ARE THERE ELIGIBILITY CRITERIA FOR USABILITY OF PLANT PROTECTION MODELS IN IPM?

ESISTONO CRITERI PER SELEZIONARE I MODELLI PER LA PROTEZIONE DELLE PIANTE IN IPM?

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Abstract
Plant protection models and other decision-support tools (DTs) have become important for integrated pest management (IPM) programs. Directive 128/2009/EC on sustainable use of pesticides defines the role of DTs in supporting decision making on whether and when intervene to protect the crops from harmful organisms. The Italian Action Plan assigns to Regional governments the responsibility of defining DTs suitable to the scope and making them (or their output) available for professional users. Several plant protection models exist in literature, which have been developed for different purposes, by using diverse approaches, in different climatic conditions and agricultural contexts. The criteria for comparing and selecting models for being usefully integrated in the Italian IPM schemes are discussed in this talk, including: model purpose and approach, biological mechanisms accounted for, driving variables, transparency, possibility of adaptation to local conditions, validation, evaluation of usefulness. Searching for a consensus on these criteria would be useful for developing a platform in which the suitable models can be made available for use.

Keywords
Decision-support tools, Directive 128/2009/EC, mechanistic models, empirical models, integrated platform
Parole chiave
Supporto delle decisioni, Direttiva 128/2009/EC, modelli meccanicistici, modelli empirici, piattaforma integrata

Introduction

The directive 128/2009/EC on sustainable use of pesticides (SUD) makes integrated pest management (IPM) mandatory in the EU territory. Article 14 of the SUD, declares that all Member States shall establish or support the establishment of necessary conditions for the implementation of IPM. In particular, Member States shall ensure that professional users have at their disposal information and tools for pest monitoring and decision making. ANNEX III of the SUD lists the general principles of IPM, including that harmful organisms must be monitored by adequate methods and tools, which include observations in the field and warning, forecasting and early diagnosis systems, as well as the use of advice from advisors. Based on the results of the monitoring, professional users decide whether and when to apply plant protection measures. Sound threshold values are also essential components for decision-making.

IPM is based on dynamic processes and requires careful decision making at strategic, tactical, and operational levels. Strategic, tactical, and operational disease and pest management problems differ at both temporal and spatial scale (Rabbinge et al., 1993). Strategic decisions involve one to several years at both the farm level (e.g, crop rotation) and the crop level (e.g., the variety sown); farm owners or directors usually make these decisions. Tactical decisions are made by crop managers day by day, or within a day, in response to what is happening at the crop level (e.g., a disease outbreak that requires control actions). Operational decisions involve a fast response to crop or within the crop situations (e.g., the sprayer setting based on the canopy size and shape) or to unpredicted events (e.g., the decision to postpone a plant protection product, PPP, application because of wind), and are mainly made by the employees who implement crop protection measures (Rossi et al., 2012).

The decision-making process in modern agriculture has increased in complexity; therefore, farmers must invest time in management, business planning, identification of required skills, and training to ensure that the correct crop management operations are selected (McCown, 2002). IPM also requires investment in data collection and detailed record keeping. In addition, decision makers must be provided with adequate methods and tools as well as threshold values to help them in determine where, when, and what kind of treatment is needed, and they must be aware of the full set of up-to-date information for the specific crop, pest, or disease. Decision makers must also know where to obtain expert advice, and they must be willing to accept scientific and technical innovations that benefit environment, food quality, and economic performance, and that can be integrated into the crop management as soon as they become reliable (EISA, 2001).

Figure 1 shows that strategic (e.g., prevention and reduction of the pest inoculum), tactical (e.g., whether and when protecting the crop, what protection action, which PPPs to use and at which doses), and operational (e.g., what sprayer setting) decisions are all relevant in IPM (Rossi et al., 2012).

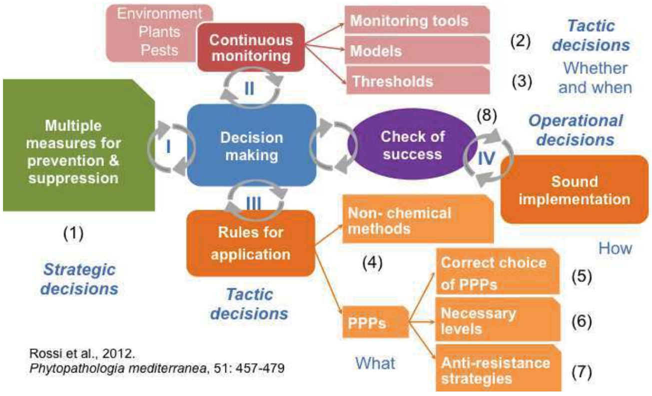

Fig.1- Diagram linking the 8 principles of IPM (Arabic numbers in brackets) of the SUD and the decision-making processes (Latin numbers). Decision tools support users in making knowledge-based decisions in strategic, tactic and operational decisions.
Fig.1 – Schema organizzativo dell'IPM con indicazione degli 8 principi elencati nella Direttiva 128/2009/EC (numeri arabi fra parentesi). I DT forniscono supporti per le decisioni strategiche, tattiche e operative.

Tools for decision-making in IPM

A large number of models for forecasting harmful organisms and their management, risk algorithms, decision rules, intervention thresholds, and decision support systems (DSSs) have been developed to support decision-making in crop protection. These tools, collectively named decision tools (DTs) synthesize information for improving strategic, tactic and/or operational decisions. In some cases, these tools have been validated, adapted to local conditions, and are being used. DTs have been developed/adapted by: i) public research and extension centres; ii) plant protection organisations; iii) private companies/groups selling PPPs or services, or providing consultancy to farmers.
The state-of-the-art of DTs for IPM was reviewed by Rossi et al. (2012). DTs are currently used locally in IPM programs, being interfaced with public early warning systems, in on-site physical devices (such as, e.g., weather stations), and decision support systems (DSSs) (Rossi et al., 2012).
Despite the large number of DTs developed, and the keen interest of farmers in reducing uncertainty in pest control decisions, the access to DTs for users (farmers, advisors, policy-makers) is still fragmented and restricted to particular areas and user groups. This is because of the so-called 'problem of implementation', i.e., the "lack of sustained use in a way that influences practice" (Rossi et al., 2014). Several factors influencing the non-adoption and failure of DTs by agricultural users were identified, which can be ascribed to both technological and technical limitations and to farmers' attitude towards decision-making and DTs (Gent et al., 2011; Matthews et al., 2008). Among these factors are: profitability, user-friendly design, time requirement for DSS usage, credibility, adaptation of the DSS to the farm situation, information update and knowledge of the user (Kerr, 2004).
If properly mobilized, these DTs could have a much greater use and impact for IPM than today. Indeed, a number of these DTs can potentially be used in climatic areas and agricultural circumstances that are much wider than their current range of use. Sharing and integrating DTs has therefore great potential for: i) providing wider access to the existing knowledge; ii) incorporating IPM solutions in existing agricultural systems; iii) supporting relevant plant health policies, in particular the implementation of the SUD. This requires efforts and synergies in a multi-actor approach that involves developers of DTs, ICT specialists, scientists, advisors, farmers, and policy makers. Sharing, however, is only possible if all the stakeholders, including public entities and private companies holding DTs, envisage benefits.
For the implementation of the SUD in Italy criteria are needed for comparing and selecting models to be usefully integrated in the Italian IPM schemes. These criteria include: model purpose, modelling approaches, biological mechanisms accounted for by the model, influencing (driving) variables, endorsement by the scientific community (peer-reviewed vs black boxes), possibility of adaptation/calibration to local conditions, validation for accuracy and robustness, evaluation of usefulness.

Criteria for selection of DTs

1. Purpose of the DTs. Clear definition of the specific plant protection problem addressed by the DT is a key step. It requires an accurate analysis of the specific problem and a flow of information from expert users (e.g., technicians, consultants, growers) to modellers.
DTs should be aimed at forecasting specific characteristics of epidemics or pest phenology and abundance, particularly those crucial for crop protection. If DTs' output concerns aspects of little significance for decision-making, DT use will be of little benefit.
Examples of useful tools are: i) decision support on whether prevention (e.g., use of resistant cultivars) and/or suppression/sanitation measures are necessary (e.g., the tool predict the potential for infestation of soil or crop residue); ii) decision on whether and when it is necessary/profitable to protect the crop (e.g., prediction of infection periods, of relevant pest stages, or of relevant crop damages, including contamination by mycotoxins); iii) definition of action thresholds (e.g., attainment of pest population thresholds); iv) optimisation of pest monitoring programs in crops (e.g., prediction of the likely onset of a disease or first adults in insect traps) and in food products (e.g., private/public monitoring programs for mycotoxin contamination); v) optimum use of different PPPs (e.g., preventative vs curative fungicides, stage-dependent insecticides for insect); vi) selection of the right dose of pesticide to be used (e.g., sprays tailored to the crop); and vii) information on the duration of pesticide efficacy after application.

2. Approaches for DT development. DTs can be mathematical models, risk algorithms, decision rules, decision algorithms, thresholds, etc. allowing growers to respond in a timely and efficient manner by adjusting crop management practices. Madden et al. (2007) proposed the concept of risk algorithm as 'any calculation that uses observations of identified risk factors from the host crop, the pathogen population and the environment to make an assessment of the need for crop protection measures'. A prediction of low disease risk, for instance, may result in reduced pesticide application with positive economic and environmental effects.

Plant disease models – an important kind of DTs - produce predictions about the epidemic or single epidemic components that can be used as risk indicators. Such models also produce predictions about plant disease epidemics that can be used for decision-making concerning plant disease management in production fields at the different spatial scales.

Mathematical models are simplified representations of reality (De Wit, 1993), and plant pest and disease models are simplifications of the relationships between harmful organisms, crops, and the environment that cause the organism to develop over time and space.

There are different models and modelling approaches used in DTs for plant pest and disease control (Zadoks, 1984; Campbell and Madden, 1990; De Wolf and Isard, 2007; Rossi et al., 2010). Initially plant disease models have been developed as simple rules, graphs, or tables, and later as descriptive tools; these models are empirical because they are based on mathematical relationships estimated using dataset collected in the field and valid within the range of data variation used for estimation of model parameters. Advances in environmental monitoring, automatic data processing, and biological research had an important role in promoting new developments and an increase in complexity of pest and disease models. However, empiricism dominated the scene for long time and most of the models available in the literature are still empirical, even though the mathematical/statistical procedures have been improved by including multivariate and non-parametric analyses, neural networks, Bayesian and stochastic modelling. Strengths and weaknesses of empirical models are summarised in Table 1.

Relevant improvements have been obtained with the mechanistic (i.e., process-based) dynamic models (Table 2). These models, following a bottom-up approach, describe mathematically how the basic bio-ecological processes influence the system dynamics under the influence of external driving variables (weather conditions, host characteristics, control measures, etc.). Accuracy and robustness (i.e., accuracy in a range of different climatic and agronomic conditions) of these models significantly increased compared to the empiric ones.

Even though empirical and mechanistic models have different approaches, many empirical models incorporate biological aspects, and mechanistic models usually have many empirical elements (Madden and Ellis, 1988).

Tab.1 – Main strenghts and weakenesses of emprical models.

Tab.1 – Principali vantaggi e svantaggi dei modelli empirici.

Strengths	Weaknesses
Easy to develop	Wide and representative field data are needed for model development
Complete biological knowledge not needed	No prediction is possible outside the range of input data (extrapolation)
No expertise on the organism is required	No information is provided on biological processes
	Validation and calibration is mandatory when used in new/changing agricultural contexts

Tab.2 – Main strenghts and weakenesses of mechanistic models.

Tab.2 - Principali vantaggi e svantaggi dei modelli meccanicistici.

Strengths	Weaknesses
Detailed knowledge on biological processes is needed	Modellers may have deep expertise on the organism
Outputs are accurate and robust	Development often requires research for filling knowledge gaps
Prediction is possible in a wide range of agricultural contexts	
High flexibility	

3. Transparency of DT algorithms. Transparency in the algorithms and model documentation are key aspects to be considered when selecting DTs. Unfortunately, it's often difficult to gain full access to algorithms because DTs can be: i) black-boxes (i.e., content is unknown to users); ii) published in journals, with partial description (of assumptions, algorithms, initial conditions, parameterisation, etc.); iii) tweaked models with no documentation of the improvements made, which therefore remain unknown to users. Transparency and documentation are also important for model validation, calibration and adaptation (see section 4.).

Open-source and knowledge sharing are two approaches for ensuring transparency. The open-source approach implies that all the DT software is: i) released using established open source development practices; ii) licensed under a general public licence, enabling that anyone has the right to freely read, use, improve and redistribute the source code for such software; is made available on an open repository. The "knowledge sharing" approach implies that knowledge (i.e., information, skills, or expertise) is made available and exchanged among individuals and organizations. For explicit knowledge sharing, it is necessary that: i) knowledge providers describe the information; ii) knowledge-recipients are made aware that knowledge is available; iii) knowledge recipients access the knowledge; iv) the body of knowledge is defined and access to it is guaranteed; v) a holistic approach is used for knowledge sharing.

4. Validation and adaptation. A DT can gain farmers' trust through: i) validation by people the users recognise as expert and believable, ii) testimonials, and iii) extended use. Validation consists in comparison between DT output and observations in representative conditions; it requires knowledge about the DT (biological background, data used, modelling approaches, algorithms, etc.) and validation procedures. Unfortunately, procedures for validation are usually not available or not detailed. As a consequence, local experts do not adequately validate DTs so that DTs do not gain sufficient credentials.

5. Evaluation of usefulness. Once a DT has been validated for its ability to correctly represent the real system - e.g., it is able to predict occurrence of infection periods – the usefulness of its use in IPM programs should be verified. For that purpose, experiments should be carried out in which an IPM program based on DT's output is compared with the common practice, and advantages are demonstrated in term of pest or disease control, use of plant protection products, crop yield and quality. Economic and environmental advantages should be also evaluated.

Conclusions

Since 2014, IPM is mandatory across Europe, and Member States have in charge to provide farmers with the necessary knowledge, supports, data and tools. Practical adoption of IPM practices, especially the more stringent ones of advanced IPM, is growing at lower rates than expected, with large crop and geographic differences (European Commission, 2017). Complexity and constrains are among the main reasons for slow adoption of IPM by farmers. Making decision-making for crop protection easier and faster by means of DTs may increase the on-farm use of IPM practices. The practical use of IPM may increase also by demonstrating to farmers that protecting the crop only when really needed and adopting other innovative IPM practices (e.g., dose reduction through crop adapted sprays) helps in addressing some gaps (e.g., the increasing problem of pest resistance to pesticide, reduction of available active ingredients). This also creates opportunities for reducing production costs and increasing farm competitiveness.

In the frame of implementing the SUD, there is an increasing interest by multiple stakeholders to get access to DTs, evaluate and (if needed) adapt them to local conditions, and finally use them for improving IPM programs and increasing the on-farm use of IPM techniques.

To address this need, a great improvement could derive from the development of a web platform for sharing reliable DTs for pest and disease control and for supporting decision-making in IPM in various geographical areas and agricultural contexts across Italy.

In a wider and more advanced perspective, the Platform supporting IPM should be placed in a complex environment aggregating tools and data sources for the three main components of integrated crop management: i) a component making available agro-meteorological data from different sources and networks available across Italy (Agro-Meteorological data Platform, AMP); ii) a component providing crop production models and data collected in a properly designed network of monitoring fields (Crop Production modelling Platform, CPP); iii) a component making available DTs for pests and diseases, and data on the phytosanitary status of the monitored fields (Pest and Disease modelling Platform, PDP).

The design and the development of each of the three components require multiple expertise and the support of research institutions guarantee the coordination and integration of different knowledge and experience. The functional integration between the three platforms is very important in order to provide advanced services for diverse categories of users (farmers, agronomists, advisors, and policy-makers).

The platform for the dynamic simulation of plant pests and diseases (PDP) should be developed in two parallel directions. First, it would require the collection, adaptation and standardization of the existing DTs, making them available for the Platform. The second direction, to be eventually activated at a later stage, concerns the development of new DTs. In both cases, to make the PDP usable by stakeholders, a procedure is required comprising the following steps: i) the validation of existing and newly developed DTs; ii) the implementation of the DTs in the information infrastructure and their integration with the other platforms; iii) the definition of protocols and requirements for accessing and using the PDP; iv) the generation of output and methods for communicating the results.

The PDP should be designed with the overall goal of helping farmers and related stakeholders in facing the complexity related to the implementation of IPM as envisaged by the SUD.

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