



DSS LANDS: A Decision Support System for Agriculture in Sardinia

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Received 9 July 2020; Revised 18 August 2020; Accepted 23 August 2020; Published 01 September 2020

Abstract

Recently, the use of DSSs application has been strongly increasing in the agricultural sector due to continuous climate change and the need to conduct more productive and sustainable agriculture. In this paper, we describe the prototype agricultural DSS LANDS developed for monitoring the main crop production in Sardinia. The DSS collects, organizes, integrates, and analyzes several types of data with different mathematical models. In particular, a case study on forecasting potato late blight is presented. We employed the *Negative Prognosis* model and the *Fry* model to forecast the period in which it is opportune to carry out fungicide treatments useful against the appearance of the pathogen. The experiments allowed us to outline the best criteria for local conditions, and the evaluation showed the effectiveness of the approach in a concrete case study.

Keywords: Decision Support System; Decision-Making; Data Analysis; Precision Farming.

1. Introduction

Decision Support Systems have become notable tools to enhance the agricultural production. Agricultural production is highly dependent on weather, climate and water availability and is adversely affected by the weather and climate-related disasters [1]. Natural disasters can result in complex issues related to crop production. It is not always possible to prevent the occurrence of these natural events, but a proper planning can considerably reduce their effects. So far farmers have made in-season decisions based on their experiences and intuition. Nevertheless, their experiences are insufficient to predict a decision-making process for a long term, which can improve yield productivity and avoid unnecessary cost related to harvesting, use of pesticide and fertilizers. In addition, by 2050, according to the Food and Agriculture Organization (FAO), the climate changes are expected to cause water scarcity and serious declines yield of the most important crops in developing countries. It means that the agriculture process will have to adapt to climate change, but it can also help mitigate the effects of climate change through the recent technologies as Decision Support Systems (DSS).

A DSS can be defined as a computer-based system that supports decision makers in solving a decision problem [2]. These tools can lead users through clear steps and suggest optimal decision paths or may act more as information sources to improve the evidence base for decisions [3]. Recently, they have been introduced in the agriculture as an indispensable tool to face the growing challenge of conducting sustainable agriculture which increase the quantity and quality of agricultural output while using less input (water, energy, fertilizers, pesticides, etc.). This new modern farm approach that bases its applicability on the use of technologies to detect and decide what is “right” is called *Precision*

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<http://dx.doi.org/10.28991/HIJ-2020-01-03-05>

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Farming (PF) [4, 5]. Nowadays, many governments in the world are investing big amount of money to encourage the researchers and companies to develop Decision Support Systems which use agricultural data to help the adoption of Precision Farming.

In this paper, we describe the system and the tests conducted through the DSS LANDS (*LAORE Architecture Network Development for Sardinia*) developed. It supports Sardinian farmers in decision-making and it manages different data in order to forecast and increase yield productivity and decrease the costs of agricultural operations. The DSS, it has been developed in collaboration with the *LAORE Sardinia Agency*. *LAORE Sardinia Agency* deals with providing advisory, education, training and assistance services in the regional agricultural sector.

The paper is structured as follows. Section 2 provides background information and outlines the reasons that drove the adoption and no-adoption of DSSs in Europe, especially in Italy. Section 3 describes the architecture and the forecasting models used in the short case study. We conclude the paper in section 4.

2. Decision Support Systems

DSS have evolved significantly since their early development in the 1970s. Over the past three decades, DSS have taken on both a narrower or broader definition, while other systems have emerged to assist specific types of decision-makers faced with specific kinds of problems [2]. One of the first definitions was given by Keen and Morton [6] that defined decision support systems as computer systems that collect resources and use the ability of computer to increase quality of decisions by focusing on semi structured problems. Recently, a DSS is defined as human-computer systems which collect information, process information and provide information based on computer systems [7]. However, the researchers agree that the main objective of DSSs is to support and improve decision making [8].

DSS can be composed of four main subsystem which are Data Management subsystem, Model Management subsystem, Knowledge-based subsystems and User Interface subsystem [8]. The functionality of Data Management subsystem is to manage the data that will be used as information to make decisions in the Knowledge-based subsystem. The Model component consists of a variety of models that assist decision makers in decision making. The Knowledge-based is the hearth of the system and it manages the problem- solving process to generate the final solution. The User Interface allows the users to encourage the interaction with the system to obtain information.

Generally, DSS has been classified into three categories based on problems for decision making: structured, unstructured and semi-structured.

2.1. Agricultural Decision Support System

DSSs have been introduced in the agriculture as an indispensable tool mainly for two reasons. First, to face the continuous climate changes that cause serious damage to production. Second, to conduct a more sustainable agriculture which increase the quantity and quality of agricultural production while using less water, energy, fertilizers and pesticides, or rather, to support the Precision Farming technologies.

In the last decade, their applications have increased thanks to the advent of new technologies, such as Cloud Computing, Data Mining, Machine Learning, Artificial Intelligent and major investments by numerous research agencies and governments all over the world.

Agricultural DSSs perform the following activities: (i) they collect, organize, and integrate several types of information required for producing a crop; (ii) they analyse and interpret the information; and (iii) they use the analysis to recommend the most appropriate action or action choices. For example, DSSs can provide farmers information on plant growth or plant disease risk useful for scheduling treatments according to the actual need of the plant [9]. However, designing a DSS is quite complex; it requires knowledge from various multidisciplinary areas, such as crop agronomy, computer hardware and software, mathematics and statistics to analyse data. For example, to understand crop growth, it is necessary to know how each variable affects crop growth [10].

In a global level, in the agricultural sector, there is not a single agricultural DSS adopted worldwide, but over the years several DSSs have been developed for a wide range of cultivation practices concerning crop management and crop irrigation. Many of them have been developed and evaluated with different crops and different climatic conditions.

Manos et al. (2004) [11] identified five fields of applications: Diagnostic-Forecasting DSSs, Advisory DSSs, Control DSSs, Educational – Informational DSSs, Operational DSSs. Although the use of DSS simplifies decision-making in agricultural production and it is applied in several application sectors, DSSs have not been adopted with great enthusiasm by managers of farms. Their adoption has been low. Many researches have been conducted for understanding the reason of DSSs non-adoption in agriculture. These researches identified the following factors that influence the adoption of DSSs by farmers: profitability, user-friendly design, time requirement for DSS usage, credibility, and adaptation of the DSS to the farm situation, information update, and level of knowledge of the user

[12]. However, many of these factors, have been reduced by the increased availability of personal computers, increased access to the Internet, and increased development of web-based systems [13]. The adoption and the development of agricultural DSSs in Europe was faster than in Italy. The factors that have limited its diffusion have been identified in Mipaff (2017) [14] that recognize as the main cause the difficulty of using precision technologies in a heterogeneous territory with particular characteristics.

In the Europe context, Holzworth et al. (2015) [15] identifies the most relevant DSSs from two thousand to today: DSSAT, APSIM, CropSyst, EPIC and STICS. The *decision support system for agrotechnology transfer* (DSSAT) is a collection of independent programs that operate together. It incorporates models of 16 different crops with software that facilitates the evaluation and application of the crop models for different purpose [16]. The *Agricultural Production Systems Simulator* (APSIM) contains an array of modules for simulating growth, development and yield of crops, pastures and forests and their interactions with the soil. It has been used in a broad range of applications, including support for on-farm decision making, farming systems design for production or resource management objectives, assessment of the value of seasonal climate forecasting [17]. The *cropping systems simulation model* (CropSyst) CropSyst is a suite of programs designed to work co-operatively, providing users with a set of tools to analyse the productivity and the environmental impact of crop rotations and cropping systems management at various temporal and spatial scales [18]. The *Environment Policy Integrated Climate* (EPIC) is able to manage decisions related to drainage, irrigation, water efficiency, erosion (wind and water), atmospheric conditions, fertilizer, the control of pests, sowing dates, tillage and waste management cultivation [19]. The *Simulateur multiDisciplinaire pour les Cultures Standard* (STICS) simulates crop growth as well as soil water and nitrogen balances driven by daily climatic data. It calculates both agricultural variables (yield, input consumption) and environmental variables (water and nitrogen losses) [20].

In spite of the European context several DSSs have been adopted since their appearance in the agricultural sector, in Italy few DSSs have emerged to provide decision support systems. Recently, their adoption is intensifying thanks to increase in the use of Precision Farming technologies. The diffusion of these technologies has been slow due to the following factors: heterogeneous environments, territorial characteristics, age/level of education and company size [14]. To Incentivise employment and scientific research is the Ministry of Food and Forestry Agricultural Policies, which in Mipaff (2017) [14] emphasizes the importance of developing specific tools for data analysis, with DSS functions to tackle the ongoing climate changes that are compromising the main crops of the territory. Since today, in Italy have emerged DSSs for crop management, mainly for wine and cereal production and irrigation management. Analysing the literature, among the major contributions emerge *Vite.net* for the decision-making support of the vineyard, *Granoduro.net* for decision support durum wheat crop and IRRINET for decision support for irrigation. *Vite.net* is developed for sustainable management of vineyards and is intended for the vineyard manager. The system provides in real-time several information for each vineyard as the defence against fungal disease and insects, the growth of the plant, the thermal and water stresses and many others [9]. *Granoduro.net* provides plot-specific and up-to-date decision supports about weather, fertilisation, crop growth, weed control, and disease and mycotoxin risk [21]. IRRINET system provides to farmers a day-by-day information on how much and when to irrigate crops, implementing a real-time irrigation scheduling [22]. The latter is also used in Sardinia.

The contribution of this paper is the development of an agricultural DSS for monitoring the main crops in Sardinia, where the DSSs adoption have been slow due to the conformation and heterogeneity of the territory that requires the development of specific decision support systems.

3. DSS LANDS Project

DSS LANDS was developed to help LAORE technical and Sardinian farmers in decision- making about agricultural management based on the principles of Precision Farming. It was designed mainly to take data-driven decision and not to replace the decision maker.

The goals of LANDS are to: (i) optimize the resources management through reduction of certain inputs (e.g., chemicals and natural resources, etc.) (ii) predict crop risk situations (e.g., diseases, weather alerts etc.) (iii) increase the quality of decisions for field management (iv) reduce environmental impact and production cost. It integrates different and specific modules for monitoring the main crop productions in Sardinia: citrus, artichoke, wheat, corn, olive, potato, peach, tomato, rice, vine. Currently, the DSS proposed is a prototype being tested for monitoring the potatoes crop.

3.1. Architecture

The agricultural DSS is composed of three components [24]:

- An *integrated system* for semi-real-time monitoring of crop components and storage of their data; These sources include ARPAS (*Regional Agency for the Protection of the Sardinian Environment*) weather stations, field sensors and external providers;
- A *models system* which performs through several mathematical and forecasting models a cross and dynamic analysis of different types of data. Their elaboration and interpretation allow us to provide the best strategies to be applied in the field in order to forecast possible risk event situations which can damage the production [25, 26];
- A *cross-platform application* used by LAORE technical and farmers to upload crop data collected during the field survey and to visualize the up-to-date information for managing the cultivation in the form of alerts and decision supports. It is available by smartphone, tablet and personal computers with different operating systems. These features allow the farmers to take advantage of the application without worrying about the device in use, to access it in any place (e.g., in the field, in the company etc.) and to simplify and enhance the agricultural management process. All information is in a graphic format that uses symbols and colors to advice and inform in an immediate, effective and unambiguous way the status of each crop management component. Internet connectivity also allows a timely updating of the features as soon as new analysis results are available and without any user intervention.

The Figure 1 describes a conceptual diagram of the system with three main stages. In the first stage the data are collected at fixed intervals from different sources: weather stations, external providers and data uploaded to the cross-platform by LAORE technical during the field survey. In the second stage, the data are received from the *Data Receiver* which manages and controls the quality of data and then it stores them into *Env DB* (*Environmental Database*) and *Potato DB*. After that, the data are analysed through several agricultural mathematical models.

Finally, in the third stage, the output is stored and sent to the cross-platform application for the interpretation by the decision maker. The output is visualized in the application as graphs and guidelines through different and specific dashboards. Each dashboard is a collection of widgets that give to the farmer an overview of the metrics and let them monitor many metrics at once, so they can quickly check the health of their cultivation.

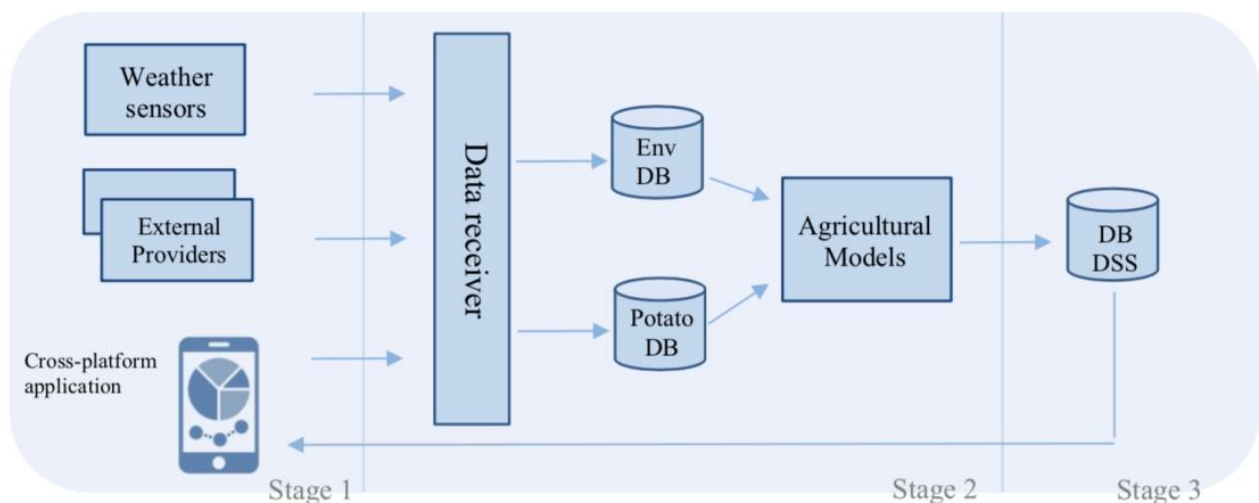


Figure 1. Conceptual diagram of the system

3.2. Case of study

LANDS was tested during the 2018 spring season to forecast and tackle the risk of *Phytophthora Infestans* cryptogamic attacks for potato crop also known as *late blight* or *potato blight*. Potato blight is one of the most devastating diseases of potato world over, including Sardinia. In the Region the continuous climate changes such as the rains close together, the high humidity and the abrupt changes of the temperatures are putting at risk the potatoes production. For this reason, the experimentation phase started as a support in the decision- making process of this cultivation.

The tested are conducted in the potato fields monitored and managed by the LAORE Agency. We have implemented two disease prediction models retrieved from literature: *Negative Prognosis model* [23] and *Fry model* [27, 28]. The joint use of the two algorithms allows to forecast the period which it is opportune to carry out fungicide treatments useful against the appearance of the pathogen.

The models identify the number of treatments need during a growing season as a function of time and meteorological data acquired continuously from ARPAS weather stations.

The analysis of the *Negative Prognosis Model* predicts the period where the late blight epidemics are not likely to occur and the timing of the first treatment. In order to achieve an accurate prediction, the system receives, manages and stores with fixed frequency the following data: hourly temperature of the day, hourly humidity of the day, hourly winds, day degrees calculated with different methodologies, Eto calculated with different mathematical formulas. From these data, the model takes as input: hourly temperature (°C), relative humidity (%), and rainfall (mm). After the server has received the input parameters the model calculates with different formulas the risk values and the accumulated risk values. This last, is the values that allows to determinate the date of the first treatment. The Figure 2 shows the trend of the accumulated risk index recorded from 12/03/2018 to 29/04/2018.

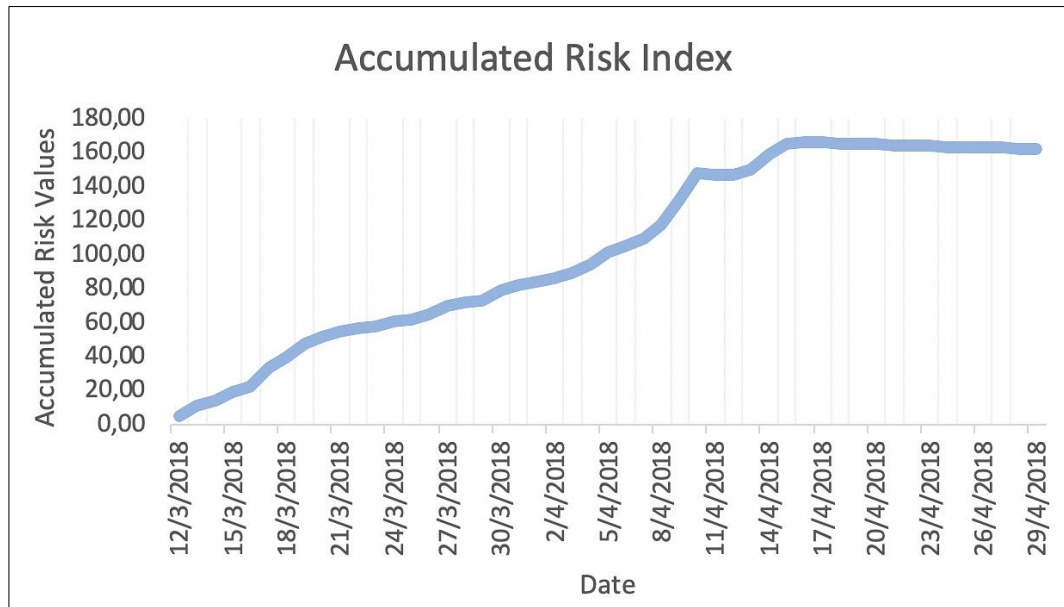


Figure 2. Accumulated risk recorded from 12/03/2018 to 29/04/2018

The tested conducted allowed to identify a local threshold which recognize when the disease is expected to occur. The warning period is indicated when the accumulated risk value exceeds the threshold of 130 and the first treatment is applied when the threshold reaches the value 150. In the case of Figure 3 the first treatment was carried out 13/04/2018.

To estimate the treatments after the first we developed the *Fry model*. The model calculates the spraying intervals based on the *blight units* and *fungicide units*. Blight units are calculated according to the number of consecutive hours that relative humidity is greater than or equal to 90%, and average temperature falls within any of six ranges (< 3, 3-7, 8- 12, 13-22, 23-27 and >27 °C). Fungicide units are calculated based on daily rainfall (mm) and time since last fungicide application. Decision rules about when fungicide should be applied are generated based on cumulative blight units or fungicide units since last spray.

The experiments carried out allowed to outline the best criteria for local conditions through the *Fry model* developed. The treatments after the first are indicated when one of the following cases occurs: (i) the accumulated precipitations are greater than 20 mm, (ii) the risk value of the previous night is 8 and also the sum of the blight units exceeds 40 for cultivar susceptible.

4. Conclusion

In the present paper, we have seen how the DSSs are widely used in the agricultural sector. They have become notable and indispensable tools to conduct a more sustainable and productive agriculture which is difficult to sustain due to the continuous climate changes. Although several DSSs for monitoring various cultures have been developed, their adoption has been slow for two reasons: technical limitations of the DSSs and farmer attitude towards DSSs.

Today, the situation is changing thanks to the increased availability of personal computers, increased access to the Internet and increased development of web-based systems. Even in Italy and especially in Sardinia few DSS have been adopted. The major contribution of this work is the development of the DSS LANDS in collaboration with the LAORE Sardinia Agency to monitor the main crops in Sardinia, a place where the adoption/diffusion of DSS is complicated for the territory heterogeneity. Currently, the DSS is a prototype being tested for monitoring the potato culture. In particular, the DSS through the *Negative Prognosis Model* and the *Fry Model* elaborates weather data from meteorological stations to forecast the period in which is opportune to carry out fungicidal treatments against the

pathogen late blight outbreak. The short case of study conducted allowed to adapt, calibrate and outline the local parameters in order to produce accurate predictions.

However, LANDS is at an early stage of the project. To date, it is still early to be able to assess the benefits of its use in the field. Future experiments will allow to validate predictive dynamical models and evaluate if LANDS is the tool able to respond to the challenges emerging in the agricultural field according to Precision Farming methods.

5. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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