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Models as essential prerequisite for decision support systems to adapt agriculture to climate change –represented by the LandCaRe-DSS

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1. Introduction

Land management for food production is a fundamental human activity, supporting the livelihood of everyone on this planet. More than 2 billion tons of grains are produced yearly for food and feed, providing roughly two-thirds of total direct and indirect protein intake; about 10% of this total, or 200 million tons, is traded internationally [13].

The most important challenge that agriculture will face in coming decades is represented by the need to feed the increasing mankind and to conserve the soil and water resources.

At the same time there is a significant concern about the impacts of climate change and its variability on agricultural production worldwide. Current research confirms that the impacts of high temperatures, altered patterns of precipitation and possibly increased frequency of extreme events such as drought and floods will probably combine to depress yields and increase production risks in many regions of the world, widening the gap between rich and poor countries [6].

On the one hand, there is the demand for climate protection measures [8,4] and, on the other hand, there is the need for agriculture to adapt to climate change. Adaptation to climate change requires knowledge on the potential regional and local impacts of climate and weather extremes but also knowledge about the expected long-term consequences of land use activities. From the agricultural side, various options are possible for adapting to climate change, such as the cultivation of new crop species and drought-resistant varieties, extended crop rotations, increasing soil humus content, adaptation of agro-management timetables, conservation tillage, as well as adapted fertilisation, irrigation and plant protection regimes. Therefore farmers have to examine separately, how they can reduce the vulnerability to climate change and increase desirable outcomes with the lowest costs under consideration of the different regional and local economic and soil-climate conditions.

For the identification of correct and sustainable decisions it is required to assess the impacts of climate change and different land use systems on the most important agricultural landscape indicators, the risks for agricultural enterprises or farmers and nature as a whole, and their changes over time. These assessments, which must also take into account future changes, can only be made with the help of spatial data and robust and well validated models for different agricultural landscape indicators. For decisions to be made based on many scenario simulations, these must be part of interactively model-based decision support systems (DSS). The development of a DSS for this purpose, however, remains a major challenge.

Due to the complexity of such a challenge, only a few spatially applicable DSS have been developed and made available, such as ADSS [12], GPFARM [1], EET (Elbe-Expert Toolbox)/GLOWA Elbe [14] and Elbe-DSS [2], which were developed for specific regions or water catchments and which as prototypes are not available to the public.

2. The decision and support system LandCaRe-DSS

Because there was a gab in good model based decision support systems for adaptation of agriculture to climate change on the regional and local scale years ago, in Germany the collaborative research project LandCaRe 2020 (Land, Climate and Resources in 2020) was started [7] which investigate effects of regional climate change on agricultural production as well as water and matter fluxes to provide a knowledge-based framework for adaptation. Central objective of the project LandCaRe 2020 is a model-based DSS, known as LandCare-DSS developed by the Leibniz-Centre for Agricultural Landscape Research (ZALF) Müncheberg, Germany. As a prototype it was validated for two contrasting regions of East-Germany in the dry lowlands of the State of Brandenburg and in the humid mountain area of the Free State Saxony. The conceptual framework and the integration of different models and modules within the LandCaRe–DSS are represented in Figure 1.

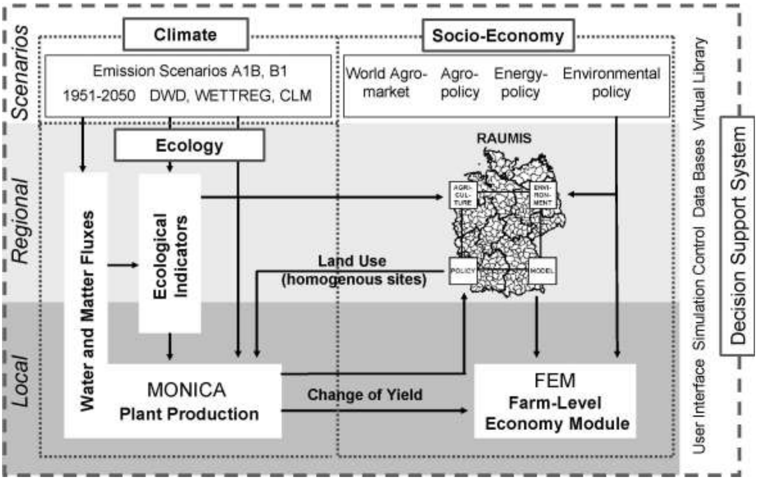


Figure 1 – Conceptual framework and levels of integration of different models and modules in the LandCaRe-DSS [16]

2.1. System components and characteristics

The LandCaRe-DSS consists of five basic system components:

- Information and advisory system concerning climate and climate change,
- Analysis of climate data and climate impacts on crop phenology/ontogenesis,
- Climate change impact assessment for agriculture on national level,
- Climate change impact assessment on regional and farm level,
- Simulation and integrated assessment of different agricultural adaptation strategies to climate change.

The basic principle of operation, which can be characterized as an iterative procedure from the scenario definition, the evaluation of different agricultural farm management adaptation strategies, up to the decision, what is the best adaptation strategy for the concrete farm to climate change, is shown in Figure 2.

As distinguished from other DSS, the LandCaRe-DSS offers the following special features:

- Interactivity
  (The user decides which simulations and calculations to execute and runs almost all models by himself.)
- Dynamic

(A large variety of simulations can be run, analysed and compared with each other by the user. The chosen preconditions will affect the simulation results.)

- Spatial-orientation
  (The user chooses the desired level of detail by zooming between national, regional or farm level. Based on this choice different well-validated models can be activated for execution.)
- Web-integration
  (Central support, control and update of the entire DSS software and all supporting data)
- Extendability
  (Open for further add-ons; frequent update of information, knowledge and data.)

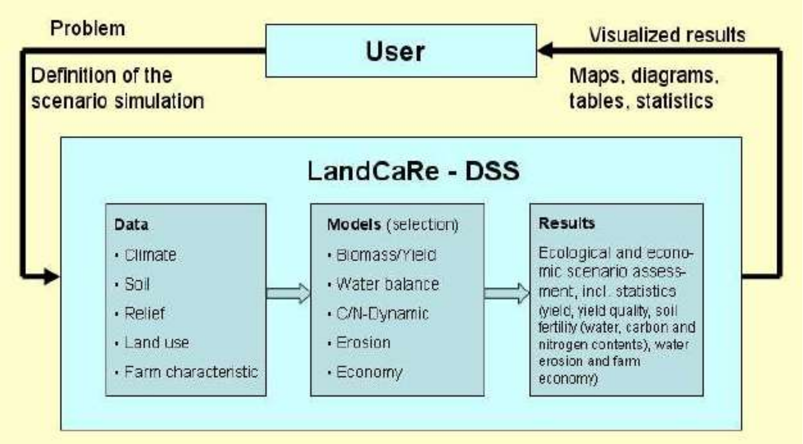


Figure 2 – Basic principle of operation of LandCaRe-DSS [16]

2.2. Impact models available in LandCaRe-DSS

Supporting decision making for adapting regional and local land use management to climate change in LandCaRe-DSS a wide range of models of different types is available, i.e. more than 10 different statistic and dynamic ecological and economic models are incorporate and linked together within the LandCaRe-DSS. All these models are grouped according to their application and briefly described below.

Economy

RAUMIS (**R**egionalised **A**gro- and environment (**UM**welt) **I**nformation **S**ystem) is an economic optimization model, which describe the impacts of changes of crop yield and price-cost-relations on land use systems and land use intensity on higher spatial scales.

FEM (**F**arm **E**conomic **M**odel) calculates in detail the cost-benefit-relationships of different farm management and climate adaptation strategies in dependence on price-cost relations, expected yields, expected nitrogen fertilizer and irrigation water demands.

Land use

LANUVER (model for **LA**nd use (**NU**tzung) distribution (**VER**teilung)) is a model, which simulates the spatial distribution of agricultural used crops on arable land taking into account the ratio of agricultural crops on district level given by the DSS-user, the compatibility between crops and soil types, and the economic excellence of agricultural crops.

Climate analysis

TREND (***TREND*** analysis) is an approach for long-term climate data analysis and trend calculations (temperature, precipitation, climatic water balance, heating and cooling degree days, Ellenberg index for forest trees, Huglin index for vine, Schwärzel index for fruit trees).

SAISON (***SAISON***al data analysis) in an approach for the saisonal analysis of long-term climate data (temperature, precipitation, frost and ice days, summer, hot and tropical days, heating and cooling days).

FREQUENCY (***FREQUENCY*** distribution) is an approach for frequency and value distribution for temperature and precipitation for long-term climate data.

Phenology and Ontogenesis

VEGPER (***L***ength of ***VEG***etation ***PER***iod) calculates the length of the vegetation between vegetation begin in spring and vegetation end in autumn.

PHENO (***PHENO***logy) model) computes the start of typical phenological phases of different wild plants (indicator types) in dependence on climate variables.

ONTO (***ONTO***genesis model) calculates the different stages of plant ontogenesis of agricultural crops in dependence on site specific weather, respectively climate conditions.

Yield and Ecology

YIELDSTAT (***YIELDSTAT***istic model) is a statistical based hybrid model to estimate the yield of more than 15 agricultural crops in dependence on site characteristics, weather/climate, CO2 and progress in agro-technology and plant breeding.

MONICA (***MO***del for ***NI***trogen and ***C***arbon in ***A***groecosystems) is a dynamic process oriented Soil-Plant-Atmosphere-Model on a daily time step, which simulates the interconnections between site characteristics, specific weather/climate conditions, farm intensity, the water-, nitrogen- and carbon dynamics in soil and plant, the plant ontogenesis and the biomass and yield accumulation.

GLPROD (***G***rass***L***and ***PROD***uctivity model) is a statistical based model, primarily specialized for grassland ecosystems, which can be used to calculate the impacts of changes in climate and grassland management on grassland yield and yield quality.

SVAT-CN (***S***oil ***V***egetation ***A***tmosphere ***T***ransport model **–** ***C***arbon and ***N***itrogen fluxes) is an evapotranspiration- and photosynthesis model of the "big leave-model-family", with a high temporal resolution and is used here to calculate the potential primary production of different forest trees and grassland.

EROSION (model of potential ***EROSION*** risk) is an empirical water erosion model, which describe the impacts of farm management technology and climate on the potential erosion risk on different scale.

BAGLUVA (***BAG***ROV and G***LU***GLA algorithm for calculation of long-term averages of actual e***V***apotranspiration and ground w***A***ter recharge) is a regionalized water balance model for calculation of long-term averages of actual evapotranspiration and ground water recharge.

BERBEDUE (model for identification of irrigation poverty (***BER***egnungs***BEDUE***rftigkeit)) can be used to identify the general site specific irrigation poverty in dependence on site conditions, agricultural land use and weather/climate.

ZUWABE (model for irrigation water demand (***ZU***satz***WA***sser***BE***duerfigkeit)) can be used to calculate the site specific irrigation water demand in dependence on soil characteristics, crop rotation and site specific climate conditions.

A detailed description of the impact models incorporated into LandCaRe-DSS is given in [15].

2.3. Short description of the simulation functionality

As a prerequisite for the development of the Decision Support System, potential users like agricultural administrations, farmers, water agencies and agro-business were included in the research process. As far as possible their specific demands of knowledge and decision support could be considered. In the result the spatial DSS is interactive and dynamic. It allows multi model and multi scenario simulation runs with various data sets and parameters by the user. LandCaRe-DSS includes regional weather data of the past, recorded by climate stations of the German Weather Service (DWD) since 1950, as well as different future climate scenarios based on the ECHAM5 Global Circulation Model with dynamic downscaling (20 to 1 km grid length) using the

Europe-wide regional climate model CLM [3] and results of the statistical-dynamic model WETTREG [5]. LandCaRe-DSS also can use different management data, an economic data base and a lot of parameter sets specific for the used models. In LandCaRe-DSS also can be incorporated a wide range of spatial information such as GIS-maps for soil type, surface slope, hydromorphy, soil quality and others. All these data, information and parameter are linked together with the models for spatial model simulations. In the result spatial result maps are produced for different agricultural indicators such as crop yield, erosion risk, evapotranspiration or irrigation water demand. Figure 3 show the model GIS coupling within the LandCaR-DSS.

As already mentioned above, LandCaRe-DSS is a model-based system for decision making. The system allows it to analyse interactively scenarios and thus offer adaptation and utilisation options for agricultural used landscapes or individual farms under the influence of regional climate change and socio-economic framework conditions. A short demonstration of how LandCaRe-DSS works can be watched on YouTube (https://youtu.be/tbUHaeA6-dl) for application examples in Germany and Brazil.

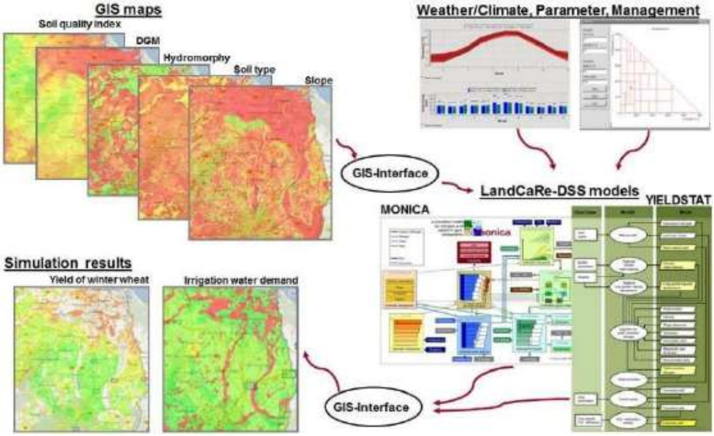


Figure 3 – Model - GIS - coupling within LandCaRe-DSS using the dynamic MONICA and the statistic YIELDSTAT models for simulating winter wheat yield and irrigation water demand for the Uckermark region, Germany

2.4. Examples of LandCaRe-DSS use

Analysis of climate and phenological data

For the adaptation of agro-management to climate change information on the impacts of climate change on the ontogenesis of agricultural crops are very important. Using the example of winter wheat, Figure 4 shows the lengths of different ontogenesis stages between sowing and harvest in comparison for two climate time periods.

The user of the LandCaRe-DSS can chose different climate scenarios, different time periods and different sowing dates for running the ONTO model. In the result the DSS-user gain information on the crop reaction and he can adapt his agricultural management.

Climate change impact assessment on national scale

At the national scale maps with information on changes in crop yields, cropping structure, farm economies and irrigation demand for different time periods as a consequence of climate change are presented to the stakeholders. The maps were created by a research group of the Thünen Institute Brunswick, Germany using the simulation model RAUMIS. Within the LandCaRe-DSS the user can carry out statistical analyses which are exemplary shown in Figure 5 (winter wheat yield for Germany expected in 2025).

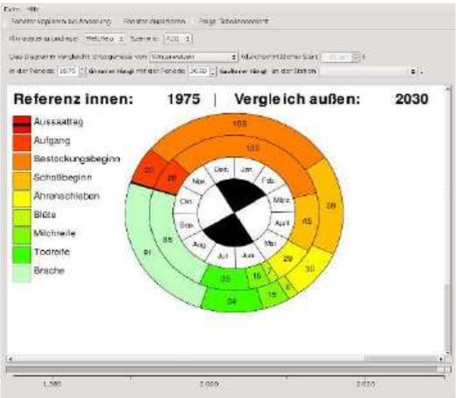


Figure 4 – Length of ontogenesis stages for winter wheat (in days) between sowing and harvest in comparison between 1975 (inner circle) and 2030 (outer circle)

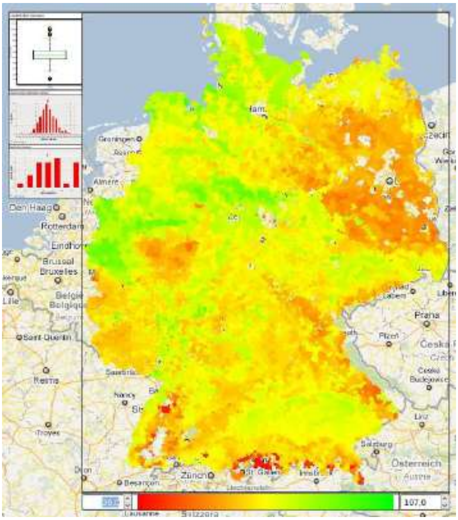


Figure 5 – Winter wheat yields across Germany expected in 2025 (simulation model: RAUMIS; climate scenario: A1B; climate regionalization method: WETTREG)

Climate change impact assessment on regional scale

On the regional scale the ecological impact assessment of climate and land use changes are realized on a high spatial resolution, i.e. on a minimum pixel size of 1 ha (100m x100m). Most of models mentioned above can be activated, but without a coupling with the economic model on this scale. Using different models, calculations are possible for the expected impacts of climate change on yields for arable and grassland, on the potential erosion risk, on evapotranspiration and ground water recharge, on the irrigation water demand and others. At this regional scale statistical analysis (average, median, histogram, …) automatically are realized. In Figure 6 for the Uckermark region (Germany) the spatial distribution of winter wheat yields for the climate period 1991-2020 (climate scenario A1B) calculated with the YIELDSTAT model is shown. Winter wheat is grown in a crop rotation with winter oilseed rape.

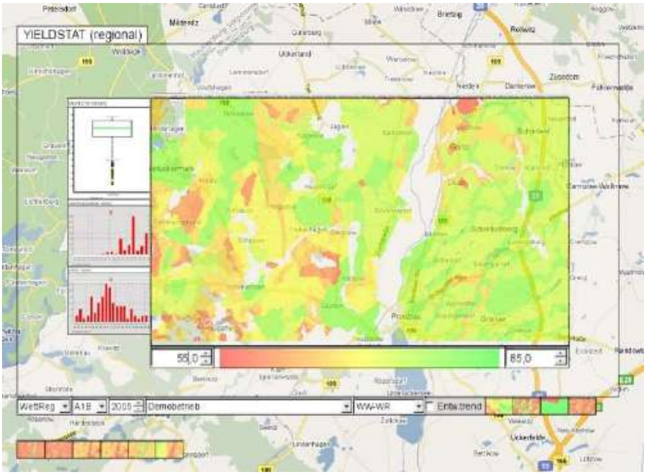
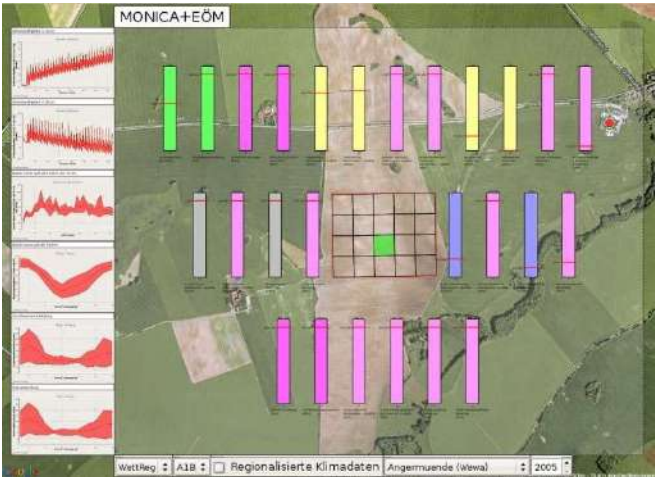


Figure 6 – Spatial distribution of winter wheat yield in the Uckermark region, Germany for the climate period 1990-2020 (climate scenario A1B) in the crop rotation with winter oilseed rape (simulation with the YIELDSTAT model)

Local or farm scale

At local or farm scale an interactive simulation and integrated impact assessment of agricultural adaptation strategies to climate change (crop rotation, soil tillage, fertilisation, irrigation, price and cost changes, …) is offered by the LandCaRe-DSS. The user of the system will be informed about changes of crop productivity (yield, yield quality), soil fertility (water, carbon and nitrogen contents), water erosion and farm economy. At farm level the dynamic agro-ecosystem model MONICA [11] and the statistical-based model YIELDSTAT [9] for yield prediction are coupled with the farm economy model (FEM; [10]). The LandCaRe-DSS user receive information on different economic parameters, fertilizer amounts and costs, irrigation water demands and costs and finally on crop yields and sales profits. For all output information the variances of results are given, based on up to 90 simulation runs. The results are visualized using normalised bar graphs for a better comparison between different scenario runs. Figure 7 shows an example for the visualized simulation results of the model MONICA for a small part of a farm, based at the Google-map background. The bar graphs with information on economic values, yield values, fertilization and water related values are arranged around the fixed part of the farm which is subdivided in 1 ha (100 x 100 m) pixels. In the upper part first the data of the actual scenario run can be chosen. Secondly all input information can be activated and presented. At the left site of the figure there are shown parts of the dynamic results of MONICA as average for the cropping year and as time course (for example the soil carbon dynamics) for the chosen 30-year climate period.



WettReg | A1B | ☐ Regionalisierte Klimadaten | Angermuende (Wewa) | 2005

Figure 6 – Visualisation of simulation results for the combined MONICA and FEM models at farm level for a small part of a farm within the Uckermark region, Germany (crop rotation: winter wheat – winter oilseed rape; climate scenario: A1B; climate data regionalization method: WETTREG; climatic period: 1991-2020)

3. Conclusions

While the international community has focused on climate change mitigation, the issue of adaptation to climate change is an equally pressing issue and must be put on the international negotiation agenda. This is primarily crucial for many countries that have contributed little to greenhouse gas emissions but have to bear the brunt of the negative impacts of climate change and variability.

A first application of LandCaRe-DSS for Germany shows that

- the impacts of climate change on crop production are geographically unevenly distributed,
- in the first decades of the 21th century the expected impacts of climate change on agriculture in Germany are relatively low, but the second half of the century is expected to bring more severe biophysical impacts,
- the most important agricultural adaptation strategies in Germany to cope with climate changes are irrigation, flexible multiple crop rotations, change to low and no till farming systems and conservation of a good soil fertility,

- the continued technological progress (plant breeding and new agro-technologies) can play a crucial role for climate adaptation.

Despite the scientific progress in the last decades there are many uncertainties of climate change impact assessment on ecosystems and environment There are uncertainties of the regional occurrence of future climate change, uncertainties of the global and regional economic development, but also uncertainties in the understanding of dynamic key processes describing the interactions of elevated CO_2 with other climate variables, including extremes, with the soil and the water quality, with pests, weeds and diseases and with the ecosystem vulnerability. In general, greater collaboration across disciplines is necessary to bridge some of the existing knowledge gaps and better to understand related uncertainties.

For a decision support system it means, that it should be open for further developments and integration of new good validated models for a spatial use. The regional and local focus of the LandCaRe-DSS allows the development of more specific actions for an adaptation of agriculture to climate change. It will further provide a better understanding of the potential range of climate change impacts and specify required research to improve model parameterisation and validation by future local and spatial experimental work.

The presented methodology could be also of interest for the agricultural landscapes in Russia. It could be helpful to find more sustainable farming systems and suitable adaptation strategies to climate change.

4. Acknowledgement

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УДК 51-76+574.34+574.5

Особенности влияния зоопланктона на динамику фитопланктона

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Важнейшей подсистемой водных экосистем является пелагиаль, в которой функционируют специфические сообщества, не имеющие аналогов в наземных экосистемах [1]. Фитопланктон – нижний трофический уровень водной экосистемы, его функционирование обеспечивает жизнедеятельность всей экосистемы. Межвидовые взаимодействия в фитопланктонном сообществе играют существенную роль в его жизнедеятельности [2]. В то же время существенное воздействие на динамику обилия фитопланктона оказывает зоопланктон, который, в свою очередь, является кормовой базой для многих видов рыб. Зоопланктон также является многовидовым сообществом, в котором, как правило, выделяют следующие группы беспозвоночных: коловратки (Rotatoria), ветвистоусые раки (Cladocera), веслоногие раки (Copepoda) [3].

Ключевые особенности развития сообщества фито- и зоопланктона с учетом внутри и межвидового взаимодействия можно описать при помощи следующей схемы (рисунок 1).