Chapter 15
Smart Farming for Sustainable Agricultural Production

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Abstract The chapter describes DataBio's pilot applications, led by NEUROPUBLIC S.A., for sustainable agricultural production in Greece. Initially, it introduces the main aspects that drive and motivate the execution of the pilot. The pilot set-up consisted of four (4) different locations, four (4) different crop types and three (3) different types of offered services. The technology pipeline was based on the exploitation of heterogeneous data and their transformation into facts and actionable advice fostering sustainable agricultural growth. The results of the pilot activities effectively showcased how smart farming methodologies can lead to a positive impact from an economical, environmental and societal perspective and achieve the ambitious goal to "produce more with less". The chapter concludes with "how-to" guidelines and the pilot's key findings.

15.1 Introduction, Motivation and Goals

The global population is expected to reach 9 billion by 2050 and feeding that population will require a 70% increase in food production (FAO 2009[1]). At the same time, farmers are facing a series of challenges in their businesses that affect their farm production, such as crop pests and diseases, with increased resistance along with drastic changes due to the effects of climate change. These factors lead to rising food prices that have pushed over 40 million people into poverty since 2010, a fact that highlights the need for more effective interventions in agriculture (World Bank 2011[2]). In this context, agri-food researchers are working on approaches that aim to maximize agricultural production and reduce yield risk. The benefits of the

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[1] https://www.fao.org/fileadmin/user_upload/lon/HLEF2050_Global_Agriculture.pdf.

[2] https://www.worldbank.org/en/topic/agriculture/overview.

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ICT-based revolution have already significantly improved agricultural productivity; however, there is a demonstrable need for a new revolution that will contribute to "smart" farming and help to address all the aforementioned problems (World Bank 2011). There is a need for services that are powered by scientific knowledge, driven by facts and offer inexpensive yet valuable advice to farmers. In this context, smart farming is expected to reduce production costs, increase production (quantitatively) and improve its quality, protect the environment and minimize farmers' risks.

The main focus of the pilot activities is to offer smart farming advisory services referring to the cultivation of olives, peaches, grapes (pilot application scenario (1) and cotton (pilot application scenario (2) based on a unique combination of technologies such as earth observation (EO), big data analytics and Internet of Things (IoT).

The pilot activities exploit heterogeneous data, facts and scientific knowledge to facilitate decisions and field applications. They promote the adoption of big data-enabled technologies and the collaboration with certified professionals helps to manage the natural resources better, optimize the use of agricultural inputs (i.e. agrochemicals such as fertilisers) and lead to increased product quality and farm productivity.

Smart farming services provide advices for fertilization, irrigation and crop protection, adapted to the specific needs of each pilot parcel and offered through flexible mechanisms to the farmers or the agricultural advisors.

The main aspects that motivate and drive this pilot are:

- to raise the awareness of the farmers, agronomists, agricultural advisors, farmer cooperatives and organizations (e.g. group of producers) on how new technological tools could optimize farm profitability and offer a significant advantage on a highly competitive sector,
- to promote sustainable farming practises over a better control and management of the resources (fresh water, fertilizers, etc.),
- to increase the technological capacity of the involved partners through a set of pilot activities involving big data management data for high-value crops.

15.2 Pilot Set-Up

This section contains pilot set-up descriptions for the two (2) distinct pilot application scenarios that are considered together as they are provided by the same team of partners and are based on the same big data pipeline that has been adjusted to address their distinct needs. More specifically, pilot application scenario 1 worked with three (3) different crop types in three (3) different pilot areas offering a set of advisory services for irrigation, fertilization and crop protection:

- Chalkidiki (Northern Greece), where the pilot worked with olive groves of 600 ha for the production of table olives,

- Stimagka (Southern Greece), where the pilot worked with vineyards of 3.000 ha for the production of table grapes,
- Veria (Northern Greece), where the pilot worked with peach orchards covering an area of 10.000 ha.

At the same time, pilot application scenario 2 worked with one (1) crop type in one (1) site offering irrigation advisory services in the context of arable farming:

- Kileler (Thessaly), where the pilot worked with cotton of 5000 ha (Fig. 15.1).

The underlying reason for selecting these particular crop types is the great economic impact they share in the Greek farming landscape. As an example, olive tree cultivation accounts for nearly 2 billion euros in annual net income, while peach and grape cultivations reach close to 460 million and 390 million annual net income, respectively (Table 15.1).

In the pilot sites, NP was leading the activities, supported by GAIA EPICHEIREIN as the primary business partner and liaison with the farming communities, IBM (only contributing in application scenario 1) and FRAUNHOFER joined the pilot activities as technology providers. By the end of the project, a set of validated fully operational smart farming services were developed, adapted at each crop type and the microclimatic conditions of each pilot area.

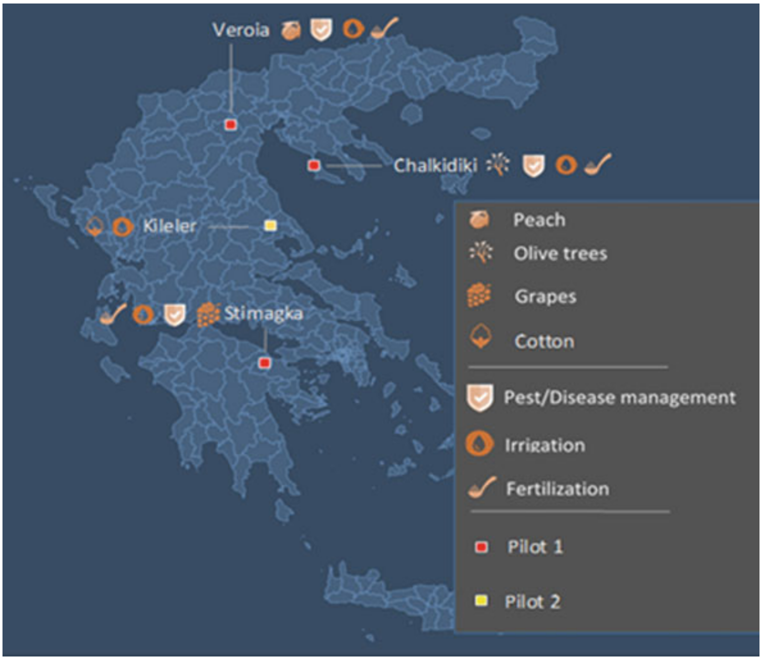


Fig. 15.1 Pilot application scenario 1 (marked as Pilot 1) and pilot application scenario 2 (marked as Pilot 2) joint high-level overview indicating pilot sites, targeted crop types and offered advisory services

Table. 15.1 Overview of the big data-driven smart services deployed at the four pilot sites

Service	Pilot application scenario 1 locations			Pilot application scenario 2 Location
	Chalkidiki (Olives)	Veria (Peaches)	Stimagka (Grapes)	Kileler (Cotton)
Irrigation	+	+	+	+
Fertilization	+	+	–	–
Crop protection	+ Exploitation of scientific models for 1 pest and 1 disease)	+ Exploitation of scientific models for 3 pests and 4 diseases)	+ Exploitation of scientific models for 2 pests and 3 diseases)	–

Goal achievement was measured by defining specific key performance indicators (KPIs). For each goal, baseline KPIs were measured and compared to achievements after the pilot activities finished (after two consecutive trial seasons).

15.3 Technology Used

15.3.1 Technology Pipeline

The technology pipeline of the solutions applied in these pilot activities (both application scenarios) consists on a high level of abstraction of data collection, data processing and data visualisation components (Fig. 15.2).

Data collection: To provide advice related to irrigation, fertilization and crop protection, a set of heterogeneous data is required, capturing critical parameters for crop status monitoring in different spatial and temporal resolutions. Weather, soil and plant-related data, crowdsourced samples, observations and information for the applied farming practices, intra-field—inter-field EO-based vegetation indices consist of different data flows that find their way into the technology pipeline.

Moreover, historical data from at least one cultivating period prior to pilot activities is required for calibrating/fine-tuning the scientific models that constitute the backbone of the advisory services.

For addressing the pilot needs in terms of data collection, the following technological modules are being exploited:

- In situ telemetric stations provided by NP, called gaiatrons, that collect field-level data related to weather, soil and plant (Fig. 15.3),
- Modules for the collection, pre-preprocessing of earth observation products, the extraction of higher level products and the assignment of EO-based vegetation indices at parcel level,

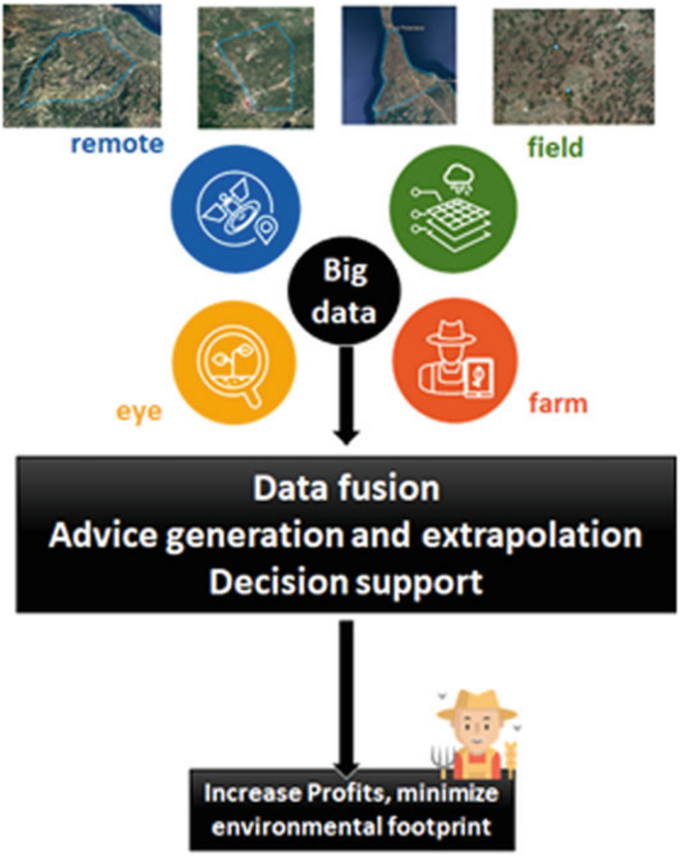


Fig. 15.2 Concept underpinning the pilot activities

- Android apps for crowdsourcing data from farmers (farm logs), agricultural advisors and agronomists about field status and the applied farming practices,
- Web-based user interfaces for collecting and updating the available farm data.

Data processing: The collected datasets are processed by several complementary data processing components provided by the pilot partners. Big data components that should be mentioned in this context are:

- GAIABus DataSmart Real-time streaming Subcomponent (offered by NP): This component allows for: the real-time data stream monitoring resulting from NP's telemetric stations installed in all pilot sites; the real-time validation of data and the real-time parsing and cross-checking.
- PROTON (offered by IBM): PROTON is an early warning system for managing pests and diseases using sophisticated temporal reasoning for olives, grapes and

Fig. 15.3 NP's IoT agro-climatic station used in the pilot activities

peaches (it is used only in pilot application scenario 1). It exploits the numerical output (risk indicator) of NP's crop and area-tailored scientific models for pest/disease breakouts. In total, NP sends one (1) pest and one (1) disease risk indicator from each pilot site (6 scientific crop protection models are sent in total), namely:

- spilocaea oleaginea and bactocera olea (for olives cultivation)
- downy mildew and lobesia botrana (for grapes cultivation)
- grapholita_molesta and curl leaf (for peaches cultivation).

PROTON conducts sophisticated complex event processing on top of the risk indicators offering even earlier alerting/warning before conditions reach critical states. The results are being sent back to NP at specified intervals (e.g. once a week) for integration.

- Georocket, Geotoolbox, SmartVis3D (offered by FRAUNHOFER): The integration of these components has a dual role: It offers a back-end system for big data preparation, handling fast querying and spatial aggregations of data, as well as a front-end application for interactive data visualization and analytics.

Data visualisation and presentation: After all data is processed, it needs to be provided in an understandable and decision-relevant way suitable for the pilot end-users (farmers, agronomists). The primary data visualization component used in the pilot is NeuroCode (offered by NP). Neurocode allows the creation of the main pilot UIs that support the provision of smart farming advisory services for optimal decision making. An additional DataBio component explored for its information visualization functionalities was Georocket (offered by FRAUNHOFER) (Fig. 15.4).

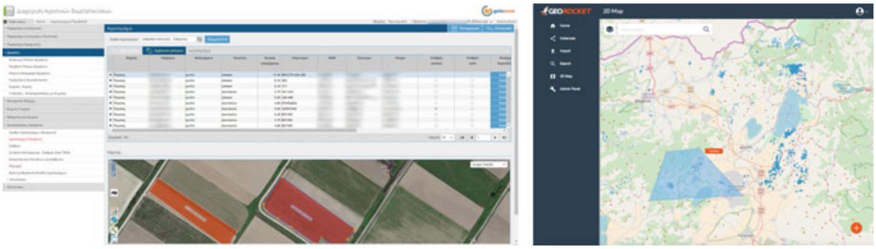


Fig. 15.4 Data visualization tools that were used in the pilot activities (Left: Neurocode, Right: Georocket)

15.3.2 Data Used in the Pilot

The specific pilot uses four (4) different data types as graphically depicted in Fig. 15.2. More specifically, the pilot exploits the following data assets:

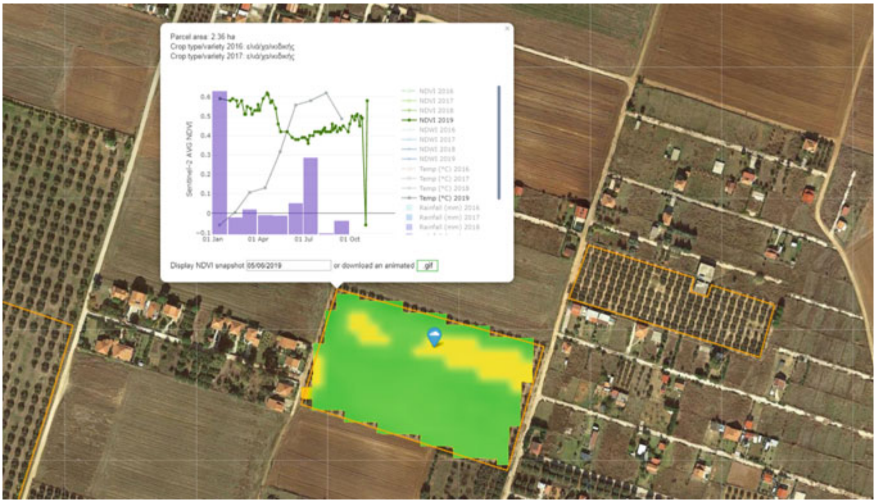
- agro-climatic data recorded by in-situ IoT sensing units (field dimension),
- remote sensing data from satellite missions (remote dimension),
- farmer calendars and logs that capture farm profile and the applied field applications (farm dimension),
- samples, observation and field measurements offered by certified professionals (eye dimension).

However, the datasets that can be acknowledged for their big data aspects (in terms of volume, velocity, etc.) are the following:

- **Sensor measurements (numerical data) and metadata (timestamps, sensor id, etc.)**: This dataset is composed of measurements from NP's telemetric IoT agro-meteorological stations (gaiatrons) for the pilot sites. More than 20 gaiatrons are fully operational at all pilot sites, collecting >30MBs of data per year each with current configuration (offering measurements every 10 min).
- **EO products in raster format and metadata:** This dataset is comprised of ESA's remote sensing data from the Sentinel-2 optical products (6 tiles). High volumes of satellite data are continually being processed in order to extract the necessary information about each crop type and parcel participating in the pilot.

15.3.3 Reflection on Technology Use

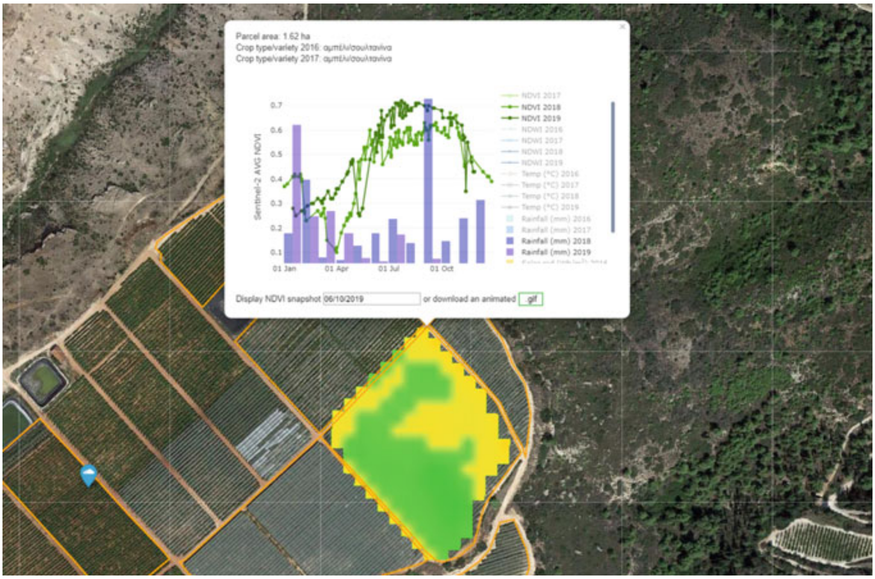
The pilot has completed two rounds of trials. It conclusively demonstrated how big data-enabled technologies and smart farming advisory services can offer the means for better handling the natural resources and optimizing the use of agricultural inputs. The following figures indicate how technology can provide added value to farmers and lead to improved farm management (Figs. 15.5, 15.6 and 15.7).



Parcel area: 2.36 ha
Crop type/variety 2016: ελιά/χαλκιδικής
Crop type/variety 2017: ελιά/χαλκιδικής

Display NDVI snapshot 05/06/2019 or download an animated .gif

Fig. 15.5 Parcel monitoring at Chalkidiki pilot site indicating intra-field variations in terms of vegetation index (NDVI) and cross-correlations among the latter with: **a** ambient temperature (°C) and **b** rainfall (mm)



Parcel area: 1.62 ha
Crop type/variety 2016: αμπέλι/σουλτανίνα
Crop type/variety 2017: αμπέλι/σουλτανίνα

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Fig. 15.6 Parcel monitoring at Stimagka pilot site indicating intra-field variations in terms of vegetation index (NDVI) and cross-correlations among the latter with **a** NDVI from 2018 cultivating period and **b** rainfall (mm) from 2018 and 2019 cultivating periods

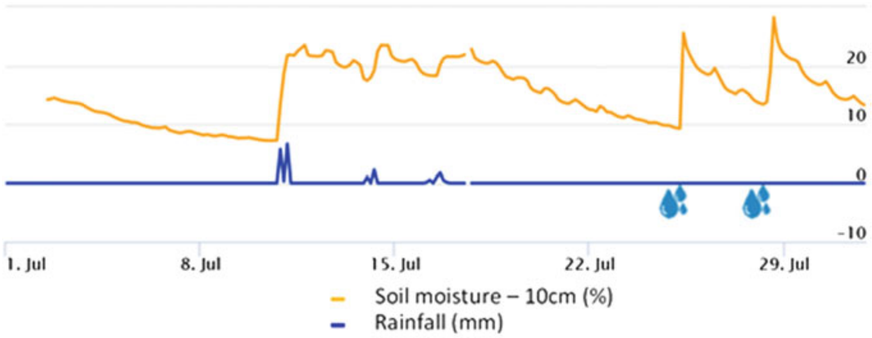


Fig. 15.7 Irrigation monitoring at a Veria pilot parcel showing two (2) correct irrigations (water drop icons) after following the advisory services during 2019 cultivating period. The impact of rainfalls in the soil water content is obvious (~10/6) and if translated correctly can prevent unnecessary irrigations

Getting more in-depth regarding irrigation advice generation, a critical factor that influences its provisioning is daily evapotranspiration. It essentially reflects the water content being lost each day from both the plant and the soil. By calculating this parameter using EO or model-based approaches, the requirement for installing a tense network of irrigation sensors for monitoring soil moisture ceases to exist. This significantly reduces infrastructure costs and leads to economy of scale, as irrigation advices can be extrapolated for a large number of parcels that share similar agro-climatic characteristics (soft facts) (Figs. 15.8, 15.9 and 15.10).

The technology pipeline can be easily used at other crop types and locations. This will require, however, an initial period of data collection (one cultivating period) to be used for the precise and complete documentation of the soil and microclimate

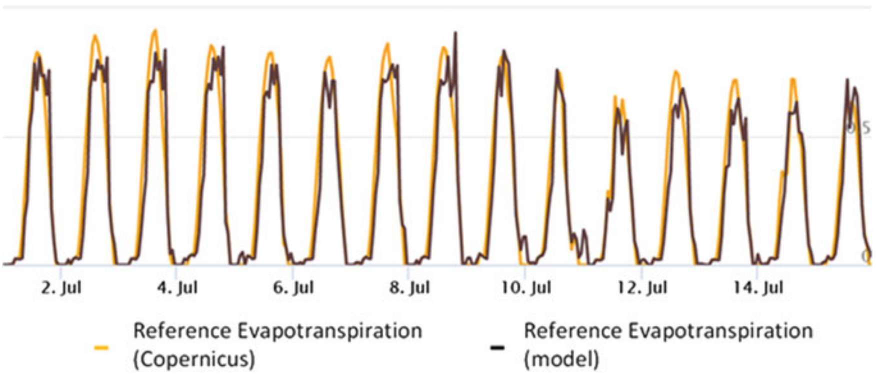


Fig. 15.8 Reference evapotranspiration monitoring at Kileler (both modelled using ML methods developed by NP and based on Copernicus EO data) for July 2019

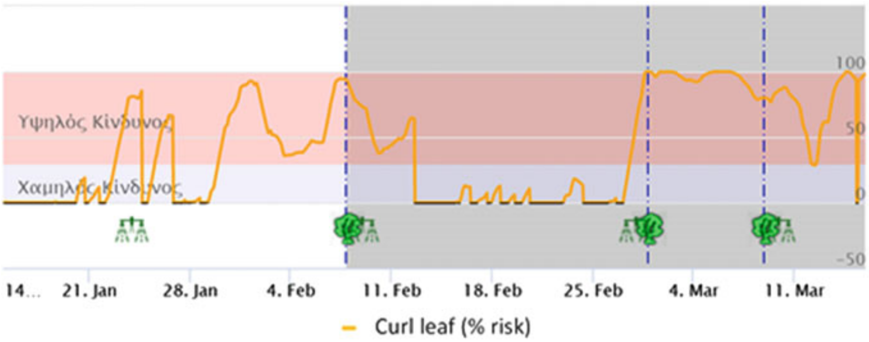
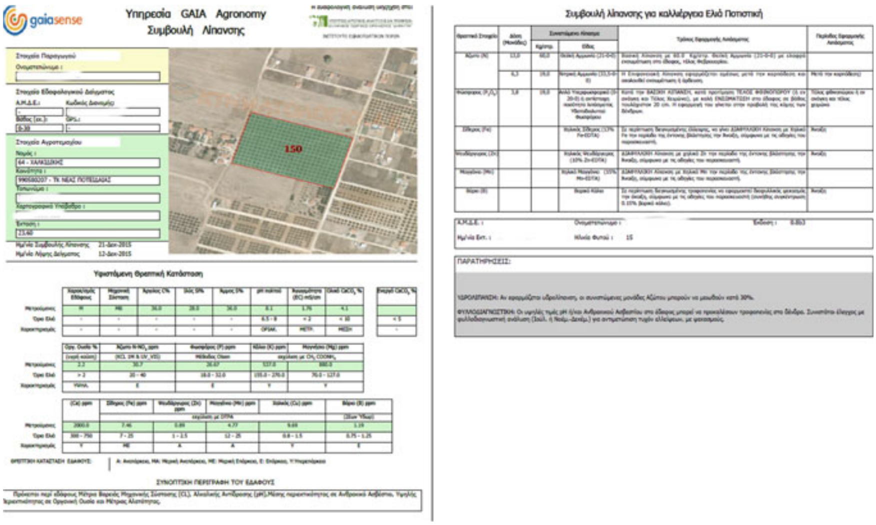


Fig. 15.9 Crop protection monitoring at a Veria pilot parcel showing four (4) correct sprays (spraying icons) after following the advisory services and the indications for high curl leaf risk during 2019 cultivating period (high risk is when the indicator passes to the pink zone). The dashed vertical lines indicate critical crop phenological stages


gaiasense

Υπηρεσία GAIA Agronomy
Συμβουλή Λίπανσης

150

Υφιστάμενη Θρεπτική Κατάσταση

ΣΥΝΟΠΤΙΚΗ ΠΕΡΙΓΡΑΦΗ ΤΟΥ ΕΔΑΦΟΥΣ

Συμβουλή λίπανσης για καλλιέργεια Ελιά Ποτιστική

ΠΑΡΑΤΗΡΗΣΕΙΣ:

Fig. 15.10 Fertilization advice for a Chalkidiki pilot parcel

conditions that apply in the specific area, the cultivation activities undertaken by the producer, the measurement of the characteristics of the specific crop type, etc.

15.4 Business Value and Impact

15.4.1 Business Impact of the Pilot

Both pilots managed to achieve the expected results for input cost reduction, which was validated by the quantification of the results after trial stages 1 and 2. This was achieved as farmers and agricultural advisors showed a collaborative spirit and followed the advice generated by DataBio's solutions. Aggregated findings can be found at the following figures (Figs. 15.11 and 15.12).

For pilot application scenario 1, it is clear that in certain cases (irrigation), the results exceeded the initial set targets for input cost reduction. This is due to the

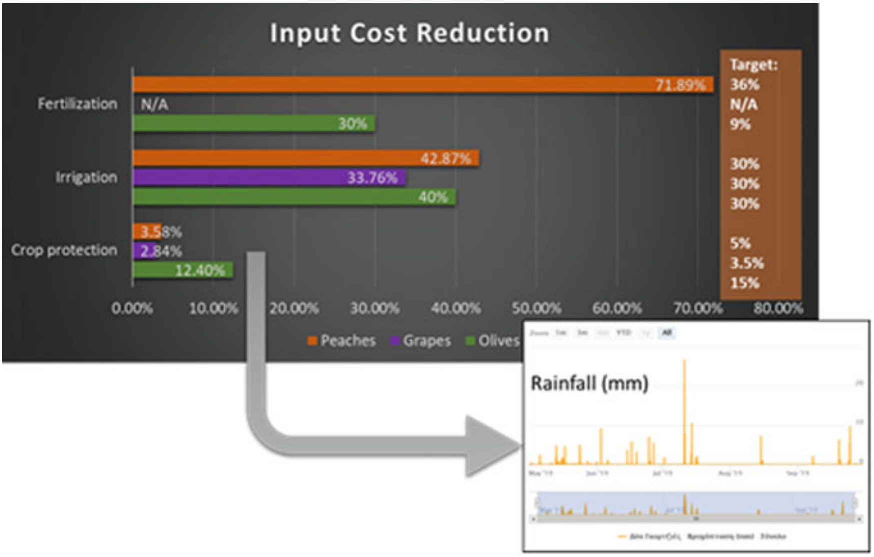


Fig. 15.11 Pilot application scenario 1 aggregated findings

Fig. 15.12 Aggregated results of pilot application scenario 2 in comparison with the target values

fact that the farmers both: (a) showed collaborative spirit and adapted their farming practices using all advice offered and (b) were benefiting from the weather conditions (rainfalls during June, July 2019) and this reduced the freshwater requirements during critical phenological stages. The aforementioned phenomenon was the underlying reason for slightly not reaching the targeted crop protection goals. The farmers chose to conduct additional proactive sprays for securing their production against threatening situations (e.g. fruit mucilage presence at the stage of swelling in Veria pilot site). In terms of fertilization, the exhibited deviation (under-fertilization) is part of the farmers' overall strategy that derives from the fact that fertilization advice is offered with a two-to-three-year application window. This allows them a window for taking fertilization measures and is expected that this deviation will be acknowledged and significantly shape the fertilization strategy over the next cultivating periods.

The KPIs used in the pilots are listed in the following table, along with the final DataBio results (measured values) that support the exploitation potential of the pilot. The following table sums the measured savings of the pilots per hectare (Table 15.2).

It is evident that the pilot's business impact would be further validated and reach more conclusive insights as KPI measurements from more (and different) cultivating periods get aggregated over the years. More trials would allow to get more business-related KPI measurements maximizing the pilot's impact.

The achieved results allow for the following conclusions regarding the business impact:

- The findings show that technology use results in real financial savings per hectare for all considered crop types and regions. As different crop types have various input necessities from an agronomical point of view, the technology used results in different savings. Scalability and transferability of the technology in different crop types/regions is apparent, as a new set-up would require gathering data for calibration/fine-tuning of the scientific models for irrigation, fertilization and crop protection of an acceptable amount of time (one cultivating period) prior to producing initial advice to the farmers.
- The findings also show that it was possible to achieve the results because the farmers were cooperative and acted according to the advice proposed by the technology.

Besides these gains, other factors can be quantified and add value to the solution:

- By reducing the number of sprays, the farmer increases the productivity of spraying and saves time that he or she can invest in other value-creating activities. This also means that the cost for labour decreases as well.
- Further gains can be achieved also by increasing the harvest from the field supported by the technology. Even though this might be difficult to measure because at the end the quality and quantity of the harvest might depend on many factors than the ones controlled by the technology. However, the more factors influencing the growth and quality of the plants can be controlled by technology, the higher the output in terms of quantity and quality should be.

Table 15.2 Quantification of business gains (baseline–achieved measured value) in both pilot application scenarios

	Pilot application scenario 1			Pilot application scenario 2
Saving	Chalkidiki (olive trees)	Stimagka (Grapes)	Veria (Peaches)	Kileler (Cotton)
Reduction of the average cost of spraying per hectare	250 − 219 = 31 Euro/Hectare	990 − 963 = 27 Euro/Hectare	810 − 781 = 29 Euro/Hectare	
Reduction of the average number of unnecessary sprays per farm	5 − 1.4 = 3.6 Number of sprays	4 − 1.8 = 2.2 Number of sprays	4 − 1.6 = 2.4 Numbers of sprays	
Reduction of the average cost of irrigation per hectare	330 − 198 = 132 Euro/Hectare	3030 − 2007 = 1023 Euro/Hectare	870 − 497 = 373 Euro/Hectare	2670 − 1881 = 789 Euro/Hectare
Reduction of the amount of fresh water used per hectare	817 − 492.4 = 324.6 m^3/Hectare	1868 − 1232 = 636 m^3/Hectare	1703 − 971.18 = 731.82 m^3/Hectare	
Reduction of the nitrogen use per hectare	230 − 161 = 69 Kg/Hectare		220 − 161 = 59 Kg/Hectare	
Quantify % divergence in the cost of the applied fertilization	−40 + (−11.27) = 51.27 %/Hectare		20 − 44 = −24 %/Hectare	
Increase in production	10,375 − 7010 = 3365 Kg/Hectare	17,117 − 18,011 = − 894 Kg/Hectare	49,825 − 52,044 = −2219 Kg/Hectare	
Decrease in inputs focused on irrigation				2670 − 1881 = 789 m^3/Hectare

As multiple parameters (climate and crop type related) affect agricultural production, it became clear that a “one-fits-all” solution is not applicable. Several factors need to be taken into consideration in translating the trial results (e.g. biennial bearing phenomenon in olive trees, heavy seasonal/regional rains, multi-year fertilization strategies, etc.).

15.4.2 Business Impact of the Technology on General Level

The pilot activities have highlighted another exploitation potential that arises from the plethora of stored heterogeneous data. The various data streams collected and stored in this pilot's context can be valuable for data scientists/researchers that could evolve their research activities and take full advantage through them.

15.5 How to Guideline for Practice When and How to Use the Technology

Farmers are constantly struggling to produce more food, to meet the increased global demand. At the same time, there is a push towards more sustainable farming practices in order to minimize the environmental impact of agriculture. In this context, the future Common Agricultural Policy (which is currently under development) focuses on digitization, inviting farmers to produce "more with less".

In order to improve farm productivity and increase their profits, farmers were traditionally asked to invest in expensive technological tools and learn how to use them—an offer usually combined with the use of specific brands of agrochemicals. This not only incurred high costs for farmers with a slow depreciation curve (in fact a high percentage of farmers—Greek farmers are in their majority smallholders—did not have the capacity to make such investments), but also required farmers to have digital skills that they lacked.

To support the business expansion of the big data-enabled technologies introduced within the present DataBio pilot, NP and GAIA EPICHEIREIN have already established an innovative business model that allows a swift market uptake—the "Smart-Farming-As-A-Service" model. With no upfront infrastructure investment costs and a subscription fee proportionate to a parcel's size and crop type, each smallholder farmer can now easily participate and benefit from the provisioned advisory services. The proposed approach takes all the complexity out of the picture and provides a simple and easy-to-use advice that both agricultural advisors and farmers can exploit.

Moreover, and as more than 70 agricultural cooperatives are shareholders of GAIA EPICHEIREIN, it is evident that there is a clear face to the market and an excellent liaison with end-user communities for introducing the pilot innovations and promoting the commercial adoption of the DataBio's technologies.

Finally, while the proposed data-driven solution of the pilot is appealing to smallholder farmers, it is also applicable to large farms and agricultural cooperatives. Thanks to their increased capacity (e.g. financial and technical), the application of smart farming services can multiply the benefits for these organizations, as they are applied in a larger scale.

15.6 Summary and Conclusions

NP and GAIA EPICHEIREIN have already launched in 2013 their smart farming program, called “gaiasense”,[3] which aims to establish a nationwide network of telemetric stations with agri-sensors and use the data to create a wide range of smart farming services for agricultural professionals.

Within the DataBio, the quality of the provided services greatly benefited from collaborating with leading technological partners like IBM and FRAUNHOFER, which specialize in the analysis of big data. Moreover, feedback from the end-users and lessons learnt from the pilot execution significantly fine tuned and will continue to shape the suite of dedicated tools and services, thus, facilitating the penetration of “gaiasense” in the Greek agri-food sector.

Thee pilot’s success was established by high profile events[4] and online articles[5] that were promoting the pilot’s findings. Consequently, the wider adoption of big data-enabled smart farming advisory services in the next years.

The sustainability of all DataBio-enhanced smart farming services, after the end of the project is achieved through: (a) the commercial launch and market growth of “gaiasense” and (b) the participation to other EU and national R&D initiatives. This will allow continuously evolving/validating the outcomes of the project, by working with both new and existing (to DataBio) user communities and applying its innovative approach to new and existing (again to DataBio) areas/crops.

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[3] https://www.gaiasense.gr/en/gaiasense-smart-farming.

[4] https://www.gaiasense.gr/en/a-greek-innovation-gaiasense-evolves

[5] https://www.ypaithros.gr/en/yannis-olive-grove-reduction-by-30-in-production-costs-and-parallel-increase-of-sales/