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# Climate Change Impact on Agricultural Productivity and Environment Influence based on Simulation Model

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**Abstract** In this paper a physical simulation model SALUS is used to explore crop productivity responses to a range of management strategies over multiple years. This research firstly set up a spatial database of experimental site rice production area polygon identified from satellite images, and collected detail daily weather data from meteorology stations for the past 30 years, with soil profile information and management strategy and genetic coefficient. Secondly, Salus model simulation was applied to accurate reflect real observed yield information to compare with simulated result. The residual mean square of the comparison proved around 90 percent of confidence that the model can successful simulated yield output changes for each year. By running model simulation under different predicted weather regime conditions arising from climate change, the effect on rice crop productivity and the output of carbon emission, nitrate leaching, and irrigation demand in the Red River Delta area of Northern Vietnam are spatially compared. The simulation results showed increased rice productivity in this field due to predicted temperature rise. However, there are high costs associated with environmental effects emanating from carbon emissions, greater nitrate leaching and water resources and fertilizer demand etc. to sustain the rice productivity. This paper examined these critical issues by integrating SALUS model and GIS function to demonstrate the possible output both economically and environmentally affect for better agricultural decision on experimental area.
**Keywords** *Climate Change; Vietnam Agriculture; Geography Information System; SALUS Model; Web-GIS*

## 1. Introduction

The environmental and socio-economic effects of climate change are major and diverse, including food production and security, water demand, health, energy, tourism, industry and ecosystem functioning (Phan D.B., et al., 2011). Through improving understanding of each of these aspects, policy-maker may make better informed decisions to facilitate sustainable development (Cowie J., 2007).

Climate change manifests as global warming and sea level rise, changes in rainfall, hurricane frequency and intensity. According to the IPCC (Inter-governmental Panel on Climate Change) Fourth Assessment Report in 2007, the 5$^{th}$ Assessment Report in 2013, the global average temperature has risen about 0.74$^0$C for the period 1906-2005 and the warming trend over the last 50 years is nearly twice that for the previous years. The observed sea level data of 1961-2003 showed an increasing rate of the average global sea level of about 1.8±0.5 mm/year. The satellite data from TOPEX/POSEIDON in the period of 1993-2003 showed an increasing rate of the average global sea level of about 3.1±0.7 mm/year, considerably faster than that of 1961-2003.

Vietnam is a long narrow country consisting of an extensive coastline, two major river deltas, and mountainous areas on its eastern and northeastern borders and is very much exposed to the risks of climate variability and climate change. Its vulnerability to climate risk has given rise to the need for the country to design and implement measures to mitigate the effects of droughts, flooding, storms, and similar events on agriculture and other sectors of the economy. Assessing the potential impacts of climate change and determining how best to adapt represents a new and significant challenge, for which past experience may be a guide, but which, given large uncertainties, requires constant reassessment.

Crop models have the capability to predict crop development and dry-weight grain as affected by the climatic conditions, soil characteristics, nitrate leaching. Crop modeling is becoming an increasingly essential tool in environment management since they can potentially provide quantitative estimates of yield under various environmental conditions and simulate the impact of climate change on yield, water balance and nutrient balance.

There are indeed numerous crop models in the literature, usually designed for particular crops, for example for wheat, ARCWHEAT (R.A.C., Mitchell et al.) and CERES-Wheat (Ritchie, J.T., et al., 1985) while still others are more generic in nature. In this paper, the SALUS model was employed in an experiment for the Red River Delta, the second largest delta in Vietnam. The Red River Delta is chosen for this analysis due to its being representative of other regions in North Vietnam in terms of climate and crop diversity (Singh, 2009). The experimental site covers a total area of 21050, 9 km$^2$ and with a population density which is the second highest in the country at 961 person/km$^2$, second only to the Mekong River Delta in southern Vietnam. Pressure on its natural resources is mounting and this issue poses considerable challenges for food security, raising concerns about the possible impact of climate change at local, regional and national levels. Effective strategies are clearly needed given the diverse threats of future climate change.

The object of this research was thus to test the performance of SALUS-web GIS in Red River Delta by comparison with the true data, for a range of climate change and food crops carried out under different management strategies. Validation of this platform will offer the opportunity to evaluate the effect climate change on crop yield which are the most important for Red River Delta, the second biggest delta in Vietnam, based on the effect of climate variability which can be applied to this model for other regions on whole country.

## 2. Materials and Methods

### 2.1. Study Area

The Red River Delta covers ten provinces (Figure 1), and cities including Hanoi, Bac Ninh, Vinh Phuc, Ha Nam, Hai Duong, Hai Phong, Hung Yen, Nam Dinh, Ninh Binh, and Thai Binh. The delta region is known to be subject to increasing population pressure.

*Climate Change in Vietnam:*

According to the most recent Ministry of Natural Resources and Environment report (MoNRE 2009), and based on the results of studies made by IPCC 2013, data on daily temperature variability, rainfall of seven climatic zones of Vietnam and sea level rise have been collated. This indicates a predicted mean annual temperature rise in Vietnam by 2.3$^{0}$C by the end of 21st century in relation to the average of 1980-1999; both total annual and wet season rainfall are expected to increase. For the entire country, annual rainfall is predicted to increase 5% by the end of 21st century compared to that of the period 1980-1999. Sea level rise is predicted to increase by about 30cm by mid of 21st century and by 75cm by the end of 21st century compared to the period 1980-1999.

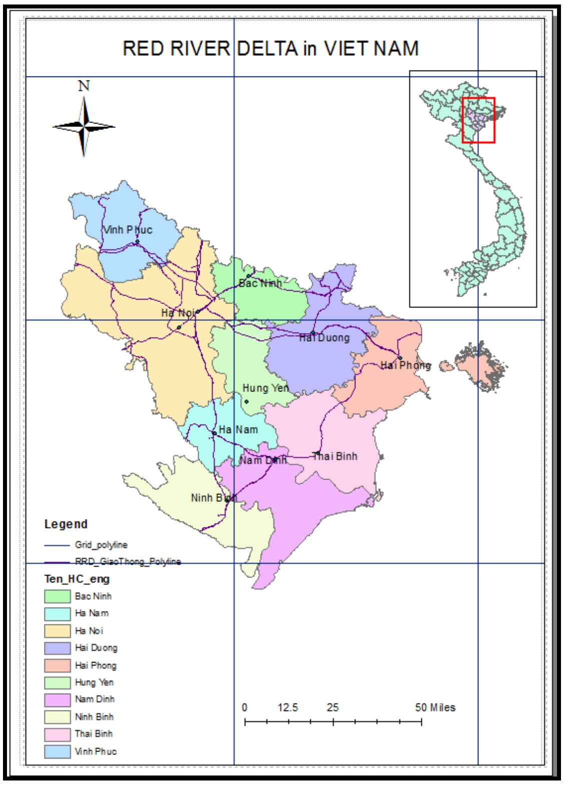



***Figure 1:*** *Map of Red River Delta in Vietnam*

### 2.2. Impact of Climate Change on Agriculture in Vietnam, and its Implication for Red River Delta

The MoNRE scenario falls in the middle of a range of alternative climate change scenarios for Vietnam when these are ordered according to climate moisture indices. The impact of the various climate scenarios on crop production has been explored using projections of runoff, as this influences the availability of irrigation water, as well as agronomic models that consider temperature and rainfall patterns, water availability for rainfed and irrigated crops, and other factors to estimate the impact of climate change on crop yields.

While the country had a rapid rate of industrialization in the last two decades, agriculture remains a major economic sector in Vietnam. Climate change is expected to affect the sector significantly and in a number of different ways.

Table 1 shows that much attention has been focused on the potential impact changes in temperature on rice yield, due to salinization and flooding. The impact of, and adaptation to, climate change on agriculture must also take account of changes in land use driven by other processes, including market prices and globalization. Higher temperature and changes in precipitation amount and seasonality may permit the cultivation of some crops in areas that were previously unsuitable for crop production. The impacts are, therefore, not necessarily all negative but appropriate planning and policy making requires accurate modelling of such potential changes.

***Table 1:*** *Possible Impact of Climate Change on Agriculture*

| Climate Change | Possible Impact |
|---|---|
| Increasing temperature | Decreased crop yields due to heat stress and increased rate of evapotranspiration |
| | Increased livestock deaths due to heat stress |
| | Increased outbreak of insect pests and diseases |
| Changes in rainfall | Increased frequency of drought and floods causing damages to crops |
| | Changes in crop growing season |
| | Increase soil erosion resulting from more intense rainfall and floods |

Climate change, together with sea level rise, affects both rice yields and production. The impacts explored in this study rely upon projections generated by a series of models, from climate models to crop-growth models. The impacts estimated in the analysis are based upon projected changes in climate variables and sea level, so they assume that all other variables. Rice yield declines by 7.2 percent to 32.6 percent, yields of other crops decline by 4.1 percent to 32.9 percent. The largest yield reduction can be with either the Dry or Wet scenarios, depending on crops. MoNRE scenario has the least yield reduction.

The Red River Delta floods frequently and in certain localities flood levels may exceed 14m above the surrounding countryside. Flood control has therefore been vital to the economy of the delta region for many centuries contain the river while at the same time providing irrigation water for rice. This ancient system has sustained a high population density and made double-cropping wet-rice cultivation possible across half the region (Zhenli et al., 2006). The delta has a tropical monsoon climate, and the climate varies among ten provinces with the mean annual temperatures ranges from 18-29°C. The dry season from November to April and the warm rainy season from May to September. The mean annual rainfall: 600-5,000mm, about 80-90% is concentrated in the short rainy season. Vietnam is clearly vulnerable to tropical storms and typhoons, since large populations live in the low-lying Mekong and Red River delta areas. Present day climate extremes and potential changes in the typhoon regime as a result of increased inter-annual climate variability in the future are obvious threats. However, an analysis of the climate regime by itself can not predict the extent to which the population – may become more vulnerable to the impacts of climate extremes so that the analysis presented here focuses on the complex interplay of processes influencing agricultural productivity in the context of climate change and using Red River Delta region as a case study.

## 2.3. Crop Model

Brief overview of SALUS model (Figure 2)

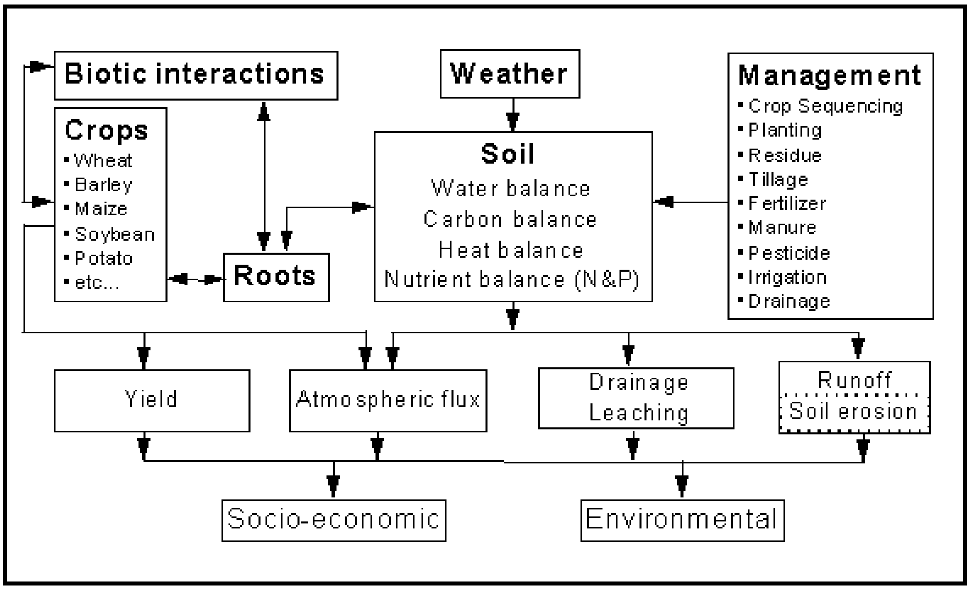



***Figure 2:*** *The Components of SALUS*

The SALUS (System Approach to Land Use Sustainability) program is designed to model continuous crop, soil, water and nutrient conditions under different management strategies for multiple years (Figure 2). These management strategies have various crop rotations, planting dates, plant populations, irrigation and fertilizer applications, and tillage regimes. The program simulates plant growth and soil conditions on a daily basis (during both the growing season and fallow periods) for any time period given known or simulated weather conditions on the days in question. The model allows several different management strategies to be applied simultaneously in a simulation run, in so allowing comparison of the effects of different management interventions on crops and soil under the same weather conditions. This also provides a framework of different areas managed under contrasting management practices that 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 as follows: management practices, water balance, soil organic matter, nitrogen and phosphorous dynamics, heat balance, plant growth and plant development (T.Y. Chou et al., 2011). The water balance component includes 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 sub-model simulates organic matter decomposition, nitrogen mineralization and formation of ammonium and nitrate, nitrogen immobilization, gaseous nitrogen losses and three pools of phosphorous. The development and growth of plants incorporates the environmental conditions (especially temperature and light) to calculate potential plant growth rates which are then adjusted to account for water and nitrogen limitation (T.Y. Chou et al., 2011).

The biophysical sub-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 model (Ritchie et al., 1985) and IBSNAT (Ritchie et al., 1989) family of crop production models that were originally developed for single year, monoculture simulations (Chunzhao Liu et al., 2010). The crop growth algorithms were extracted and restructured into crop growth modules that are linked to the soil water, nutrient and management sub-models. The "C" language was set up in SALUS Model to make the memory allocation more dynamic and program code more platform independent. Maize, wheat, barley, sorghum and millet were shown in the current operational crop growth modules. Carbon consumption and dry matter production are a function of potential rates (controlled by light interception and parameters defining the different-specific growth potential) which are then reduced according to water and/or N limitations. The inputs required for the crop growth routines are the genetic (variety-specific) coefficients and day by day solar radiation as a driving variable (T.Y. Chou et al., 2011).

The soil organic matter (SOM) and nitrogen module is derived from the Century model (Parton W.J., 1996), and a number of modifications incorporated. The SALUS model simulates organic matter and Nitrogen mineralization/immobilization from three SOM pools (active, slow and passive) which vary in their turnover rates and characteristic C: N ratios (T.Y. Chou et al., 2011). There is SALUS model can be downloaded at website http://www.salusmodel.net (Bruno Basso, 2013).

### 2.4. Integrating SALUS Model – webGIS

Integrating SALUS model and webGIS

SALUS-WEBGIS is an integrated system which follows a tight coupling strategy, integrating SALUS model (Karimi et al., 1996) with EasyMap object into a web application (T.Y. Chou et al., 2011). 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 Geographic Information System (GIS) and the simulation models (Chang K.T., 2004).

SALUS-WEBGIS was deployed in a Windows environment, and is built around IIS and the Microsoft SQL Server relational database management system, which was chosen due to its ability to efficiently store, search, and retrieve data in large databases. The user interface was built by using ASP.NET and AJAX technology. The web server receives the requests from the client side and retrieves data from SQL server and maps from EasyMap (designed by GIS.FCU) object according to the requests (T.Y. Chou et al., 2011). The server also provides the KML service that follows OGC standards in generation a KML file compatible with Google Earth to facilitate visualization of the outputs.

SALUS-WEBGIS adopts ESRI shapefile as source of spatial data with geometry type limited to polygons. Polygon features were used to display the spatial variability of simulations. A management practice is called an experiment in SALUS-WEBGIS. Experiments record weather data, soil data and the strategies of cultivation including planting, irrigation, tillage, residues, fertilizer and harvest. Each polygon was linked to a unique experiment. Similarly, the simulation results of experiments were appended to the attributes of polygons (T.Y. Chou et al., 2011).

SALUS-WEBGIS has essentially an identical model kernel as SALUS model, although with some differences. In order to reduce complexity, input data were either reduced in number or set to default values. Output data were reduced because only a few simulation results proved suitable for mapping (T.Y. Chou et al., 2011).

SALUS-WEBGIS is designed to be used by advisors of farmers or agricultural officers and is intended to operate as a tool for precision agriculture. The three main components are a crop growth simulation module, ii) data management module and iii) thematic map module (T.Y. Chou et al., 2011).

The crop growth simulation module is the central controller of SALUS model and receives requests from the client (Figure 3). Subsequently, it lists all features that are selected and then starts to simulate all experiments corresponding to those features.

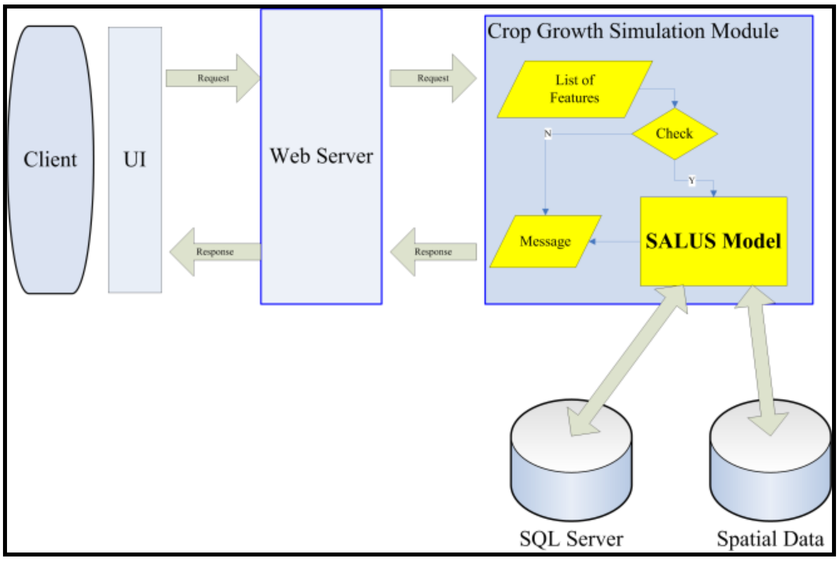



***Figure 3:*** *The Workflow of Crop Growth Simulation Module*

The thematic map module creates thematic maps from the spatial data which were linked to the simulation results (Figure 4). In SALUS-WEBGIS, the simulation results may represent multiple years. The thematic map module can therefore create Time-Series maps of a particular simulation result. After retrieving all simulation results of features, the 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. The choropleth map is published to the web server using Easymap object. Besides the web server, this module also has a KML service that can convert time-series choropleth maps into KML files which are compatable with Google Earth.

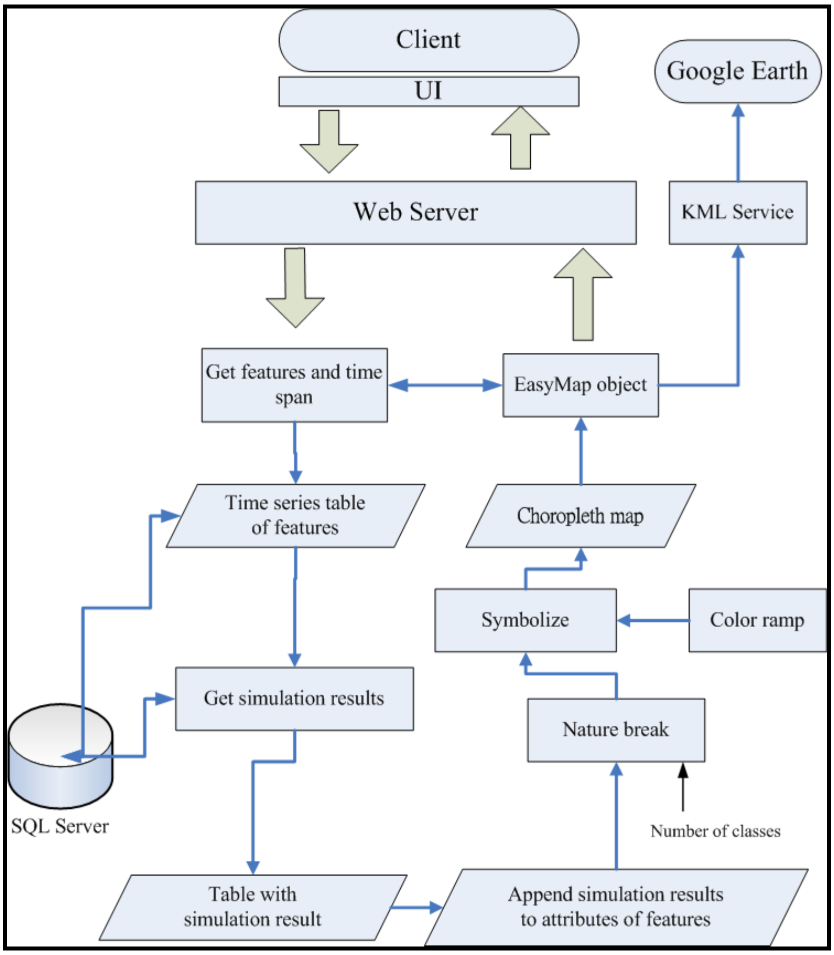



***Figure 4:*** *The Workflow of Thematic Map Module*

## 2.5. The Real Time Input Data

*The System Implementation*

The main page of SALUS-WebGIS is shown as Figure 5 below. There are three services, viz. Project, Map, and Experiment that users can access and utilise. In SALUS-WebGIS, it is not possible for users to run any simulations without maps and experiments. In the Map element, users can upload their own shapefile or digitize the area of interest on Google maps. In experiment element, users (farmers, policy-makers or other stakeholders) can create, edit or the delete an experiment. Soil data and weather data were obtained from the Vietnam Ministry of Natural Resources and Environment, and Vietnam National Centre for Hydro-Meteorological Forecasting with format data (sol or wth) or SALUS format (.sdb or .wdb). After simulating, results can be displayed in a time series choropleth map or chart.

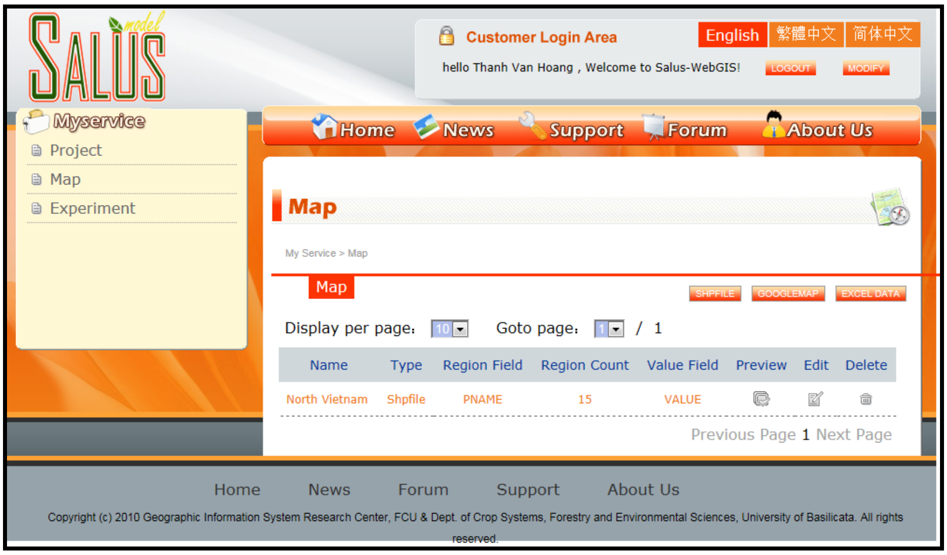



***Figure 5:*** *SALUS-WebGIS User Interface*

## 2.6. Meteorological Data

The soil data, daily weather, including daily temperature, precipitation, sunshine hour data used in this study are sourced from the Vietnam National Centre for Hydro-Meteorological Forecasting over 30 years from 1982–2011. Those data were obtained for seven major meteorology stations in the Red River Delta (Table 2).

***Table 2:*** *Seven Meteorology Stations in Red River Delta*

| | Provinces | Meteorology Station | ID Station | Latitude | Longitude |
|---|---|---|---|---|---|
| 1 | Ha nam | Ha Nam | Hnam | 20.5 | 105.9 |
| 2 | Hung Yen | Hung Yen | Hyen | 20.7 | 106.1 |
| 3 | Ha Noi | Lang | Lang | 21 | 105.8 |
| 4 | Nam Dinh | Nam Dinh | NamD | 20.4 | 106.2 |
| 5 | Ninh Binh | Ninh Binh | Nbin | 20.3 | 106 |
| 6 | Hai Phong | Phu Lien | PhuL | 20.8 | 106.6 |
| 7 | Thai Binh | Thai Binh | ThBi | 20.4 | 106.4 |
| 8 | Bac Ninh | Lang | Lang | 21 | 105.8 |
| 9 | Vinh Phuc | Lang | Lang | 21 | 105.8 |
| 10 | Hai Duong | Phu Lien | PhuL | 20.8 | 106.6 |

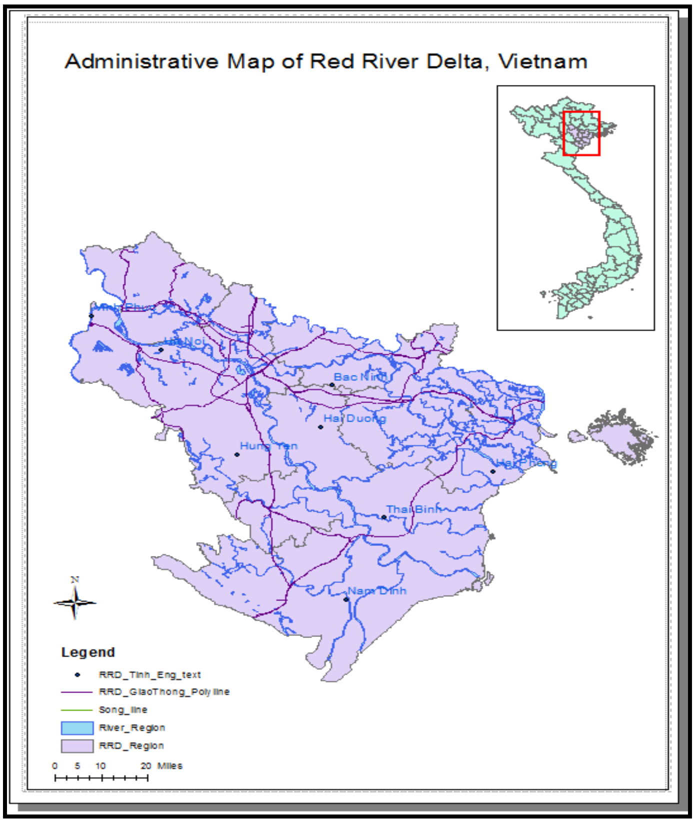



***Figure 6:*** *Location Map*

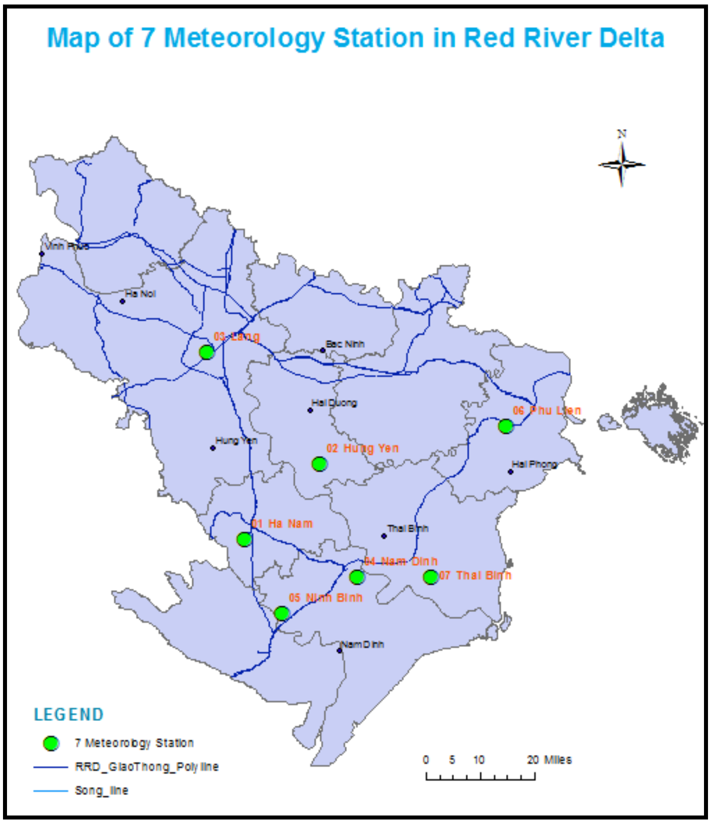



***Figure 7:*** *Location of Seven Meteorological Stations for Red River Delta*

## 3. Results and Discussion

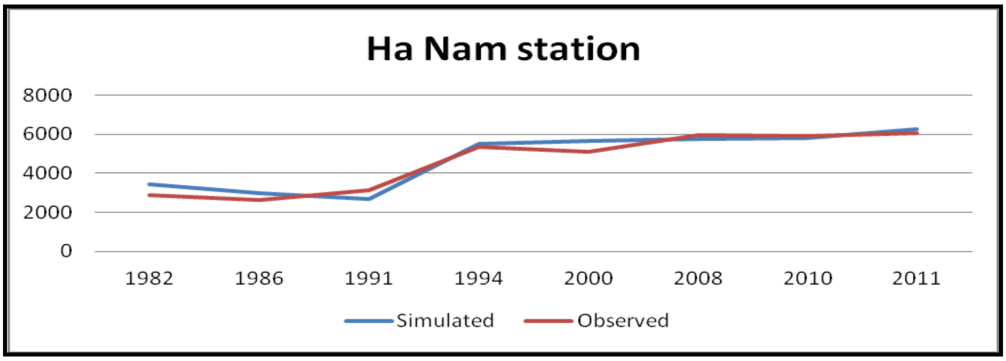
### 3.1. Comparison of Model Simulations with Observation

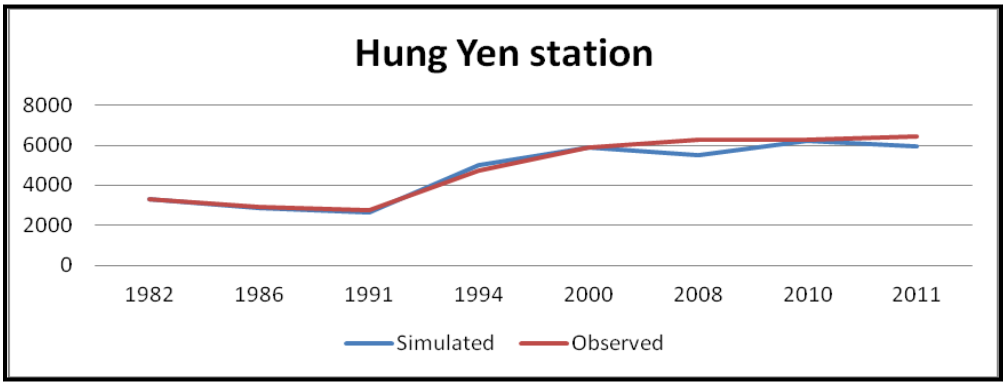
Ha Nam station: Simulated and observed for Rice Productivity from 1982 to 2011.

The SALUS model was used to simulate rice productivity for the past 30 years from 1982 to 2011. A validation model was used to adjust some parameter co-efficient inside the model such as soil, genetic, management, and real daily weather data. We tried to adjust simulation parameters to fit with observed results (Figure 8: Ha Nam station). The outcome shows that simulated results are quite fit with observed one. Hence the model can predict rice yield very well. It illustrates almost the same pattern observed ones. The model can predict for true conditions under different climates and as the simulated rice yield line fits closely to the observed one (Figure 8).

At Ha Nam station, the actual rice yield in 1982 is 2900 kg/ha, after adjusting data the simulated yield is 3436.4 kg/ha. In 2010: the observed yield is 5940 (kg/ha), after adjusting data in model, the simulated yield is 5838 (kg/ha). In 2011: the observed yield is 6080 (kg/ha), after adjusting data in model the simulated yield is 6243 (kg/ha). This process shows that rice productivity has increased during the last three decades, a good trend for the Red River Delta, the second biggest delta in Vietnam.

The reason rice yield increased is due to delta soil. Soil profiles were station specific and represented typical regional soil for rice cultivation. Soil profile data for each station were extracted from the Vietnam Ministry of Agriculture and Rural Development. Red River Delta has high soil quality. Ha Nam station have soil depth with 5 layers, the lower limit of soil water is 0.17 (it means even it is in dry weather, still have 17% of water inside this layer).



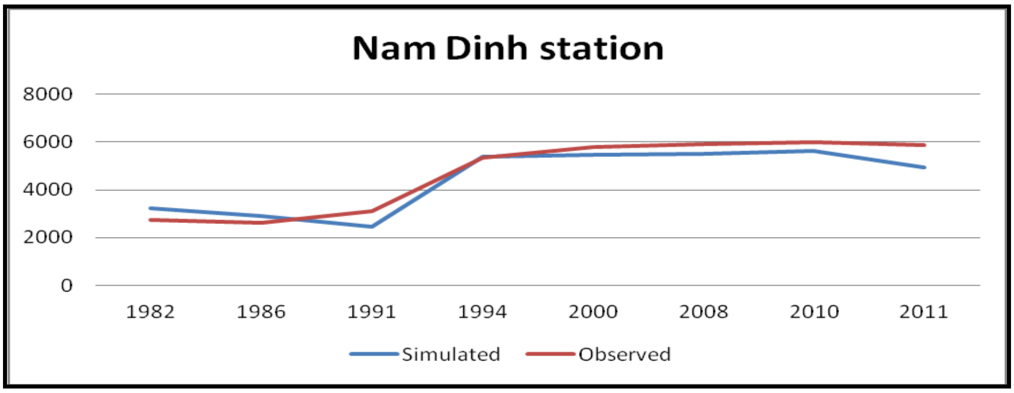



***Figure 8:*** *Observed and Simulated Rice yield from 1982-2011*

### 3.2. Validation of SALUS Model

Rice is the most important staple food crop of the world's population. For each station and rice growing season we used experiment records from one year for model parameters calibration, and the records of several other years for model validation. The experiment records included detailed information on crop phenology, management practices such as irrigation, fertilization, tillage) and crop yield and yield component. Each crop has two crop growing seasons including winter crop, and spring crop. Automatic planting was defined as planting once soil temperature and moisture conditions.

Soil profiles were station specific and represented typical regional soils for rice cultivation. Soil profile data for each station were extracted from Vietnam Ministry of Agriculture and Rural development. We evaluate the accuracy of models by calculating the root mean square error (RMSE) between the observed and simulated value:

$$RMSE = \sqrt{\frac{1}{m}\sum_{k=1}^{m}\left(t_k - y_k\right)^2}$$

Where, $t_k$ is the actual value, $y_k$ is the predicted value produced by the model, and m is the total 31 observed years. In the two validation studies with the CROPSYST model, RMSE was between 383 and 560 kg ha-1 (Bellochi et al., 2002). In the study with the APSIM model, RMSE was obtained from simulated and observed above ground biomas at 1200 kg ha-1. In our study RMSE range from (-1000) to 294. The measure weather data were provided by Vietnam National Centre for Hydro-meteorological Forecasting and from each local meteorological station located about 10-20 km away from the study area. Soil input data (sand, silt and clay content, bulk density, organic carbon and water limits) were determined, to minimize the RMSE values for the complete field and obtain an average percentage difference between simulated and measured values of yield within the stable zone (T.Y. Chou et al., 2011).

The simulation accuracy regarding the soil water contents shows two different patterns. The simulation quality was evaluated using also RMSE obtained from simulated and observed rice yield. RMSE obtained from the comparison of observed yield with those simulated by SALUS model. The grain yield was obtained in the model from a conversion that R2 = 0.8715 the model (Figure 9) shows that the observed data fits closely to the simulated data.

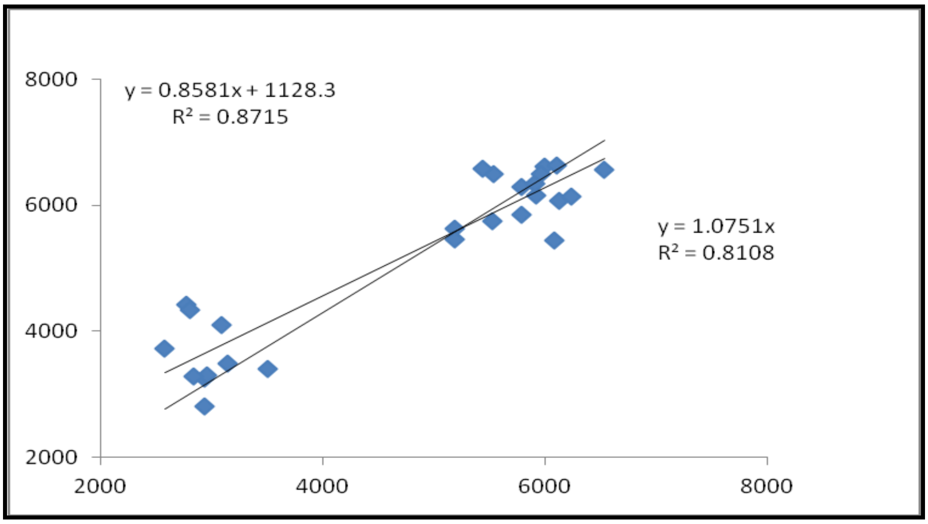



***Figure 9:*** *Simulated with Observed Rice Yield for 30 years*

Using the data in the past 30 years was shown that SALUS model is a very good model to simulate the impact of climate change on grain yield (Figure 8).

SALUS generates precipitation, daily maximum and minimum temperatures, and solar radiation. For each station, we first parameterized SALUS by using daily precipitation data from 1982-2011 as well as daily maximum (Tmax) and minimum (Tmin) temperature and solar radiation data. SALUS helps the users prepare and analyze weather data for parameterization and generation. SALUS model was used to generate 30 years (1982-2011) of daily weather data of maximum and minimum temperature, precipitation, and solar radiation for each station to represent the baseline climate conditions. To evaluate the performance of SALUS, we extracted 30 years of daily weather data, and compared these values with actual daily weather data.

### 3.3. Climate Change Projection in Study Areas

According to International Food Policy Research Institute (IFPRI) 2010, a brief overview of climate change in temperature and rainfall in the Red River Delta, and their projection features on the study stations are presented in Table 3, and Table 4. Those illustrate substantial differences in projected $CO_2$ concentration trajectories. Based on IFPRI 2010 the time series of global warming as projected, changes in temperature in the Red River Delta range from 1-2 degree Celsius, and changes in rainfall range from (-14)–10%, hence we created climate change scenarios for the Red River Delta in this research.

***Table 3:*** *Average Annual Temperature (in degrees) Increase Compare Red River Delta among Agro-Ecological Zone*

| Agroecological Zone | IPSL-2030 | IPSL-2050 | GISS-2030 | GISS-2050 | MONRE -2030 | MONRE -2050 |
|---|---|---|---|---|---|---|
| North West | 1.18 | 2.22 | 0.91 | 1.39 | 0.80 | 1.33 |
| North East | 1.18 | 2.22 | 0.89 | 1.41 | 0.73 | 1.28 |
| Red River Delta | 1.19 | 2.21 | 0.87 | 1.42 | 0.70 | 1.28 |
| North Central Coast | 1.14 | 2.02 | 0.85 | 1.41 | 0.85 | 1.55 |
| South Central Coast | 0.86 | 1.61 | 0.99 | 1.62 | 0.53 | 0.93 |
| Central Highlands | 0.84 | 1.57 | 0.94 | 1.55 | 0.50 | 0.85 |
| South East | 0.81 | 1.49 | 0.78 | 1.30 | 0.63 | 1.03 |
| Mekong River Delta | 0.84 | 1.54 | 0.78 | 1.31 | 0.62 | 1.02 |

Source: Authors' calculations.

***Table 4:*** *Average Percentage Changes in Annual Precipitation Compare Red River Delta among Agroecological Zone*

| Agroecological Zone | IPSL-2030 | IPSL-2050 | GISS-2030 | GISS-2050 | MONRE -2030 | MONRE -2050 |
|---|---|---|---|---|---|---|
| North West | -16.5 | -12.7 | 9.8 | 19.4 | 1.7 | 2.8 |
| North East | -16.5 | -11.8 | 10.5 | 13.5 | 1.8 | 3.0 |
| Red River Delta | -14.2 | -9.2 | 8.6 | 10.1 | 2.1 | 3.5 |
| North Central Coast | -11.9 | -7.0 | 7.6 | 10.0 | 2.2 | 3.6 |
| South Central Coast | -7.8 | -9.7 | 5.2 | 5.7 | 1.6 | 2.8 |
| Central Highlands | -11.0 | -5.6 | 4.3 | 6.0 | 0.1 | 0.0 |
| South East | -10.7 | -5.0 | 5.1 | 6.3 | 0.7 | 1.3 |
| Mekong River Delta | -10.5 | -6.3 | 5.2 | 6.3 | 0.9 | 1.5 |

Source: Authors' calculations.

The scenarios for Red River Delta catchment used in this study are based on two strong changing forces based on temperature and/or precipitation. Scenario from the past 30 years from 1982-2011 follow:

Scenario A: For temperature – plus, minus 1 degree, Rainfall – plus, minus 10%; $CO_2$: 550ppm

Scenario B: For temperature – plus, minus 2 degree, Rainfall – plus, minus 14%; $CO_2$: 550ppm

After adjusting all parameters, we run the model again the outcome from those figures follows:

Comparison of Dry-weight grain among 3 scenarios:

At Ha Nam station:

The outcome of Dry-weight grain is always uncertain as it depends on climate variables. A correlation between achieved Dry-weight grain during the 30 year study period and cumulative irrigation totals during the growing season is evident. The results of Dry-weight grain are compared with observed yield for the years 1982-2011 are presented in Figure 10. The figure shows that every year was 2 crop rotations, and most Dry-weight grain yields are increased. Out of three scenarios, grain yield in scenario B dramatically increased under climate change. Especially in 1984, grain yield in scenario B is increased double than the past 30 years scenario, from 3343 to 6503 kg/ha.

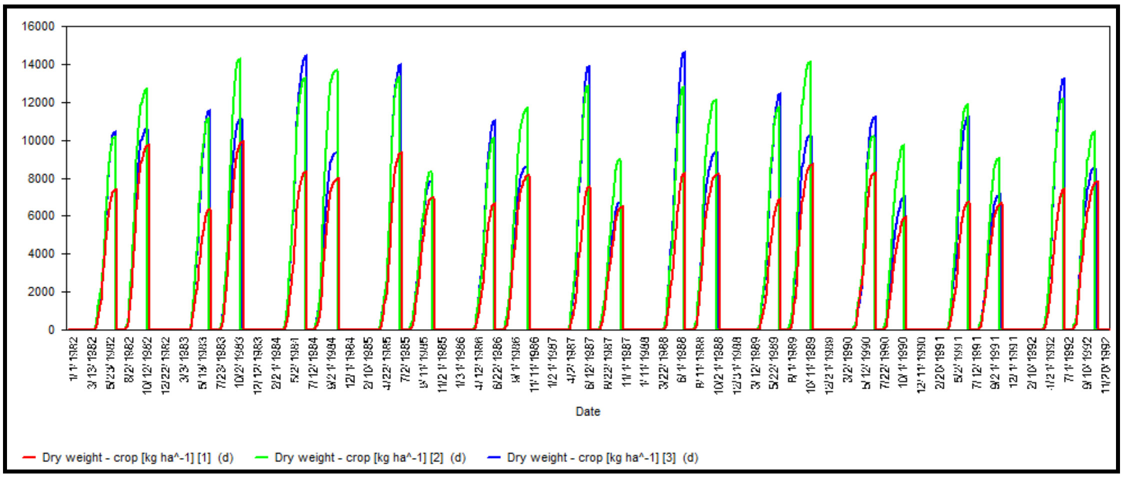



***Figure 10:*** *Dry Weight-Crop in Ha Nam Station from 1982-1992*

Ha Nam station: The figure shows that cumulative irrigation.

The simulation results of the SALUS model estimating the effect of the conventional tillage, minimum tillage and no tillage on carbon loss from the soil surface as carbon dioxide ($CO_2$) are presented in the figure below (Bruno Basso et al., 2006). The no tillage clearly showed a reduction in C losses through $CO_2$ as expected due to lower soil mineralization and higher accumulation of organic matter. The Figure 11 shows that the no tillage treatment sequestered in the soil about 20000 kg ha-1 of carbon compared to the minimum and conventional tillage treatment in the simulated period of 30 years. There were no significant differences. Tillage practices were observed between the two tilled treatments. Tillage practices disturb soil structure lead to fracturing which increases the movement of $CO_2$ out of the soil and oxygen into it (Reicosky et al., 1995; Lal, 1997; Lal, 2004a). In this study, the reduction of $CO_2$ emission in the no tillage systems converts into an increase in carbon storage which builds organic matter and long term productivity.

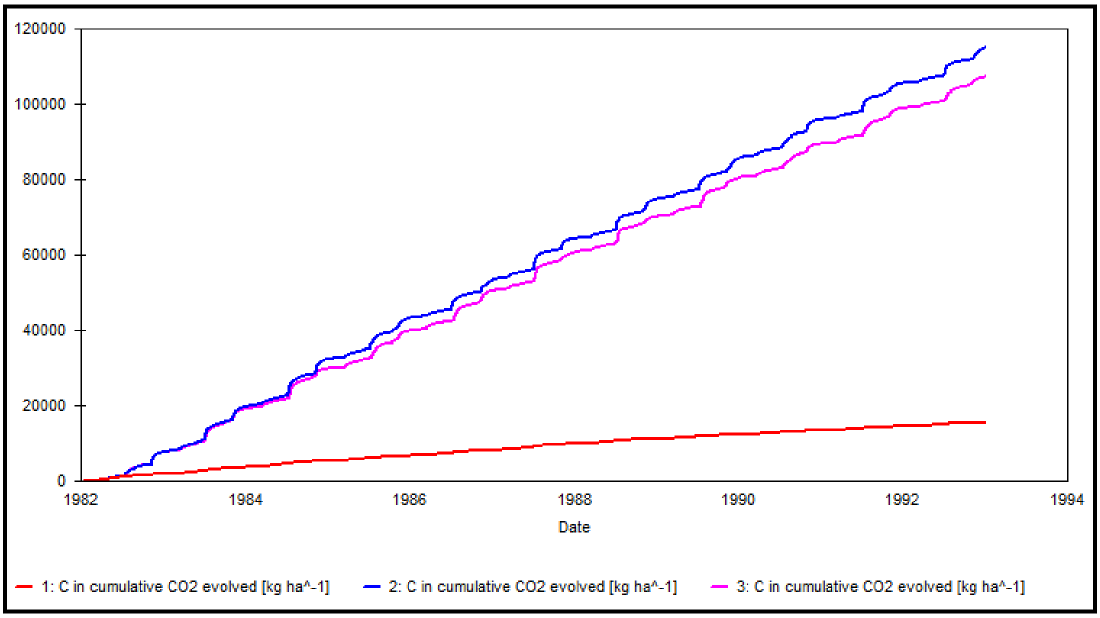



***Figure 11:*** *Simulated Carbon in Cumulative $CO_2$ Evolved from a Loamy Soil under Different Tillage Systems (Ha Nam Station, Red River Delta, Vietnam)*

### 3.4. Water Use

In this context water resources will play a key role as crops and livestock need a lot of water to grow (WWAP, 2012). Irrigation plays an important role, but in the past, irrigation areas have varied across the different countries. Climate change will have a particularly strong impact on water resources. The most direct impact of higher temperatures and drier periods is the decrease of soil moisture and thus a decrease of the water availability for plants. An increasing demand of irrigation water might consequently contribute to increased competition for scarce water resources. The outcome shows rice yield in Red River Delta, and carbon in cumulative $CO_2$ evolved are also increased, it is good for agriculture productivity but it means pressure on future water demand and availability in Red River Delta may increase.

In Vietnam, Red River Delta is the second biggest delta, and there is an urgent need to understand the dynamics of the local climate and make predictions to respond to climate variability and change. Climate change is a serious problem in Vietnam, and a serious challenge to social and economic development in developing countries such as Vietnam.

## 4. Conclusion

The results from the study suggested that the effect of predicted future climate change on rice productivity can be determined using the SALUS model together with GIS platform. Climate changes pose severe challenges to the adaptive capacity of rural households and communities and, given that - Vietnam is one of the country's most vulnerable to climate change. It is important to try and understand how these ways vary from region to region according to the type of agriculture. The SALUS model proves quite successful in quantifying climate change impacts on agriculture farmland in the Red River Delta of northern Vietnam. Results of the experiment establish that such maps can show the spatial variations in the impact of climate change and $CO_2$ emission on rice production in an agricultural context. With sufficient data, the SALUS model can be used to simulate these elements for entire countries.

Based on the results of this study, yield changes vary widely across crops and agro-ecological zones under climate change impact. $CO_2$ emission should theoretically tend to increase yields and can play a positive role in plant growth. Recognizing potential impacts of climate change, the government of Vietnam recognizes the potential impact of climate change on its agricultural economy and has developed a legal framework for sustainable development and climate change that includes policy instruments and energy efficient strategies for agriculture. The SALUS-WebGIS tool can assist decision makers in understanding the applicability of various management practices to relevant regions.

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