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Research Paper

Decision making models embedded into a web-based tool for assessing pest infestation risk

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Current practices in agricultural management involve the application of rules and techniques to ensure high quality and environmentally friendly production. Based on their experience, agricultural technicians and farmers make critical decisions affecting crop growth while considering several interwoven agricultural, technological, environmental, legal and economic factors. In this context, decision support systems and the knowledge models that support them, enable the incorporation of valuable experience into software systems providing support to agricultural technicians to make rapid and effective decisions for efficient crop growth. Pest control is an important issue in agricultural management due to crop yield reductions caused by pests and it involves expert knowledge. This paper presents a formalisation of the pest control problem and the workflow followed by agricultural technicians and farmers in integrated pest management, the crop production strategy that combines different practices for growing healthy crops whilst minimising pesticide use. A generic decision schema for estimating infestation risk of a given pest on a given crop is defined and it acts as a metamodel for the maintenance and extension of the knowledge embedded in a pest management decision support system which is also presented. This software tool has been implemented by integrating a rule-based tool into web-based architecture. Evaluation from validity and usability perspectives concluded that both agricultural technicians and farmers considered it a useful tool in pest control, particularly for training new technicians and inexperienced farmers.

1. Introduction

The agricultural sector in Spain exerts great influence on its national economy, especially in the south-east of the country. The province of Almería has been called “the larder of Europe” because of its intensive horticultural greenhouse production; almost the entire vegetable production of Almería is destined for export to other European countries.

In this context, agricultural managers have to make daily decisions affecting their business, some of which are critical and others not; but they face an extra difficulty in so far as their crop is a biological system and not simply an economic system. This dilemma is well illustrated in the use of

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Nomenclature

DSS	Decision support systems
KBS	Knowledge-based systems
IPM	Integrated pest management
PCOP	IPM pest control problem, also called IPM-PCOP
$\mathbf{V} = \{v_1, v_2, \ldots v_e\}$	Set of possible plants varieties
v_i	A plant variety
$\mathbf{D} = \{d_1, d_2, \ldots d_m\}$	Set of possible pathogen agents
d_j	One of the m pathogens which might appear according to the plant biology
O	Observations
$\mathbf{S} = \{s_1, s_2, \ldots s_l\}$	Data about the growing season
$\mathbf{G} = \{g_1, g_2, \ldots g_r\}$	Gathered data
$\mathbf{T} = \{t_1, t_2, \ldots t_n\}$	Tracking data
$\mathbf{E} = \{e_1, e_2, \ldots e_h\}$	Economics of the crop
$\mathbf{A} = \{a_1, a_2, \ldots a_q\}$	Set of possible actions to perform on the crop
a_z	An action to be performed on the crop
P	Set of elemental problems
p_k	An elemental problem
R	Set of selected remedial actions
BPMN	Business process model and notation
CML	Conceptual modelling language

pesticides: From an economic point of view, the use of pesticides in crops has been considered the correct course of action over several decades since the cost of chemical products and their application is usually lower than the economic losses caused by pests. However, from the biological and ecological standpoint, the use of pesticides involves undesirable residues and potential toxicity in both the crop and the environment, thus their application has to be minimised. Indeed, the improper use of pesticides in Almería, some years ago, had a negative impact because certain vegetables were contaminated with pesticide residues above the legal limits, which led to a number of products from Almería not being able to be marketed in the European market.

Plant health care is therefore of prime importance to present day agribusiness given its impact on the sector's economy and its significant effect on the environment. Decision support systems (DSS) have become an indispensable tool by incorporating valuable experience and knowledge into software systems, providing agricultural technicians with the information needed to make rapid and efficient decisions for effective pest control and to train practitioners. These kinds of software systems gather, treat and present data from a wide range of sources, helping the users to make appropriate decisions supported by the system's advice about how to act in complex situations.

The use of computerised DSS in agriculture has no clear starting date. The first references to agricultural expert systems (Beck, Jones, & Jones, 1989; Plant, 1989) led over the coming years to larger and more complex DSS (Chauhan, Wright, Holzworth, Rachaputi, & Payero, 2011; Gonzalez-Andujar, Fernandez-Quintanilla, Izquierdo, & Urbano, 2006; Lopez-Morales, López-Ortega, Ramos-Fernández, & Muñoz, 2008; Mansingh, Reichgelt, & Bryson, 2007). Later DSS applied certain artificial intelligence techniques and knowledge engineering approaches to provide intelligent decision support for some of the most important tasks in agricultural production, such as pest and disease diagnosis (Lopez-Morales et al., 2008; Mansingh et al., 2007), analysis of water conditions (Cardona et al., 2011), fertiliser application (Busato et al., 2013; Gonzalez-Andujar et al., 2006), irrigation control (Chauhan et al., 2011), amongst others. In recent years, most of these DDS, also known as knowledge-based systems (KBS), have been developed by taking advantage of the possibilities offered by the internet (Grove, 2000; Yao & Yao, 2003). For example, the uses of internet-based DSS in agriculture include an irrigation decision-making systems using a service oriented architecture (Xu, Chen, Chen, & Gao, 2011); a prototype for a web-based decision support system capable of assisting farmers by using mobile technologies (Antonopoulou, Karetsos, Maliappis, & Sideridis, 2010); the estimation of biomass production and transportation costs with regard to input requirements, internal processes, and output, (Busato & Berruto, 2014); and the web-based information system SAIFA, which allows the integrated production monitoring of the Spanish olive crop (Orellana, del Sagrado, & del Águila, 2011).

Pest control is an important issue in agricultural management due to the significant economic and ecological losses that pests and diseases may cause. A valuable method for decreasing the impact of such pests and diseases is integrated pest management (IPM) (Norris, Caswell-Chen, & Kogan, 2003). IPM aims to suppress pest populations below an action threshold - the pathogen population density at which action must be taken to prevent yield loss (Nutter, Teng, & Royer, 1993). When this level is reached, IPM proposes a suitable action with combined biological, cultural, mechanical and chemical control mechanisms to control the pest. One of the greatest contributions from scientific organisations and policy makers in the promotion of IPM has been the definition and deployment of quality regulations and programs in the agrarian politics to assure quality and healthiness of the products applying IPM. An example is the EU directive 2009/128/EC which requires national action plans for a reduction in pesticides and the implementation of IPM by 2014 (EC, 2009). These regulations help position products within markets. Within the IPM framework, a crop is perceived as a complex agricultural ecosystem, or agroecosystem, made up of several components: plants, animals and microorganisms, some of which may be beneficial (i.e. beneficial insects that eat or parasitise target pests) and others which may be harmful (i.e. pests) (Gliessman, 2006). Each component of the agroecosystem has its own functions and interrelationships with other components, together defining the behaviour of the whole system. IPM emphasises the growth of a healthy crop with the least possible disruption to agroecosystems. An effective monitoring of this system leads farmers to a substantial improvement in crop yield. Furthermore, IPM aims to reduce the expenditure associated with the use of chemical pesticides by replacing them with biological treatments that have minimal environmental impact and are often of lower cost; thus enhancing economic profits within the agricultural sector (Lechenet et al., 2014). The deployment of IPM has characteristics: on the one hand, it looks for an environmentally