

# **I-SALUS: NEW WEB BASED SPATIAL SYSTEMS FOR SIMULATING CROP YIELD AND ENVIRONMENTAL IMPACT**

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## **ABSTRACT**

We developed a web-based agronomic decision support system - named i-Salus - to help farmers optimize their irrigation and nitrogen management practices over space and time. We focused on a approach that combines existing software to demonstrate how the adoption of ICT for decision making in agriculture can meet important challenges such sustainable food production and environmental integrity through sustainable agricultural management. i-Salus allows users to evaluate the best management strategy to improve yield and quality of the crops, to increase economic net return and at the same time to reduce greenhouse gas emissions and groundwater contamination from nitrate leaching. I-Salus lays its foundation on the Salus model (System Approach to Land Use Sustainability) which was designed to simulate the impact of agronomic management on yield and environmental impact. i-Salus is composed by two interfaces: a simple interface and Web-GIS interface. SALUS with the simple interface is a user friendly system s targets at farmers or extension specialists who can simulate the impact of different management strategies on yield, and environmental impact. SALUS-WebGIS is a web-based GIS integrated with Google Earth and Salus model to simulate in a spatial explicit manner the effect of climate-soil-genotype-management interaction on crop yield and environmental impact. Both systems are available at [www.salusmodel.net](http://www.salusmodel.net)

*Keywords:* i-Salus, webbased-GIS; agronomic management, crop yield environmental impact

## **INTRODUCTION**

Management practices found to be sustainable at one site might not be equally sustainable at another site due to variations in weather, soil and landscape. Crop-soil-weather simulation models quantify soil water and soil nutrient processes and integrate knowledge from various disciplines to provide support and recommendations for decision making in agricultural management independent of location, season, crop, cultivar, and management. Because of the difficulties in obtaining long-term data on spatial variability of crop yield, computer simulation models of soil, water and crop growth are necessary tools for agricultural scientists to interpret long-term productivity. SALUS (System Approach to Land Use Sustainability) model was developed from CERES model (Ritchie et al., 1985) to simulate the impact of agronomic management on yield and environmental impact. SALUS model contains several new approaches and algorithms for simulating soil carbon, nitrogen, phosphorous, tillage, soil water balance and yield components compared to CERES model.

Crop models are not normally used directly by farmers and extension because some complexity in the model input quantification. We have simplified the interface of SALUS program and developed a web based version of SALUS models. Users can now use this model through the Internet to identify the most sustainable management practices for their fields. Crop growth model and Geographic Information System (GIS) have been implemented in the past (i.e. AEGIS WIN software imbedded in DSSAT) but they were neither able to import yield maps, remote sensing images, nor be fully integrated with Google Earth with online digitizing capabilities to select their spatial area to simulate.

The objectives of this paper are to: i) illustrate the SALUS model; ii) introduce SALUS with simple interface and SALUS-WEBGIS; iii) report the workflows of these two systems.

## **SALUS MODEL DESCRIPTION**

### *SALUS model*

SALUS (System Approach for Land Use Sustainability (Fig.1) program is a validated crop simulation model developed by Basso and Ritchie and their collaborators (Basso et al., 2010, Senthilkumar et al., 2009; Basso et al., 2006; Syswerda et al., 2012; Basso et al., 2011; Giola et al., 2012) designed to model continuous crop, soil, water and nutrient conditions under different management strategies for multiple years. These strategies may have various crop rotations, planting dates, plant populations, irrigation and fertilizer applications, and tillage regimes. The program will simulate plant growth and soil conditions every day (during growing seasons and fallow periods) for any time period when weather sequences are available. For any simulation run, a number of different management

strategies can be run simultaneously. By running the different strategies at the same time we can compare this effect on crops and soil under the same weather sequences. This also provides a framework whereby the interaction between different areas under different management practices can be easily compared. Every day, and for each management strategy being run, all major components of the crop-soil-water model are executed. These components are management practices, water balance, soil organic matter, nitrogen and phosphorous dynamics, heat balance, plant growth and plant development. The water balance considers surface runoff, infiltration, surface evaporation, saturated and unsaturated soil water flow, drainage, root water uptake, soil evaporation and transpiration. The soil organic matter and nutrient model simulates organic matter decomposition, N mineralization and formation of ammonium and nitrate, N immobilization, gaseous N losses and three pools of phosphorous. The development and growth of plants considers the environmental conditions (particularly temperature and light) to calculate the potential rates of growth for the plant. This growth is then reduced based on water and nitrogen limitations.

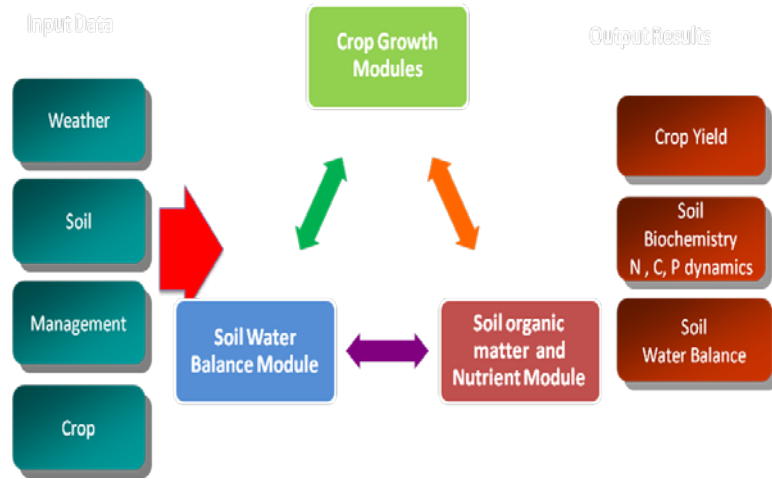
The biophysical model is composed of three main structural components: i) a set of crop growth modules; ii) a soil organic matter and nutrient cycling module and; iii) a soil water balance and temperature module.

The crop growth modules are derived from the CERES (Ritchie, 1985) and IBSNAT (Ritchie, 1989) family of crop production models that were originally developed for single year, monoculture simulations. The crop growth algorithms from these were extracted and restructured into crop growth modules that are linked to the soil water, nutrient and management sub-models. SALUS has been programmed in the "C" language to make the memory allocation more dynamic and program code more platform independent. Current operational crop growth modules include maize, wheat, barley, sorghum and millet. A generic grain legume module (e.g., soybean, dry beans) and alfalfa growth modules are being added to the system. The basic controls on production processes are the same as in the original models. Physic development is controlled by environmental variables (e.g., degree days, photoperiod) governed by variety-specific genetic coefficients. Carbon assimilation and dry matter production are a function of potential rates (controlled by light interception and parameters defining the variety-specific growth potential) which are then reduced according to water and/or N limitations. The main external inputs required for the crop growth routines are the genetic (variety-specific) coefficients and daily solar radiation as a driving variable.

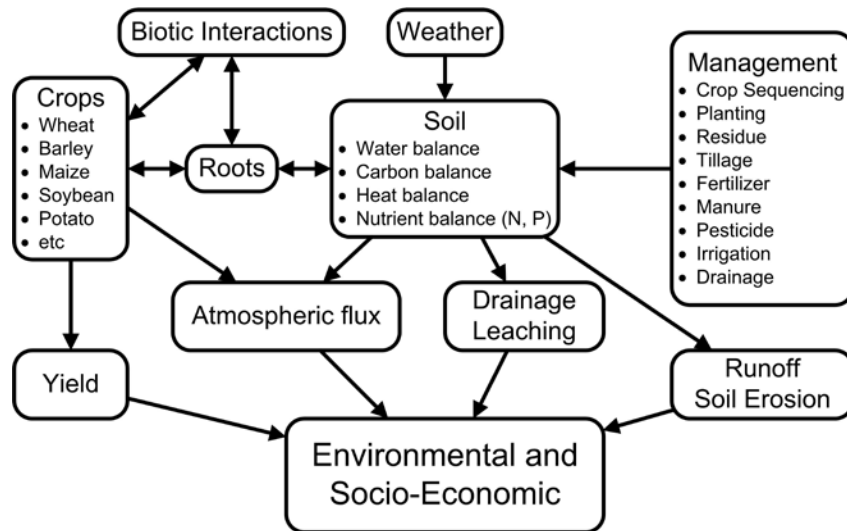
The soil organic matter (SOM) and nitrogen module is derived from the Century model, with a number of modifications incorporated. The model simulates organic matter and N mineralization/immobilization from three SOM pools (active, slow and passive) which vary in their turnover rates and characteristic C:N ratios. There are two crop residue/fresh organic matter pools (structural and metabolic), for representing recalcitrant and easily decomposable residues, based on residue lignin and N content. A surface active SOM pool associated with the surface residue pools was added to better represent conservation tillage systems and perennial crops. The soil phosphorous (P) model incorporates inorganic and organic phosphorous dynamics. Inorganic P is divided into three pools i) labile; ii) active; and iii) stable.

The soil water balance module is based on that used in the CERES models but incorporates a major revision in calculating infiltration and runoff. In SALUS, a time-to-ponding (TP) concept is used to replace the previous runoff and infiltration calculations which were based on SCS runoff curve numbers.

The SALUS model does not explicitly include sub-models to predict pest and disease outbreaks or the occurrence of extreme weather events (e.g., hail). We recognize that these factors can have a major impact on crop production and yield and the sustainability of a particular management system. However, the multitude of potential pest species and disease-causing organisms of major crop species in the U.S. precludes the inclusion of pest dynamics sub-models explicitly within a general cropping systems model such as SALUS. Similarly, it is unrealistic to attempt to predict the occurrence of extreme weather events within the model structure. Salus model can be downloaded at <http://www.salusmodel.net>.



a



b

Figure 1. Description of SALUS model input, engines and output (A); Applications of the SALUS model (B)

## Web-based SALUS systems

### *SALUS with simple interface*

SALUS with simple interface was design to perform online simulation of climate-soil-genotype-management interactions with a friendly user interface. This version does not require any software installation as it can be executed from the website [www.salusmodel.net](http://www.salusmodel.net). The user needs to responds to seventeen questions provided by the system in common English (Table 1) to set up the minimum input data requirement to run the simulation. The output result table reports information on crop yield, nitrate leaching into the groundwater, N<sub>2</sub>O emission (N<sub>2</sub>O emission are based on IPCC emission factors) and CO<sub>2</sub> emission from soil and soil organic carbon change over time for the selected management practices. The summary result table presents data in simplified way by reporting the average value, the best value and the worse value for each of the output variables. SALUS with simple interface is a three tier architecture system (Fig. 2). On the client side, Macromedia Flash was used to build a Rich Internet Application (RIA) to meet the needs of a simple interface. On the server side, a web service receives the input data from the client side and starts to simulate SALUS model. After simulating, the web service will store the results into the SQL server database and pass the results to the client side.

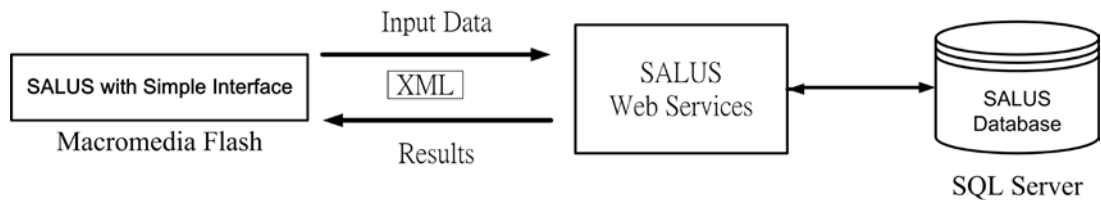


Figure 2. The architecture of SALUS with simple interface

TABLE 1. QUESTIONS OF SALUS WITH SIMPLE INTERFACE

|   | Catalog             | Questions   |
|---|---------------------|---|
| 1 | Soil                | What is your soil type?   |
| 2 |                     | How deep is your soil?  |
| 3 |                     | What is your soil organic matter?                               |
| 4 |                     | What is your soil nitrogen content?                             |
| 5 |                     | Is your field flat?   |
| 6 | Weatehr             | Select your location? or is your village close to any of these? |
| 7 | Initial conditition | What was the crop yield last year?                              |
| 8 |                     | How do you handle crop residues?                                |
| 9 | Crop                | What crop are you planting?                                     |

|    | Catalog    | Questions                                  |
|----|------------|--|
| 10 | Management | How do you till the soil?                  |
| 11 |            | In which month do you plant the crop?      |
| 12 |            | How much Nitrogen fertilizer do you apply? |
| 13 |            | In which month do you apply N fertilizer?  |
| 14 |            | Do you apply manure or compost?            |
| 15 |            | Do you irrigate the crop?                  |
| 16 |            | Do you have problems of weeds?             |
| 17 |            | Do you have problems of plant diseases?    |

### *SALUS-WebGIS*

SALUS-WebGIS was developed using a tight coupling strategy (Karimi,1996) integrating SALUS model with Easy map object<sup>1</sup> into a web application. SALUS model is converted into a dynamic link library that can be called from the new application and linked to it at runtime. This allows a smooth integration between GIS and the simulation models. SALUS-WebGIS was deployed in a windows environment, and is built around IIS and the SQL server relational database management system, which was chosen due to its ability to efficiently store, search, and retrieve data in large databases (Fig. 3.). The user interface was built by using ASP.NET and AJAX technology. Web server receives the requests from client side and retrieves data from SQL server and maps from Easy map object according to the requests. SALUS-WEBGIS adopts ESRI shapefile as source of spatial data. The geometry type of features was limited to polygons. Polygon features were used to display the spatial variability of simulations. Climate, soil and management details are spatially determined and the output results are visualized as attributes of polygons (Fig. 4). SALUS-WEBGIS has the same model kernel as SALUS model but planned as support tool for precision agriculture application to assess spatial and temporal variability. The three main features in SALUS-WEBGIS are: crop growth simulation module, data management module and thematic map module.

Crop growth simulation module is the controller of SALUS model (Fig. 5). It receives requests from the client, then it lists all features that are selected and proceeds with the simulations for these selections. Data management module consists of all functions relating to data management include spatial data and non-spatial data (Fig. 6). Spatial data was controlled by Easy map object. Users can view, create and edit maps through Easy map object. Non-spatial data include input data and simulation results were accessed through ADO.NET. Thematic map module creates thematic maps from spatial data which were linked to simulation results (Fig. 7). Before creating a thematic map, users have to select a result that will be appended to the attributes of features. In SALUS-WEBGIS, simulation results may have multiple years. Thematic map module can build a

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<sup>1</sup> Easy map object is a web mapping API, developed by Geographic Information System Research Center, Feng-Chia University, Taiwan. (<http://www.gis.tw>)

time series map of a particular result. After retrieving all simulation results of features, module appends all results to the attributes. Jenks' natural breaks classification was used to classify the values of all features in a map in order to create a choropleth map.

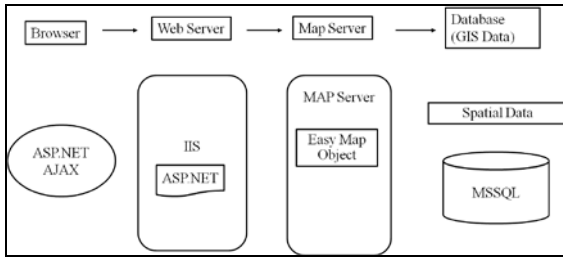


Figure 3. The architecture of SALUS-WEBGIS

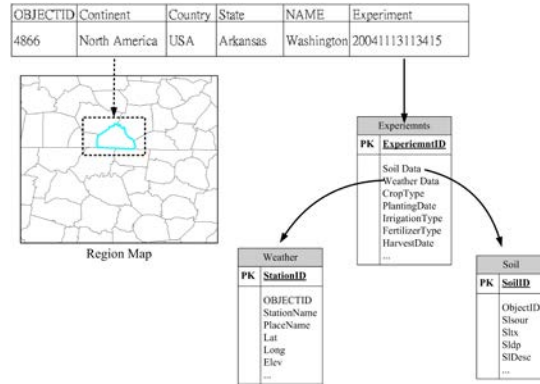


Figure 4. The integration of polygons and SALUS data

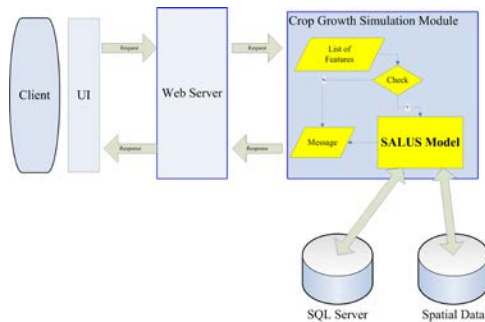


Figure 5. The workflow of crop growth simulation module

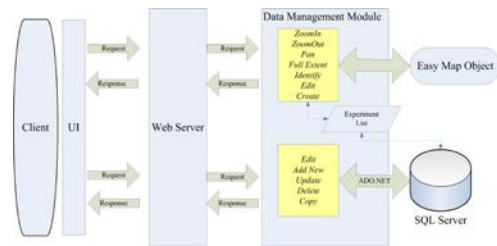


Figure 6. The workflow of data management module

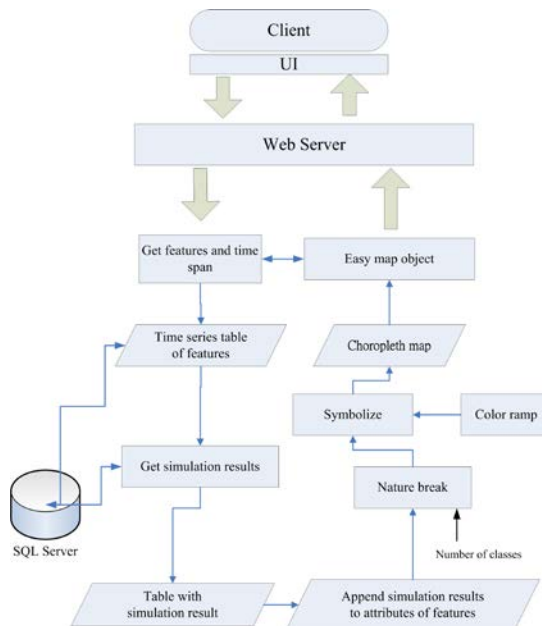


Figure 7. The workflow of thematic map module



Figure 8. The simulation results of SALUS with simple interface

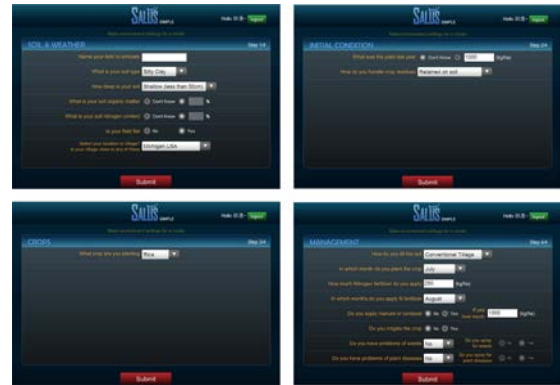


Figure 9. The dialogue boxes of SALUS with simple interface



Figure 10. Comparative table of simulation results

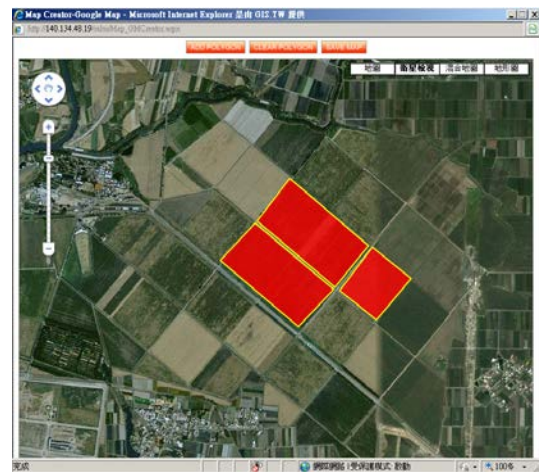


Figure 11. Users can use Google map to create new map for SALUS-WebGIS

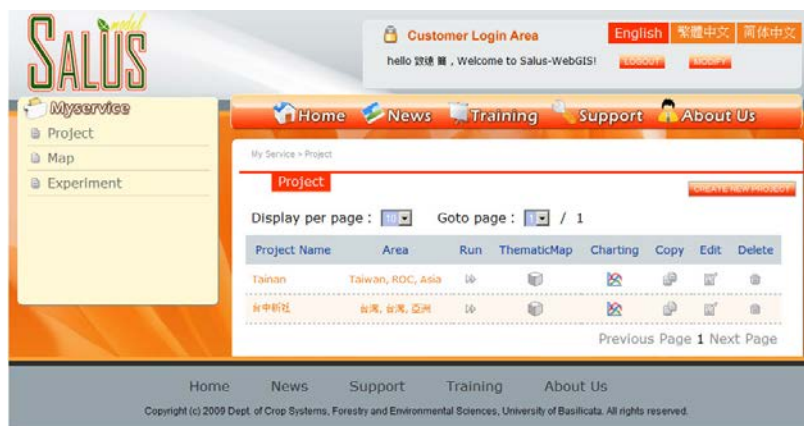


Figure 12. The main page of SALUS-WEBGIS



| Soil Name                   | Site    | SoilID     | Copy | Edit | Edit Layers | Delete |
|-----------------------------|---------|------------|------|------|-------------|--------|
| DEFAULT - DEEP SILTY CLAY   | Generic | IB00000001 |      |      |             |        |
| DEFAULT - MEDIUM SILTY CLAY | Generic | IB00000002 |      |      |             |        |

Figure 13. Soil data and weather data can be create by importing DSSAT or SALUS data.

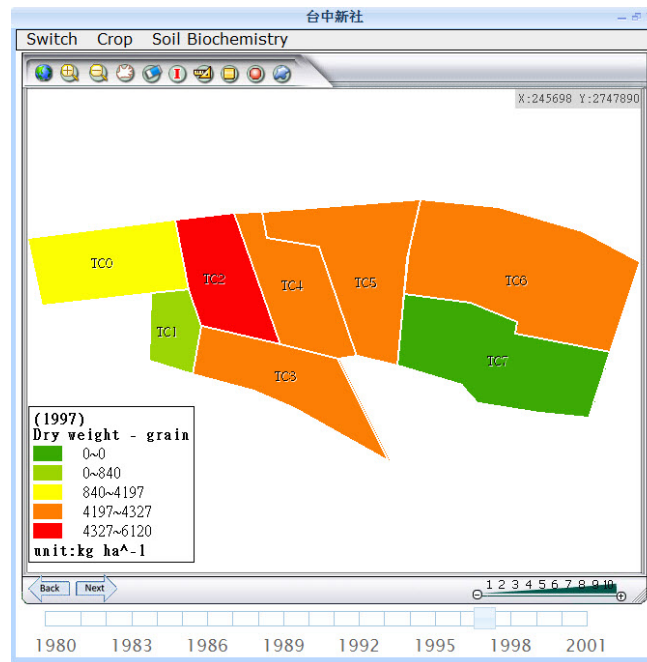


Figure 14. The time series thematic map of simulation results

The main page of SALUS-WEBGIS is shown as Figure 11. Project, Map, and Experiment are three main tabs for the user to fill. Users cannot run any simulations without prior selection of spatial domains (maps) and experiments details. In Map tab, users can upload their own shapefiles or digitize the area of interest on Google map (Fig. 12). In Experiment tab, users can create, edit, and delete the experiment. Soil data and weather data can be created by uploading DSSAT format data (.sol or .wth) or SALUS format data (.sdb or .wdb) (Fig. 13). In the Project tab, users can setup a simulation project from maps and experiments. Each project has a unique map that covers the area of interest. Each feature of a map is linked to a particular experiment. After simulating, results can be displayed in a time series thematic map or charts (Fig. 14).

SALUS is a powerful model to assess sustainability of land use. SALUS with simple interface could engage more people to understand the importance of sustainable development and try to improve on agronomic management. SALUS-WEBGIS overcomes the limits of point-based data in visualization and displays

spatial variations and temporal variations of the results. I-Salus can help decision makers understand the applicability of various management practices spatially and function as tool for technology transfer to help environmental and agricultural managers achieve sustainable use of natural resources and agricultural land.

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