Technical Note

Profitability Assessment of Precision Agriculture Applications—A Step Forward in Farm Management

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Abstract: Profitability is not given the necessary attention in contemporary precision agriculture. In this work, a new tool, namely ProFit, is developed within a pre-existing farm management system, namely ifarma, to assess the profitability of precision agriculture applications in extended crops, as most of the current solutions available on the market respond inadequately to this need. ProFit offers an easy-to-use interface to enter financial records, while it uses the dynamic map view environment of ifarma to display the profitability maps. Worked examples reveal that profitability maps end up being quite different from yield maps in site-specific applications. The module is regulated at a 5 m spatial resolution, thus allowing scaling up of original and processed data on a zone-, field-, cultivar-, and farm-scale. A bottom-up approach, taking advantage of the full functionality of ifarma, together with a flexible architecture allowing future interventions and improvements, renders ProFit an innovative commercial tool.

Keywords: precision agriculture; site-specific fertilization; digital agriculture; ifarma

1. Introduction

1.1. The Problem

The financial success of a business can be evaluated by its profit and profitability. Profit refers to the absolute measure of earnings minus the expenses involved in achieving a particular outcome. In a market-driven economic system, it is imperative for entrepreneurs to prioritize profit realization, as failure to do so compromises the sustainability and longevity of their enterprise [1]. Apart from maximizing profits, though, the goal of any agricultural enterprise is also to minimize costs.

Profitability represents a relative measure of a company's effectiveness, allowing for a comparison between the achieved outcome and the associated costs [2]. To ensure the profitability of an agricultural enterprise, efficient management is essential, typified by tasks such as soil tillage, crop planting, irrigation, weed management, pest and disease control, and harvesting.

Further, effective farm management requires a combination of knowledge, skills, and experience and often involves the use of technology and data-driven decision-making. The key lies in effectively utilizing production resources and adopting advanced techniques to produce crops [3]. It is crucial for businesses to prioritize maximizing their profits within the limitations of available resources, including financial and credit resources, material support for production, and the necessary skills to carry out the tasks of the workforce [4].

Precision Agriculture (PA) is one of several methodologies that can improve farm management by providing timely, thorough, site-specific crop information within a decision-making framework. Data can be retrieved from a variety of sources, such as soil sampling, sensors, weather stations, satellite or drone images, and yield monitors.

As a tool facilitating farmers to more efficient management of their land, precision agriculture significantly and variously impacts farm management. According to global trends, the application of precision agriculture worldwide is estimated to increase in the next four years, with the market value doubling from USD 17.41 billion in 2022 to USD 34.1 billion in 2026 [5].

The main goal of precision agriculture research is to define a decision support system (DSS) for whole farm management with the aim of optimizing returns on inputs while preserving resources [6–8]. However, farming is a complex endeavor involving many factors and inputs, such as land cost, labor, expensive machines and various tools, fertilizers, pesticides, and irrigation. In most cases, farming activities are not properly logged, at least not in a systematic and analytic way, and most data are fragmented, dispersed, and difficult to use [9].

According to a recent review based on a 23-year meta-analysis [10], profitability, consultancy, and computer use had only a moderate effect on the adoption of precision agriculture. However, these findings should be viewed cautiously due to issues of sample size and heterogeneity embedded in some of the reference studies, while at the same time, other factors had a negligible effect on adoption. Precision agriculture must be distinguished from "smart agriculture", regarding the concept of site-specificity. Smart agriculture is associated with various types of sensors used (soil, moisture, climatic, etc.) to derive crop information (and potentially return a decision), regardless of satisfaction with within-field spatial variability, as it happens with precision agriculture practices.

1.2. State of the Art

Lately, several farm management platforms and technologies have become available to support precision and smart agriculture applications; below are some indicative platforms in English available in the market:

- Climate FieldView is an integrated digital platform that collects and analyzes field data, helping farmers make more informed decisions regarding crop management, planting, and harvesting. The available tools allow farmers to manually delineate management zones (https://www.fieldview.com.au/ (accessed on 11 August 2023));
- Granular's Farm Management Software (FMS), credited as the first cloud-based mobile-centric program of its kind, offers an intuitive breakdown of everything a farmer needs to consider, from financial to soil management to operations. The platform is mostly oriented toward sensors and smart agriculture (https://www.corteva.com/resources/media-center/granular-provides-new-digital-nitrogen-management-options-to-farmers.html (accessed on 11 August 2023));
- Farmers Edge, a comprehensive smart agriculture platform that includes field-centric data collection, satellite imagery, variable rate technology, and weather analytics to optimize farm operations (https://farmersedge.ca/ (accessed on 11 August 2023));
- Agworld is a collaborative farm management platform that allows farmers, agronomists, and other stakeholders to work together on planning, budgeting, and reporting farm activities. It incorporates add-in applications for specific works (e.g., Satamap for satellite image display) (https://www.agworld.com/us/ (accessed on 11 August 2023));
- Taranis, a platform using artificial intelligence (AI)-driven image analysis, combines high-resolution aerial imagery and field-level weather data to detect and predict pest and disease issues, thus enabling farmers to make proactive decisions (https://www.taranis.com/ (accessed on 11 August 2023));
- Trimble, a platform offering a range of precision agriculture solutions, mostly oriented to equipment and automation, including guidance and steering systems, flow and application control, yield monitoring, and water management tools

(https://agriculture.trimble.com/en/products/software/trimble-agriculture-software (accessed on 11 August 2023));

- Sentera, a platform that integrates drone and satellite imagery with sensor data, enables farmers to monitor plant health, track growth, and identify potential issues (https://sentera.com/ (accessed on 11 August 2023));
- John Deere Operations Center, a web-based platform that helps farmers track equipment, manage field data, and analyze agronomic information to optimize their operations (https://operationscenter.deere.com/ (accessed on 11 August 2023));
- Topcon Agriculture, a suite of visualization and decision-making tools including auto-steering systems, variable rate control, yield monitoring, and farm management software (https://tap.topconagriculture.com/ (accessed on 11 August 2023));
- Raven Industries provides automations like guidance and steering systems, application controls, and field computers to help farmers optimize their operations (https://ravenind.com/ (accessed on 11 August 2023)).

Most of the above commercial solutions, although quite technologically advanced, respond only partially or even inadequately to the need for integrated site-specific management within the framework of precision agriculture case studies. Moreover, economic records stored in the database (if they even exist) are not always effectively linked to relevant precision farming data, or if they are, the platform leaves the user alone to carry out the analysis or make the decisions. Therefore, in all cases, there is a gap between available data, decision-making on site-specific applications, and their economic evaluation.

To bridge this gap between farm management and precision agriculture applications, two Greek enterprises, Agrostis and Ecodevelopment, cooperated in 2022 to incorporate a site-specific fertilization service (namely PreFer) into a pre-existing Farm Management Information System (FMIS) (namely ifarma) [9].

The ifarma platform was introduced to the Greek market in 2014 by Agrostis, as a cloud-based farm management information system (FMIS). The data model of ifarma integrates all information relevant to a farm, such as fields and land parcels, crops, farming activities on fields, and inputs and resources used to plan and execute these activities. This data model organizes the information in a hierarchical manner, with the farm at the top. Today, ifarma is a well-known trademark recognized as the best farm management software for agricultural holdings in Greece [11].

PreFer, a service developed by Ecodevelopment, produces prescription maps, which, together with a variety of spatial layers (including soil properties, agronomic information, crop indices, statistical and predictive climatic parameters, and yield records), become available to the farmers on a regular basis at 5 m spatial resolution. The prescription maps are created within a GIS, where big data are analyzed using machine learning methodologies [12].

1.3. Objectives

Going a step further, the objective of this research was to offer a complete and easy-to-use commercial solution for the profitability assessment of precision agriculture applications in extended crops on an annual basis.

Accordingly, a new module was developed within the ifarma farm management platform using PreFer functionalities, especially its mapping environment and algorithms, thus facilitating interoperability, swiftness, and ease. In this respect, the next Section will present the materials and methods employed; Section 3 will demonstrate the results along with discussion; and Section 4 will provide the main conclusions of this work.

2. Materials and Methods

2.1. System Architecture

The new profitability module, namely, ProFit, is an independent module of the ifarma FMIS in terms of interface and algorithms, although it cooperates with the PreFer module of ifarma for exchanging map data. More specifically, ProFit takes spatial data from the

PreFer database as input into its algorithms and returns output maps for display in the map viewer of PreFer. In this way, the original PreFer (say, v.1) is upgraded into a new version (say, v.2) after integrating with ProFit (Figure 1).
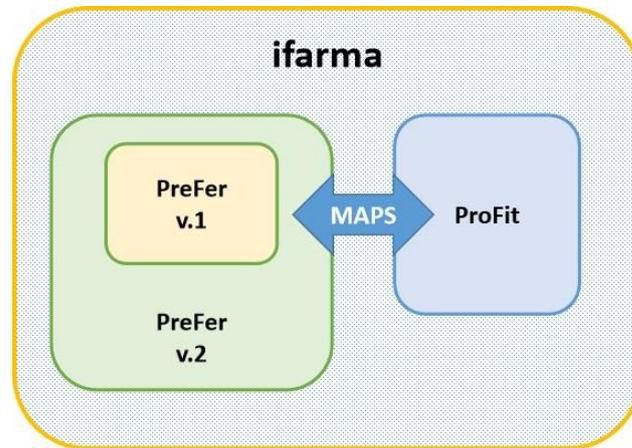
Figure 1. The architecture of ProFit, based on its conjunction with the PreFer module of ifarma.

ProFit alone comprises two components (Figure 2). A site-specific cost component, which is fed by the database of PreFer, where the precision agriculture applications are stored and displayed. A shared cost component for other (non-precision agriculture) practices, where the required records are manually entered as lump sum amounts. The site-specific cost component takes input from two kinds of spatial data: (a) the fertilizer application maps and (b) the yield maps. The former is used to calculate fertilization cost at every surface unit (of 25 m^2) after the multiplication of the fertilizer's rates with its corresponding unit cost; the latter, meanwhile, is used to calculate earnings at every surface unit after the multiplication of the yield with the price of the corresponding cultivar in the market.
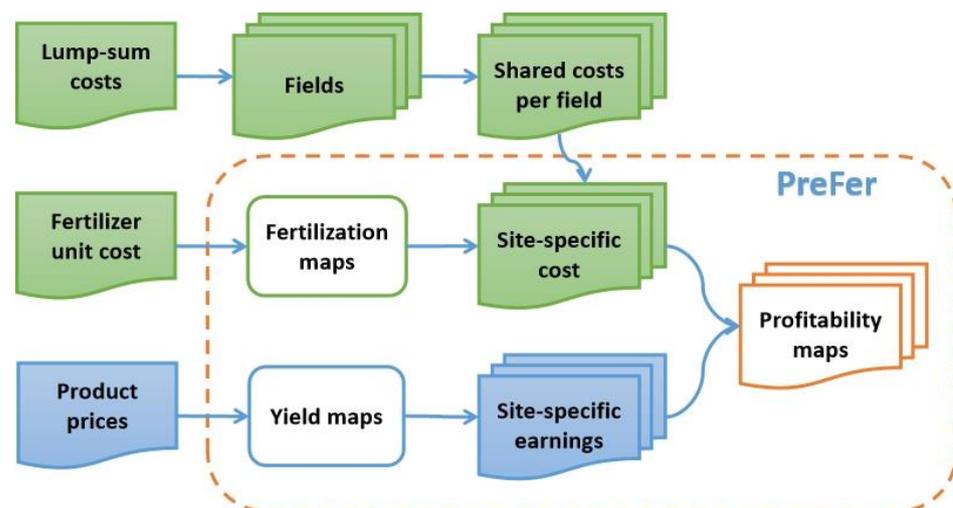
Figure 2. The structure of the profitability module in ifarma (partially functioning within the PreFer module).

The shared cost component holds the lump sum amounts per expenditure category. The distribution of these lump sum costs is then based on an empirical classification of the fields of the farm according to a degree of difficulty (or weighting factor) on a categorical scale of 1–5, with "1" corresponding to the easiest field and "5" to the most

difficult for each of the agriculture practices applied (e.g., soil tillage, irrigation, weed management, etc.).

The output data will be in two forms: (a) descriptive statistics of cost, earnings, and profit per field; and (b) profitability maps (cost, earnings, and profit maps) at a 25 m^2 surface unit. The calculations will be done automatically according to embedded formulas.

2.2. Data Requirements

The data entry of the shared cost records in ProFit is carried out manually through a new form that is divided into two sections, each corresponding to a number of agricultural practices. The site-specific data will be read from the maps stored in the PreFer database.

The shared cost data are related to total annual amounts for the entire cultivation and can be divided into the following categories (using a common ordering regardless of change of category):

Section A (related to categorized total annual costs):

1. Land rent
2. Seeds
3. Irrigation
4. Fertilizers
5. Weed killers
6. Pesticides/Insecticides
7. Harvest
8. Machinery

   (a) Depreciation
   (b) Maintenance
   (c) Spare parts

Section B (related to total annual costs per field):

9. Land rent (absolute amounts)
10. Degree of difficulty per field for shared cost (weighting factor: 1–5)

    (a) Seeds
    (b) Irrigation
    (c) Fertilizers
    (d) Weed killers
    (e) Pesticides/Insecticides
    (f) Harvest
    (g) Machinery

2.3. Algorithms Developed

A set of interrelated functions have been setup for ProFit, which carry out arithmetic, categorical, and logical operations and transfers of tabular data. The overall arrangement is integrated and executed in a prototype Excel spreadsheet, where all internal functions and options and the external data feed are arranged. The monetary rate unit is set to euros per hectare (€/ha), the fertilizer amounts in kilograms per hectare (kg/ha), and the yield in tons per hectare (t/ha) (Figure 3).

SHARED COST

CATEGORIES	SEEDS [2]	IRRIGATION [3]	FERTILIZERS [4]	WEED KILLERS [5]	PESTICIDES & INSECTICIDES [6]	HARVEST [7]	EQUIPEMENT DEPRECIATION [8]	EQUIPEMENT MAINTENANCE [9]	FUELS [10]	LABOUR [11]	TOTAL COST (€)
ANNUAL TOTALS (€)	460	3,392	9,162	2,925	542	10,033	2,950	740	3,312	1,670	51,013

FIELDS	CULTIVARS	SURFACE (ha)	[1] LAND RENT (€/ha)	RATE OF DIFFICULTY										
006	CL 111	3.79	950	1	1	2	5	3	1	2	1	1	1	
007	CL 111	3.75	1,010	1	1	2	1	2	1	2	1	2	1	
008	RONALDO	4.37	1,100	2	1	1	3	1	1	1	1	2	2	
009	RONALDO	5.05	1,050	2	1	1	2	1	1	1	1	4	1	
TOTAL SURFACE		16.96	AVERAGE UNIT COST (€)	27	200	540	172	32	592	174	44	195	98	9,162
NUMBER OF FIELDS		4		TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE	

BALANCE SHEET PER FIELD

FIELDS	CULTIVARS	SURFACE (ha)	[1] RENT COST (€)	AMOUNTS (€) [2]	[3]	[4]	[5]	[6]	[7]	[8]	[9]	[10]	[11]	TOTAL COST (€)	UNIT COST (€/ha)	EARNINGS (€)	PROFIT (€)
006	CL 111	3.79	3,601	66	758	2,835	1,207	218	2,242	913	165	312	297	12,613	3,328	20,193	7,580
007	CL 111	3.75	3,788	65	750	2,805	239	144	2,218	903	164	617	294	11,986	3,196	19,800	7,814
008	RONALDO	4.37	4,807	152	874	1,634	835	84	2,585	526	191	720	684	13,092	2,996	27,610	14,517
009	RONALDO	5.05	5,303	176	1,010	1,888	643	97	2,987	608	220	1,663	395	14,991	2,969	32,724	17,733
TOTALS		16.96	17,498	460	3,392	9,162	2,925	542	10,033	2,950	740	3,312	1,670	52,683		100,327	47,644
AVERAGE		4.24	1,032	27.1	200.0	540.2	172.5	32.0	591.5	173.9	43.6	195.3	0.1	FALSE	3,106	TRUE	47.5%
																	PROFIT RATIO

BALANCE SHEET PER CULTIVAR

FIELDS	CULTIVARS	SURFACE (ha)	PRICE (€/kg)	MEAN YIELD PER CULTIVAR (t/ha)	INCOME (€)	COST (€)	PROFIT (€)	UNIT PROFIT (€/ha)
006 & 007	CL 111	7.54	0.48	11.1	39,993	24,599	15,394	2,042
008 & 009	RONALDO	9.42	0.54	11.9	60,334	28,084	32,250	3,424
TOTALS					100,327	52,683	47,644	2,809

SITE-SPECIFIC COST

FERTILIZERS	UNIT COST (€/kg)	COST (€)
ALZON	1.00	6,610
TSP	0.73	855
K2SHO4	0.85	1,697
N40	0.78	3,043
TOTAL		9,162
TRUE	AVERAGE	540

	TOTAL	53,749
	€/ha	3,169
	INPUT	
	OUTPUT	

SITE-SPECIFIC DATA INPUT (MAPS)

FERTILIZATION MAPS

FIELD	FERTILIZERS	MEAN APPLIED UNIT (kg/ha)	TOTAL APPLIED AMOUNT (kg)
006	ALZON	390	1,478
006	TSP	81	307
006	K2SHO4	150	569
006	N40	230	872
007	ALZON	390	1,463
007	TSP	59	221
007	K2SHO4	127	476
007	N40	230	863
008	ALZON	389	1,700
008	TSP	58	253
008	K2SHO4	100	437
008	N40	230	1,005
009	ALZON	390	1,970
009	TSP	77	389
009	K2SHO4	102	515
009	N40	230	1,162
OVERALL		806	13,678

FERTILIZERS	TOTAL APPLIED AMOUNT (kg)	MEAN APPLIED UNIT (kg/ha)
ALZON	6,610	390
TSP	1,171	69
K2SHO4	1,997	118
N40	3,901	230
TOTAL	13,678	TRUE

YIELD MAPS

FIELD	CULTIVAR	MEAN YIELD (t/ha)	TOTAL YIELD (t)
006	CL 111	11.1	42.1
007	CL 111	11.0	41.3
008	RONALDO	11.7	51.1
009	RONALDO	12.0	60.6
OVERALL		11.5	195.0

SUBSIDIES

	€/ha	€
GREENING	300	5,088
RIGHTS	60	1,018
TOTAL		6,106

Figure 3. The prototype Excel spreadsheet of the ProFit algorithm, filled with true data from the 2022 cultivation year (four indicative fields); orange colour indicates input cells, while green the output ones (not applicable in the contributing databases, on the right side); the other colours are used only to emphasize the structure of the table; numbers [1], [2], etc. refer to the cost categories, as described earlier in the manuscript.

The basic formula for cost, earnings, and profit calculations applied per field is shown simplified below:

Cost (per field) =
Field Rental Cost [9] +
Field Shared Cost for Seeds [10a] +
Field Shared Cost for Irrigation [10b] +
. . .
Field Shared Cost for Machinery [10g] +
Quantity of Fertilizer-1 [Input from the Fertilization Maps of PreFer database] × Price of Fertilizer-1 (manual input in relevant table) +
Quantity of Fertilizer-2 [Input from the Fertilization Maps of PreFer database] × Price of Fertilizer-2 (manual input in relevant table) +
. . .
Quantity of Fertilizer-n [Input from the Fertilization Maps of PreFer database] × Price of Fertilizer-n (manual input in relevant table)
(n: the number of different Fertilizers)

Earnings (per field) =
Earnings from Cultivar-1 = Yield (t/ha) [Input From the Yield Map] × Cultivar-1 Price (monetary unit/kg) [Input from the Crop List] +
Earnings from Cultivar-2 = Yield (t/ha) [Input From the Yield Map] × Cultivar-2 Price (monetary unit/kg) [Input from the Crop List] +
. . .
Earnings from Cultivar-m = Yield (t/ha) [Input From the Yield Map] × Cultivar-m Price (monetary unit/kg) [Input from the Crop List]
(m: the number of different Cultivars)
Profit = Earnings − Cost (per field)

Cost, Earnings, and Profit figures can be calculated per Cultivar if only the fields with a specific Cultivar are selected at a time. Finally, by summing up of all the fields, the entire farm's figures can be found.

For splitting the shared cost lump sums of the different agricultural work categories into cost items per field, a stepwise procedure is followed (Figure 4):

1. First, the rate of difficulty of each field is multiplied by the field's extent and then divided by the number of fields under consideration to give a weighted rate of difficulty;
2. Then, the weighted rate of difficulty of each field is divided by the total weighted rate of difficulty to give the cost share for the field (for each of the shared cost categories);
3. Finally, the cost share of every field is multiplied by the total cost of the category and divided by the number of fields to give the absolute cost per field (for that cost category).

Total cost of work (€)	2,925						
FIELDS	SURFACE (ha)	Rate of difficulty (1-5)	Weighted rate	Cost share	Cost per field (€)	Unit field cost (€)	Relative cost
006	3.79	5	4.7	1.65	1207	318.6	184.7%
007	3.75	1	0.9	0.33	239	63.7	36.9%
008	4.37	3	3.3	1.14	835	191.1	110.8%
009	5.05	2	2.5	0.88	643		
Totals	16.96		2.9	1.00	2,925		
Number of fields	4			Control	TRUE		
Average unit cost (€)	172.5						

Figure 4. The prototype of the cost lump sum splitting-per-field algorithm, here applied for work category [5] Weed killers as an example (use of the same dataset as in Figure 3); orange colour indicates input cells, while green the output ones; the other colours are used only to emphasize the structure of the table.

Therefore, for every category, the algorithm retrieves the lump sum amount for the entire cultivation from a manually filled table and the field extents from the farm's geo-database (i.e., from PreFer). Thus, the only inputs required by the algorithm are the rates of difficulty per field and for each work category. An internal control function will check if the earlier entered lump sum for the working cost category is equal to the one calculated by the algorithm.

3. Results and Discussion

3.1. System Functionality

The new module ProFit comprises a spatial component and a non-spatial component. The spatial component is developed in the pre-existing module PreFer within the ifarma FMIS. As a result, the output maps of ProFit (i.e., Cost maps, Earnings maps, and Profit maps) follow the same standards as those of the PreFer module, i.e., a spatial resolution of 5 m (a surface unit of 25 m^2), thus allowing scaling up of original and processed data on a zone-, field-, cultivar-, and farm-scale and a classification of the original values into 7 categories.

The non-spatial components include output tables, which at the same time contain the entire input information. Thus, the user gets the whole economic picture of cultivation in a single tabular arrangement.

Most of the existing platforms in the market are top-down, providing financial management as a parallel service to another (main) service, e.g., fleet management, crop calendar, etc. In several cases, too, they merely serve an already established market player to promote its products, services, or goods through the concepts of precision agriculture.

Conversely, ProFit on ifarma follows a bottom-up approach, starting from the fertilization applications and taking account of all the farming details to conduct a thorough economic analysis while enabling spatially distributed outputs in terms of maps.

3.2. System Interface

The ProFit module is available as an option in the main menu of the ifarma interface, specifically in the "Management of works, inputs, and yields" group. By clicking the ProFit button (which is set below the "PreFer" option), the input form for entering values for the required economic items is launched in a single web page (Figure 5). For convenience, the output fields are displayed in a different form after the execution of the calculations and can be exported to spreadsheets.

Apart from the tabular output data (e.g., statistics per field and the entire cultivation), which are displayed on a different web page of the ifarma environment, the output maps are displayed within the PreFer map viewer. The options for displaying the cost, earnings, and profit maps for every cultivation are available inside the "Performance" group of options in the PreFer map viewer menu (which also includes the yield maps).

3.3. Experiences

The development team was significantly assisted by several farmers who implemented precision agriculture over the course of years, through their ideas and experience and by using and testing the module with authentic farming data from the 2022 cultivation year in Greece.

Using real data combined with some notional options, for example, in the selection of the difficulty factors per field, to test the module under extreme data ranges, it was noticed that yield maps might be quite different from profitability maps (especially between fields) (Figure 6).

Figure 5. The input data form for profitability assessment by ProFit (on ifarma).
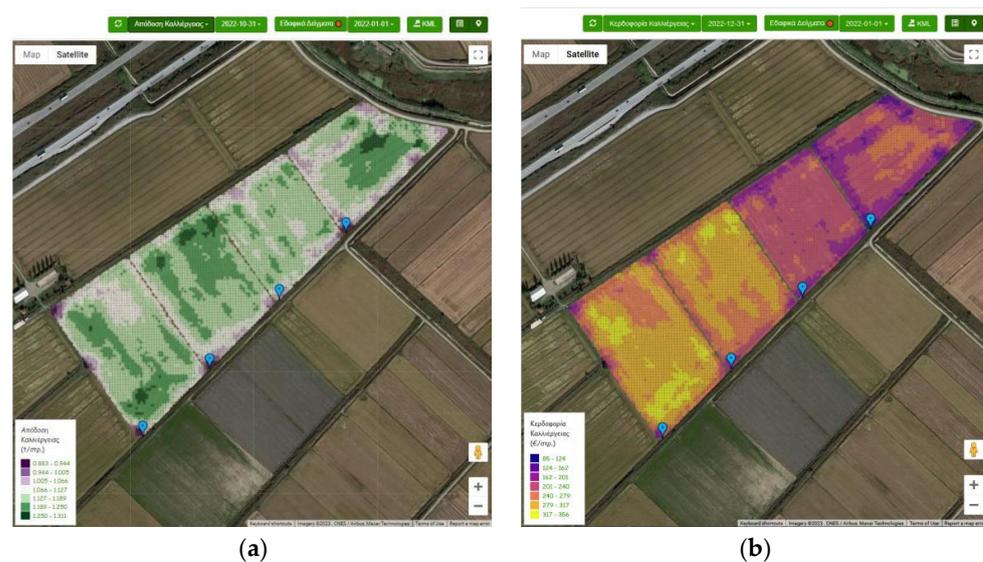
Figure 6. An example of a yield (**a**) vs. profit (**b**) map of the same fields and year displayed in the ifarma/ProFit environment; different spatial patterns in some of the fields are apparent.

In a working example, 10% differences in rice yield between rice farms in the 2022 cultivation season may translate into 35% differences in profit and different spatial patterns within every field. These numerical differences can be explained by the fact that an amount of 6 t/ha yield in rice is considered a baseline in the cost/earnings balance of the annual rice cultivation budget in Greece.

By exploring the profitability maps, the farmers can allocate zones that are more profitable than others—and not only more productive; parameters affecting profitability include specific fertilizer types, fertilization rates, soil types (e.g., heavy or light), cultivars, etc.

4. Conclusions

In this research, an innovative module for assessing the profitability of precision agriculture applications was developed, namely ProFit. In terms of architecture, ProFit is embedded within a cloud-based farm management information system, namely ifarma, while taking advantage of pre-existing functionalities, such as a precision agriculture database provided by other ifarma modules, like PreFer.

ProFit offers an easy-to-use interface, which encourages farmers to enter economic records quickly and reliably while using an empirical method to share apportionable expenditures between fields (when and where site-specific maps are not available). At the same time, it uses the map view environment of PreFer to display the profitability maps.

ProFit moves farm management one step forward by operationally bridging the gap between precision agriculture applications and profitability assessment. Future work will focus on widening the range of precision agriculture practices (i.e., beyond fertilization) within ProFit, such as soil tillage, seeding, irrigation, weed management, and crop protection.

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