Using multi-agent modeling technique to regionalize key processes and patterns of sustainable agricultural cropping systems in the North China Plain

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1.0 Background

Agro-ecosystem simulation activities face increasing regionalization demands at field or farm level researches in the last years (Engel et al. 1999, Heinemann et al. 2002, Faivre et al. 2004). This is due to a growing intensity of interdisciplinary and regional research e.g. on the water scarcity topic. However to access environmental research, up-scaling of such limited information is crucial because it is based on generalised information and e.g. border-line effects must be considered. All common is the fundamental aspect lay upon the detection of environmental dependencies over an area larger than that for which it has been developed. Faivre et al. (2004) call this "spatialising" a crop model. Large areas show for example heterogeneity of soils, climate and management practices. Consequently, spatialized information of a crop model can raise serious problems on data requirements and sensitivities, such as from the fact that the basic concepts, hypotheses and validity domains of crop models are derived on the point/ plot scale so spatial and temporal declarations are limited. Another set arises from the lack of adequate and sufficient data to run the model on a regional scale. So the overall aim has to be the linkage between points or field based simulation data of any crop model on one hand. On the other hand if possible to use capabilities of GIS based approaches, as the basis of spatialsing a data base, to overcome spatial limitations. But GIS techniques, even newer implications, have several limitations, for example an inappropriate statistical analysis and generalization aims. Hence to overcome these differences is time-consuming and could be managed by expert knowledge only. Following these basic rules a system is searched which possesses the ability to combine field specificity together with exemplarity of spatialised data. The aim of this paper is the description and evaluation of different regional up-scaling approaches of agronomic key variables (Roth 2008). Regional solutions are necessary on the background of growing resource depletion and unsustainable agricultural techniques, e.g. in the North China Plain.

2.0 Comparing different approaches for regional up-scaling and simulation

In order to investigate our research objective, the regionalisation of agricultural key features towards sustainable agricultural and to improve productivity in the North China Plain (NCP) we primarily have to identify these core features. On the economic side we determine “farmer income” to be an appropriate factor. The ecological side is served by the determination of “water use efficiency” (WUE) and yield. Both factors have to be further verified on their plausibility for our research aim by project member discussion. Next an evaluation of multiple computational approaches towards their practicability was investigated. Relay on both existing GIS data in the projects AIES data base and additional data provided by our colleagues from the Chinese Agricultural University (CAU). Primarily the *Cellular Automata* (CA) concept based on previous work as well as statistical analyses, Data mining and cell neighbourhood relations was investigated. This approach has to be denied due to insignificant neighbourhood relations and the fact that no appropriate computing environment was found. Secondly a model combination of *Markov Chain* and Cellular Automata as it is proposed by remote sensing software techniques (e.g. *IDRISI*) has been evaluated. This approach combines stochastic probabilities for cell transitions with classical GIS and remote sensing facilities. Again no statistic significance of spatial transitions due to farmer decisions was found. The 3rd actual approach *Multi Agent System* (MAS) is believed to be the most promising one. We were able to set up a MAS modelling environment and primarily results will be described in this paper. Results will be shown at IAAE Meeting in August in Beijing 2009. For future purposes the ecological key features WUE and yield might be investigate by the use of the *DSSAT* crop model.

For the same objective, agricultural land use optimization was more focused on by scientists on the CAU side. Land use system is an interface connecting all the key features and relating the process of agricultural system changing. Agricultural systems are being challenged by the simultaneous requirements for increased productivity, more diversified products and reduced environmental impact, creating potential conflict situations in land use objectives among various stakeholder groups (Roetter 2005). These conflicts are characteristic for North China Plain in particular. Traditionally agronomic research is focused on well-controlled field experiments, the majority of these experiments are fertilizer or water trials aimed at the construction of dose response relationships of ideally managed crop systems, and there are other issues focused on improving crops and their management (through weed control, fertilizer gifts and their timing, etc.), while soil scientists have tried to improve soil tillage techniques and introduced soil-related site-specific management practices or precision farming (Veldkamp 2001). All these techniques focus on the plant or field level. However agricultural systems seem to be more complex regarding its economic and social factors. Regional level land-use optimization is to allocate land resources in order to balance the multiple, sometimes conflicting objectives of ecological, economic, and social activities (Chen Y. 2008). In our opinion, an integrated land use planning of quantitative and spatial methods will be a promising way to contribute solving the problems and also seems to be a method to up-scaling results of field experiments to regional level.

2.1 Regionalisation based on key features up-scaling approaches

During the past project periods the project database was constructed continuously. The *Agricultural Environmental Information System* (AEIS) consists primarily of spatial GIS data on soils, land-use and remote sensing images. Additionally agricultural management, climate data and statistical data of field measurements as well as official Chinese statistical censuses are included in the data base. Our main aim is to model the appropriate key features outlined by the research question on these informations.

However regionalisation by its definition tries to extrapolate information on a given scale. So primarily as example we want to introduce simulation coupling experiences between crop models and GIS or GIS extensions towards regionalization. During the last decade a forthcoming development in software/ computer and therefore GIS sciences and computer processor velocities can be observed. This development led to vast numbers of scientific simulation/ computing programs on different disciplines. Spatial researches based on cartographic data, for example land and water sectors, was analysed and visualized mainly in geographical information systems (GIS). Analytical Methods in GIS are described firstly by (Goodchild 1992) they are subject to refining process in order to match research initiatives as well as extended format development of different GIS concepts. The central advantage of Analytical GIS approaches is the combination of extended databases facilitates together with data handling and storage. Those GIS approaches may be used as combined information systems for agricultural suitability researches (Verboodt et al. 2005). In our research project primarily relational databases software was used to examine stored data with the data mining concept (Bode and Doluschitz 2007). This was done in order to provide statistical parameters of specific data sets and transform these to transition orders for the Cellular Automaton approach. A first set of conclusions was used for land use suitability classification. These outcomes identify further options for regionalisation purposes. However in the following the concept of Cellular Automata (CA) is described which should transfer this gained knowledge to an appropriate model regionalisation approach.

2.2 Evaluation of the Cellular Automata (CA) concept

In order to simulate spatial dependent variables primarily the access to these parameters must be provided by specific geographical information systems. This statement is true for all our approaches discussed here. In our case the AEIS data base provide appropriate data sets for a primarily up-scaling initiative. We chose the Quzhou County to be the first ‘case study’ to prove our recommendations. The reason was, that here our research station Quhzou is located. Hence a detailed data base is accessible including statistical household data as well as environmental constraints and landscape data. In our case the core question is whether CA is the appropriate tool to regionalise site specific measurements or survey data. This would be the case if the correlation between the assumed *a* and *b* variable is solely explicable by neighbourhood relationships. Otherwise for the aim of regionalisation simple spatial correlations serve well (Ostendorf and Reynolds 1993). Hence the key feature the farmer income should be a unique spatial dependent variable. To test this hypothesis literature research as well as comparable modelling initiatives has been investigated. In literature it was constated that a small budget of farmer income only is created outside his native village. So the above made statement has to be denied. Additionally to build an appropriate computing environment needs expert knowledge and is time consuming so we reject for the simulation of ‘farmers income’ the pure CA approach.

2.3 Multi-Agent-System (MAS) Approach

As indicated above the aim of this approach is primarily to simulate farmer income based on GIS derived background information. The adaption of the spatial relevant site characteristics of income is the main point here. Other farmer income MAS modelling approaches translates the farmer economic decisions to evaluate its ecological perception (Schreinemachers et al. 2007). To us the appropriate approach is found in the Multi Agent System (MAS) concept. It is believed to be the most promising for several reasons. We chose *NetLogo 4.0.3* as appropriate computing environment. First it includes GIS data extensions, above this it is a powerful free designable and *Java* programmable cross-platform user interface. The hypothesis is the following, agents (farmers) acting in space, interfere and interact in spatial scales corrupting their entities (arable land) and thus their income. NetLogo is is a programmable modelling environment for simulating natural and social phenomena. It was authored by (Wilensky and Tisue 1999) and is in continuous development at the Centre for Connected Learning and Computer-Based Modelling/Northwestern University Evanston Il. USA. This environment is particularly well suited for modelling complex systems developing over time and space (Schindler in prep.). Modellers can give instructions to hundreds or thousands of "agents" all operating independently. This makes it possible to explore the connection between the micro-level behaviour of individuals and the macro-level patterns that emerge from the interaction of many individuals. Primarily we chose as case study to simulate the Quzhou County and included GIS based data.

This was done because an IRTG research station is located and thus necessary data amounts are available here. To parameterise the model first the basis for simulations local map data was included. The programming language is feasible and users may handle first steps by following a programming guide suited for individual usage delivered with the model. Actually included are villages and residential areas, roads, water streams and soils GIS point or polygon data. Next work was the definition or parameterisation of agents. Primarily we had to identify main factors corrupting farmer income (Fig. 1). At the actual status of modelling approach we possess two basic data sets: soil and agricultural activity (*agents*). These were included in our MAS Quzhou to start from (Fig. 2). The fundamental concept of MAS is the inter-connection and interaction between the set of agents. Actually we evaluate the ratio between horizontal agent interaction and vertical soil patch property of each agent.

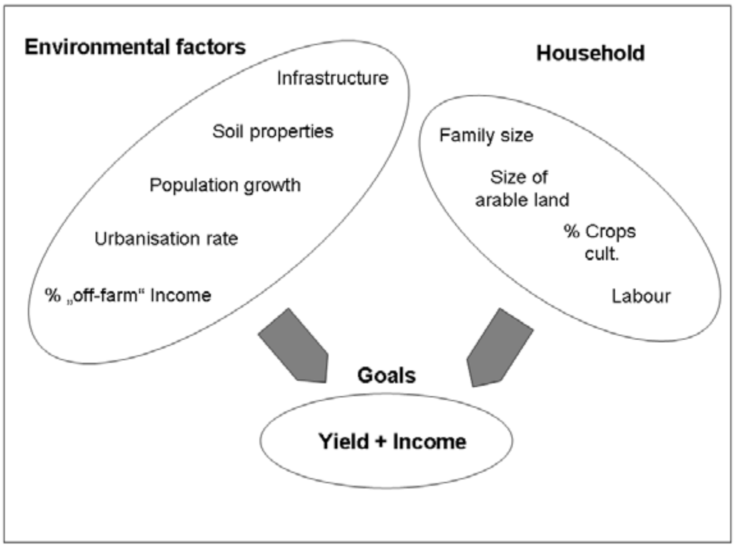

Fig. 1: Side conditions influencing farmer income in Quzhou County (own illustration)

These patches are now predefined by soil and cultivated crop both in this step unchangeable. This definition provides an exact analysis and adaption of parameters defining agent interaction. The correlation between agents is balanced above this by threshold values of generated income evoked by crop cultivated and soil quality (Fig. 3). Thereby each agent evaluate own value to its four nearest neighbours. Higher value increases the probability of agent changing individual cultivated crop to the alternative. Gradually functionalities according to the above mentioned input factors are included.

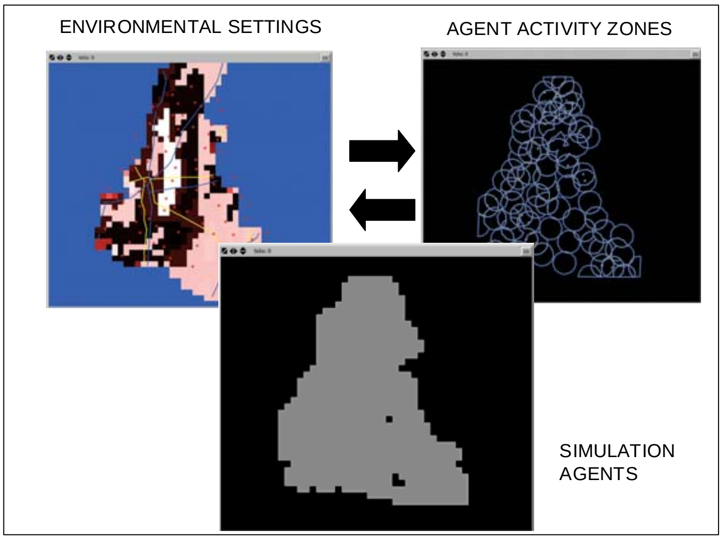

Fig. 2: Shape and functionality of MAS Quzhou (own illustration)

The particular advantage of this model is the inter-change module provides the opportunity to receive or exchange data with other applications. An explicit point in an interdisciplinary research project presented here.

The individual agent has the conscience of patches own soil property but so far is not able to change the cultivated crop (Fig. 3). This procedure according to a list of appropriate crops will be one of the next steps in parameterisation scheme. The important milestone so far is the conscience of each agent to ‘recognise’ its own status of income. Secondly the comparison of each agent with four neighbouring agents and the perception of differences. Then in the next simulation loop the probability to change cultivated crop in order to increase income.

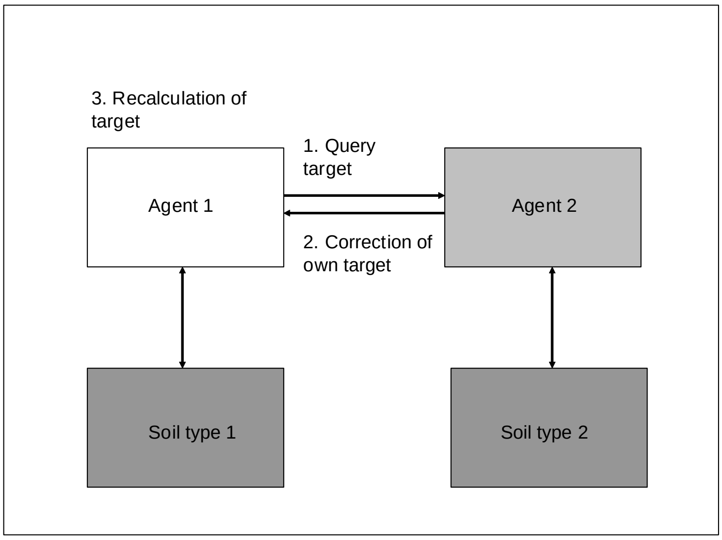

Fig. 3: Conceptual approach of agent query for MAS Quzhou simulation (own illustration)

2.4 Regionalization with an integrated land use planning modeling approach

The integrated planning method might be separated in two parts: first the quantitative planning and second the spatial planning. The framework Land Use Planning and Analysis System (LUPAS) will be used here for quantitative planning purposes (van Ittersum 2004; Roetter 2005). The aim of LUPAS is to further improve the scientific basis for land use planning. It is a decision support system (DSS) for strategic planning, based on the interactive multiple goal linear programming (IMGLP) technique (Roetter 2005). The evaluation and definition of NCP land use systems was based regional maps of land suitability. The input and output coefficients of cultivated crops will be derived from household survey data. Additionally the results on yield and associated water and fertilizer demand derived by CAU agronomists will be used on the whole region level. Finally scenarios of alternative development for the whole region will be designed. The land use structure of each scenario (sown area of each crop) could be estimated using IMGLP.

Land cover and land use patterns as well as social, economic, and demographic characteristics change because the spatial structures are themselves inherently unstable and typically exposed to external phenomena that also force change (White and Engelen 2000). Models are useful to predict and evaluate the complex suite of socio-economic and biophysical forces and pathways that influence the rate and spatial pattern of land use change (Verburg 2004). Our modelling approach, the Conversion of Land Use and its Effects (CLUE-S) will be used to optimize spatial distribution (Verburg 1999b). The NCP results of quantitative planning will be introduced to the CLUE-S model as a parameter. Land use simulations will be conducted based on the land suitability and neighborhood effects of each map type. The sum of pixels of each land use type in best case will be consistent with the results of quantitative planning of the associated scenario.

2.5 Parameterization, improvement and application of a spatial planning model (CLUE-S model)

The Conversion of Land Use and its Effects (CLUE-S) is a dynamic, multi-scale and spatially explicit model to analyze land-use patterns and model near-future changes in space developed by the research group of Land Use Change (Veldkamp 1996; Verburg 1999a; Verburg 1999b). Land suitability and neighborhood effects are the two major aspects of spatial dependent variables considered in the model (Verburg 1999a; Chen 2008; Duan 2004). The aspect of distances which is in our opinion the major aspect of neighborhood effects in the CLUE-S model has not been sufficiently discussed so far.

A case study of Miyun County which is one county of Beijing located on the edge of NCP was generated on the effects of neighborhood distance to increase the simulation accuracy (Pan, 2009 paper submitted). Here considered distance means the radii of surrounding pixels affecting the central pixel in the modeling process. A simulation from 1991 to 2004 in Miyun County was calculated. Hence two years of actual land use map are compared during this study. The land use was categorized into 6 classes (construction land, irrigable land, dry land, orchard, unused and forest). Finally the whole map has been transformed to grid file format with a cell resolution of 200m x 200m. The model was set up based on the actual land use map of 1991, then simulate 11 years to 2004 applying 2 types of total 12 different distances of neighbourhood (Fig.2). The first type is a ring type with distances from 0-1200m separated in twelve 200m distance steps. The second type is a scope type with distances of 0-200m, 0-400m, 0-600m, 0-800m, 0-1000m and 0-1200m. Model validation was based on a comparison of model results to the actual map of 2004. Kappa index was used to evaluate the accuracy of the simulation results on the pixel level (Fig.3).

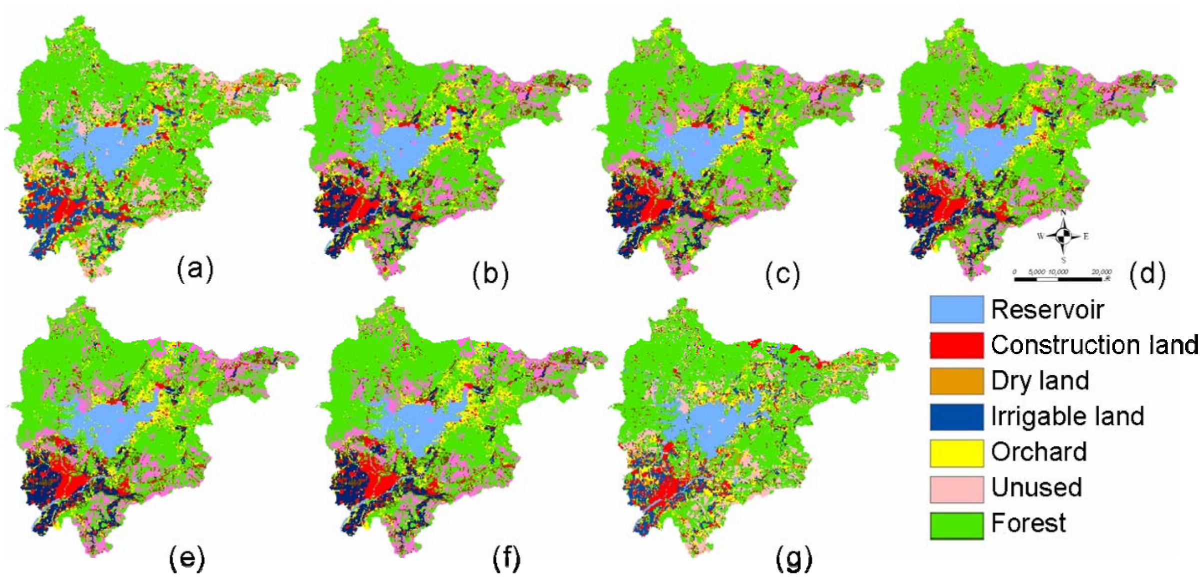

Fig. 4: Simulation results of ring type neighborhood applying different neighborhood distances
(a)200m (b)400m (C) 600m (d)800m (e)1000m (f)1200m (g)actual map of year 2004

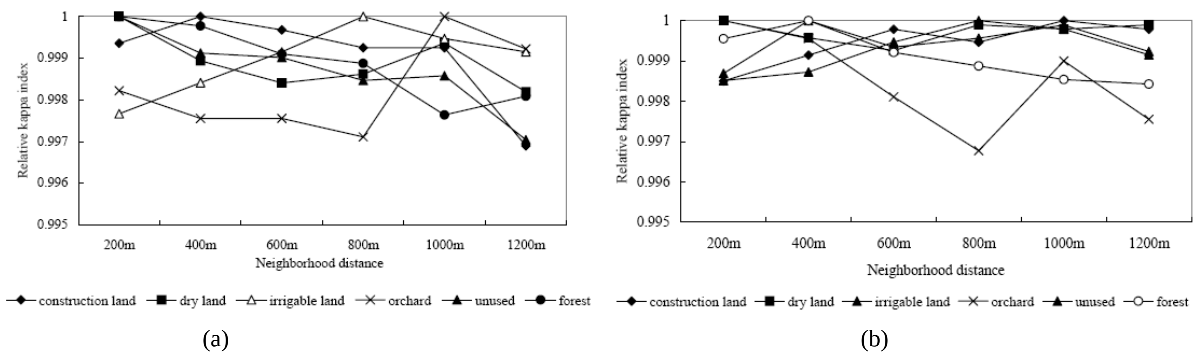

Fig. 5: Change of simulation precision with neighborhood distance using ring neighborhood (a) and scope neighbor hood(b)

The evaluation scheme depicts that the model precision indeed is sensitive to the neighborhood distance. The response and rate of accuracy change due to the variation of neighborhood distance is different according to different land use types. Model results showed that precision will decrease as neighborhood distance increase using ring type neighborhood Else highest precision will be achieved using scope type neighborhood of moderate distance. The average precision using scope type is higher than ring type neighborhood. The effect of neighborhood distance mainly depends on the distance-decay effect (White and Engelen 2000). For the ring type neighbourhood, the application of large neighborhood distance instead of small lead to a higher proportion of unimportant factors instead of important ones. For scope type neighborhood, the application of small neighborhood distance will lead to the disregard of important factors. Meanwhile large distance will lead to the equalization of significant and insignificant factors. A pre-validation of neighborhood distances is recommended in further researches according to the above conclusion.

2.6 The quantitative planning LUPAS approach

For quantitative planning, the Quzhou County had been chosen of the same reason as German colleagues.

2.6.1 Land evaluation and definition

Land evaluation was based on physiognomic, soil, groundwater status, irrigation facility and land use data. A synthetical index method and an expert system were used to evaluate actual land-use. Thereby the most significant factors of land quality: physiognomic, soil texture, soil organic matter, degree of salinity and alkalinity of the groundwater, the distance to the irrigation wells and channels were chosen. The weight of each factor was qualified by the expert system (Table 1). The synthetical index was generated by overlaying all the regionalized and normalized maps of land factors.

Table 1: The weight of each factors of land quality evaluation

Factors of land quality	physiognomy	soil texture	soil organic matter	degree of salinity and alkalinity of the groundwater	the distance to the irrigating wells	the distance to the channels
Weight	0.0798	0.2785	0.1506	0.1246	0.1595	0.2070

The land use system of Quzhou County was mainly categorized into two types: agricultural land and non-agricultural land. The agricultural part was then further categorized into three classes which are high quality agricultural land, moderate and poor quality agricultural land according to the values of the synthetical index (Table 2).

Table 2: Percentage of agricultural land in different quality

Land use system	High quality	Moderate quality	Poor quality
Hectare	16397.7	43739.2	7532.7
Percentage of area (%)	24.23	64.64	11.13

2.6.2 Actual land use structure and scenarios

Land use types with sown area larger than 1% according to the statistical data (CSY 2004) were chosen. Actual land use data (sown area) and input-output coefficients including irrigation amount, yield and price gained from household surveys (own data) were used as inputs. Two scenarios are built: one reducing water overuse, the other assumes sustainable water consumption. The available agricultural water resources under the above two scenarios were 151 million m^3 and 121 million m^3 per year, respectively (Tian 2000).

2.6.3 Quantitative planning

Multi-goals linear program was used to optimize the land use structure under the two scenarios above to maximize the farmer income and guarantee the grain production with the limitation of available water resources. The results are shown in the following (Table 3).

Table 3: Land structure of Quzhou County of actual situation/ the scenario of reducing water overuse/ the scenario of sustainable water using

Land use type	High quality land	Moderate quality land	Poor quality land
Winter wheat-summer maize	10001/10001/10001	10947/9419/6280	2964/0/0
Winter wheat-millet	0/0/0	2780/2780/2780	0/0/0
Winter wheat-cotton	0/0/0	9140/0/0	0/0/0
Winter wheat-bean	0/0/0	2999/3666/3666	0/0/0
Winter wheat-peanut	0/0/0	0/0/0	2670/2930/2930
Spring cotton	0/0/0	1860/11000/11000	0/0/0
Vegetable	2264/2264/2264	4296/4296/1645	0/0/0
Orchard	0/0/0	700/715/715	0/0/0

2.6.4 Further research focus

The scenarios constructed above were based on the present Chinese agricultural technical level. The next step will be the evaluation of input-output models of alternative technologies and scenario construction based on future policy opinions. Land use optimization will affect the cropping area. So the CLUE-S model will probably help to identify appropriate cropping system for the NCP based on land suitability and neighborhood effects.

3.0 Conclusions and further joint research focus

Concerning the actual agricultural situation in China regional factors influencing the farmer income are a matter of changing processes. Actual statistical data to built simulations upon is not always feasible. If so our preconditions for modelling key features of today's China agriculture must be subject to alteration. Our modelling approach will emphasize the bounding layers of agricultural production systems and income in the NCP. This will be discussed in detail at conference place. Modelling setup so far was successful and will extended to the accessible data bases. Profound discussion will be held with modelling and agricultural experts on the plausibility of MAS outcomes concerning farmer income. If positive signals arise the model will be parameterised to Hebei province level. Here model – model comparison will be conducted together with CAU colleagues.

The further extrapolation purposes on the ecological key features WUE and yield will be handled by the crop model *DSSAT* (Tsuji et al. 1998). The DSSAT extension AEGIS provides an environment for up-scaling purposes i.e. yield (Engel et al. 1999, Hartkamp et al. 1999, Heinemann et al. 2002). Based on this information the simulation of agricultural parameters for the NCP seems feasible and parameterisation will take place. As a group of scientists actually use the *DSSAT* crop model in varying plant sciences, certain expertises are generated in our project. This and the author personal expertise will help for a sudden parameterisation and integration of AEIS GIS dataset parameters.

Integrated land use planning as it is planned is a promising way towards sustainable agriculture. LUPAS is comprehensive tool dealing with trade-offs between different land use objects, different stakeholders and technology innovation orientations in the mean while CLUE-S is good at multi-scale, dynamic analysis and crucial location identification. The mix of advantages of these two methodologies to solve agricultural problems is what we are seeking to. The combination enables us to simulate the entire chain of agricultural decision making in the NCP .The different modeling approaches between German and Chinese partners on regionalization will provide consistent pathways of future agricultural area in the NCP.

Table 4: Synopsis of used/planned approaches, key features, mathematical definition and references

Approach	**Key feature**	**Problem cluster**	**Mathematical definition**	**Literature**
MAS	Farmer income	Income security	Probability, Neighborhood	Bahlmann 1993, Schreinemachers 2007
LUPAS	Land quality investigation	Sustainable cropping system	Statistical significance	Tian 2000
CLUE-S	Land use change	Land conversion, Urbanisation	Neighborhood, suitability	Verburg 1999
DSSAT	Yield, WUE	Water scarcity, nutrient availability	Algorithms	Tsuji et al. 1998

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