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Modeling Agricultural Land Use Change in Bangladesh: Farmer as an Agent of Change

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1.0 ABSTRACT

Agriculture in Bangladesh is already under pressure both from huge and increasing demands for food, and from problems of agricultural land and water resources depletion. To meet the increasing food demand, Bangladesh can either increase food grain import or can increase crop productivity. Since land is a scarce resource in Bangladesh, the only choice is to increase in cropping intensity.

In this research a 'Farmer Model' is developed which considers the behavioral aspects of a farmer regarding agricultural land use change focusing on crop combination and crop intensification. A farmer would adopt any land use based on cost/return comparison and risk minimization that might be associated with these actions. A biophysical crop production model 'Spatial-EPIC' was used to simulate crop production. Land use change was simulated using 'AGENT-LUC' model. In this model, an agent is considered as the decision-maker of the land use change. 'Spatial-EPIC' and 'AGENT-LUC' are integrated with 'Farmer Model' in order to develop agricultural land use change scenarios in response to rapidly growing food demand. Spatial-EPIC model has been implemented in GIS environment at 10km grid size whereas AGENT-LUC model has been implemented in GIS environment at 1km grid size.

The model was run for the period from 1995 to 2004. The output for the period 1995-98 was used for the model validation and the output onwards was used for future land use prediction. Various scenarios would be studied considering different cropping pattern, cropping intensity and policy options etc. As large amount of data sets is needed to be managed and processed for such models, GIS was extensively used as the pre and post processor of the input and output data.

2.0 INTRODUCTION

Bangladesh is one of the most densely populated country in the world. The rapid growth of population impedes the agricultural development of this country. Food grains mostly rice predominantly lead agriculture in Bangladesh. Although acceleration of rice production resulted in an increase in per capita availability and led to self sufficiency in rice by the early 1990s, agricultural growth has been under some strains since then. This has raised concerns about the sustainability of rice-led agricultural growth. Agricultural practice in Bangladesh thus seems to have arrived at a crossroads, and there is a need for devising a strategy that can deal with the new challenges and opportunities to make agriculture more flexible, diversified and efficient. The trends in food demand and agricultural output illustrates the basic parameters of the challenges facing agriculture in Bangladesh. Population will continue to increase and with it, the pressure for additional food demand (particularly food grains) will intensify. The critical issue is what these pressures will represent in terms of increased food needs and whether or not the requisite production level are within the reasonable response capability of the agricultural sector. Regardless of which scenario of food need is followed, there is an obvious requirement to augment production. To do so will require a successful confrontation with the complex process of change over a wide spectrum of the agricultural sector.

Again, increase in food production is possible either by bringing more land under cultivation or by increasing cropping intensity. Agricultural intensification has been defined by Brookfield (1972) as the substitution of inputs of capitals, labor and skills for land, so as to gain more production from a given area, use it more frequently, and hence make possible a greater concentration of production. Intensity is usually measured in terms of output per unit of land or, as a surrogate, input variable against constant land (Turner and Doolittle, 1978). But changing cropping patterns depends on socio-economic conditions and knowledge base of farmers and on change in climatic pattern as well. It is also associated with risks. In most of the cases the economy of a farmer in Bangladesh is subsistence economy. So the decision of land use change is primarily based on profit maximization and risk minimization.

3.0 OVERALL MODEL STRUCTURE

The overall model structure is presented in figure1. The 'Farmer Model' decides the agricultural land use change based on the expected income from new land use. AGENT-LUC (Rajan and Shibasaki, 1997) model is modified and termed as 'Farmer Model', which is used for simulating agricultural land use change in Bangladesh focusing on cropping intensity. In this model, a farmer is considered as the decision-maker of land use change. The decision-making processes take into consideration the prevailing biophysical characteristics of the land, the economic conditions, and the land use history along with the existing social apparatus (demographic pattern). This model uses grid based crop yield as input, which is obtained from Spatial-EPIC (Satya and Shibasaki, 1998) model. 'Spatial-EPIC' is composed of physically based components for simulating plant growth, nutrient, erosion, and related process for assessing crop productivity, determining optimal management strategies, erosion and so on. Grid based crop yield is used to estimate the income from agricultural. Besides, income from other sources is also considered. Grid based soil erosion is another important output from 'Spatial-EPIC'. Soil condition can be anticipated for the new land use decision, which may help in decision-making processes of land use change.

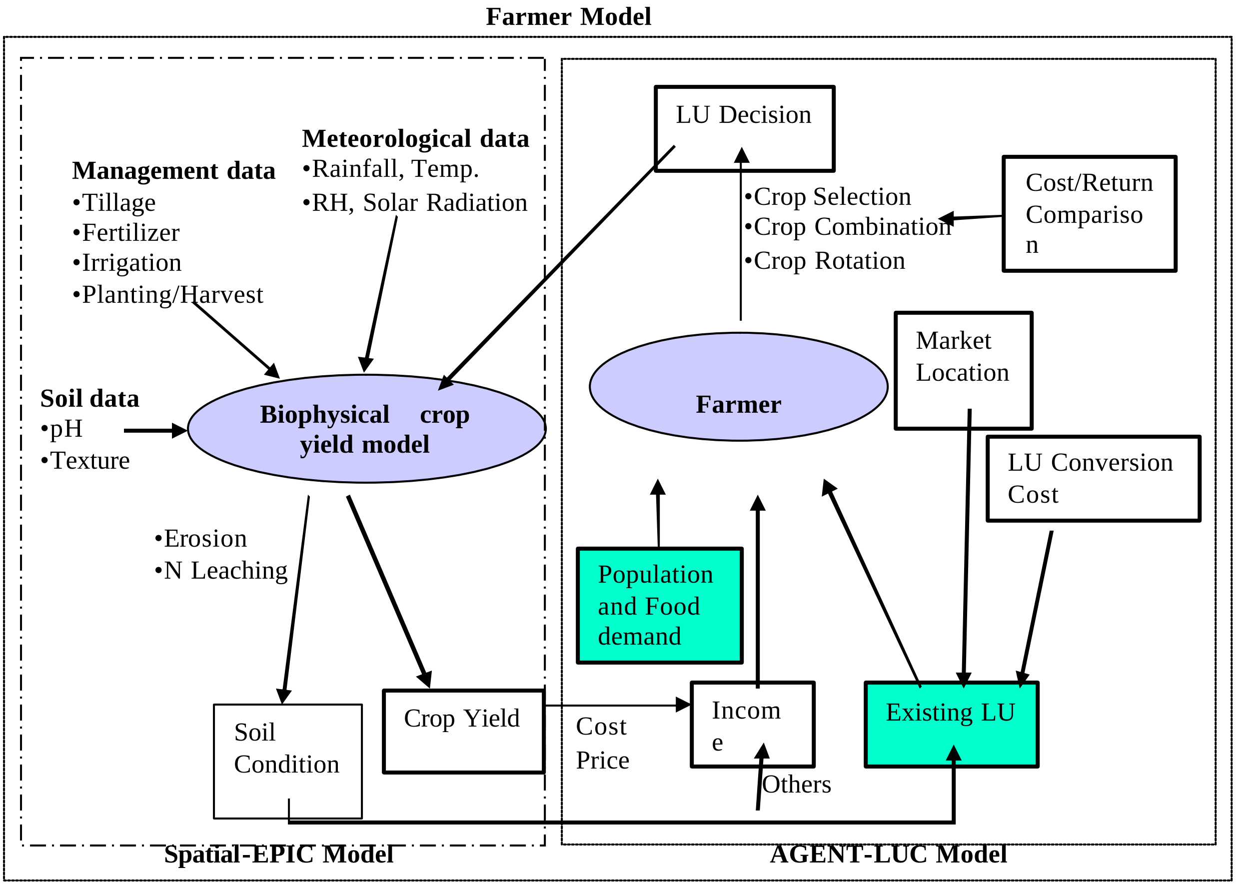

Figure 1: Overall Model Structure

4.0 MODEL DESCRIPTION

4.1 Spatial-EPIC Model

4.1.1 Model Structure: Traditional decision support systems based on crop simulation models are normally site-specific. In order to address the effects of spatial variability of soil conditions and weather variables on crop production from one place/region to other, GIS is linked with biophysical agricultural management simulation model EPIC (Sharpley and Williams, 1990), which is known as "Spatial-EPIC". With the development of this model any size of agroecosystem starting from a field to a country and even bigger ca be modeled. "Spatial-EPIC" system file structure is comprised of text files, which contain estimate of parameters of different physical processes modeled by "Spatial-EPIC". These files include Basic User-Supplied Data file, Crop Parameter File, Tillage Parameter File, Pesticide Parameter File, Fertilizer Parameter File, Miscellaneous Parameter File, Multi-Run File, Output Variables File and Daily Weather Data File. "Spatial-EPIC" is composed of physically based sub models for simulating weather, hydrology, erosion, plant nutrients, plant growth, soil tillage and management, and plant environment control. The model runs on daily time-step therefore, each model is linked subsequently and interactively with other sub models. In brief, the each sub module is dealt with their computation procedure. (1) Weather: daily rain, maximum and minimum temperature, solar radiation, wind and relative humidity can be based on measured and data and/or generated stochastically. (2) Hydrology: runoff, percolation, lateral subsurface flow are simulated. (3) Erosion: it simulates soil erosion by wind and water. (4) Nutrient Cycling: the model simulates, nitrogen and phosphorus fertilization, transformations, crop uptake and nutrient movement. Nutrient can be applied as mineral fertilizers, in irrigation water, or as animal manure. (5) Soil: soil temperature responds to weather, soil water content and bulk density. It is computed daily in each soil layer. (6) Tillage: the equipment used affects soil hydrology and nutrient cycling. The user can change the characteristics of simulated tillage equipment, if needed. (7) Crop Growth: A single crop model capable of simulating major agronomic crops. Crop-specific parameters are available for most crops. The model also simulates crop grown in complete rotations. (8) Plant Environment: It is capable of variety of cropping variables, management practices, and other naturally occurring processes. These include different crop characteristics, plant population, and dates of planting and harvesting, fertilization, irrigation, tillage and many more those are normally practiced in the field.

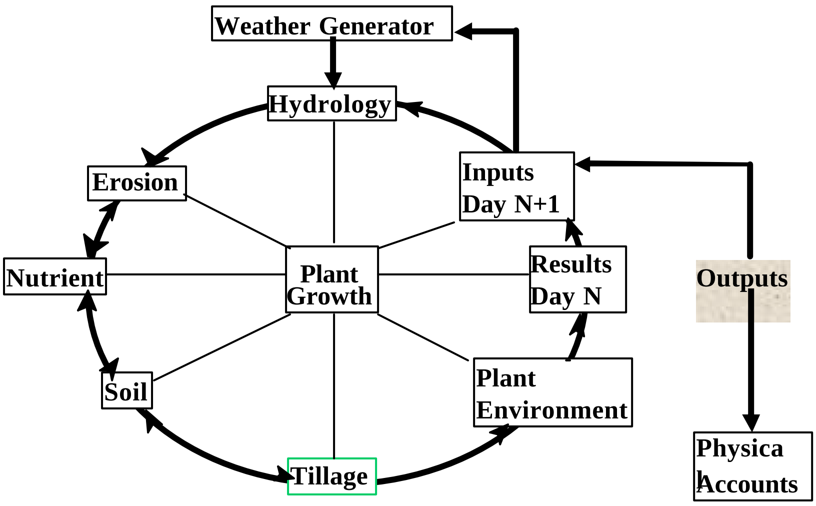

Figure 2. Spatial-EPIC Modeling Linkage Diagram

4.1.2 Inputs Data: Monthly average climatic data e.g., rainfall and maximum/minimum temperature are obtained from WMO stations which are 22 in numbers falling within the boundary of Bangladesh. These data are interpolated to generate surface for the entire country. Soil data e.g., soil texture and soil pH are obtained from 'Global Soil Data Task' prepared by FAO. Management data such as crop planting and harvesting, fertilizer and irrigation application data are taken from Yearbook of Agricultural Statistics of Bangladesh.

4.1.3 Model Output: Rice, wheat and lentil are considered for the research purposes and all the possible crop combinations were made. The model was run for all of those combinations and yields were obtained on yearly basis files. These files are fed into in house developed program to convert into Arc View or Arc/Info readable ASCIIGRID text file format. The ASCIIGRID text files are loaded back into Arc View or Arc/Info using IMPORT functionality to obtain a raster theme in GRID file formats. ArcView command SUMMARIZE ZONES was used to obtain district level average unit crop production (ton/ha). Figure 3 shows a sample output of Spatial-EPIC for the year 1995, which is converted to raster theme. Figure 4 shows district wise unit crop production comparison, which is obtained from figure 3.

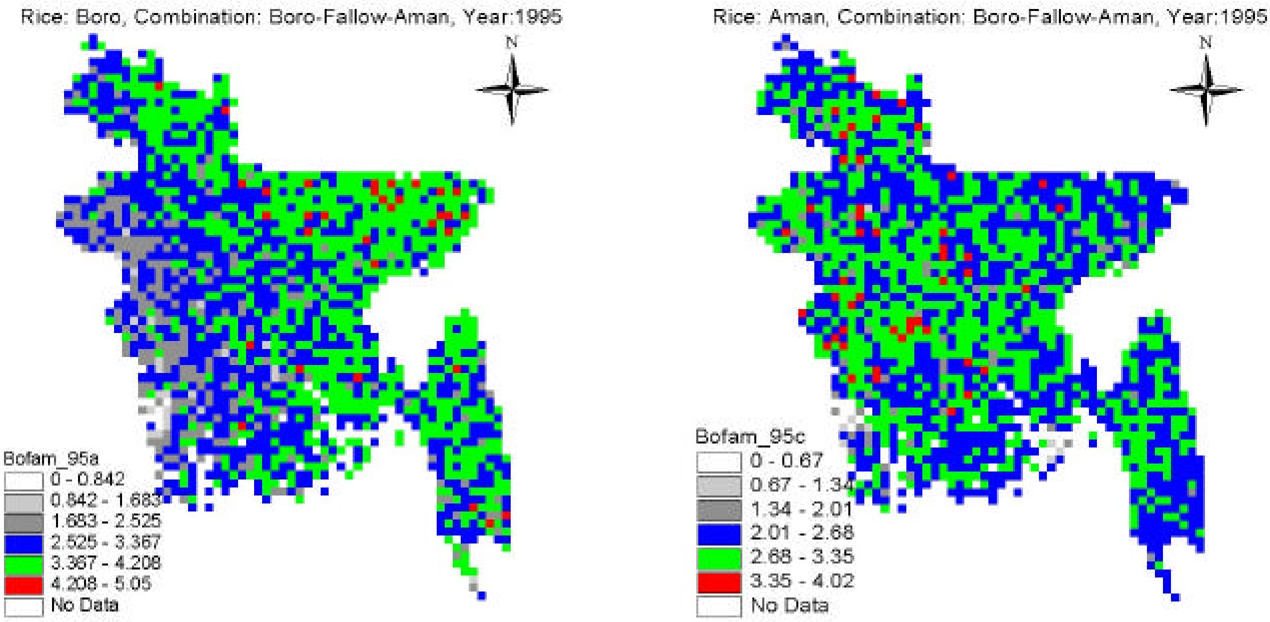

Fig 3: Grid based crop yield for Aman and Boro rice for the year 1995

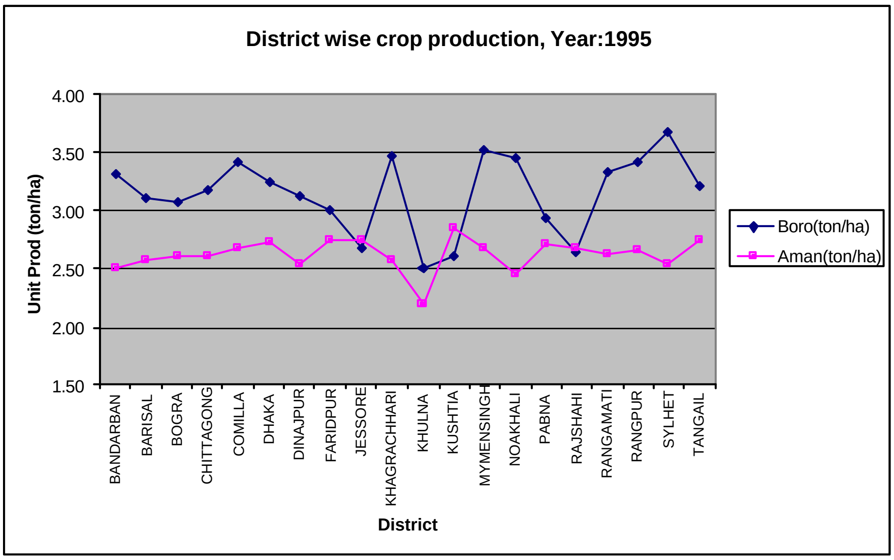

Fig 4: District wise unit crop production for Aman and Boro rice for the year 1995

4.2 AGENT-LUC Model

4.2.1 Model Structure: This model deals with the development and application of the concept of an agent as the decision-maker in simulating the land use/cover. Here, the term agent refers to an individual or a group of individuals who exist in a given area (referred to as grid) and are capable of making decisions for themselves (or the given area). The agent also acts as an interface in helping to assimilate the broader macro-information into the decision-making process at the grid level, thereby creating an action in response to the natural and economic stimuli. The decision-making process of the agent is autonomous in deciding the next course of action based on the information available to him, from both the worlds of micro and macro-information, at a particular point in time and space. The biophysical characteristics of the specific lot of land (grid) and its economic potential (based on the macro-economic information) are considered within the existing demographic conditions at a given point in time, in arriving at the choice of the land use. The changes are simulated annually and the entire process is carried out on a grid (1km square) basis and is aggregated at the different scales – from the local grid to district level and finally at the national level, to analyze and compare the results with the prevailing macro-condition. These kind of inter-scale comparison helps to develop a more realistic scenario of the land use changes. The use of GIS platform and its tools has helped in analyzing the micro-information (spatial) within the boundaries of the available macro-level (non-spatial) data.

4.2.2 Input Data: The crop yields that are obtained from Spatial-EPIC are used as input to this model to compute the expected income of farmer. First they are converted to images using GRIDIMAGE Arc/Info option. Digital Elevation Model (DEM), Slope derived from DEM, Road Network derived from 'Digital Chart of the World' are also used as input. Grid based population and literacy data are derived on the basis of land use map and reported statistical value. Population of each grid is divided into four categories and education level is divided into three categories. All of them are converted to images for the model input. Occupation data is used to compute the incomes other than agricultural. Figure 5 shows population and education data as a sample of the date sets that are used.

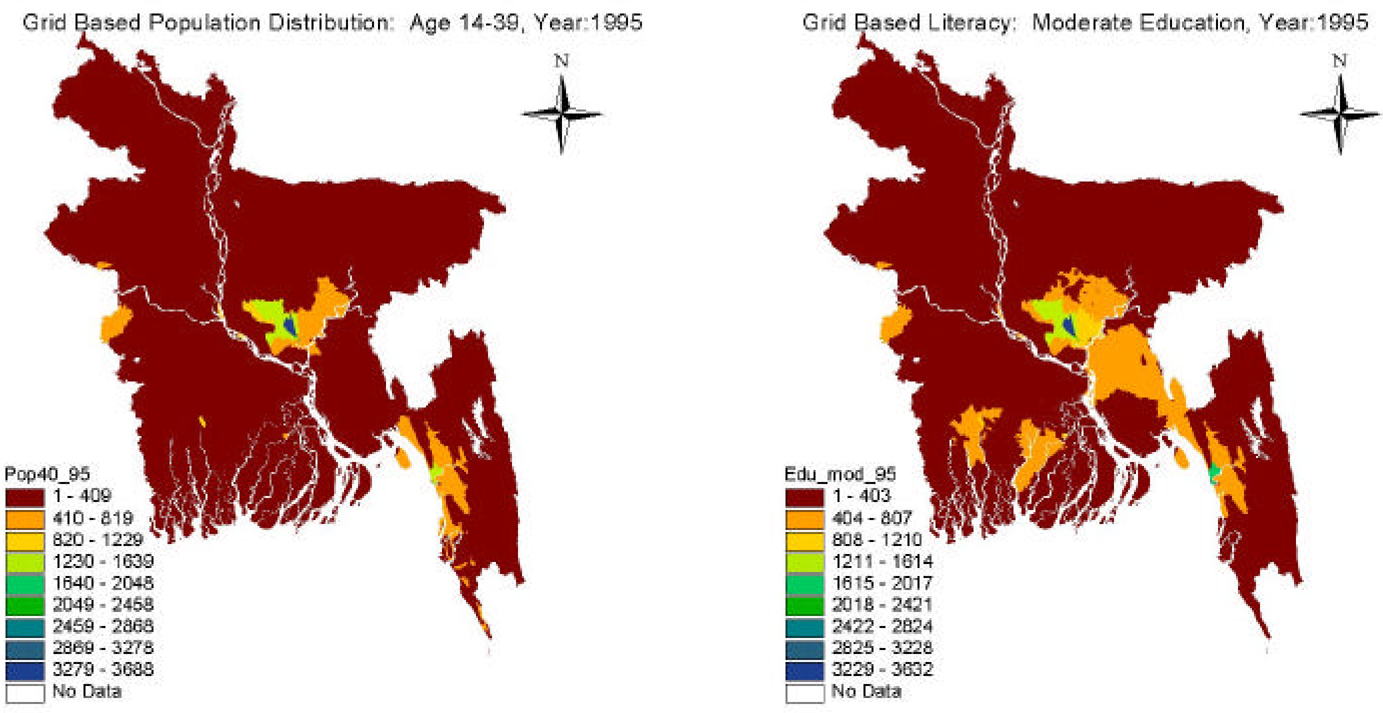

Fig 5: Grid based population and education level of the year 1995

4.2.3 Model Output: The output of this model is not obtained yet.

4.3 Farmer Model

The main theme of this model is to simulate agricultural land use change decision taken by the farmer. A farmer is considered as an autonomous decision-maker of a specific lot of land (grid). To arrive at a land use change decision, a farmer would consider his income from current land use as well as income from other sources and compare this income with what might be generated from other possible land uses. Here the land use change is assumed as any of the followings: (1) Crop selection/combination, and (2) Crop intensification. The crops that are selected for the study purpose are rice (for three different seasons, namely, aus, aman and boro), wheat and lentil. The Spatial-EPIC model output, namely, crops yield and soil erosion is used as input to the farmer model. All the possible crop selection and crop combination is considered and their yields were computed using Spatial-EPIC. For all possible crop selection/combination cost/return comparison are made with the existing cropping pattern/land use. It is assumed that a framer would select new cropping pattern, i.e., change his/her existing land use only if he is benefited from this decision as well as minimize the risk that is associated with the change. The decision of the farmer is coupled with AGENT-LUC model in order to simulate the agricultural land use change. Population group and education level of a particular grid is considered for risk minimization decision. The farmer might consider soil erosion that is associated with new land use

5.0 CONCLUSION AND DISCUSSION

Cropping pattern and crop yield in future might be affected due to global warming and the associated climate change or due to policy implications. Various scenarios are developed for the research purposes e.g., carbon enrichment, and temperature change and precipitation change as well change in input prices of irrigation and fertilizer. The crop production associated with these changes is computed for the period 1995-04. The land use change associated these cropping pattern would be examined. The final result would be presented in the conference.

6.0 REFERENCES

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