Computer-Based Estimation System for Land Productivity

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Abstract. Land productivity generally refers to the overall productivity related to various combinations of the natural characteristics of the land and socioeconomic factors. Structural change and pattern succession in land systems undoubtedly leads to changes in the suitability and quality of different kinds of land types and directly influences agricultural productivity. In this paper we describe the processes, parameters needed and methods of data preparation, which will improve the ability of readers to use this model and provide a foundation for its wide application.

Keywords: Land productivity, Parameter configuration, ESLP.

1 Principles

The land resource is a multifunctional natural resource, which is in continuously growing demand under a background of rapid population growth and fast economic development [1]. This is especially the case in China, where the economy is developing rapidly and land use patterns are undergoing unprecedented change due to pressure from these demands [2]. Structural change and pattern succession in land systems undoubtedly leads to changes in the suitability and quality of different kinds of land types and directly influences agricultural productivity.

The Estimation System for Land Productivity (ESLP) is a collection of several applications, including land suitability assessment, and the evaluation of land productivity, and some advanced applications which use the stock of land resources as fundamental input information. The outputs from the ESLP include agro-ecological zoning maps, land suitability assessment maps, and attribute data such as cropping area and crop production.

2 Parameters

The growing period for crops, influenced by seasons, is one of the important parameters in the ESLP. As a comprehensive indicator of changes to the agro-ecological

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conditions, the growing period is defined as the period from the time when moisture and temperature conditions are suitable for crop growth until the crops mature [3, 4, 5]. The thermal zone is one of the important parameters in agro-ecological zoning. It indicates the total heat available during the growing period which can usually be represented by the heat available for the crop during each day of the growing period.

The soil property information is the basis of soil mapping. Soil types are classified as different soil genus or soil species. Soil properties are influenced by the soil quality, land management and even the habits of the planted crops. The land resource stock is characterized by the combined status of land use types, and constitutes the basis of agro-ecological zoning. The climate parameters under different scenarios are useful to simulate and predict the spatial-temporal changes in land productivity under different scenarios, which can be extended with climate parameters. An effective way to increase productivity is to raise the input levels, which can include the financial investment by governments, collectives or individual farmers in fixed and current assets. The ESLP can estimate and simulate changes in land productivity for different input levels [6].

3 Function Modules

The ESLP estimates land productivity through an iterative method. The calculation procedure includes five steps as following.

The potential photosynthetic productivity is the potential land productivity as determined solely by the photosynthetically active radiation, based on the assumption that the temperature, water, soil, breeds and other agricultural inputs are all in optimal condition. It is calculated as:

$$\begin{aligned} Y_1 = Cf(Q) = K\Omega\varepsilon\phi(1-\alpha)(1-\beta)(1-\rho)(1-\gamma)(1-\omega) \\ \cdot(1-d)sf(L)(1-\eta)^{-1}(1-\delta)^{-1}q^{-1}\sum Q_j. \end{aligned} \quad (1)$$

Where Y_1 is the potential photosynthetic productivity, with the unit kg/ha; C is the unit conversion factor; K is the area coefficient; $\sum Q_j$ is the total solar radiation during the growing period (MJ/m^2); Ω is the crop solar radiation utilization efficiency; ε is the percentage of effective radiation in the total radiation; Φ is the photon conversion efficiency; α is the reflectivity of the plant groups; β is the transmittance of the luxuriant plant groups; ρ is the proportion of radiation intercepted by non-photosynthetic organs of plants; γ is the proportion of the light that exceeds the light saturation point; ω is the proportion of respiration in the photosynthate; d is the crop leaf abscission rate; s is the economic crop coefficient; $f(L)$ is the corrected value of the crop leaf area dynamics; η is the moisture content of the ripened grain; δ is the percentage of ash; and q is the heat content of the dry matter (MJ/kg).

The potential thermal productivity, the upper limit of irrigated agricultural production, refers to the land productivity determined by the natural thermal condition when water, soil, breeds and other agricultural inputs are all in optimal conditions. It is calculated from the following formula:

$$Y_2 = f(T)\cdot Y_1. \quad (2)$$

where Y_2 stands for the potential thermal productivity, in units of kg/ha; $f(T)$ is the temperature revision function for crop photosynthesis. $f(T)$ is identified from three cardinal temperatures for major crop plants at which crops can grow and high yield can be achieved and used as a benchmark in this study. *f(T)* is calculated using the following equations:

$$f(T) = \frac{(T - T_1)(T_2 - T)^B}{(T_0 - T_1)(T_2 - T_0)^B}, \tag{3}$$

$$B = (T_2 - T_0)/(T_0 - T_1). \tag{4}$$

where T is the average temperature for one period, which is an asymmetric parabolic function in the range of 0-1 determined by T_1, T_2 and T_0 which are the lower, upper and optimum temperatures for crop growth and development, respectively. In this study, the crop growth period is divided into five stages: seedling, vegetative, nutrition and reproduction, nutrition and grain-filling, and maturity stages. *f(T)*is calculated separately for each stage.

The potential climate productivity is calculated by further revising the water indicator based on the potential thermal productivity, which is calculated from the following formula:

$$Y_w = Y_T \cdot f(W)(1 - I_r) + Y_2 \cdot I_r. \tag{5}$$

where I_r is the irrigation coefficient; Y_2 is the potential thermal productivity; Y_W is the potential climate productivity. The study of the potential thermal productivity can be summed up as research on the function of water. There are no authoritative models for the water calculation at this time, so the model recommended by the United Nations Food and Agriculture Organization is used here:

$$f(W) = 1 - K_y \times (1 - Pe / ET_m). \tag{6}$$

Where K_y is the reactive yield coefficient; ET_m is the maximum evapotranspiration (mm); Pe is the effective precipitation, which can be calculated from the model designed by the US Department of Agriculture Soil Conservation Service:

$$Pe = R / 125 \cdot (125 - 0.2 \cdot R) \quad \text{(If R<250mm)}, \tag{7}$$

$$Pe = 125 + 0.1 \cdot R \qquad \text{(If R>250mm)}. \tag{8}$$

where R is the total precipitation; and ET_m is the maximum evapotranspiration during the crop growing period, which can be calculated from:

$$ET_m = K_1 \cdot ET_0. \tag{9}$$

where K_1 is the crop coefficient, which is related to the season, the crop breed and the crop colony structure; ET_0 is the reference evapotranspiration, which is calculated using the improved Penman-Monteith model:

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34 u_2)}. \tag{10}$$

where Δ is the slope of the saturated vapor pressure-temperature curve (kPa°C^{-1}); R_n is the net radiation from the crop canopy surface (MJm^{-2}h^{-1}); G is the soil heat flux (MJm^{-2}h^{-1}); γ is the hygrometer constant; T is the daily average temperature (°C); u_2 is the wind speed at 2 m height; e_s is the saturation vapor pressure (kPa); e_a is the actual vapor pressure; the soil heat flux G is calculated from the following formula:

$$G=0.1*R_n. \tag{11}$$

The potential land productivity can be obtained from the potential climate productivity (Y_w) and the validity coefficient for soil:

$$Y_L = f(s)\cdot Y_w. \tag{12}$$

Twelve factors that influence soil properties are selected and their weighting coefficients (W_i) are determined by establishing a comparison matrix based on their relative importance to soil effectiveness, soil properties and soil nutrients.The ESLP calculates the soil effectiveness coefficients using the following formula:

$$f(s) = \sum_i A_i \cdot W_i. \tag{13}$$

The ESLP uses the Cobb-Douglas function to estimate land productivity influenced by fundamental inputs and conventional production inputs as follows:

$$Y=AK_1^{\alpha}K_2^{\beta}YL^{\gamma}. \tag{14}$$

where Y is the land productivity; A is the scaling parameter of the Cobb-Douglas function; K_1 is the fundamental input for improving land conditions; K_2 is the routine productive input for specific production processes; YL^{γ} is the potential land productivity; α, β and γ meet the following conditions:

$$\alpha+\beta+\gamma=1. \tag{15}$$

The total investment is allocated between the fundamental inputs and conventional production inputs based on the profit maximization principle. Assuming that the total investment amount is M, then

$$M=K_1P_1+K_2P_2. \tag{16}$$

where P_1 and P_2 are the prices of fundamental inputs and productive inputs, respectively. So the allocation of the total investment between the fundamental inputs and productive inputs satisfies the optimum condition:

$$\text{MAX } W=AK_1^{\alpha}K_2^{\beta}YL^{\gamma}P- K_1P_1- K_2P_2. \tag{17}$$

where W is the production profit, and P is the product price. The optimum investment program is found by solving the equations above, so that:

$$K_1 = \left(\frac{1}{Y_L^{\gamma}}\right)^{\frac{1}{\alpha+\beta-1}} \left(\frac{P_1}{\alpha}\right)^{\frac{1-\beta}{\alpha+\beta-1}} \left(\frac{P_2}{\beta}\right)^{\frac{\beta}{\alpha+\beta-1}}, \tag{18}$$

$$K_2 = \left(\frac{1}{Y_L^{\gamma}}\right)^{\frac{1}{\alpha+\beta-1}} \left(\frac{P_1}{\alpha}\right)^{\frac{\alpha}{\alpha+\beta-1}} \left(\frac{P_2}{\beta}\right)^{\frac{1-\alpha}{\alpha+\beta-1}}. \tag{19}$$

The estimation of land productivity is found by substituting K_1 and K_2 into the land productivity calculation formula.

4 Summary

Land productivity is one of the important indices in the assessment of effects of the dynamics of land system change. The ESLP is a collection of several application programs, including land suitability assessment, the evaluation of land productivity, and some advanced applications which use the stock of land resources as the fundamental input information. The ESLP involves numerous parameters in the process of land productivity estimation, and the calculation processes are lengthy and complex. This chapter describes the processes, parameters needed and methods of data preparation, which will improve the ability of readers to use this model and provide a foundation for its wide application.

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