apps for citrus cultivation. Section 3 describes the methodology followed for the deployment of the proposed app, entitled Agrendar (**Agr**icultural cal**endar**). Section 4 presents the results of this research and, finally, Section 5 provides conclusions and future work.

2. Background

Smart mobile devices (e.g., smartphones and tablets) are at the core of innovation, greatly influencing people's lives [11,12]. It is notable that in 2021, the number of mobile users worldwide was 7.1 billion, with forecasts suggesting that this is likely to rise to 7.26 billion by the end of 2022 and 7.49 billion in 2025 [13]. According to recent statistics [14], as of the second quarter of 2022, Android users were able to choose from among 3.50 million apps, making Google Play the top app store in terms of available apps, followed by Apple App Store with 2.20 million apps. The number of mobile app downloads worldwide has been increasing constantly, from 140.7 billion in 2016, surpassing 200 billion in 2019 and reaching 230 billion in 2021. This has formed a great new market for mobile apps, which is expected to generate more than 613 billion U.S. dollars in revenue in 2025, with mobile games and videos holding the biggest revenue shares among all app categories [15].

According to the literature, there are several studies trying to assess current usage of smartphones, and agricultural mobile apps, by farmers [16–20]. These studies do not provide the global current status of agricultural mobile apps, since they are fragmented and specialized for particular sectors or countries. However, they provide examples of mobile apps that cover a spectrum of activities from the field to the agricultural market, such as weather forecasting for farmers [16], agricultural business news, information for agricultural machinery and equipment, agricultural-product market prices, management of agricultural product, dairy farming [16,21], management of irrigation systems, management of crop sensors [16,21–24], yield forecasting and monitoring, registration of soil types, and calculation. Most apps are developed in the USA and India and focus on local farmers' needs [25]. However, these apps are usually generic and do not specialize for specific cultivations, but rather on specific topics, such as economic records and pest or weed management. An example is the "Farm Management Pro" app, providing services for farm accounting, finance records, farm tasks, and farming notifications.

In the context of this study, the two main app stores, namely Google Play and Apple App Store, as well as scientific resources and websites, have been searched for mobile apps specialized for citrus crops. The first set of keywords included terms such as "tree cultivation" AND "mobile apps". In this case, search results showed generic apps that can be used for tree cultivations among others. An example is "Crop farmers", an app that provides farmers summarized information about crop, fruit and vegetable growing. Also, apps for recording and monitoring farming activities, for generic use in the agricultural sector, have been found, such as "Agronote", an app that provides the possibility to create expense and revenue records in several languages, including Greek. The second set of keywords included the terms "citrus cultivation" OR "citrus growers" AND "mobile apps". The search showed no related results.

3. Materials and Methods

As aforementioned, the necessity of the proposed app has been identified through a literature review. For the development process of the app, four phases, namely requirements analysis, design, development, and evaluation, have been adopted. During the last decade, mobile apps have gained a significant share of the software market. However, there are specific characteristics that distinguish mobile app development from traditional software development. More specifically, mobile app development presents new challenges for developers, such as how to effectively create apps, operating in a heterogeneous environment with limited hardware resources, while presenting high performance, response capability and efficiency. Additionally, the deployment of apps requires quick completion at low cost. Unfortunately, in some cases, app developers start a project and skip software engineering processes (e.g., user requirements, design), resulting in the deployment of low quality apps. The method followed for the development of the proposed mobile app consists of the phases below [26,27]:

- Requirements analysis: it focuses on the tasks that determine the needs of citrus growers, analyzing and documenting, system (app) requirements. It has been realized through a structured questionnaire. It is divided into three parts, namely: citrus growers' profile; smart mobile devices and apps usage; and mobile app requirements. The questionnaire was distributed in print in various places frequented by citrus growers (e.g., agricultural supply stores selling pesticides and fertilizers, a local soil-analysis laboratory, the geotechnical-survey office, various municipal services), as well as in electronic form, shared through Facebook.
- Design: this is the process by which the specifications of a software artifact intended to accomplish goals is created. It is realized through the unified modeling language (UML). UML is the de facto software industry standard modelling language for visualizing, specifying, constructing, and documenting the elements of systems in general, and software systems. It provides a rich set of graphical artefacts to help in the elicitation and top-down refinement of software systems, from requirements capture to the deployment of software components.
- Development: this is the detailed creation of working, meaningful software, through a combination of coding and debugging. The proposed app is realized through the App Inventor environment, which enables app development for smart mobile devices using the Android operating system. The App Inventor is a free and open-source programming environment, originally provided by Google and now maintained by Massachusetts Institute of Technology (MIT), Boston, MA, USA. It is web-based and properly designed, so that it can be used by both experienced and novice app developers.
- Evaluation: the functionality of the developed app has been tested according to user requirements. Specifically, a usability test has taken place concerning the different functionalities of the app. Then, the users have reported their experience, based on the Questionnaire for User Interaction Satisfaction (QUIS) [28]. The questionnaire assesses the user's satisfaction concerning the overall reaction to the app, screen design and layout, learnability and application features, through 12 questions. An online version of the questionnaire was distributed through email and Facebook.

In the following section, the aforementioned phases were implemented for the Agrendar app.

4. Results

4.1. Greek Citrus Growers' Requirements

A survey was conducted to investigate how citrus growers monitor cultivation activities, whether a personal calendar app would be useful to farmers, and what characteristics it should have. The survey was realized during the growing season 2020–2021. The questionnaire regards the following characteristics: (i) citrus growers' profile: regarding age, gender, education, type of citrus cultivation, size and number of plots; (ii) smart mobile devices and apps usage: concerning citrus growers' familiarization with mobile devices (e.g., smartphones, tablets) and intention to use mobile apps in their farming activities in the future; and (iii) mobile app requirements: regarding growers' opinion on the usefulness of recording cultivation activities on a smart mobile device, as well as future interest for a using a relevant mobile app. Parts two and three were measured using a 5-point Likert scale [29]. Two hundred and twenty-three (223) questionnaires were collected. Of these, two hundred (200) were valid. They were collected from growers in the prefecture of Laconia in Southern Greece, one of the three most significant citrus production areas in Greece.

4.2. Citrus Growers' Profile

The results regarding the citrus growers' profile are presented in Table 1. From the 200 growers in the sample, 152 were male and 48 were female. Growers can be stratified by age into <45 (56.5%), 46–55 (21%), 56–65 (14%), and more than 65 years (8.5%). Regarding the level of education, almost half of the sample (49.5%) have completed only secondary education, and 36.5% are university graduates. It must be noted that 12% have not completed compulsory education.

Table 1. Citrus growers' profile.

Measure	Item	Percentage (%)
Gender	Male	76
	Female	24
Age (years old)	18–25	7
	26–35	26
	36–45	23.5
	46–55	21
	56–65	14
	>65	8.5
Education	Primary	12
	Secondary	49.5
	University	36.5
	Masters	1.5
	PhD	0.5
Citrus types' cultivation	Only oranges	32.5
	Oranges and tangerines	44
	Oranges and lemons	2.5
	Oranges, lemons, and tangerines	20.5
	Only lemons	0.5
Citrus orchard size (hectares)	5>	76.5
	5–10	18.5
	>10	5
Number of orchard plots cultivated	1–3	50
	4–6	29
	7–9	14.5
	>10	6.5

Concerning the citrus types cultivated, 44% cultivate oranges and tangerines, 32.5% cultivate exclusively oranges, 20.5% cultivate oranges, lemons, and tangerines, 2.5% cultivate oranges and lemons and only 0.5% cultivate exclusively lemons. The results indicate the problem of small and fragmented holdings. Specifically, regarding the size of citrus orchards, the majority (76.5%) are under 5 hectares, 18.5% are between 5–10 hectares, and 5% are over 10 hectares. Moreover, the classification according to number of plots is: 1–3 (50%), 4–6 (29%), 7–9 (14.5%), more than 10 (6.5%).

4.3. Smart Mobile Devices and Apps Usage

This part distinguishes growers into non-users and users of smart devices (i.e., smart phone or tablet), posing different questions. According to the results, 55 do not own smart mobile devices, of whom 41 would like to use them in the future, and 14 were negative, even from that perspective.

However, 72.5% of the sample use/own a smart mobile device, the great majority of whom (96.6%) use mobile apps. The Android operating system dominates on their devices (84.8%) over iOS (15.2%). They also use social media, mainly Facebook (87.9%) and Viber (84.3%), followed by Instagram (61.4%), Skype (30.7%), and Twitter (12.9%). Furthermore, they use various mobile apps, namely banking (70.7%), weather forecasting (74.3%), and daily calendars (55%).

4.4. Mobile App Requirements

The growers that own a smart mobile device, or would like to use one in the future (93%), stated their opinion regarding monitoring their cultivation activities using smart mobile devices. They agreed that it was useful (91.3%), saved time (78.5%) and money (72.6%), and helped with organization (91.3%) and future planning (89.8%) of their cultivation (Figure 1). Concerning how often they plan cultivation activities, 52.2% answered always, 36% often, 7.5% sometimes and only 4.3% answered rarely.

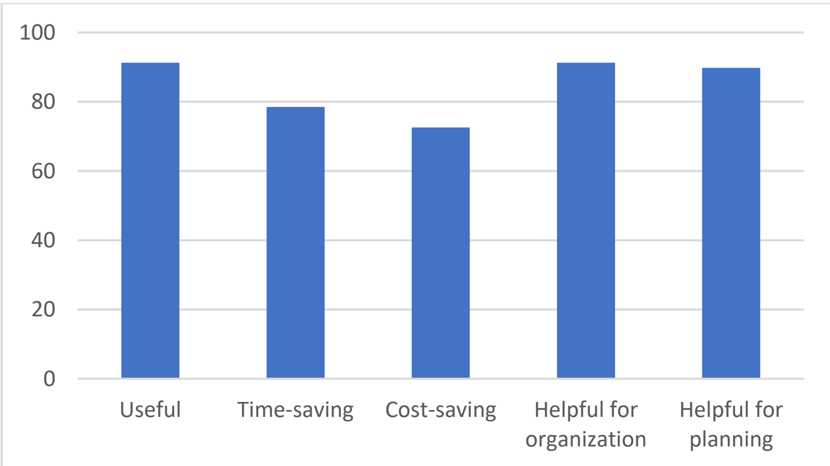


Figure 1. Citrus growers' opinion on mobile devices.

Figure 2 describes the recording frequency of different types of farming activities by citrus growers, namely spraying (88.7%), cultivation costs (87.5%), fertilizing (70.7%), weed control (66.3%), soil analysis (61.2%), irrigation (60.9%), pruning (56.9%), fruit quality control (56.9%), irrigation system control (55.7%), leaf diagnostics (55%), pest population control (47.8%), plowing (33.1%), and annual production (30%). These data are usually recorded by the grower, being handwritten in a notebook (65.6%), a diary (26.3%), or a computer file (14.4%) and (very few) through a mobile app for taking notes (5.6%). Moreover, the vast majority (85.5%) of growers showed much to very much future interest in using a mobile app for recording their activities, mainly for cultivation costs and revenue, spraying, annual production, fertilizing and weed control.

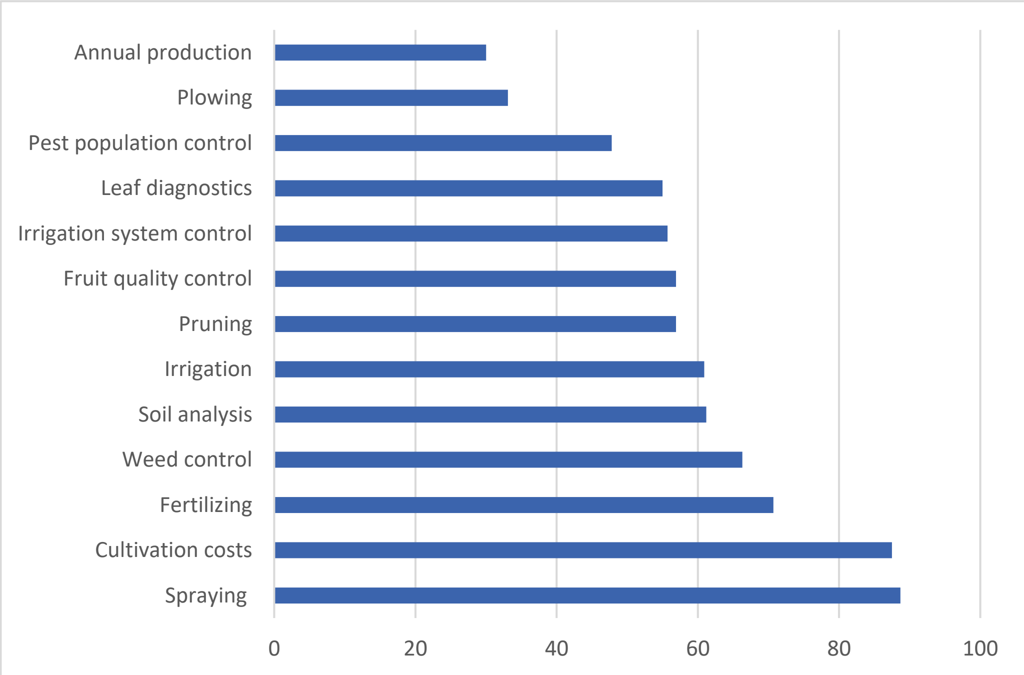


Figure 2. Recording frequency of farming activities by citrus growers.

4.5. Agrendar App Design

In the design phase, two experts in agricultural technology assessed the collected citrus growers' needs, and determined design principles and requirements for the pilot app, which were used to develop the initial prototypes of the proposed mobile app. The output was evaluated for alternative designs for covering users' expectations. To complete final app design, the UML was used. In UML, a system is described using different levels of abstraction and considering various views (i.e., business view, use case view, design and process view, implementation view) [30]. Figure 3 presents a high-level use case diagram depicting the actor and the functionalities of the app.

The actor represents any citrus grower who needs to register and monitor his/her farming activities using the Agrendar app. Fifteen UML use cases represent the Agrendar app functionalities. The three main use cases are described below:

- *Register plots:* concerns registering the plots. More specifically, the citrus grower inserts data regarding the location, area, citrus varieties, number of trees, and the irrigation system of each plot.
- *Register farming activities:* concerns the registration of farming activities for a specific plot.
- *Monitor farming activities:* concerns the monitoring of farming activities for a specific plot.

Next, uses cases and related data for the farming activities are described. All use cases require specialized data, namely the farming activity and a specific date. These use cases are mentioned below and have an "extend" relationship with the "register farming activities" use case, and an "include" relationship with the "monitor farming activities" use case.

- *Insert irrigation:* hours of irrigation.
- *Insert irrigation system control:* damages and maintenance activities.
- *Insert fertilizing:* type and quantity of fertilizer used, reason for fertilizing, and fertilizing method.
- *Insert spraying:* spraying method, agrochemical used and purpose of use.
- *Insert weed control:* weed-control methods (mechanical or spraying) and tools.
- *Insert pruning:* pruning type.
- *Insert plowing:* plowing purpose and depth.

- *Insert pest management:* infection type, pest-management method (spraying, pheromone etc.), and agrochemicals.
- *Insert soil analysis:* soil texture (i.e., sand, silt, clay), ingredient concentrations and pH.
- *Insert leaf diagnostics:* leaf-analysis results for citrus trees (e.g., concentration of N, P, K).
- *Insert cultivation costs:* expenses regarding a specific plot, according to certain categories.
- *Insert cultivation revenue:* any type of income (e.g., sales, subsidy).

Figure 3. Use case diagram for the Agrendar app.

A use case diagram translates user requirements into software requirements from the technical rationality perspective. It specifies the expected behavior of a software system. Based on the above use case diagram, the proposed app has been developed.

4.6. Agrendar App Development

The development of the app has been based on the App Inventor. This environment allows the development of apps using graphical interfaces [31,32]. It is possible to develop apps for smart mobile devices running the Android operating system using drag-and-drop building blocks; the corresponding code is already developed and associated, so the users do not need to have advanced programming capabilities.

The App Inventor environment provides an additional and very important tool for app developers. This tool is the MIT Al2 Companion. It is installed by the user on their mobile device that supports the Android operating system, and they can monitor in real time the functions of the app that they develop. This was also applied for the development of the Agrendar app, monitoring functions from the beginning until their completion.

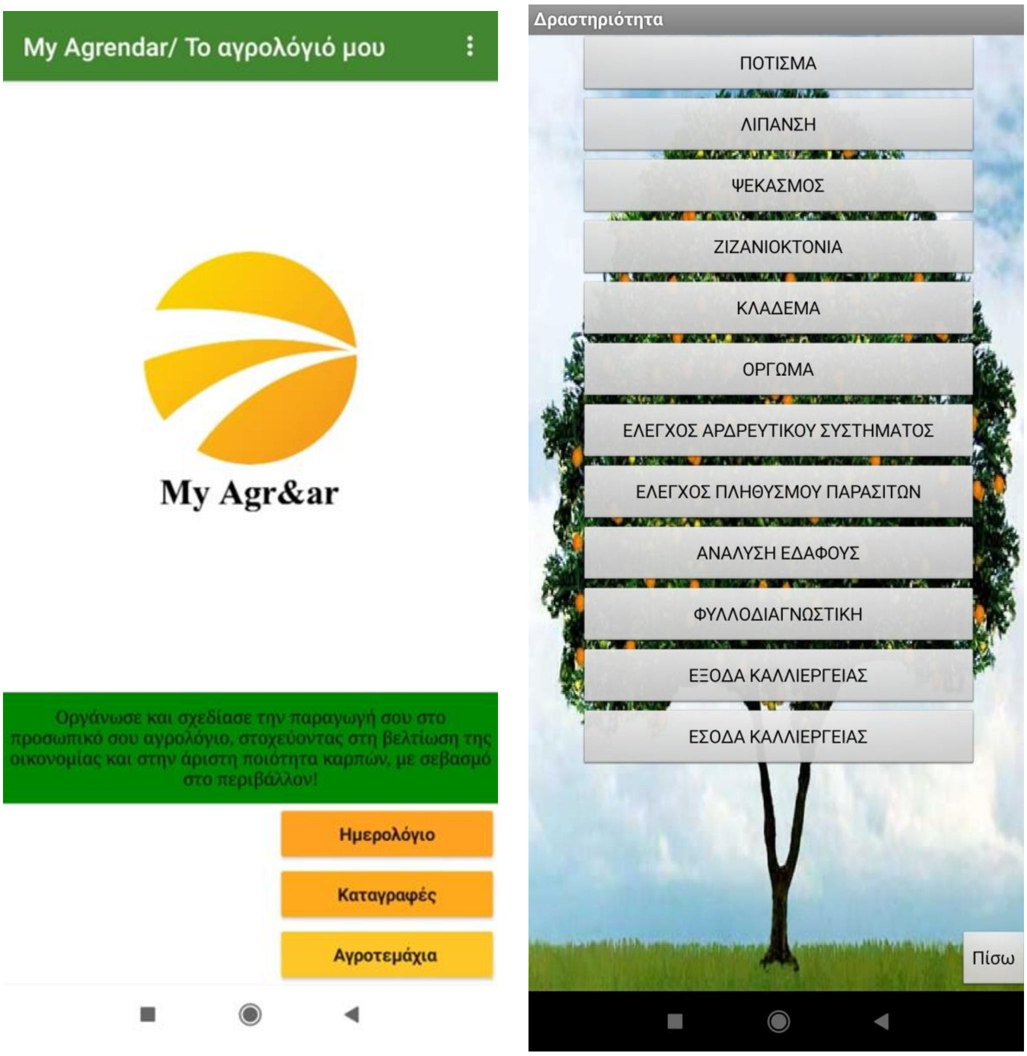
4.7. Description of Functionalities

The implemented app consists of 42 screens that implement different recording and monitoring functionalities. The citrus grower can record data even while working in the plot and remote areas. The app testing was based on several scenarios and functionality problems that were identified and corrected. It took place in the context of the MIT App Inventor standards for native apps.

Hereafter, the most important app functionalities are presented. Initially, the citrus grower installs the app on the mobile device. It must be noted that full operation of the app does not require an internet connection (which is usually not available in remote areas). After the installation, the grower must allow permission for the app to be able to use the storage space and camera of the mobile device. In this way the app can be fully operational. When the user initializes the app, the home screen (Figure 4a) appears, displaying the name of the app and a short description of its scope, and, at the bottom right, three buttons, namely "Calendar", "Records" and "Plots", which are described in detail below. When a citrus grower uses the app for the first time, they need to insert information regarding their plots.

"Plots" functionality: From the "Plots" button, the user enters a new screen, from which they can create a new record using the "New Plot". Special rules are activated when the user tries to submit incomplete or non-valid data. In this case, the app requests the user to provide the appropriate data to proceed. After a successful submission, the data are recorded in txt format on the smart mobile device and a confirmation message pops up on the screen. All new entries are stored, and the grower can view the content in the form of a table.

"Calendar" functionality: From the "Calendar" button, a screen displays a calendar box, from which the user can select a particular date. Then, the user must first select a plot and then a farming activity from a list (Figure 4b). The list includes the citrus growers' activities, namely irrigation and system control, fertilizing, spraying, weed control, pruning, plowing, pest management, soil analysis, leaf diagnostics, cultivation costs and revenue. When the grower submits data successfully, a confirmation message appears. Each of the activities has been designed in an appropriate form for the required data. For example, for the insert fertilizing functionality, the data entry form requires: date, type of the fertilizer used, quantity, reason for fertilizing, and method followed for fertilizing (i.e., water soluble, through fertilizer distributor, foliar or by hand) through a checkbox list. Among farming activities, there are options to keep track of cultivation expenses and revenue. Regarding the expenses, the grower enters the amount of money and the type of expense (e.g., fertilizer). However, the grower's annual revenue can derive from different sources, namely from citrus harvest, governmental aid, compensation (in case of yield losses) and participation in subsidized programs. For this reason, it was considered appropriate to offer the ability to distinguish these revenues. For the citrus harvest, the grower must enter the weight of production and the price per kilo. For governmental aid and compensation, the app asks for the amount and the specific justification. For participation in subsidized programs, the amount and the title of the program are required.



(**a**) (**b**)

Figure 4. Agrendar: (**a**) Home screen, (**b**) List of farming activities screen.

"Records" functionality: From the "Records" button the grower can monitor all data entries. More specifically, by selecting a specific plot, they can view all the information that corresponds to the recorded activities, presented in appropriate forms. In general, an effort has been made to make the app interface simple and user-friendly.

4.8. Evaluation

A usability evaluation test concerning the different functionalities of the Agrendar app took place in July 2021 by citrus growers from Laconia. The growers downloaded the app on an Android mobile device, and they engaged with it (e.g., screen navigation, entering and viewing data). Then, they reported their experience through a structured questionnaire, based on QUIS [28], including 12 questions referring to the user's overall reaction to the app, screen design and layout, learnability and application features. A 5-point Likert scale (from strongly disagree to strongly agree) was used. Ten active citrus growers answered the questionnaire online, namely 8 men and 2 women. Demographics are presented in Table 2.

Table 2. Evaluators' demographics.

Measure	Item	Number
Gender	Male	8
	Female	2
Age (years old)	18–25	1
	26–35	3
	36–45	2
	46–55	2
	56–65	1
	>65	1
Education	Primary	1
	Secondary	5
	University	4

According to the usability evaluation results (Table 3), it is evident that the purpose of the app has been achieved very satisfactorily. Citrus growers have a very good overall impression of the app and they consider it very easy to use. More specifically, the average overall reaction to the app was 4.68; for screen design and layout: 4.60; for learnability: 4.68; and for the application features: 4.90.

Table 3. Usability assessment.

Evaluation	Topic	Mean ± Std
Overall reaction to the app	The overall functionality of the application	4.80 ± 0.42
	The ease of use of the application	4.50 ± 0.71
	User feeling about using the application	4.50 ± 0.53
	Overall application design	4.70 ± 0.48
	Continuous usage of the application	4.90 ± 0.32
	Total	*4.68 ± 0.51*
Screen design and layout	Organizing application information	4.80 ± 0.42
	Display page sequence	4.40 ± 0.52
	Total	*4.60 ± 0.50*
Learnability	Ability to perform tasks quickly and easily	4.40 ± 0.52
	Learning the usage of application	4.90 ± 0.32
	Learning names and commands usage	3.80 ± 0.42
	Speed of loading application pages	4.60 ± 0.52
	Total	*4.68 ± 0.47*
Application features	Application validity	4.90 ± 0.32
	Total	*4.90 ± 0.32*

5. Conclusions

As mobile apps are supporting more and more various business activities, it is vital to cover agricultural needs. Farmers have different needs, since different cultivations (e.g., annual crops, trees) vary with regard to farming activities and practices [16]. Moreover, this specialization is evident even among related cultivations, such as in trees (e.g., olive trees, citrus, cherries, nuts), where there are significant differences in practices, machinery, and market needs. Therefore, farmers need to record and monitor their farming activities using mobile apps tailored to fit their needs. Such apps could provide them the immediacy to record the farming activity while at the plot. In this light, it was expected that the app market would provide a variety of apps tailored to fit the needs of each different cultivation. However, the literature and app-market review, conducted for the purposes of this study, showed poor availability of apps that could be used for recording activities for a specific type of cultivation, such as citrus cultivation, which was used as the case study.

In this work an app is proposed for recording farming activities for citrus cultivation, namely Agrendar. It enables real-time recording on site, avoiding traditional forms (e.g., notebooks). Therefore, citrus growers can record and monitor information anywhere at any time. It is based on their requirements and provides monitoring for a spectrum of activities, such as irrigation, fertilizing, revenue, and expenses. According to the citrus growers' evaluation, the app meets their expectations, since they can effectively record farming activities, they consider the app as user-friendly and easy to use, in that its use does not require specialized digital skills. This evidence leads us to believe that the proposed app can be adopted by other citrus growers in Mediterranean countries, such as Italy and Spain.

Considerations for future work include making the app available on other platforms, such as iOS, including governmental and banking transactions (e.g., payments, taxes) and providing other functionalities, such as location-based services, alerts, and cloud data storage. However, the app should be evaluated by a larger sample of citrus growers for further improvement. Therefore, the app will be published on Google Play store with appropriate metadata (e.g., localization), to collect data on ratings and reviews, location, and app activity.

In our view, farmers, and particularly smallholders, can be empowered through apps that are focused on specific cultivations, localized (i.e., corresponding to the needs of specific areas), and available in their language. Therefore, using mobile apps as working tools can be time- and cost effective. This requires the close collaboration of public and private entities and agricultural stakeholders, in order to implement customized mobile apps, with meaningful services and certified content, which can support the digital transformation and sustainable development of agriculture. Moreover, mobile government, as a new and emerging area being adopted by public agencies, can provide a boost for the diffusion of such services to agricultural stakeholders globally.

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