Using Spatial EPIC Model to Simulate Corn and Wheat Productivity: the Case of the North CHINA

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Abstract: The traditional crop productivity simulations based on crop models are normally site-specific. To simulate regional crop productivity, the spatial crop model is developed in this study by integrating Geographical Information System (GIS) with Erosion Productivity Impact Calculator (EPIC) model. The integration applied a loose coupling approach. Data are exchanged using ASCII or binary data format between GIS and EPIC model without a common user interface. The spatial EPIC model is conducted to simulate the average corn and wheat productivity of 1980s in North China. The results show that the simulation accuracy of the spatial EPIC model is acceptable. The simulation accuracy can be improved by using the detailed crop management information, such as irrigation, fertilizer and tillage schedule.
Keywords: GIS, EPIC Model, Crop Productivity, Corn, Wheat.

1. Introduction

Climate change is very likely to have a major impact on the hydrological cycle and consequently on available water resources, flood and drought potentials, and agricultural productivity. It is very important to evaluate climate-change impacts on crop productivity, especially for China.

The traditional crop productivity simulations based on crop models are normally site-specific. The scale resolution of most crop models is a single point on the earth surface. To get regional estimates of crop productivity requires either scaling the model simulations from point estimates or scaling the data inputs from point measurements and then performing the simulations. Many investigators focused on the former approach have been undertaken during the past two decades, such as Izaurralde`s assessment in the conterminous United States [1]. But only a few attentions are paid to the latter one to scale the site-specific crop model to obtain the regional, national or even global simulation results, such as Tan`s global crop productivity estimation [2].

Compared with many other crop models around agro-ecosystems, the EPIC Model seems to be more suitable to simulate crop yields for relative comparisons of soils, crops, and management scenarios and has a good accuracy to estimate field yields [2]. It was originally developed by United States Department of Agriculture to examine the relationship between soil erosion and agricultural productivity. The model integrates the major processes that occur in the soil–crop–atmosphere–management system, including: hydrology, weather, erosion, nutrients, plant growth, soil temperature, tillage, plant environmental control, and economics [3]. Extensive tests of EPIC simulations were conducted at over 150 sites and on more than 10 crop species and generally those tests concluded that EPIC adequately simulated crop yields.

The objectives of this study are to develop the spatial crop model by integrating GIS with EPIC model, and to evaluate the simulation accuracy in regional level (North China) in the baseline climate condition (1981-1990).

2. Materials and Methods

In this section, the region of study, the crop model (EPIC model) used in the analysis, the method for integrating GIS with EPIC model, and the processing methods of EPIC input data are described.

1) Study Area

The study area is the North China, which includes Beijing and Tianjin, the two municipalities, Hebei, Shanxi, Shandong and Henan Provinces (Fig.1). The area studied is 110° E-123° E longitude by 30° N-43° N latitude and about 0.69 Million Square Kilometers.

The North China lies in semi-arid and semi-humid zone. The area is one of the most important grain production bases of China and plays an important role in the national food security. The population, cultivated land and crop production in 2000 have been reached to 24%, 22% and 25% of the national total respectively.

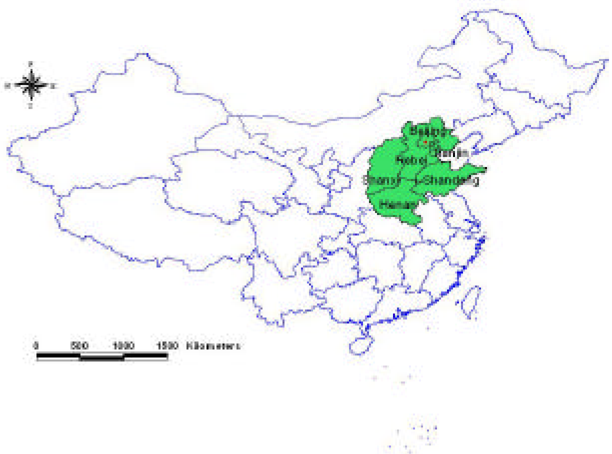

Fig. 1 The location of the study area in China

2) EPIC Model

EPIC operates on a daily time step to simulate evapotranspiration, soil temperature, crop potential growth, growth constraints (water stress, stress due to high or low temperature, nitrogen and phosphorus stress) and yield. EPIC uses a single model for simulating all crops, each crop has unique values for model parameters, which can be adjusted or created by the user as needed. The crop growth model uses radiation-use efficiency in calculating photosynthetic production of biomass. The potential biomass is adjusted daily for stress from the following factors: water, temperature, nutrients (nitrogen and phosphorus), aeration and radiation. Crop yields are estimated using the harvest index concept. Harvest index increases as a nonlinear function of heat units from zero at the planting stage to the optimal value at maturity. The harvest index may be reduced by high temperature, low solar radiation, or water stress during critical crop stages.

3) Integration Method

In order to facilitate the storage, manipulation, and handling of complex EPIC spatial information, it is necessary to input all raw spatial data into a geographical information system. The data handling and analysis, which involves data editing, conversion, interpolation, and overlay, can lead to the application of GIS. With the aid of GIS, it is possible for the EPIC to simulate crop yields efficiently at regional scale, and to allow a flexible presentation of results according to the user's needs.

There are several different approaches to integrate GIS with simulation models, such as the embedding method, loose coupling, and the tight coupling method. In this study, the loose coupling approach was used to integrate GIS with the EPIC. This approach uses two different packages directly. One is a standard GIS package (Arcview GIS3.2) and another is EPIC program (EPIC version 8120). They are integrated by combining various data layers on the physical aspects of agricultural environments such as soil, landform, and climate, via data exchange using either ASCII or binary data format between these two packages, which do not have a common user interface. The advantage of this approach is that redundant programming can be avoided. Map input, data handling, spatial analysis, and map output capabilities of GIS are used for the preparation of the land resource database required by the EPIC. The EPIC processing is outside of the GIS.

4) Input Data

Two kinds of standard data sets are developed as EPIC input files. One is basic input file, which includes miscellaneous field information such as climatic data, soil data, and management information. The other consists of parameter files such as crop parameter file, tillage parameter file, pesticide parameter file, and fertilizer parameter file. These parameters for most of the major crops have been established by USDA and do not need to be modified if there is no specific knowledge or specific application. The climate variables, the soil physical properties and the management information required by EPIC model are described below:

EPIC uses a stochastic weather generator to generate daily weather from monthly climatic parameters. The basic data set needed for each site is a record of monthly maximum and minimum temperatures, precipitation, Standard Deviation (S.D.) of maximum daily air temperature, S.D. of minimum daily air temperature, S.D. of daily precipitation, skew coefficient for daily precipitation, probability of wet day after dry day, and probability of wet day after wet day. The weather data in this study is from Global Daily Summary produced by National Climatic Data Center from 256 available terrestrial stations in China for 1981-1990. Kriging method aided by climatologically and topographically interpolation with quality control model is applied [4].

EPIC can accept up to 20 parameters for 10 soil layers. However, only a minimum of seven parameters is required: depth, percent sand, percent silt, bulk density, PH, percent organic carbon, and percent calcium carbonate. Other soil parameters can be estimated by EPIC itself. Therefore only these seven parameters in four layers are applied in this study. The soil-depth intervals are 0–0.1, 0.1–10, 10–30, 30–50, and 50–80 cm. All soil databases are provided by the Global Soil Task cooperated by the Data and Information System (DIS) framework activity of the International Geosphere–Biosphere Programme (IGBP). The highest resolution of this database is 5 min by 5 min.

EPIC requires detailed descriptions of management practices. These descriptions must specify the timing of individual operations either by date or by fraction of the growth period (i.e. by heat units). EPIC allows the user to simulate complex crop rotations with a variety of irrigation, fertilizer, pesticide, and tillage control options. There are two options for irrigation and fertilizer scheduled application in the EPIC program: manually and automatically. Only the manual option is applied in the spatial EPIC model. Some parameters of manual mode are described in details in Tab. 1[5]. The land use map at the scale of 1:1,000,000 is made by the Australian Center of the Asian Spatial Information and Analysis Network, Griffith University.

Tab. 1 The operation schedule in North China

SUMMER CORN			WINTER WHEAT		
Date	Operation	Volume	Date	Operation	Volume
Jun. 20	Irrigation	40mm	Oct. 8	Irrigation	40mm
Jun. 20	Fertilizer	72kg/ha*	Oct. 8	Fertilizer	72kg/ha*
Jun. 23	Planting		Oct. 8	Fertilizer	55kg/ha**
Aug.10	Fertilizer	48kg/ha*	Oct.10	Planting	
Sep.28	Harvest		Apr.10	Irrigation	100mm
			Apr.20	Fertilizer	48kg/ha*
			May10	Irrigation	100mm
			Jun.18	Harvest	

Note: "*" means the application amount of 100% nitrogen in chemical fertilizer. "**" means the application amount of 100% phosphorus in chemical fertilizer.

3. Results and Discussion

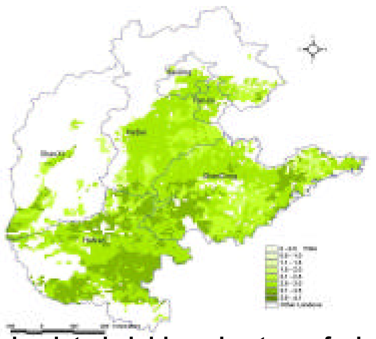

Fig. 2 The simulated yield per hectare of winter wheat

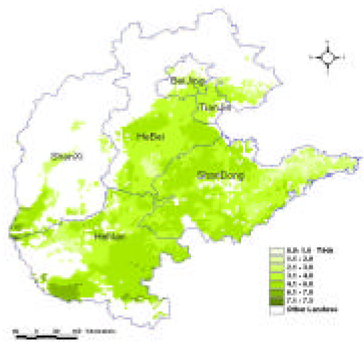

Fig. 3 The simulated yield per hectare of summer corn

The average yield of winter wheat and summer corn in North China for 1980s, simulated by the spatial EPIC model, can be seen from the Fig. 2 and 3. The simulated yields are just compared with the statistical yields from the China Statistical Yearbook from 1982-1991, due to the lack of the actual yield data. The Tab. 2 shows the comparison results. The differences in percentage between simulated and statistical yield are mostly under 10%, except the situation in Beijing and Shandong. It is evident that the crop yield of these area is underestimated by the spatial EPIC model, especially for Beijing. The reason is that Beijing and Shandong is the developed region in North China. The cropland in these regions are applied a very good field management with a better irrigation condition, fertilizer condition and so on. But only the simple and ordinary field operation parameters are inputted into the spatial EPIC model, which result in the underestimating situation. If the EPIC crop parameters established by USDA can be adjusted to be suitable for the application in North China, and the detailed field management information, such as the cropping system, irrigation schedule, fertilizer schedule and tillage schedule, can be obtained and inputted into the spatial EPIC model. The simulation accuracy could be improved.

Tab. 2 The comparison of crop average yield (Ton/hectare)

Region	SUMMER CORN			WINTER WHEAT		
	SM	SA	Error	SM	SA	Error
BeiJing	2.979	4.820	38.2%	2.598	3.959	34.4%
TianJin	3.686	3.864	4.6%	2.812	2.829	0.6%
HeBei	3.647	3.623	0.7%	2.654	2.965	10.5%
ShanDong	3.639	4.356	16.5%	2.669	3.388	21.2%
HeNan	3.706	3.323	11.5%	3.002	3.322	9.6%
ShanXi	3.796	3.993	4.9%	2.528	2.576	1.9%

Note: "SM" means simulated yield; "SA" means the average statistical yield from the China Statistical Yearbook from 1982-1991.

4. Conclusions

With integration with GIS, it is possible for the EPIC model to simulate crop yields efficiently at regional level. The crop management information, such as cropping system, irrigation schedule and fertilizer schedule, is crucial for improving the simulation accuracy. How to get the spatial distribution information of these management parameters conveniently is the future research.

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