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The purpose of this publication is to present the information technology (IT) tools and techniques that have been developed at the Systems Research Institute of Polish Academy of Sciences in Warsaw (IBS PAN) and at the German Institute for Landscape System Analysis in Müncheberg (ZALF) in the area of applications of informatics in environmental engineering and environment protection. The papers published in this book were presented in the form of extended summaries during a special workshop organized by IBS PAN in Szczecin in September 2006 together with the conference BOS'2006 organized jointly by IBS PAN, University of Szczecin, and the Polish Society of Operational and Systems Research. In the papers the problems of mathematical modeling, approximation and visualization of environmental variables are described. Moreover, some questions concerning the environmental economy are also presented.

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CHAPTER 1

Specialized Software

SPATIAL ANALYSIS AND MODELING TOOL V2.0 – APPLICATIONS TO THE LANDSCAPE INDICATORS CROP YIELD AND CROP COVERAGE

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Abstract: *A statistical developed yield matrix which combine different arable crops and grassland types with 56 different types of agricultural sites is the basis for natural yield estimation. This yield matrix was combined with additional model approaches dependent on different site charcterisics, weather/climate, plant breeding, and agro-management information, among them with fuzzy approaches for different nitrogen fertilization and plant protection levels. The integrated assessment of regional crop coverage is realized as the degree of crop coverage taken from (0,1) using crop-specific stepwise temperature sum functions. The regionalization of yield estimation and crop coverage models is realized by model integration into the Spatial Analysis and Modeling Tool (SAMT). The models are applied to the Quillow catchment located in the Uckermark region, Germany. Spatial results are presented and discussed.*

Keywords: Yield estimation, crop coverage, spatial modeling, model regionalization.

1. Introduction

Mass, water and energy cycles play an essential role within agricultural used landscapes. For the description of an agro-landscape and for the assessment of their sustainability different landscape indicators are an essential prerequisite. As landscape indicators there are biomass formation, yield potential, crop coverage, mass transfer by wind or water erosion, water percolation, nitrogen leaching, evapotranspiration and many others. Yield of agricultural crops influenced by numerous factors and site conditions (weather/climate, location/soil, management/cultivation activities) is a prerequisite for the estimation of regional productivity changes resulting from land use and climate changes.

On regional scale there is usually a limitation in the availability, amount and quality of data necessary for satisfactory yield estimation. This limitation has a lasting influence on the choice of appropriate yield estimation methods. For the assessment of consequences of land use changes on the sustainability of landscape models and algorithms are necessary which allow an extrapolation into the future. For describing landscape indicators like potential yield or crop coverage complex agro-ecosystem models can be used under certain circumstances only. They are available for some agricultural crops only. For the assessment of both regional productivity and regional erosion risk for whole regions based on potential yields and crop coverage, respectively, for a wide range of soil types, agricultural crop types and management strategies robust hybrid models are necessary which combine dynamic, statistic and fuzzy approaches.

Knowing the multi-disciplinary nature of landscapes and land use issues the usage of a methodological frame which combines different analysis methods, GIS, and modeling functions is an indispensable prerequisite for spatial land use studies and scenario runs.

This article describes two spatial applications: yield assessment and assessment of crop coverage. The assessments were realized on the basis of data from the „Quillow" catchment in the North Eastern region of Germany.

2. Model descriptions

2.1. Yield estimation model

On the basis of thousands of yield observations on fields representative distributed on arable and grasslands of more than 300 large agricultural enterprises within different climatic regions of East Germany up to the beginning of the 90th for comparable climatic conditions a statistic approach for estimation of basic natural yields was developed by Kindler (1992). The developed basic natural yield matrix combines different arable crops (winter wheat, winter barley, winter rye, triticale, spring barley, oats, potatoes, sugar beet, winter rape, maize for silage, clover, clover-grass-mix, lucerne, lucerne-grass-mix, field grass) and two grassland types (intensive grassland, extensive grassland) with 56 different types of agricultural sites. For winter wheat and triticale the natural yield matrix is given in Table 1. The agricultural site types base on the Medium Scale Site Map (MMK) for arable land (Schmidt and Diemann, 1991) which exists for the whole territory of the eastern part of Germany.

In the second step the basic natural yield is corrected giving positive or negative yield extra charges in dependence on site specific characteristics (stoniness (SK_MMK), slope steepness (HaHe), altitude (HüNN), hydromorphy (HfT_MMK), soil quality index[1] (AZ), growth temperature (WaWiTemp) according to Adler (1987), mesoscalic climatic zones (KlT) according to Adler (1987), climatic water balance (KWB, precipitation minus evapotranspiration)) using modified extra charge functions according to Kindler (1992). These functions were modified in dependence on availability of site specific data. Instead of the long term average values for the KWB the KWB values for the real growing year are used, and for calculation of potential evapotranspiration the approach according to Wendling et al. (1991) is used which need the daily values for global radiation and temperature only.

In dependence on site specific characteristics the calculation algorithm for yield extra charges (Ekorr) for winter rape (WiRa) is given in Equation (1). For winter wheat the corresponding calculation algorithm is given by Mirschel et al. (2003).

Because the statistical approach basis on observation data from the 90th only the genetic and plant breeding level as well as the agro-management level of this time period is taken into account. But in the last decade there was a significant development step in the field of breeding of new varieties of agricultural crops which are more productive and additional there was also a quick development in agro-management, especially in fertilization and plant protection. All this focus in higher crop yields. To take into account all this it is necessary to create a yield estimation procedure which is applicable for time periods after 1990 up to now and also for the future. This is the reason for combining the yield estimation procedure with a yield trend approach. A site and crop variety invariant linear yield trend was assumed to take into account the development in breeding and agro-management. On the basis of the 20-years (1980-2000) crop yield statistics of the State of Brandenburg (Germany) linear yearly trends were calculated: 0.121 t $ha^{-1}a^{-1}$ for winter wheat, 0.081 t $ha^{-1}a^{-1}$ for winter rye, 0.082 t $ha^{-1}a^{-1}$ for winter barley, 0.11 t $ha^{-1}a^{-1}$ for triticale, 0.023 t $ha^{-1}a^{-1}$ for oats, 0.025 t $ha^{-1}a^{-1}$ for spring barley, 0.277 t $ha^{-1}a^{-1}$ for corn, 0.030 t $ha^{-1}a^{-1}$ for winter rape,

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[1] The soil quality index which ranges from 1 to 100 is assumed on the basis of the parent material of the soil, its pedogenetic development stage and the hydrological boundary conditions. Lowest values are attributed to the poor diluvial sandy soils and highest values with the chernozoms from loess. The soil quality index was developed for the land evaluation of agricultural used land in Germany starting in the thirties.

1.118 t $ha^{1}a^{1}$ for sugar beet and 0.587 t $ha^{-1}a^{-1}$ for potatoes. For the extrapolation of the yield estimation procedure into future the same yearly trends are assumed well knowing that this is a first approximation only.

Table 1. Natural yield (NY, t ha^{-1}) for winter wheat (WW) and triticale (TR) in dependence on MMK-site types (StT) (according to KINDLER 1992, modified and expanded).

diluvial soils			alluvial soils			loess soils			disintegrated soils		
StT	NY_{WW}	NY_{TR}	StT	NY_{WW}	NY_{TR}	StT	NY_{WW}	NY_{TR}	StT	NY_{WW}	NY_{TR}
D1a	3.5	3.7	Al1a	6.1	5.6	Lö1a	7.6	7.1	V1a	7.0	6.5
D2a	3.7	4.2	Al1b	5.8	5.3	Lö1b	7.2	6.7	V2a	6.5	6.0
D2b	4.0	4.6	Al1c	5.5	5.0	Lö1c	6.8	6.3	V2c	6.1	5.7
D3a	4.4	4.6	Al2b	5.6	5.1	Lö2c	6.6	6.1	V3a	6.1	5.7
D3b	4.7	4.7	Al2c	5.2	4.8	Lö2d	6.4	5.9	V3b	6.0	5.5
D3c	4.5	4.4	Al3a	6.2	5.7	Lö3a	7.6	7.1	V3c	5.0	4.6
D4a	5.4	5.2	Al3b	5.9	5.4	Lö3c	6.8	6.3	V4a	5.6	5.2
D4b	5.7	5.5	Al3c	5.7	5.3	Lö4b	6.8	6.3	V4b	5.0	4.8
D4c	5.7	5.4				Lö4c	6.3	5.8	V5a	5.9	5.4
D5a	6.0	5.4				Lö5b	6.7	6.2	V5b	5.8	5.5
D5b	6.5	5.7				Lö5c	6.5	6.0	V5c	5.0	5.4
D5c	6.5	5.6				Lö6b	6.4	5.9	V6b	5.5	5.3
D6a	6.2	5.8				Lö6c	6.0	5.5	V7a	5.4	4.9
D6b	6.7	6.2							V7b	5.5	5.1
D6c	6.7	6.2							V7c	4.8	4.7
									V8a	5.5	5.5
									V9a	4.4	4.9

$$E_{korr}(WRa) = \begin{Bmatrix} 0.04 * KWB; & 1 \le KIT \le 14 & and & KWB < -25 \\ 0.03 * KWB; & 14 < KIT \le 18 & and & -25 \le KWB \le 100 \\ 0.02 * KWB; & 18 < KIT \le 25 & and & KWB > 100 \\ 0; \quad else & & & \end{Bmatrix} -$$

$$- \begin{Bmatrix} \begin{Bmatrix} 0; & 0 \le HaNe \le 9 \\ 2.0; & 9 < HaNe \le 14 \\ 4.0; & HaNe > 14 \end{Bmatrix}; StT \in (V1a...V9a) \\ \begin{Bmatrix} 0; & 0 \le HaNe \le 9 \\ 1.0; & 9 < HaNe \le 14 \\ 2.0; & HaNe > 14 \end{Bmatrix}; StT \in (V1a...V9a) \end{Bmatrix} +$$

$$
+\left\{\begin{array}{ll} 0.04 * AZ; & KIT \in (3 \ldots 6.15 \ldots 18) \\ 0; & else \end{array}\right\} -
$$

$$
-\left\{\begin{array}{l} \left\{\begin{array}{ll} 0; & SK\_MMK < 25 \\ 1.0; & 25 \le SK\_MMK \le 100 \\ 2.0; & SK\_MMK > 100 \end{array}\right\}; HaNe \le 14 \\ \left\{\begin{array}{ll} 0; & SK\_MMK < 25 \\ 0.5; & 25 \le SK\_MMK \le 100 \\ 1.0; & SK\_MMK > 100 \end{array}\right\}; HaNe \le 14 \end{array}\right\} + \qquad (1)
$$

$$
+\left\{\begin{array}{ll} 3.0; & HfT\_MMK \in (S3, G3) \quad and \quad KWB < -15 \\ 2.0; & HfT\_MMK \in (GS2, GS3, G2, S2) \quad and \quad KWB < -15 \\ 1.0; & HfT\_MMK \in (G1, S1) \quad and \quad KWB < -15 \end{array}\right\} +
$$

$$
+\left\{\begin{array}{ll} 2.0; & HfT\_MMK \in (S3, G3) \quad and \quad KlZo \in (3 \ldots 6.15 \ldots 18) \\ 3.0; & HfT\_MMK \in (GS2, GS3, G2) \quad and \quad KlZo \in (3 \ldots 6.15 \ldots 18) \\ 1.0; & HfT\_MMK \in (S2) \quad and \quad KlZo \in (3 \ldots 6.15 \ldots 18) \\ 2.0; & HfT\_MMK \in (S1, G1) \quad and \quad KlZo \in (3 \ldots 6.15 \ldots 18) \\ 0; & else \end{array}\right\} -
$$

$$
-\left\{\begin{array}{ll} 2.0; & StT \in (V1a \ldots V9a) \quad and \quad 600 < HüNN \le 700 \quad and \quad WaWiTemp < 4.0 \\ 4.0; & StT \in (V1a \ldots V9a) \quad and \quad HüNN > 700 \quad and \quad WaWiTemp < 4.0 \\ 0; & else \end{array}\right\}
$$

In an agricultural used region there are many different agro-management conditions. Especially in fertilization and pest management there are farm-specific management regimes which are different from usual management regimes. These deviations have significant influences on crop yields and have to be taken into account in the procedure for a spatial yield estimation. So it is necessary to use uncertain fertilizer and pest management information. To cope with this fact a fuzzy approach for taking into account the influence of fertilization and pest management on crop yields is used. The fuzzy approach has three inputs, first the natural yields estimated for average agro-management conditions, second the nitrogen fertilization amount, and third the pest management level. The fuzzification is realized using trapeze functions for all three inputs. The chosen fuzzy approach has 30 rules. If the spatial distributed information about nitrogen fertilization are not available from the farmers in detail these information are derived from the natural yield level and the crop dependent nitrogen fertilization range according to Kersebaum et al. (1995). The fertilization amounts additional are provided with a stochastic noise of +/- 15 %. In the case of non-availability of spatial distributed information about plant protection level these information are derived using a uniformly randomized distribution of values taken from (0,1), i.e. „0" means without any plant protection and „1" means with a maximum preventive plant protection.

2.2. Crop coverage model

Crop coverage is a dynamic process with a crop type dependent time course within the vegetation period and is described as the degree of crop coverage (DCC) taken from (0,1). Crop coverage, for instance, is an important value for an operative irrigation scheduling system on field level on the one hand and a prerequisite for the spatial erosion risk assessment within a whole region on the other hand. DCC depends on plant development (ontogenesis) which mainly is driven by temperature. DCC is described by a stepwise temperature function with a linear interpolation between steps.

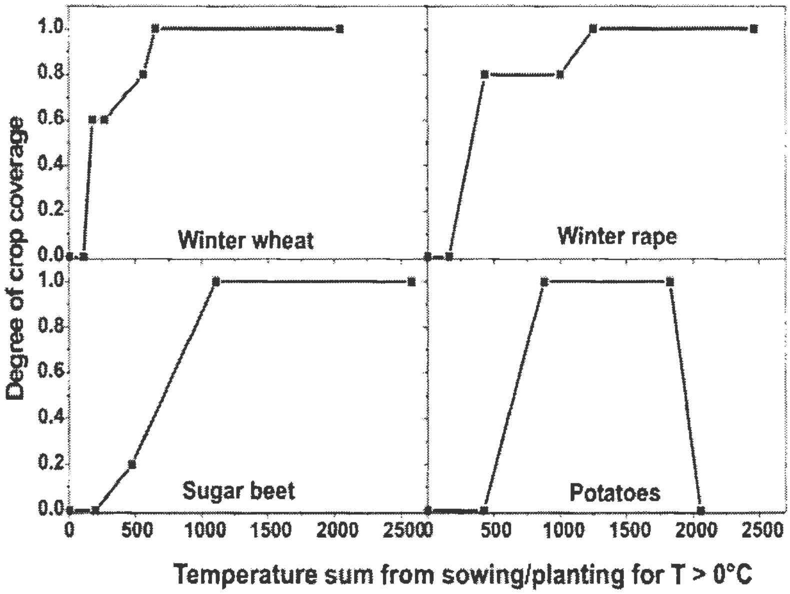

Figure 1. Crop type dependent stepwise temperature function for describing the degree of crop covering.

The temperature is taken into account as temperature sum above 0 °C, starting from sowing date for periodical crops and from begin of vegetation time for continuous crops or set-aside. On the basis of only time (days after emergence) dependent DCC like it is used for an irrigation scheduling system (Mirschel and Wenkel, 2004) a new temperature sum based DCC model approach was deduced and parameterized for the most important agricultural crops grown in the North Eastern part of Germany. For it long term temperature data sets from different meteorological stations were used. In this climatic region a full crop coverage is reached at a temperature sum of 653 °C for winter wheat, of 611 °C for winter barley, of 1109 °C for sugar beet, of 1124 °C for silage maize and of 397 °C for fodder pea. Examples for the stepwise temperature functions are given in Figure 1.

For scenario comparisons an average DCC for the whole region (DCCarea) over the cropping year is necessary which is calculated as follows:

$$DCC_{area} = \frac{1}{t_b - t_a} \int_{t_a}^{t_b} \left(\frac{1}{A} \int\int_{G} DCC\left(x, y, t, \sum T_t\right) dxdy \right) dt \qquad (2)$$

Here t_a is the begin of the cropping year, t_b is the end of the cropping year, A is the area of the region, DCC is the degree of crop coverage, G is the whole region, x and y are grid coordinates, t is the day in the year and T_t Tt is the mean day temperature.

2.3. Model regionalization

The described models for a spatial yield estimation and a spatial crop coverage assessment are implemented into a methodological frame and software package, the Spatial Analysis and Modeling Tool (SAMT) which was designed by the Institute for Landscape Systems Analysis of the Leibniz-Centre for Agricultural Landscape Research (ZALF) Muencheberg.

The model regionalization is realized on the basis of SAMT. Within SAMT the whole region is subdivided into 100-m-grids. All model input information exist as grid-maps and are managed by SAMT. Integrated into SAMT also is a special Fuzzy-toolbox for an effective design of fuzzy approaches and their regionalization. A detailed description of the open source system package SAMT in its latest version 2.0 is given by Wieland et al. (2004) and Wieland et al. (2006). Integrated into SAMT also is a special

Fuzzy-Toolbox (SAMT-FUZZY) for an effective design of fuzzy approaches and their regionalization (Holtman at al., 2004).

As an example the implementation scheme of the natural yield estimation algorithm into SAMT is given in Figure 2.

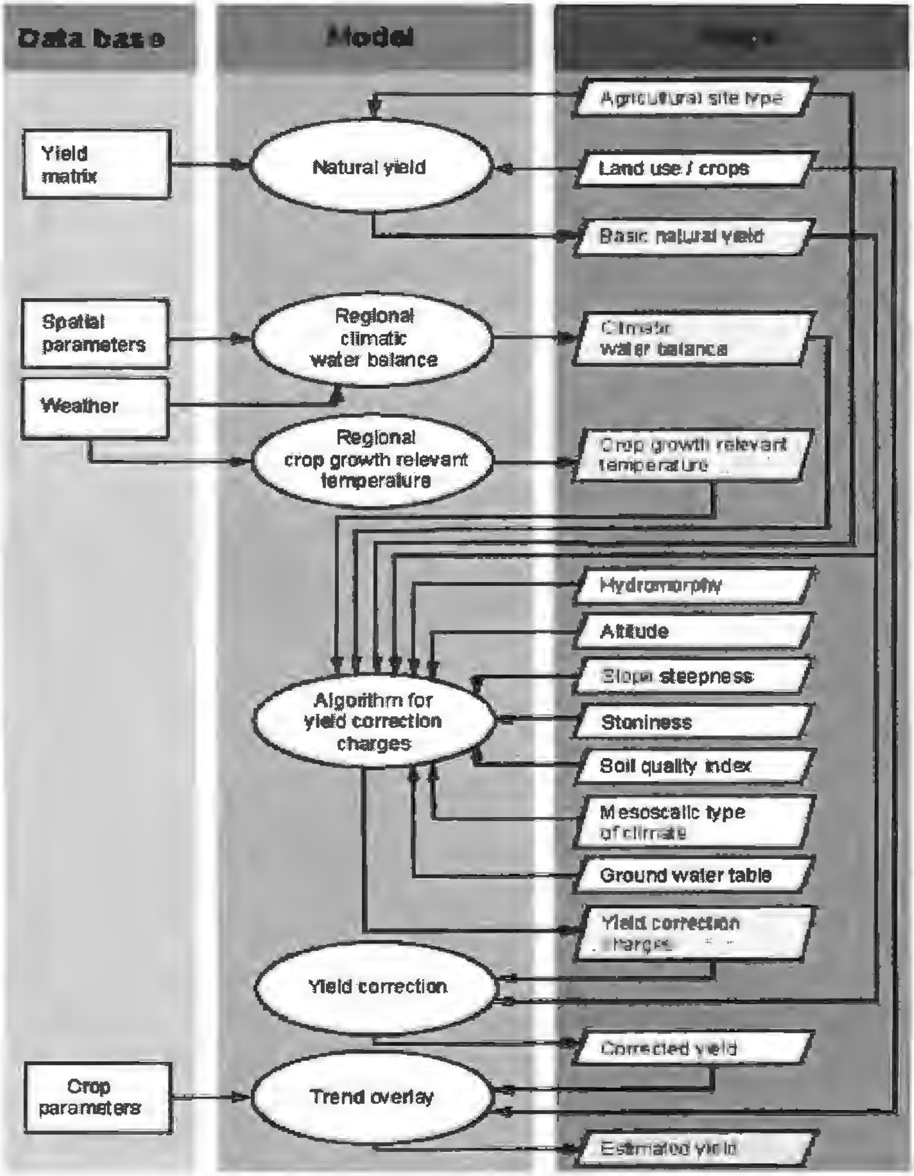

Figure 2. Implementation scheme of the natural yield estimation algorithm into the Spatial Analysis and Modeling Tool (SAMT).

3. Model application to the Quillow catchment

3.1. Region of application

The Quillow catchment with about 168 square kilometres is a mostly agricultural (77 %) used area. The catchment is located in the Uckermark region in the North Eastern part of Germany (state of Brandenburg and state of Mecklenburg-Western Pomerania, see Figure 3).

Figure 3. Location of the Quillow catchment area.

The river Quillow which is one of the important geographic feature in the area is 27 kilometres long and flows into the river Ucker. The area fully or partially consists the territories of 15 villages and is divided into 54.000 grid cells (100 x 100 meters, 180 in the north-south direction and 300 in the east-west direction). Within a grid cell homogeneous conditions are assumed.

For the Quillow catchment soil map information based on the MMK (a map in the scale of 1:25.000) are available, i.e. maps for site type, soil type (99 soil association groups), slope steepness, substratum, hydromorphy and topography (DEM 25) and additional maps for altitude, soil quality index, long-term average of climatic water balance (precipitation minus evapotranspiration) and mesoscalic climatic zones. The meteorological standard data (temperature, sunshine duration/global radiation, precipitation) for the Quillow catchment are taken from the meteorological station Prenzlau for the years from 1950 as real data and for the future time period up to 2050 as climate scenario data according to Gerstengarbe (2003).

3.2. Spatial yield estimation results

The model results for estimation of natural crop yield are shown exemplarily for winter wheat and sugar beet only. The results show that only 84 % of the arable land of the Quillow catchment are suitable for cropping winter wheat and only 77 % for cropping sugar beet. For the growing year 2000 the different spatial distributions of natural yields for both, winter wheat and sugar beet are shown in Figure 4.

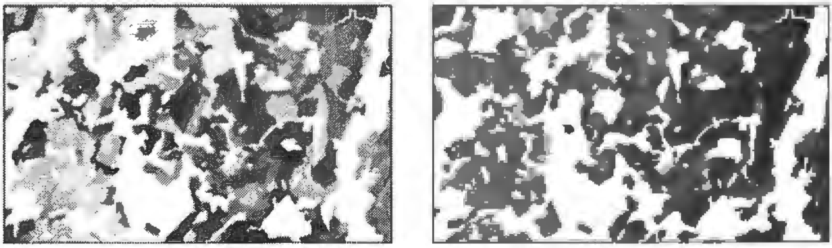

Figure 4. Spatial distribution of natural yield in the year 2000 for winter wheat (left) and sugar beet (right) for the Quillow catchment (the more grey the lower the yield; white: non-arable land or not suitable for cropping).

The winter wheat yield distribution in the Quillow catchment is similar to the soil type distribution, i.e. on poor sandy soils there are the lowest natural yields and on the best loamy soils there are the highest natural yields. Sugar beet is not cropping on fields with sandy soils. The distribution of sugar beet natural yield in the Quillow catchment in the dry year 2000 with a water deficit in the KWB of more than 250 mm is mainly influenced by the water supply during growing period. Here the yield gradient decreased from west to east is similar to the annual precipitation gradient decreased from west to east also.

Within the Quillow catchment the estimated natural yields range between 4.4 t ha^{-1} and 8.1 t ha^{-1} with an catchment average of 6.9 t ha^{-1} for winter wheat and between 43.7 t ha^{-1} and 59.3 t ha^{-1} with a catchment average of 51.3 t ha^{-1} for sugar beet.

For a comparison with observed winter wheat yield data in 2000 it is necessary to correct the natural yields using fuzzy nitrogen fertilization and plant protection level information. Using the estimated natural yield values for the Quillow catchment in 2000 nitrogen fertilization regimes according to Kersebaum et al. (1995) between 100 and 180 kg N ha^{-1} were derived. For taking into account the plant protection level between 0 and 1 a randomization algorithm was used because of missing of concerning farmers information. In the result of the SAMT-FUZZY approach for winter wheat using the three input grids „Natural yield", „Nitrogen fertilization" and „Plant protection level" the estimated winter wheat yields in the year 2000 for the Quillow catchment range from 3.9 t ha^{-1} up to 8.5 t ha^{-1}. The observed winter wheat yields in the same year range from 3.2 t ha^{-1} up to 10.0 t ha^{-1}.

A comparison of the natural winter wheat yield between the time decade 1990-1999 with real weather data and the time decade2040-2049 with scenario weather data according to Gerstengarbe (2003) shows an only climate change dependent yield decrease by 7.7 % in the average of the whole Quillow catchment not taking into account the breeding trend and the advantages in the cropping technologies. The main reason for this yield decrease is the increase of water supply deficite in the result of a temperature and evapotranspiration increase, i.e. the mean KWB for the decade 2040-2049 was lower by 95 mma^{-1} in comparison with the mean KWB for the decade 1990-1999. A larger range between minimum and maximum yields in the decade 2040-2049 in comparison with the decade 1990-1999 is an other effect, i.e. 14 % in 1999 vs. 26 % in 2040-2049. A possible reason for this effect is the increase of frequency in extreme weather events within a year or in years with extreme averages in temperature and/or precipitation.

3.3. Crop coverage estimation results

Based on a simulated land use map for 2000 (Mirschel et al., 2006) for the whole Quillow catchment an annual DCC average of 0.528 was calculated. The DCC time course over the whole year range between 0.12 in autumn and 0.97 in early summer (see Figure 5).

During winter the average of DCC is about 0.6 because of the proportional high share of winter cereals among the arable crops which were grown in 2000. In connection with the temperature increase up to June/July 2000 the crop growth is forced and the DCC increases up to about 1. With the harvest of all winter cereal in July/August the DCC is decreased rapidly. Afterwards the DCC continuously is decreased up to 0.12 up to October because of harvesting all other crops like buckwheat, corn, potatoes and sugar beet. The minimum DCC value in October is fixed by the permanent crops, grassland and set-aside areas. After sowing of winter cereals anew the DCC increases continuously up to the begin of the winter and is constant on a DCC-level of about 0.6 during the winter period.

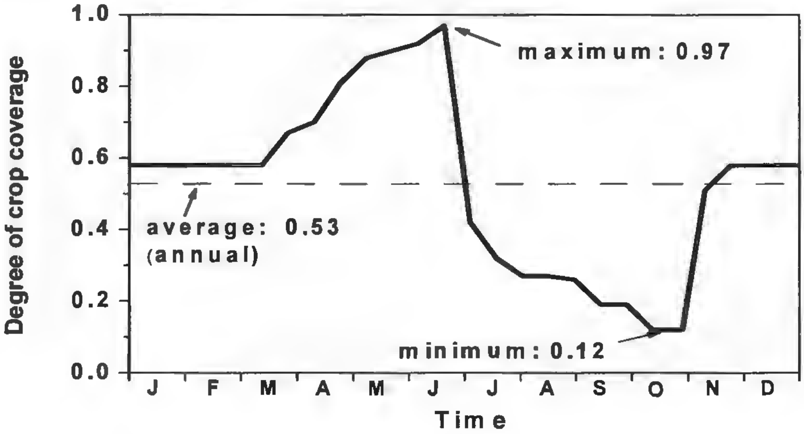

Figure 5. Average of the degree of crop coverage for the Quillow catchment area for the cropping year 2000 (daily course).

The spatial DCC distribution for the Quillow catchment is shown in Figure 6 at three different times within the year 2000.

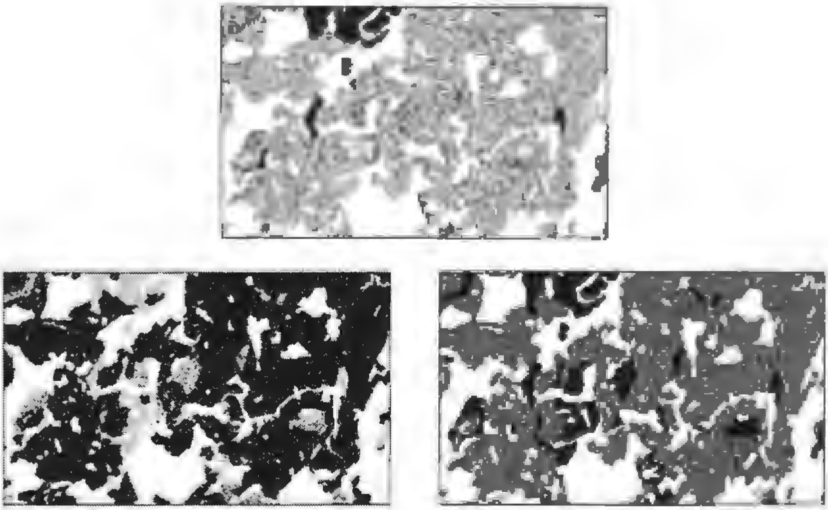

Figure 6. Spatial DCC distribution for the Quillow catchment at different times in 2000 (at 31st of March (top), 31st of July (bottom, left), and 31st of October (bottom, right)); the darker the grey level the lower the degree of crop coverage; white characteristics non-arable land (Mirschel et al., 2006).

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ECO – INFO AND SYSTEMS RESEARCH

This book presents the papers that describe the most interesting results of the research that have been obtained during the last few years in the area of applications of informatics in environmental engineering and environment protection at the Systems Research Institute of Polish Academy of Sciences in Warsaw (IBS PAN) and at the German Institute for Landscape System Analysis in Müncheberg (ZALF). The papers were presented in the form of extended summaries during a special workshop organized by IBS PAN in Szczecin in September 2006 together with the conference BOS'2006 dedicated to the applications of systems research in science, technology and economy and organized jointly by IBS PAN, University of Szczecin, and the Polish Society of Operational and Systems Research. They deal with mathematical modeling, approximation and visualization of environmental variables and with development of computer aided decision making systems in the area of environmental informatics.

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