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E. Capri
S. Brenna

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Sustainable Use of Pesticides: an Innovative Experience in Lombardy Region, Italy

C. Riparbelli a, A. Di Guardo b, A. Serrano b, E. Capri c and S. Brenna a

a Ente Regionale per i Servizi all’Agricoltura e alle Foreste, Milano – Italy (carlo.riparbelli@ersaf.lombardia.it)
b Informatica Ambientale, Milano – Italy (diguardo@iambientale.it)
c Istituto di Chimica Agraria ed Ambientale, Università Cattolica del Sacro Cuore, Piacenza – Italy

Abstract: Pesticide contamination may affect the quality of different environmental compartments as soil, water and air and, consequently, may pose a risk to human beings and ecosystems. The current environmental and agricultural policies of the European Union are aimed at the development of sustainable agriculture production. Therefore, decision makers need innovative instruments to plan pesticide use, while farmers need directions to fight pests in a sustainable way in order to maintain reasonable cost-benefit balances for the farm. A decision support system called SuSAP Network – Supplying Sustainable Agriculture Production – has been developed for an intensive agricultural area of North Italy (Lombardy Region) to promote the sustainable use of pesticides at farm scale. SuSAP Network is a web-based software which integrates existing environmental data from different sources to calculate the environmental risk of pesticides, an innovative web service for managing model simulations and a WebGis which displays geographic data.

Keywords: Pesticide; Risk indicator; Web services; Decision support system.

1. INTRODUCTION

Pesticide may have the potential to kill or control harmful organisms such as pests, but can also cause unwanted adverse effects on non-target organisms, human health and environment. The possible risks associated with the use of pesticides are accepted to a certain extent, because of the direct benefits that it generates. These substances are employed on a large scale and generally considered as essential in modern cropping systems since they contribute to ensuring reliable supplies of affordable and healthy agricultural products of high quality. Unwanted amounts of certain pesticides can however still be found in environmental media (in particular soil and water) and residues exceeding regulatory limits still occur in agricultural produce. For these reasons, sustainable agricultural systems, characterised by technologies and crop protection strategies, able to safeguard the groundwater resources and aquatic ecosystems, have become one of the themes of modern agriculture.

A concrete and frequently applied example of a sustainable use of pesticides could be considered the so-called Integrated Pest Management (IPM), an integrated farming system which offers real solutions to many of the problems encountered on farms throughout Europe today. A quantitative reliable demonstration of the beneficial effects of IPM eco-compatible practices could lead agronomists and consultants to suggest a reduction up to 30% of the pesticides applied to the most common crops like maize, rice and vineyard. This kind of practices should result in a lower pesticide impact on the environment, but also in a money safeguard for the farmers and enhancing of eco-compatible productions.
The most recent environmental and agricultural policies (see for example [Dir. 91/414], [COM2006 373]), at national and European level, pursue these aspects and try to develop strategies integrating environmental problems in the management of the natural resources. Following this need for the decision makers, the first objective is to define and to carry out finalised action plans at regional and local level based on real data and scenarios. The objective of this paper is to describe a decision support system, dedicated to the extension services and farmers, called SuSAP Network – Supplying Sustainable Agriculture Production – developed within an intensive agricultural area of North Italy (Lombardy Region) to promote the sustainable use of pesticides at farm scale. At present the system takes into account the comprehensive information on the life cycles of pests and their interaction with the environment; it is expressly be tailored to address the IPM practices, characterized not only by a single pest control method but, rather, by a series of pest management evaluations, decisions and controls. The extensive use of SuSAP will suggest to the extensions services and to the farmers a pool of technically-based choices for pesticide treatments on the main crops of the region.

2. SuSAP NETWORK, THE SYSTEM

SuSAP Network has been conceived as a regional service and therefore it presents an easy-to-use web interface which exposes several functionalities to the users, mostly farmers and agronomical technicians. The main topic we discuss here relates to the possibility to find the best crop protection strategies (Figure 1) using different pesticide application scenarios and simulating their behaviour in the environment by the means of internationally acknowledged models. SuSAP Network uses these different layers of data to feed its coupled models:

- at predefined time steps it acquires the regional cadastral map and all the related information, supplied by the Agriculture Information System of the Lombardy (SIARL);
- a layer of soil data at scale 1:50.000;
- 12 years of weather data for 13 meteorological station spread over the regional territory;
- phenological data and default irrigations for the main crops cultivated in the Region;
- a complex sub-database of pesticides and active ingredients constantly updated by an external source.

Each pesticide application scenario built with the information above can be simulated to provide an estimate of the feasible impacts to the environmental compartments considered - soil, groundwater, surface water, air - and to provide a set of recommendations. [Riparbelli et al. 2006].
Calculation is performed according to the spatial variability of soil properties, meteorological conditions, crops and patterns of pesticide applications for a user-defined homogeneous area - Landscape Farm Unit – (LFU) derived by the integration of the cadastral map and the cartographic databases of the region (Figure 2).

The current release of SuSAP Network calculates the Predicted Environmental Concentrations (PECs) of the used pesticides for each environmental compartment by means of a two steps procedure; it calculates at first the EPRIP index using EPRIP 2.1 [Padovani et al. 2004] [Trevisan et al. 2007], which rapidly estimates the overall impact of the pesticide to the environmental compartments and provides an estimation of the environmental risk using six classes (none, negligible, small, present, large and very large). The user can later refine the EPRIP evaluation performing a model simulation of pesticide leaching to groundwater using the one dimension models RICEWQ-VADOFT 2.0 [Williams et al. 1999] [Capri et al. 2002] for the rice flooded crop or PELMO 3.2.2 (PEsticide Leaching MOdel, [Klein et al., 1995]) for the other crops. The two models have been integrated in SuSAP to estimate the pesticide leaching potential through the soil horizons based on an extended cascade model; moreover, RICEWQ calculates the runoff of pesticide to surface water for flooded rice; these processes include estimation of soil...
temperatures, pesticide degradation, sorption, volatilisation, and potential evapotranspiration. The above models have been selected among those indicated and validated by the FOCUS (FOrum for the Co-ordination of pesticide fate models and their USE), jointly established since 1993 by the European Commission and the European Crop Protection Association to provide guidance to the Member States in EU pesticide registration process. At the end of the simulation process, the user can compare the predicted environmental risk, the efficacy of the treatments simulated and the costs of each plant protection product and therefore evaluate the sustainability of crop protection strategies. Hence using their own databases as well as their pesticide plans, farmers can identify the best calibrated strategies, since all the available data in SuSAP Network have been validated and is up-to-date.

3. THE SOFTWARE ARCHITECTURE

SuSAP Network is a web portal that follows the standard n-tier architecture that guarantee the higher level of software modularity, allowing any of the tiers to be upgraded or replaced independently as requirements or technology changes. The architecture is composed of three main tiers: the user interface tier (“presentation”), the functional process logic tier (“business rules”) and the data access tier (“computer data store”). The business rules tier is composed by the application logic and two additional levels conceived as web services: an environmental data provider service and an easy-to-use model engine service. The next sections will describe each of them.

3.1 The Web Portal and the Database

The web portal has been developed using Microsoft ASP.NET 2.0, enhanced with the AJAX extension library v1.0 whenever possible to provide fast and smooth server response to user interactions. Using the portal, the user can describe and configure different pesticide application scenarios that can be simulated in order to evaluate the risk of the selected pesticides to the environmental compartments and to provide a set of recommendations. Pesticides can be selected from the set of those registered in Italy, information that is kept up to date by the means of an online interaction with the pesticide database of the ICPS Institute (International Centre for Pesticides and Health Risk Prevention). The portal allows the users to keep a pesticide treatment notebook that can be used to generate a yearly report due by the current legislation. Coupled to the web portal, the user can find a WebGIS client that serves as an interactive tool to visualize and select several cartographic parameters, such as the soil type or the fields to analyze, the cadastral spatial information of the “in use” farm from where he can create the LFU. The cadastral and farm GIS layers used to by the WebGIS client are constantly updated by SIARL (Sistema Informativo Agricolo della Regione Lombardia) and are linked to detailed soil and climatological region-wide informational layers. The core of the system is the database, which stores the data and defines the complex relationships relating the different datasets.

Basic soil data have been surveyed at scale 1:50,000 (Figure 3) where several representative soil profiles have been characterised by field and laboratory analysis in order to collect specific hydrological parameters necessary to calibrate model applications. The collected samples were compared with data calculated by a set of pedo-transfer functions (PTF); the best fitting PTF was used to estimate field capacity, wilting point [Rawls et al., 1982] and bulk density [Manrique & Jones, 1991], necessary for the models execution. Rainfall, temperature, wind, solar radiation, relative humidity and evapotranspiration data from 125 meteorological stations covering the Lombardy region were collected and interpolated with geostatistical methods to obtain spatial patterns of rainfall and temperature. The integrated analysis of soil and meteorological data allowed us to identify 15 macro-areas, each one defined by a reference meteorological station.
More than 500 pesticides, including their chemo-physical properties, ecotoxicological data and the related plant protection products along with their information on the date, number and rate of application and the efficacy against pests have been stored. The physiological characteristics of each crop, its phenological stages, weeds and pests affecting it, complete the SuSAP database. Several set of irrigation amounts, dates and types have been calculated by means of CropSyst 3.04 model [Stöckle et al., 1999], applied to 10 soil scenarios representative of the different soil and weather conditions of the Lombardy Region.

3.2 The Model engine service

In order to build a scalable and powerful system and to speed up the evaluation process, an innovative simulation engine service (Web Environmental Model Simulation Service – WEMSS) has been introduced. It is a separated and independent environmental model manager, capable to expose its functionalities through a remotely located web service, accessible via the Internet and the TCP/IP protocol. WEMSS permits to aggregate several environmental models (related to a single compartment or to different ones) providing a shared infrastructure to manage the input variables, the output ones and the internal parameterization, by the means of XML configuration files.

Since each model uses a custom set of environmental variables, the first need was to harmonise them among models. To accomplish this, an ontology structure [Athanasiadis et al., 2006] has been developed that unambiguously define the environmental concepts used throughout the software. Since an ontology can be defined as a representation of a set of concepts within a domain and the relationships between them, we defined for each concept a descriptor that qualify it with important information like its validity range, its unit of measure and its default value (among others).

For each concept, WEMSS provide a generic descriptor, which exposes validity ranges foreseeable in real world. The modeller can then modify these descriptors adjusting their values to the needs of the model used or to the location in which they will be applied (for example the temperature in the real world ranges generally between -70 °C and 60 °C, but a particular model can treat only values between -10 °C and 40 °C).

Since all of the ontology concepts are stored in xml files (see an example in Fig. 4), it is simple to publish their values and descriptor in different formats using XSLT transformation files.

The structure of the WEMSS web service provides a set of functionalities that can be used independently of the models it exposes, hence providing a common and useful context that simplify the interactions with the models. This aspect is really important because it allows the user to focus more on the environmental aspects and the quality of the input data rather than arranging and organizing these input data to satisfy the model specifications, operations transparently accomplished by the service. Each model in facts interacts with the WEMSS infrastructure by the means of a specific wrapper class, which implements some functionalities (web methods) inherited by an interface of the model engine. These methods provide a common way to read and manage input values from external sources and to provide output values requested by the user. Moreover, each wrapper class implements a
“validate” method that uses the variable descriptors to check the data structure values for consistency, and an “execute” method that prepares the input data for the wrapped model and run it each time it is needed.

```xml
<VariableDescriptorsSet Name="Generic">
  <Variables>
    <Variable type="Double" Name="Temperature" Description="Soil temperature" Nullable="false" MinValue="-30.0" MaxValue="100" DefaultValue="20" UnitOfMeasure="°C" />
    <Variable type="Int" Name="GiulianDay" Description="Day of year in julian format" Nullable="false" MinValue="0" MaxValue="366" DefaultValue="0" UnitOfMeasure="day" />
    <Variable type="String" Name="Speed" Description="Qualitative speed" Nullable="false" DefaultValue="Medium" UnitOfMeasure="" />
    <Values>
      <Value>VeryFast</Value>
      <Value>Fast</Value>
      <Value>Medium</Value>
      <Value>Slow</Value>
      <Value>VerySlow</Value>
    </Values>
  </Variables>
</VariableDescriptorsSet>
```

Figure 4. An example of a three generic variable descriptor

When a simulation requests a model calculation, the SuSAP Network application fills the input data structure provided by the model wrapper class, sets the correct parameters and instantiate a new executor class; when the model terminates its calculations, the wrapper class fills the output data structure of the model and make available the results to the caller. Using this approach the models can be piped and combined to create unique composed models to get better results. The WEMSS can automatically map the output variables of one model to the input variables of the next one using the variable descriptors for each piped model. For now just linear pipes are allowed, but as a future enhancement nonlinear, conditional and cyclical model executions will be permitted, as well as the possibility to persist these created pipes to be reused at future executions.

Each model run is executed in a separated pool providing the facility to better monitor the engine (for example making error checking and exception handling) and to parallelize the computational work by the means of an executor’s grid architecture (Grid Computing) , for example in regional-wide applications.

WEMSS has been used as the model engine for the SuSAP Network portal: the two models PELMO and RICEWQ/VADOFT are inserted into the framework and their functionalities can be reached through the common interface provided.

### 3.3 Environmental Data Web Service

Linked to WEMSS, an environmental data web service has been developed to store and provide soil and weather data. The web service is simply a remote repository and it has two main functionalities: to increase its capacity in terms of environmental information and to provide data to external users. To accomplish this, the service uses an internal structure optimised for massive saving and loading operations of environmental data, in particular time series. The data can be manipulated by external users using a set of web methods; Figure 5 shows two of these web methods related to the meteorological data supply (ImportMeteoFile) and data retrieve (GetMeteoFile). Each operation provides several informations to the web service by the means of an XML file:

- the meteo station;
- the data types of the variables to be supplied or retrieved;
• the format of the file provided of returned;
• the initial and ending dates;
• the time step;

The access to the repository can be filtered using a strong authorisation mechanism to guarantee the protection of the stored data and its authorized use. The web service can be coupled with external software components in order to offer data generation capabilities: for example the new PTF component [Acutis et al., 2008] recently made available can be used to generate soil structure data using the internal set of Pedo-Transfer functions and provide them in real time to the user.

```csharp
/// <summary>
/// Imports a meteo file containing meteo series into
/// the internal storage.
/// </summary>
/// <param name="meteoFile">Lines of the meteo file.</param>
/// <param name="descriptor">XML descriptor of the
/// time series file.</param>
/// <param name="overwrite">true to overwrite the
/// existing data, false to leave the existing data.</param>
/// <returns>an object describing the result of
/// the operation.</returns>
[WebMethod]
public ClassFileMeteoWSResponse ImportMeteoFile(string[] meteoFile, 
XmlDocument descriptor, bool overwrite) { }

/// <summary>
/// Builds and retrieves a meteo file containing
/// meteo series from the internal storage.
/// </summary>
/// <param name="descriptor">XML descriptor of
/// the time series file.</param>
/// <returns>An object describing the result of
/// the operation.</returns>
[WebMethod]
public ClassFileMeteoSWSResponse GetMeteoFile(XmlDocument descriptor) { }
```

**Figure 5.** Web methods that manage meteorological files

### 4. CONCLUSIONS

The starting up of SuSAP Network service and its diffusion in the agriculture of Lombardy could assure a better environmental protection as well as a higher food safety, resulting in higher quality of agricultural productions. Actually the use of this system could give to farmers an important contribution to the certification of eco-compatible productions, in which pesticides are used under Integrated Pest Management (IPM).

These objectives are consistent with the regional strategic projects, aimed at safeguarding cultivated areas and at upgrading the quality of the agricultural environment, as is stated in the Regional Rural Development Program. SuSAP Network users, as farmers, farm operators and local authorities will benefit when proper advices may be given to them about the use of the more environmentally safe products. Three types of benefits are expected:

• better pesticide environmental impact assessment due to the easier access to representative data sets;
• better use of pesticides because adviser and farmers would have access to this information;
• increase of the awareness about the use of soil and climate data for pesticide use.

It is impossible to exactly compute the amount of money saved by the SuSAP Network application in Lombardy, but it will be very significant because a better use of pesticides is becoming more and more a critical point in modern agricultural systems management.

REFERENCES


