Asia-Pacific Network for Global Change Research

Agriculture Land Use in East and South Asia-Rapidly Changing Landscapes and its Impacts on Regional Food Security

Final report for APN project: ARCP2006-04CMY-Rajan

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Final Report submitted to APN

Overview of project work and outcomes

Non-technical summary

Agricultural Land use changes have been influenced by both the natural variability in the climate, water and soil changes; socio-economic factors like markets; and the cropping practices. Of this the influence of the anthropogenic causes have been the most significant in the last few decades, moving towards intensive irrigated cropping practices. In addition, it is anticipated that the climate changes in the near and mid-term can cause further impact on these cropping systems. In this project, we have simulated the crop yields of the state of Andhra Pradesh in India and Hefei, Anhui Province in China for the period of 1990 to 2025 for the changed climatic scenario. Future climatic input was from the MIHR climate model for the SRES B1 scenario. The Mod-EPIC model should that the winter (Rabi) season crops will show no change or increasing yields, while the impact on summer/rainy (Kharif) season, mainly on rice will be marginally lower yields. Also, the research identified the gaps in the data and how it limits the utility of the models. Also, there is a need to improve the modelling framework to incorporate feedbacks between crop yields and land use changes.

Objectives

The main objectives of the project were:

1. Model the crop growth and simulate the yields of the recent past (1990-2000), to validate the model
2. Understand the impact of climate change on the major crop yields and its impact on the food production in the region
3. Understanding of the land use characteristics in the region -biophysical potentialities and socio-economic conditions

Amount received and number years supported

1. 2005/06: USD 24,000
2. 2006/07: USD 22,500

Activity undertaken

1. Review of the crop model (Mod-EPIC) used in the AGENT-LUC model
2. Creation of a Geodatabase for running the crop model – climatic, soil, elevation, land use map; and socio-economic assessment for the regions of our interest
3. Discussions on how to improve the model and make it available to other scientists
4. Crop Model simulations for estimating yields till 2025 in the 5 major crops in Andhra Pradesh, India and 2 cereal crops in Anhui, China.

Results

Mod-EPIC model, the modified and readapted EPIC crop model, was run for a period of 1990 to 1999 and 2001 to 2025, to get the crop yields of the different crops that have been choosen for this study. The 1990 to 1999 period was used to verify and understand the crop dynamics in the respective study regions and make suitable modifications to the crop parameters to get yields that are similar to the reported yields in these regions.

The model simulation showed that the crops – cereals and pulses grown in the Rabi (dry/winter) season in India will marginally benefit and the yields can be 5 to 10% higher than the current ones, while for the Kharif (rainy) season, yields will marginally drop for Rice and other crops.

Relevance to APN's Science Agenda and objectives

This work explored the possibility of simulating the crop growth and the land use pattern in the agricultural areas of India and China. Also, it was one of the few projects on land use that looked at the socio-economic factors as an integral part of the study and was able to identify a set of actions that can help improve modelling. It also has strong links to the Human Dimension of Global Change and LUCC/GLP programs. Also, the project has been successful in linking the researchers of China and India, with very different systems, in such a venture of interdisciplinary modelling effort. This work was able to show what modelling can do, and helps APN's efforts at promoting that.

Self evaluation

Such International cooperative research is a challenge in itself in bringing the collaborators to work together to a common goal, especially when they have been following different approaches. I should thank APN for making this possible and also constantly managing it effectively. In this work, we were able to create a good database of relevant data, modify the EPIC and recode it into Mod-EPIC model and evaluate the crop yields in the near future. One sticking point is that we were unable to complete the land use modelling part due to lack of relevant data, even after interactions with experts, since very little quantitative data is available to derive the relevant land use output.

Potential for further work

There is a need to extend this work to understand the dynamics of land use change in the changed scenarios of crop yields due to climatic changes and changes in economic value of the crops, and assess its impacts on land productivity, crop pattern changes, out migration from rural areas and such related human-land interactions. Also, there is a need for systematic data collection and repository building – a major hindrance to development and application of models. The current model needs to be applied to a larger region and see the interactions between the different sub-regions, if any of them is constrained and also see the shifts in land use that this can induce.

Publications

Early efforts were presented at FAO, Rome in Jan 2006 during a LCCS workshop
Crop simulations for different SRES scenarios will be compared and effots will be made to publish it in Current Science (Indian journal) and other journals like Ecological Modelling.

Acknowledgments

(1) NRSC, ISRO Hyderabad is acknowledged here for proving the classified land use maps of 2004-05 for the study region.
(2) We thank APN for providing us with the support to carry out this research work and facilitating the cooperation with multiple institutions.

Technical Report

Preface

Agricultural land use depicted as the cropping practices needs to be understood for not only climatic impacts leading to decrease or increase in yields but also to understand the changes from one crop to another have on the local and regional environment. Modelling provides us with a framework to evaluate these conditions and the possible outcomes. In this project, the major crops grown in select regions of India and China will be simulated for the recent past (1990-2000) and future (2000-2025) to study its impact on the overall production and food security of these regions.

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1.0 Introduction

Agricultural landscape has been changing quite fast in the last four decades, since the start of the green revolution, leading to intensive use of the land for food production. In India, China and other parts of Asia, this growth has come from Irrigated fields leading to multiple cropping in the same parcel of land, increased inputs like fertilizers, and macro-economic policies of the regional or national governments. In spite of all of these, there are large variations in the crop yields owing to not only the eco-climatic characteristics of the regions but also to the choice of crop varieties, water resource constraints, and crop practices in these areas. For example, within the Indo-Gangetic plain the productivity ratio of east to west is $2/5^{ths}$ leading to more than thrice the poverty levels. Also, the recent economic development in combination with the population (additional 500mil in next 20years, UN estimates) has and will cause rapid change of land use structure and pattern ranging from further input-output intensification in the agricultural fields, shift to commercially more important cash crops, land abandonment due to rapid degradation, etc. In a complex way, these changes interact with biophysical characteristics and have aggravated the environmental concerns – soil degradation, land salinization, erosion and groundwater depletion; thus proving as obstacles to regional sustainable development. In the last couple of years, it is increasingly being recognized that land use and land cover changes (LUCC) contributing upto $1/3^{rd}$ of the GHG emissions and climate change leading to the IPCC incorporating LUCC as one of the major factors of human-environment interactions. There is an urgent need to understand the land use patterns and the processes that drive them, along with capacity building efforts for better macro and meso-scale policies that can effectively manage these towards sustainable development. In addition to understanding these processes, there is also a need to simulate these changes and study the possible impacts due to climate change in the near future, necessitating the need for development and application of crop production models and use them further in land use models. These models can then provide a good support to the framing of good policies for sustained progress and not resort to blanket macro-level policies that disturb the practices on the ground.

Agricultural Land use changes is a complex interaction of the natural biophysical processes with the socio-economic characteristics of the corresponding regions and can exhibit itself in many different ways, though it is measured as only the cropping practice of the land parcel. There have been various types of land use models ranging from statistical models to agent-based models, at coarse national scales to very local scale (one or more villages) models, and top-down to bottom-up approaches. Most of these models are data-hungry and depend on a large set of parameters. In addition, since the main constituent of agricultural economy is the crop yields, any futuristic simulation of the agricultural landscape needs to model crop yield outputs.

1.1 Main Objectives

In this project, the main effort was at building a framework for modelling the agricultural land use patterns in select regions of India and China. The focus was on (i) simulating the crop yields of the recent past to the year 2030; (ii) understand the climate change impacts in these regions using IPCC AR4 data; and (iii) to study the possible land use changes that can occur due to the changed yields
In addition, the research focused on identifying critical gaps in data, information and policy that are essential in such studies.

1.2 Case Study Regions

India – State of Andhra Pradesh

The state of Andhra Pradesh (see Fig. 1) was choosen for this study, since it is one of the leading agricultural areas in India and is part of the rice bowl of the country. Also, the main sector of the state is Agriculture, which employs almost 70 percent of the state's population. The other important crops are sugarcane, oilseeds (groundnut), and pulses (green gram, etc). It is spread over an area of 275,045 sq.km and has two major river basins – Godavari and Krishna, which irrigate around 6 million hectares (14.8 million acres) of farmland, the large parts of which grow rice and other crops in these irrigated lands.

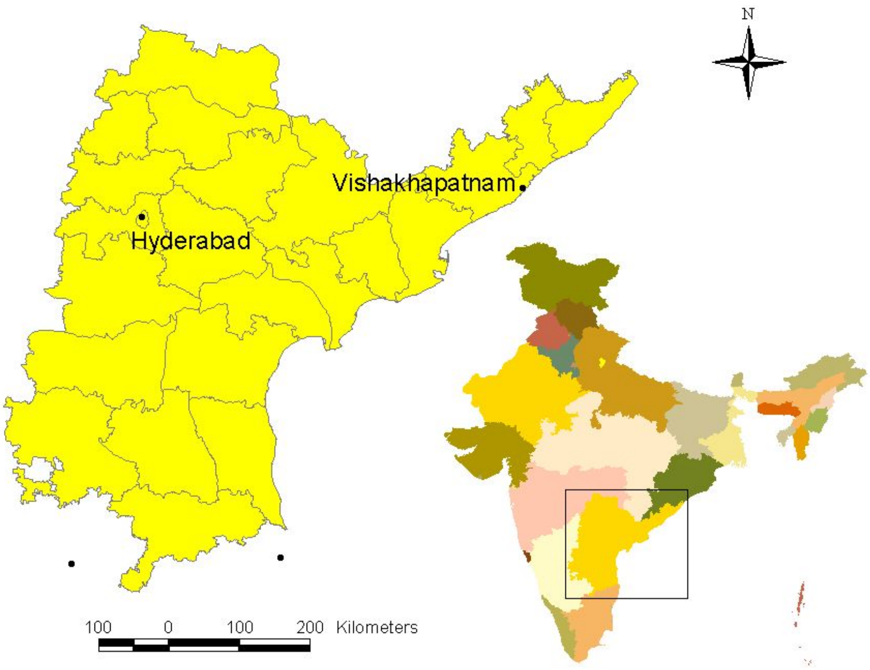

Figure 1. Map of Andhra Pradesh, and India (inset)

China – Anhui Province

The region in and around the Hefei city has been choosen for this study (see Fig. 2). Though it is the provincial capital of Anhui province, it does still have large migrant population and agriculture is the main economic function. It has an area of around 7,266 sq.km. Anhui province is one of the major winter wheat growing areas of central china during the months of October to May. Rice is also sown in this region, once a year during the early part of May.

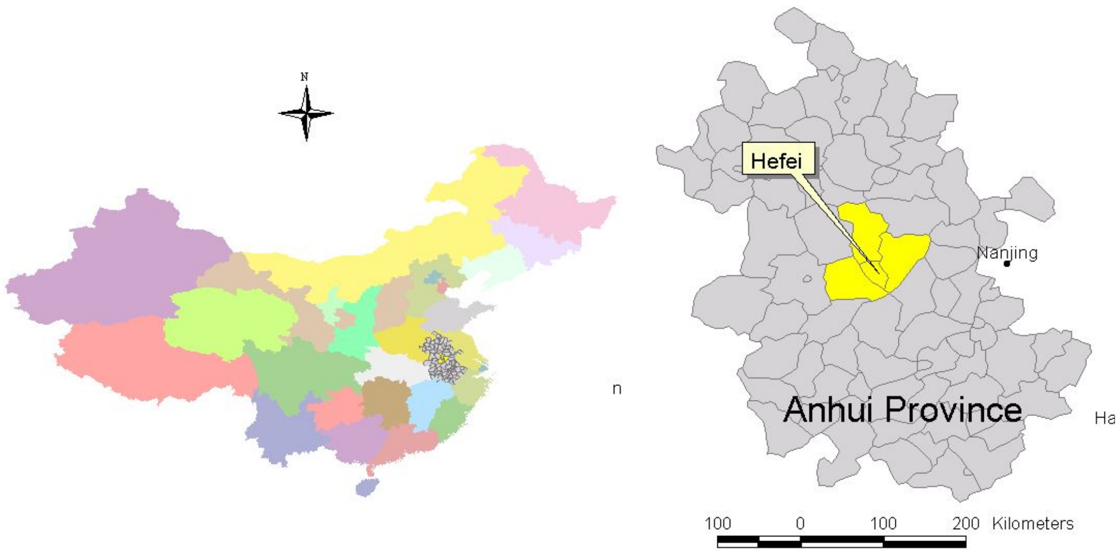

Figure 2. Map of China (left) and Anhui Province (right)

2.0 Methodology

The research framework consist of mainly the adaptation of the in-house modified crop model and simulation for the eco-climatic conditions and its further use in a land use model within the limited data availability conditions in these regions on socio-economic characterization at the micro and meso levels. Though, relatively macro level information is available, it did pose a challenge to convert and extrapolate this information to the spatial simulation scale of 1km x 1km square grids. Some of these challenges are highlighted in the model modifications that have been applied here.

2.1 Choice of IPCC AR4 Model

To understand the impact of changing climate in these major agricultural regions of the two countries, the crop models were run till the period 2030. The climatic parameters were taken from the IPCC AR4 simulated results for Asia. The research deliberations within the collaborators were centered on which GCM model to use and it was narrowed down to the following –

(i) UKMO-HadCM3 of the Hadley Centre for Climate Prediction and Research, Met Office, UK

(ii) MIHR and MIMR - These are the two models developed jointly by the CCSR (Center for Climate System Research, The University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC), Japan. MIHR stands for the High resolution MIROC3.2 model, while MIMR is the medium resolution model.

After checking through the variables of the GCM outputs and checking for the spatial resolution provided by them, it was decided to choose the MIHR Model outputs for the crop yield simulations. The data and its characteristics are listed in the later database section. The MIHR GCM results were monthly values for the different variables and these were then converted to a quasi-daily time-step to suit the adapted crop model.

2.2 Crop Yield Modelling

Simulation models describe the dynamic processed of the system that is modeled. Most of these crop models are based on the current knowledge and insights from different areas including crop physiology, agro meteorology, soil science, agronomy, and phytopathology, to make dynamic simulations of crop growth. There is considerable literature on the different types of crop models, their applicability and utility for a region, the kind of data they need on the crop parameters, weather variables, crop management practices and others. Models like ORYZA 2000 (IRRI, Wageningen University and Research Centre (WUR) 2001) for Rice are crop specific models; while CENTURY (Parton et al. 1987) is more of a grass-crops model; while others like CROPWAT (Smith 1989) cater to water budget and irrigation management.

In the research work carried out here, a modified version of the EPIC model (Williams, 1989), viz., Mod-EPIC, has been used to simulate crop productivity in the selected case study regions. EPIC (Erosion Productivity Impact Calculator) is widely used as simulation model for crop productivity and environmental impact. Initially, the Epic model was developed in 1981 to support assessments of soil erosion impacts on soil productivity for different soil, climate, and cropping conditions. Gassmann et al., (2005) discuss the various applications of the EPIC model. The primary advantage of EPIC over other crop models is that it allows for modelling around 80-odd crops including tree crops and uses close to 50 parameters for describing the crop and its growth characteristics. This reducing the complexity of fine tuning multiple models depending on the crop varieties in use in a particular region and helps deploy the model for regional scale studies. It has to be noted here that the grid size of 1kmx1km has been choosen keeping the EPIC models basic character – since it was developed from field based studies, it has been recommended not to use the model for fields larger than 100 Hectares. The framework of the EPIC model adopted is shown in Fig. 3.

2.2.1 Modifications to the Crop Model – *Mod-EPIC*

The EPIC Crop modelling framework allows for studying the variations and impacts on the local environment based on a multitude of factors ranging from crop parameters to soil and weather parameters to the crop management practices that are followed by the farmers. The model's applicability at the farm level is well established by numerous studies, and some attempts at applying this model at higher spatial scales of sub-basins or basins (Terrafusca, 2006) and state level (Priya, 2001) have been done. In most of these studies the various parameters are fine tuend repeatedly to achieve the statistically significant results.

In this work, we have adopted a slightly different approach. Since one of our aims of modelling the crop yield is to later use it in a land use model, the differential yields and hence the agricultural revenues needs to be well correlated. So, instead of focusing all efforts at collecting rather detailed estimates on input variables other than eco-climatic parameters, the approach is to use *yield-factors*. Also, since changes in climate and its impact on the crop is being studied here, the stresses induced by them have been given importance in this approach, as can be seen from Fig 3.

What are yield-factors? Many crop parameters like the potential heat units, length of growing season, crop height and root zone penetration are depended on the crop cultivar like High yielding variety (HYV) or Short high yielding variety (SHYV) and the sensitivities of these to the various bio-physical parameters. If the spatial variability of the sowing of these different varieties is known in a given region, then that can be incorporated by changing the crop parameters like Biomass-to-energy ratio, harvest index, etc suitably or generating spatially (regionally) explicit crop parameters, which can then be used in the model. But, in reality, when analyzing an area of the size of a district or province, a large variety of cultivars are used ranging from traditional ones to HYVs and SHYVs. To overcome this, we have developed and used the *yield-factor* which will suitably help enhance or reduce the yields at each grid depending on the overall performance at the lowest administrative level at which data is available from which an inference of the cultivar can be made.

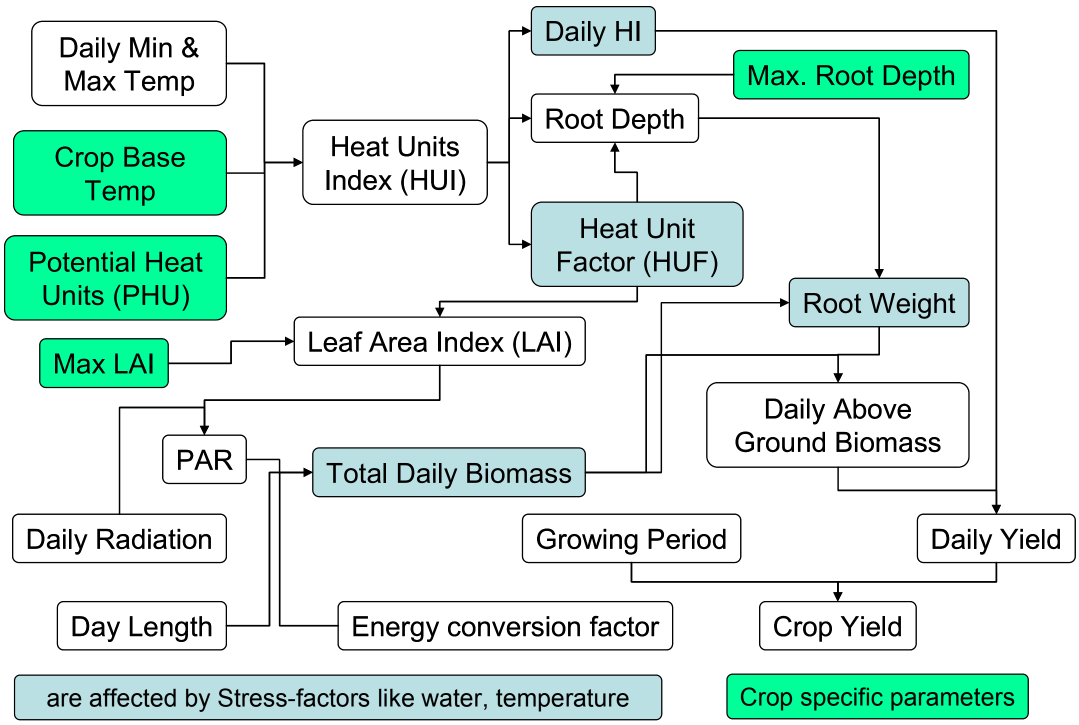

Figure 3. Framework of the Bio-Physical Crop Yield Model
(based on the EPIC model)

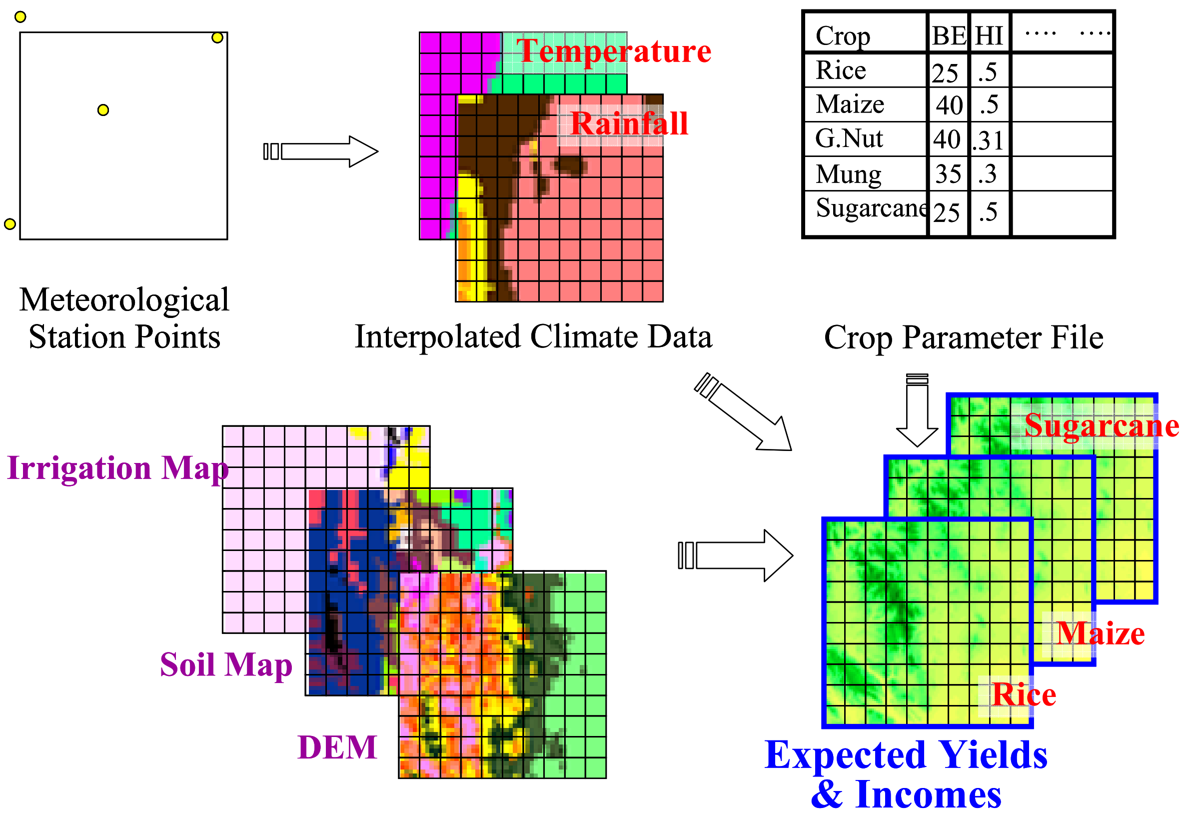

Figure 4. A Schematic representation of the Crop Model Inegration – GIS raster model approach. Each square represents a square grid of 1km by 1km

Fig.4 shows the schematic representation of the different datasets and the pre-processing of the data (for rainfall and temperature) that was done and the flow of the crop model integration with the inputs and grid-wise yield data that it generates.

2.2 Land use Model

Land cover changes, through different land use practices are needed to be understood for understanding the processes of human-environment interactions. In this work, the AGENT-LUC model (Rajan and Shibasaki, 2000) has been applied to understand the effect of crop yield changes on the agricultural land use. The model is an ABM, where the *agent* (farmer or land owner) makes a decision based on the biophysical characteristics of the specific lot of land (grid) and its economic potential (based on the macro-economic information) within the existing demographic conditions at a given point in time, in arriving at the choice of the land use (see Fig 5.). The land use outcomes are simulated annually at a spatial resolution of 1km square grids. The inputs to this model ranges from spatial data of current land use, crop yield maps elevation; to non-spatial data of farm gate prices, economic progress, and other input costs. As the model considers the agent behaviour explicitly and at the same time considers the different drivers to landuse, the model can also be used to understand the human responses to the changes in the environment.

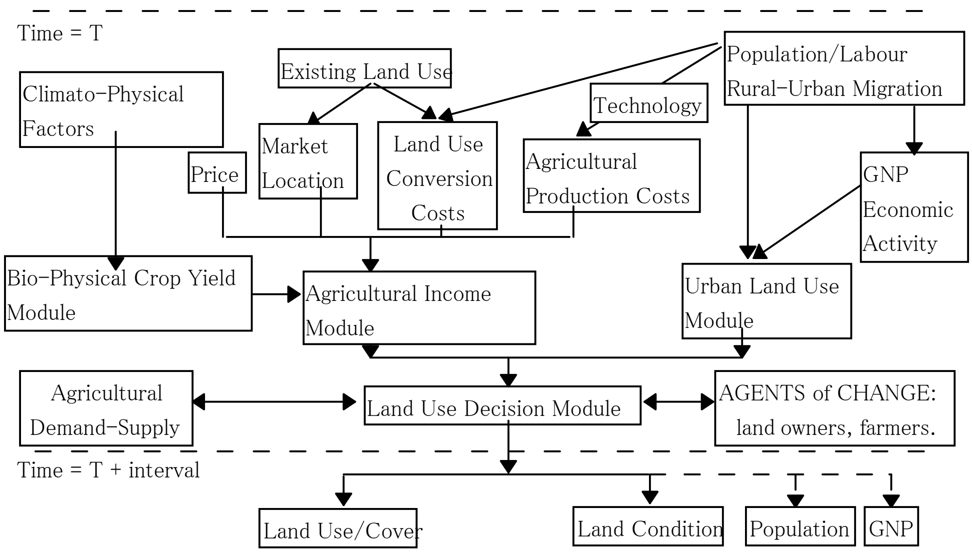

Figure 5. Simplified Framework of the AGENT-LUC Model

One of the important characteristic of the AGENT-LUC model is to consider the rural economy as one that is larger than just the agricultural revenue (= yield x price) and inclusive of all other on-farm and off-related sources of income. This is important since the Model assumes that Land use extensification is driven primarily by the relocation of populations or migrations, which is also simulated in this model. The migration is an outcome of dwindling rural incomes and the promise of the urban lands of higher incomes. The estimates for the later are difficult and a proxy variable of per capita GDP and its changes are considered in this model.

As large amounts of data are needed to be managed and processed for such a model, a Geo-database was created and GIS was extensively used as the platform for managing and visualizing both the input and output data.

Limitations to the Model application
Apart from the crop yield based income, a difference sum between Agricultural revenue and the costs of production, it is also important to know the other economic activities and map them to the same spatial resolution for use in the model. The efforts at collecting the economic activities data at the local administrative level of village or sub-district was almost not possible in the study regions that we choose, even after repeated attempts at it – indicating a major gap in the data for the model. Also, another limiting factor is the lack of clear data on the agricultural inputs, and cultivars used in the different regions.

Thus in this project, though the feasibility of running the land use model was evaluated, the application and derivation of the land use outcomes based on the climate induced changes to the cropping practices are difficult to implement. This has been the difficult part of this research project.

2.3 Database Development

As part of the project, the various datasets that are needed for the two major models that drive this work was collected. Table 1 shows the types of data, its characteristics and outcome of the data collection and processing exercise.

The salient features of the Geodatabase are as follows –

1. Spatial resolution: 30 arc sec square grids (~ 1km by 1km grids)
2. Projection: Geographic
   Since the data came from multiple sources and the important datasets like climate (GCM outputs) were all referenced with Latitude and Longitude values, all the other data were projected into geographic coordinates.
3. Global vs local sources: since the model is being applied in India and China, wherever possible the global datasets were used instead of the local data sources to provide a level of consistency.

Table 1. The contents of the Geodatabase

Type of Data	Data Characteristics (min. requirements)	Remarks, if any (source, limitations, etc)
Biophysical Data		
1. Climatic data (a) Precipitation (b) Temperature	Need daily or monthly totals of the rainfall; Temperature - need both Min. and Max. temperature on a daily or atleast Monthly data If not, these are generated form the mean temperature dataset.	Terrestrial Air Temperature and Precipitation: Monthly and Annual Time Series (1950 - 1999) (V 1.02) was used for 1990 to 1999. http://climate.geog.udel.edu/~climate/html_pages/download.html#lw_temp Resolution: 0.5 degree by 0.5 degree For the 2001 to 2030 period : GCM climate outputs were obtained from the IPCC AR4 Data distribution centre http://www.mad.zmaw.de/projects-at-md/ipcc-data/ Resolution: varied MIHR had a x-interval of 1.125

		degree while y was based on the Gaussian projection used
2. Soil Data	Soil Surface Characteristics including Proportion of Sand, Silt and Clay, along with the Soil type	Global Gridded Surfaces of Selected Soil Characteristics (IGBP-DIS) CD-ROM It has a spatial resolution of 5x5 arc-minute, is coarser than our model run, but is the only spatially explicit data available http://daac.ornl.gov/SOILS/guides/igbp-surfaces.html
3. Irrigation Map	Used to determine whether there is water stress	The paper map available for India was at 1:4million scale, but was not recent enough to be used. IWMI's Global Irrigated Area Mapping Project's output was used, though it is at a coarser resolution of 10km.
4. Elevation data	Atleast 1km DEM data is needed	GTOPO 30-arc sec dataset http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/gtopo30_info
5. Landuse data	1km resolution data or digitization of scales higher than or equal to 1:1million	- USGS 1990 Land cover map - GLC2000 Land cover dataset - Land use and Land cover Map of India for the periods 2004-05 and 2005-06, from NRSC/ISRO. Extracted the state of AndhraPradesh, and was reprocessed to match this project needs
Crop Related		
6. Crop Parameters	Parameters like Biomass to energy ratio, harvest index, potential heat units, and other 20 are needed	Most of the parameters have been adapted from the EPIC program inputs parameters table. Since most of the study region use HYVs and SHYs, the BE ratio and the HI have been suitably modified to get a base yield matching the regional cultivars, biophysical characteristics and crop management practices
7. Crop Calendar	This data is needed at the lowest possible admin boundary levels for the crop choices made in these regions.	This data is mainly used to develop a statistically consistent base map of land use which reflects the cropping practices in

		the region, from the land cover data. Also, this pattern is used in the model to determine the possible choices and changes in land use practices. India:Andhra Pradesh – this was prepared based on expert knowledge and agri statistics China: Anhui – based on field observation data
8. Agricultural statistics of the region	Crop harvested area and yield	This data is used to compare the crop model outputs and improe the known and unknown parameters, to the extent possible.
9. Price for crops	This refers to the farm gate price and not the crop retailer price.	Used in the Land use model to determine the agricultural revenue
10. Costs of Production	The input costs incurred for buying seeds, fertilizer, pesticide, machinery, water, labor, etc., at the lowest administrative level is best.	The data availability varies a lot from region to region and depends on the data collection agencies. Mostly available at the aggregate level and some disaggregate data. This Non-spatial data is then categorized into - a. Fixed cost – land rent, etc b. Variable cost based on land size c. Variable cost based on Yield
Socio-Economic data		
11.Administrative boundary map at county level / sub-district level	The boundaries used should match the Census data boundaries	Used primarily as an area mask in yield calculations and for studying the aggregate response
12. Population data including age structure	Need population data at the lowest administrative level in different age groups, atleast divided at an age threshold of 40yrs. In addition, if the Urban-rural breakup at local administrative units, if available is useful	Initially, this non-spatial data is converted into a population distribution map. This base population map is then used to study the migration pattern and the population changes at each grid. The post-2000 data is from the IPCC SRES scenario.
13. Household economic activities data	Data should contain the breakup of the sources of income at the lowest	In the land use model, this is used to calculate the entire income of the landowner or tenant farmer. Helps to take into

	possible boundary level.	account the multi-source income besides farming that helps the agriculture in many regions
14. GDP or GNP data	At equivalent per capita values either in the local currency or USD	Available only at the national level, used as an index of affluence and determines the attract ability of the urban centers. The post 2000 data is based on the IPCC SRES scenarios.
15. Road Map	At 1:1mil spatial resolution or better. If possible the class of the roads may also be marked	Has been used to derive the time-distance maps, that help in crop transport costs estimations (mainly for cash crops). Also, is an important factor in the modelling of spatially explicit urban expansion, where accessibility plays a more important role in land use change. DCW derived road maps have been used here.

3.0 Results & Discussion

3.1 Crop Yield Simulations

Mod-EPIC model, the modified and readapted EPIC crop model, was run for a period of 1990 to 1999 and 2001 to 2025, to get the crop yields of the different crops that have been choosen for this study. The 1990 to 1999 period is used to verify and understand the crop dynamics in the respective study regions and make suitable modifications to the crop parameters to get yields that are similar to the reported yields in these regions. Once these parameters were obtained then the model has been run for the IPCC GCM climate variables to see the changes in the yields of these regions.

3.1.1 Andhra Pradesh, India

The agricultural practices in the state of Andhra Pradesh in India, is primarily influenced by the Monsoon system and hence the crop year, different from the calendar year, starts from early or mid June and last till the end of May of the following year. The most important crops in the state are Rice (45% in both the seasons), Maize (15-16% in both seasons), Pulses (15% in Kharif and 30% in Rabi), and Groundnut (23% in Kharif and 9% in Rabi). Though Sugarcane is only around 3% of the total cultivated area, in Vishakapatnam, Chittoor and West Godavari districts it is grown in 15-10% of the area and has been reported to be increasing. We have considered sugarcane as the Cash crop, while Mung represents all the Pulses and Groundnut the oilseeds that are grown in this state. (see Table 2).

Table 2. Major Crops Grown in the respective Districts of Andhra Pradesh in the Kharif (rainy) and Rabi (dry/winter) Seasons

District	Kharif Season	Rabi Season
Adilabad	Pulses, Maize, Rice	Maize
Ananthapur	G.Nut	Pulses, G.Nut
Chittoor	G.Nut, Sugarcane	Rice, G.Nut
Cuddapah	G.Nut, Rice	Pulses, G.Nut
East Godavari	Rice	Rice, Pulses
Guntur	Rice, Pulses	Pulses
Karimnagar	Rice, Maize	Rice, Maize
Khammam	Rice, Pulses	Maize, Pulses
Krishna	Rice, Pulses	Rice, Pulses
Kurnool	G.Nut, Rice, Maize, Pulses	Maize, Pulses, G.Nut
Mahbubnagar	Maize, Pulses, Rice	Rice, Maize, G.Nut
Medak	Maize, Pulses, Rice	Rice, Maize, Pulses
Nalgonda	Rice, Pulses	Rice
Nellore	Rice	Rice, Pulses
Nizamabad	Rice, Maize	Rice, Maize
Prakasham	Pulses, Rice, Maize	Rice, Pulses
Rangareddy	Maize, Pulses, Rice	Rice, Maize
Srikakulam	Rice	Pulses
Visakhapatnam	Rice, Maize, Sugarcane	Pulses
Vizianagaram	Rice, G.Nut	Pulses
Warangal	Rice, Pulses, Maize	Rice, Maize, G.Nut
West Godavari	Rice, Sugarcane	Rice

Table 3. Calculated yield factors for Kharif Rice crop for each District

District	Yld Factor
Adilabad	0.76
Anantapur	1.12
Chittoor	0.95
Cuddapah	0.80
East Godavari	1.32
Guntur	1.14
Hyderabad	1.30
Karimnagar	1.18
Khammam	0.99
Krishna	1.25
Kurnool	1.14
Mahbubnagar	0.76
Medak	0.95
Nalgonda	1.26
Nellore	1.24
Nizamabad	1.15
Prakasam	1.47
Rangareddi	0.96
Srikakulam	0.76
Vishakhapatnam	0.69
Vizianagaram	1.03
Warangal	0.99
West Godavari	0.89

Mod-EPIC uses the yield factors, described in the early section, and it has been calculated at each district level to help better asses the cultivars in use in the different regions during the respective seasons. Table 3 shows the yield factors for the Kharif season and it can be seen from the table that the unmodified EPIC yield values could be overestimated (by 45% for Vishakhapatnam) or underestimated (by 32% for Prakasam). So, it is important to consider these in the regions where the cultivar level information is poor.

Mod-EPIC has been run for these five (5) crops and the results are presented in the figures that follow in this section. Figure 6 shows the spatial distribution of the rice crop yields for a few of the simulated years between the period 1990 to 2025. As can be seen from the Figure, it is clear that in the Kharif season the yields are dropping over most of the regions, except the Nagarjunsagar irrigation command area in the Krishna Basin. But from the figure 7, it is clear that the changes in the Kharif yield pattern in the overall state will be marginally lower than the ones in the last decade of 1990's. In contrast for the Rabi season, the rice crop yields are generally more than the Kharif yields. Also, if proper water resources are available it shows that the yields in this season will not show any major changes due to the warmer climate in the near future.

Mung has been simulated as the representative crop of all the pulses. Fig 8 shows the maps for a few years of the Mung crop yields for the period of 1990 to 2025.

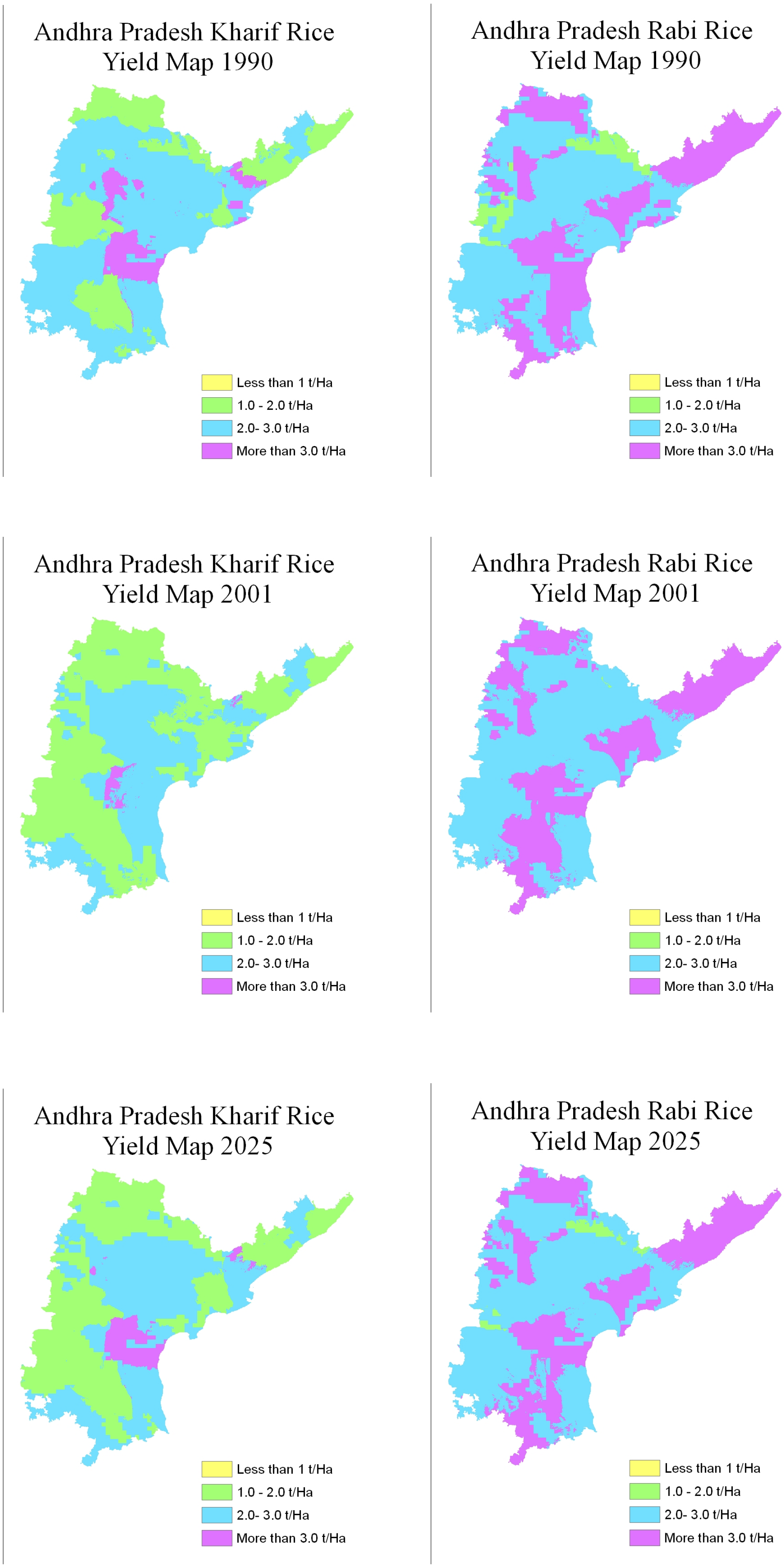

Figure 6. Snapshots of the Simulated Rice crop yields for Andhra Pradesh, India during the Kharif (Rainy) and Rabi (dry/winter) season for 1990 to 2025

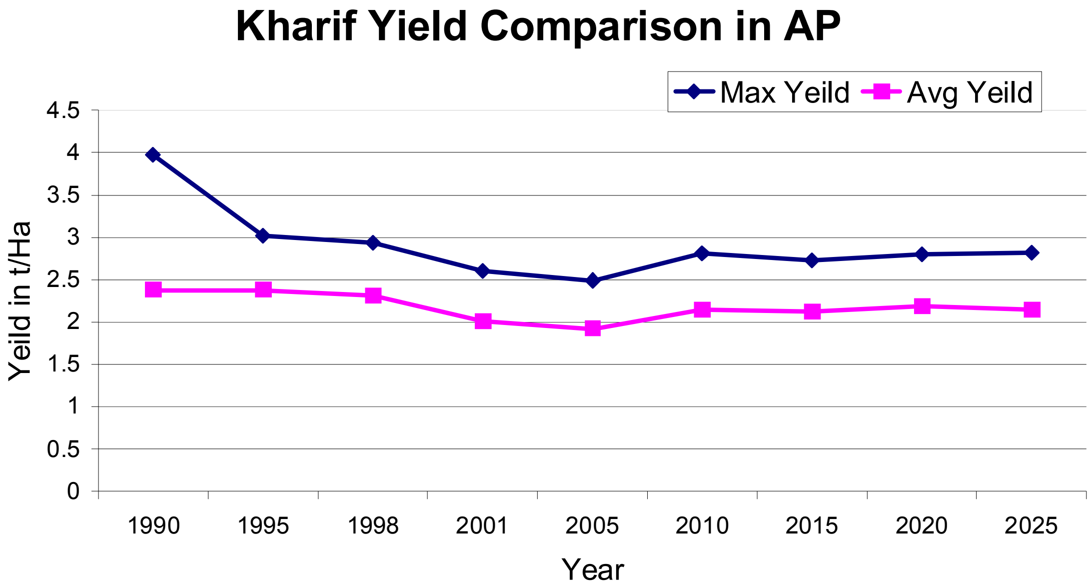

Figure 7. Plot showing the average and maximum annual yields all over Andhra Pradesh, for the entire period of simulation.

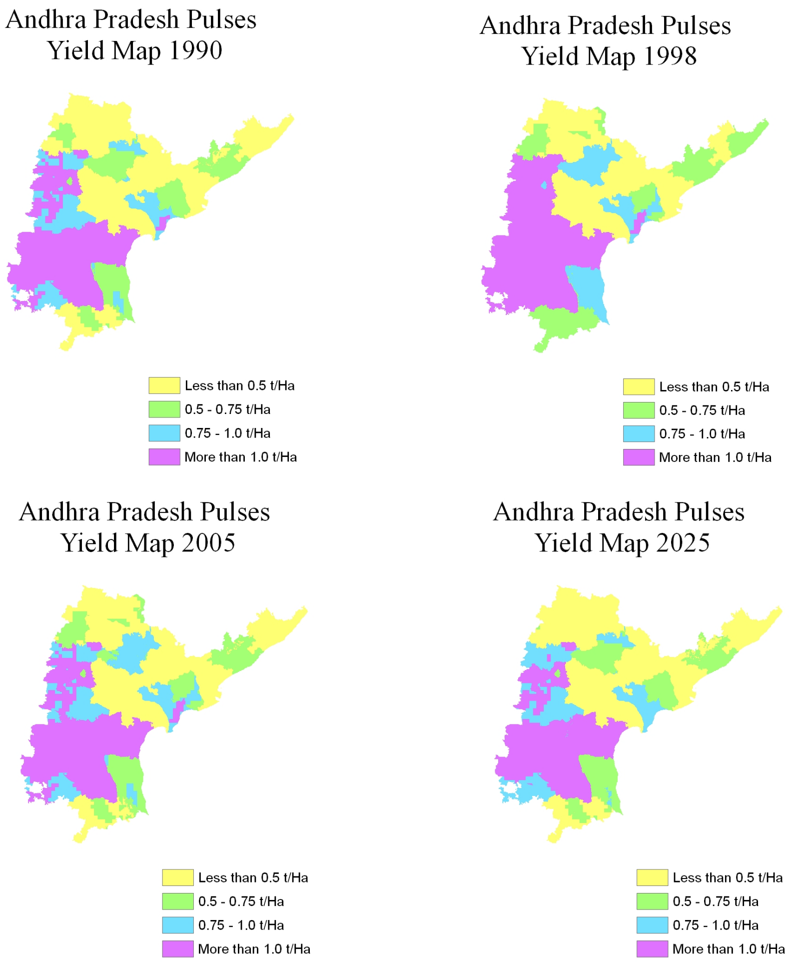

Figure 8. Snapshots of the Simulated Mung (Pulses) crop yields for Andhra Pradesh, India during the Rabi (dry/winter) season for 1990 to 2025

The yields of Mung in the Kharif season is generally higher than the Rabi season, though it is not grown as the main crop in that season. Fig 8 shows the spatial spread of the yield output of Mung crop for the Rabi season - the main season for this crop. As can be seen from the fig, the changing climate has a negative impact on the northern and western parts of the state, though overall the average yield in the state is nearly the same (Fig 9). The localized effects can exaggerate the change from one crop to another if this drop in yield continous to occur over time.

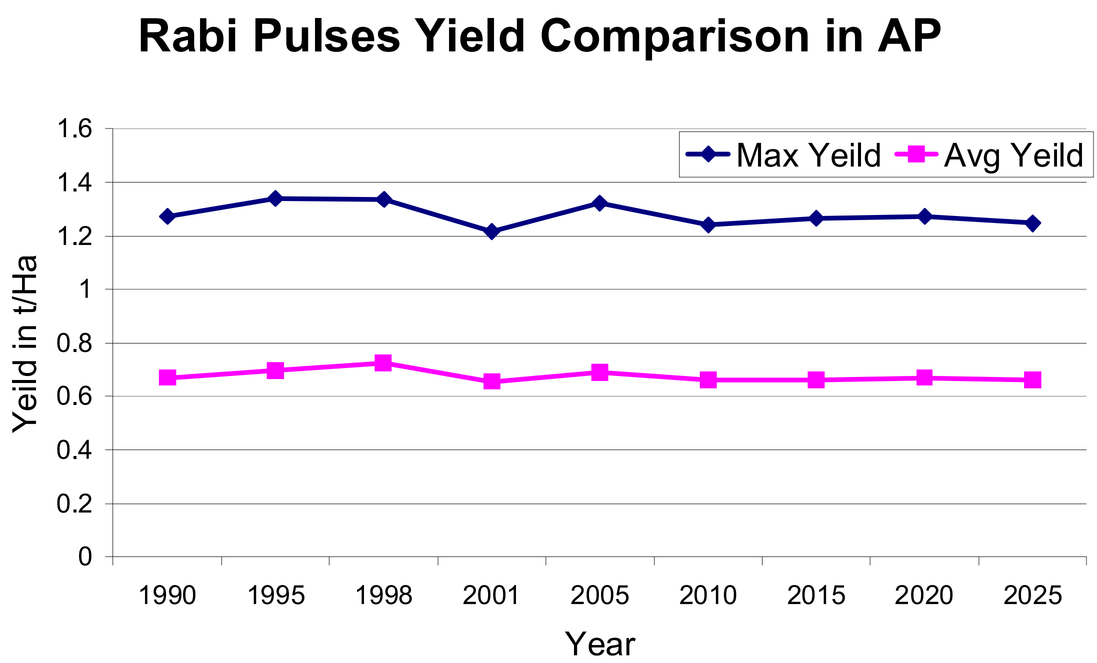

Figure 9. Plot showing the average and maximum yields all over Andhra Pradesh, for the entire period of simulation for Mung (Pulses)

3.1.2 Hefei area, Anhui Province, China

The central part of the Anhui province, in and around the city of Heifei city was suggested as the study area for simulating the crop yields for the period of 1990 to 2025. The province in Central China is primarily Agricultural and hence it is interesting to see the effects of the climate change on this part of China. It is thought that similar effects may be visible in its neighbouring provinces and the central region of China. The major cereal crops grown in Anhui are Rice, Wheat and Maize and cereals occupy around 56% of the total sown area (8.58 mil Hectares) and total cultivable area of 5.97mil Ha, of which Rice (2.145 mil Ha) and Wheat (2.057 mil Ha) occupy almost equal areas and are grown in different seasons of the crop year. The growing period for Rice is from early part of May to mid September, while wheat is grown during the months of October to May. The average yield of the cereals in the year 2000 in Anhui was 4975 kg/hectare.

Mod-EPIC outputs are shown in Figure 10 to 13 for Hefei. Fig. 10 shows that wheat yields in Hefei are more than 4 t/ha in most of the regions, though the model simulates lower yields at the beginning of this cycle. As can be see from both Fig 10 and the graph in Fig 11, the warming of the climate seems to be beneficial to the winter wheat yields in this part of china. Most of the change is visible in the northern latitudes of the region and can indicate that the increasing temperatures in the IPCC GCM model variables actually show an increase in the yield output.

For the rice crop, unfortunately the Mod-EPIC results are not at all in conformity with the agricultural statistics of the region. While the later shows that the average yields are of the order of 4 to 5 t/Ha, the model shows a maximum of 1.5 to 2 t/Ha (Fig 12 and Fig 13). In the lack of information on the cultivars, the physiological modifications, and the variability in the application of fertilizer, it is found that it is difficult to use Mod-EPIC to simulate the rice yields in the temperate regions.

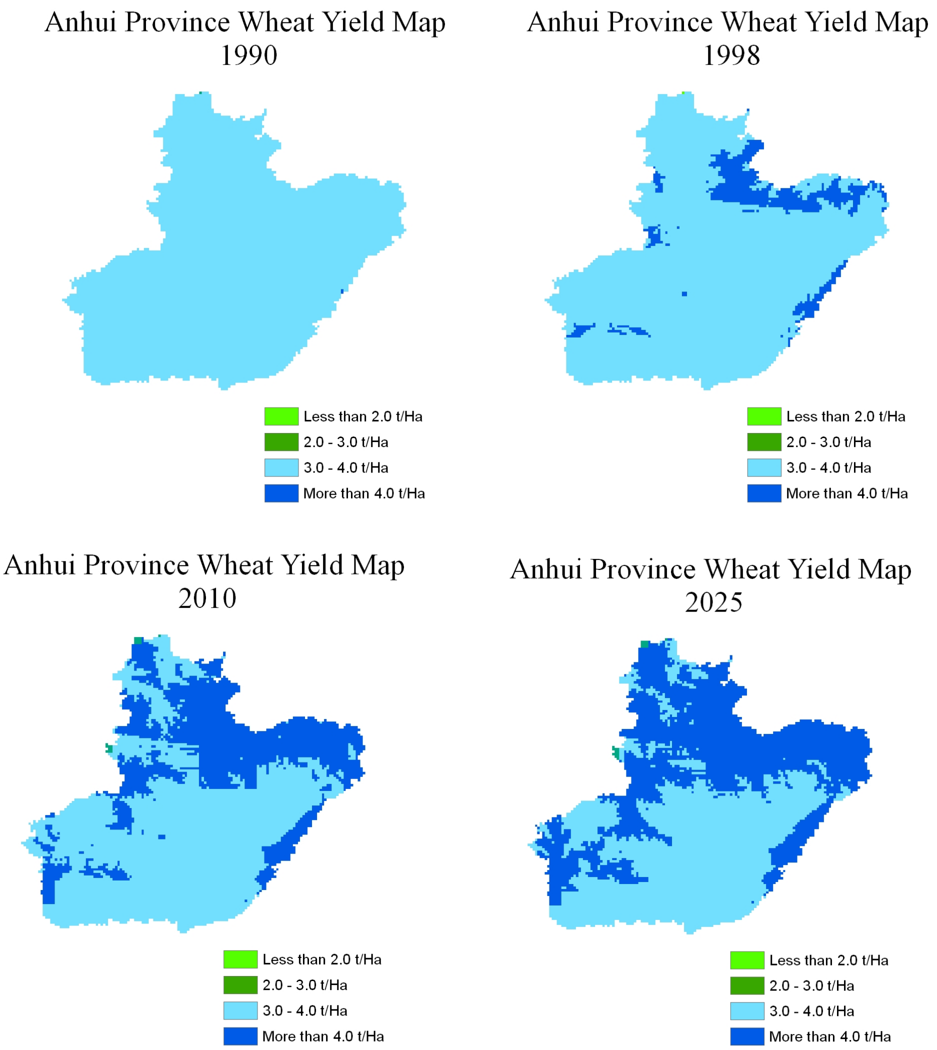

Figure 10. Snapshots of the Simulated Winter Wheat crop yields for Hefei, Anhui Province in Central China during period 1990 to 2025

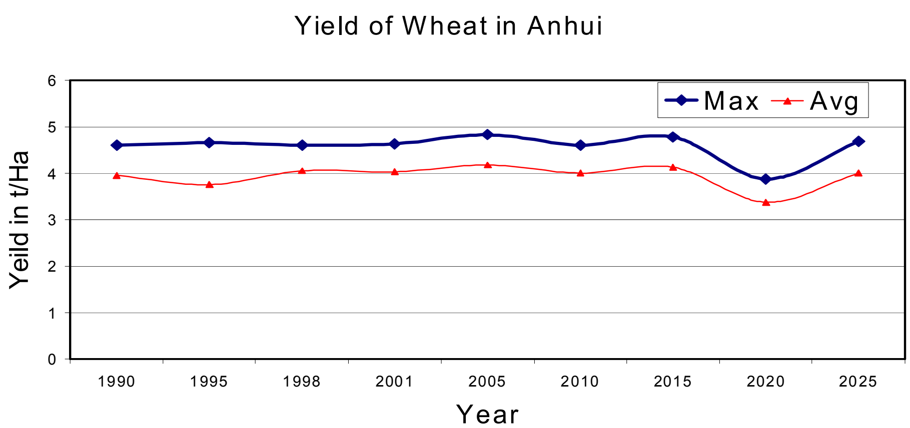

Figure 11. Plot showing the average and maximum yields all over Hefei, Anhui province for the entire period of simulation for Wheat

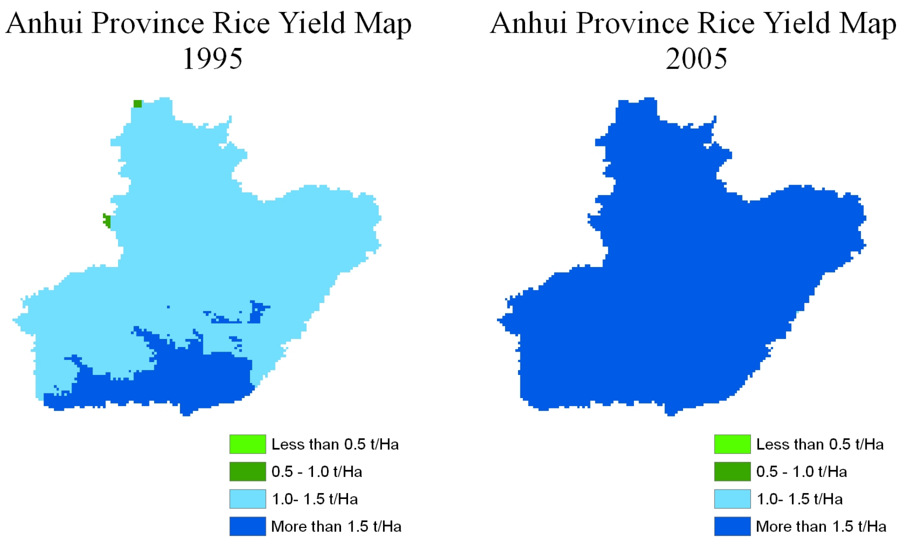

Figure 12. Snapshots of the Simulated Rice Crop yields for Hefei, Anhui Province in Central China during period 1990 to 2025

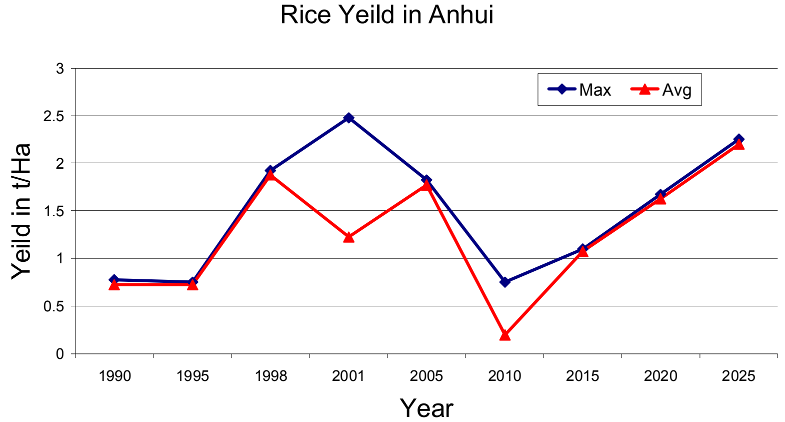

Figure 13. Plot showing the average and maximum yields all over Hefei, Anhui province for the entire period of simulation for Rice

3.2 Discussion

From the Mod-EPIC simulations it is clear that for the tropical Monsoonal regions of India, there is a benefit in terms of cereal crop yields in the Rabi (dry/winter) season, while for the Kharif, yield marginally drops for Rice and other crops. But the predominant factor that controls the change in the land use or agricultural practice is the availability of abundant water resources for the rice and other cereal crops, which may not be sufficiently available in the Rabi season. In contrast, the yields of Pulses are generally higher in the Kharif than Rabi, but since most of the land area is under the cultivation of Rice systems, there is barely any land parcel available for growing pulses except in some pockets where they are traditionally grown in the rainy season.

On the other hand, two problems arose for the application of the Mod-EPIC model to Hefei, Anhui province. One, the crop parameters for rice has to be recalibrated and modified to take into account the changes in the agricultural practices and the input intensive type of agriculture that is being practiced in this region. Another problem is that since the application area was limited to a small region, it is difficult to analyze the outputs in both spatial and temporal ranges to see what could hae caused this problem.

Problems in simulating the land use: Apart from simulating the crop yields, the application of the land use mode was also planned for. But, since the yields for the

Chinese region of one of the major crops was not able to be improved based on the current level of knowledge, it was difficult to simulate the outcome of the Land use model based only on wheat for China. Also, the economic datasets on the multiple occupations of the households, population redistribution, and realistic values of the agricultural cost of production and its prices have not been easy to collect for the regions of our interest. The data has generally been available in bits and pieces. The danger of creating data based on those bits and pieces of information will lead to lots of assumption and will be difficult to understand the processes of land use changes. Another major problem in applying the land use model is the base land use map. Since we would like to model and simulate the changes in the cropping areas due to changes in market demand, prices of these crops and yield of these crops, it is needed to create a base map which shows the location of the major crops. This exercise was expected to be done as part of another activity and we had planned to use it in this study, but unfortunately this did not happen making it difficult to run the land use model.

4.0 Conclusions

In this project the focus was on simulating the crop yields of the major crops fro mthe year 1990 to 2025 and see if there is an impact of the changing climate and other conditions on the future availability of the cereals and other major crops of these regions. The study was able to effectively demonstrate that for the MIHR climatic model variables, the effect on the crops are marginally and at best improves the yields in the winter/dry season in both India and China for the cereal crops – Rice (both countries), Maize (only India), Wheat (only china). For the pulses, the yield is expected to raise in the Rabi season due to the higher atmospheric temperatures that suit these crops. The yields of Groundnut and sugarcane show a drop a little more than marginal drop in yields and this needs to be investigated further to see whether good irrigation facilities can alleviate some of these effects.

While there was an attempt at simulating the agricultural land use patterns, mainly the changes in the cropping pattern, this was unable to be fully implemented for reasons discussed in the earlier section. One important outcome is that though there has been numerous efforts at creating a wealth of information, there is still a dearth of the relevant socio-economic datasets for application of such models. This is an important gap that needs to be focused on and such dataset creation will go a long way in better understanding the human-land-environment interactions.

Further, through this research work, the partners were able to build a better understanding of the critical gaps in understanding, model building approaches, data unavailability and the need to evaluate a range of policy instruments.

5.0 Future Directions

This work start out with trying to build a comprehensive database and then apply it to model both the crop yields realistically and the land use pattern changes. Mod-EPIC needs to be further evaluated rigorously and suitable crop parameter tables needs to be prepared, so that the crop growth of a wide variety of cultivars can be studied effectively and can then further be used to understand the adaptation and mitigation possibilities for any future drop in the crop production. It was also felt, during the discussions and implementation that there is a need to build a set of basic variables that can be used in a Land use model when there is a shortage of data – how to deal with this needs to be explored.

The current approach was to model the crop productivities independent of the land use changes, and see the impact of such land use changes on reduced land availability, etc. There is a need to further couple these crop/vegetation dynamics to human actions (in the form of land use changes) and the intensity of them, either as a loosely coupled system based on IO or with sufficient feedbacks at annual timesteps.

The work started here will be further extended by the collaborators in their respective organizations in both their research activities and will stirive to build scientific awareness and capacity to further improve on our understandings.

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Appendix

Conferences/Symposia/Workshops

1. A one-day workshop cum meeting *was conducted on August 15, 2005 at the* National Institute of Natural Resources and Regional Planning, Chinese Academy of Agricultural Sciences to kickstart the research discussions. The presentations included on the current works of similar nature from the collaborating organizations.
2. Brainstorming Workshop on Agricultural Land Use Modelling, at IIIT-H, Hyderabad. 22^{nd} Feb to 24^{th} Feb 2006
   A total of 20 participants took part in the discussions, including from IIIT-H (5), Univ of Tokyo (1), INRRP, China (2), NRSC (4), AFPRO (1), ICRISAT(1), IARI (2)

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Glossary of Terms

ABM: Agent Based Models
AGENT-LUC: AnthropoGenically ENgineered Transformations of Land Use and land Cover, a land use model
AR4: Fourth Assessment Report of the IPCC
EPIC: Erosion Productivity Impact Calculator, a crop growth and environmental impact calculator model
GCM: Global Circulation Model
GIS: Geographical Information Systems
GLP: Global Land Project, an IGBP & IHDP project
LCCS: Land Cover Classification System, developed by FAO
LUCC : Land Use and Land Cover Change, an IGBP & IHDP project
HYV: High Yielding Varieties of the Crops, denotes new varieties of cultivars
IPCC: Intergovernmental Panel on Climate Change
SHYV: Short High Yielding Varieties of the Crops, denotes new varieties of cultivars
SRES: IPCC Special Report on Emission Scenarios, provides the storyline for each of the possible simulation scenarios