Forest Management Model based on Photosynthesis Model and Market Simulation

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Abstract. In order to mitigate the impact of climate change, it is necessary to make rational use of forest resources for carbon cycle. Firstly, based on the actual data of tomato single leaf light and rate, this paper establishes rectangular hyperbolic model, exponential model and non-rectangular hyperbolic model, and photosynthesis model based on light and effective radiation, temperature and carbon dioxide concentration of three environmental factors. Finally, it is analyzed through simulation experiments, The improved rectangular hyperbolic model with the best simulation effect is determined. The model based on photosynthesis designed in this paper is helpful to the decision-making of forest management.

Keywords: Photosynthesis; Market Simulation Method; Per-unit Value; Forest Ecological Management.

1. Introduction

Widespread concern about global climate change has led to interest in reducing emissions of carbon dioxide (CO_2). Forests are a significant part of the global carbon cycle. Forest carbon sequestration is the process of increasing the carbon content of the forest through processes that remove carbon dioxide from the atmosphere (i.e. photosynthesis). Plants use sunlight to convert CO_2, water, and nutrients into sugars and carbohydrates, which accumulate in leaves, twigs, stems, and roots. Plants also respire, releasing CO_2. Plants eventually die, releasing their stored carbon to the atmosphere quickly or to the soil where it decomposes slowly and increases soil carbon levels. Once sequestered the carbon is stored in the forest within living biomass, soil and litter and contributes to the forest carbon stock.

At the worldwide level, forest management strategies and decisions should be made on the basis of balance between the logging value and the sequestration value, and at the same time, take conservation and biodiversity aspects, recreational uses, and cultural considerations into consideration.

2. Establishment and Analysis of Photosynthesis Model

2.1 The Light Response Model of Crop Leaves

According to the principle of photosynthesis, net photosynthetic rate P_n in leaf photosynthesis can be expressed as a formula[1]:

$$P_n = P_z - R_d \tag{1}$$

Where P_z is the total photosynthetic rate and R_d is the respiration rate[2].

At present, rectangular hyperbolic model, exponential model and non-rectangular hyperbolic model are widely used in different light response models based on the response curve of leaf photosynthetic rate and photosynthetically active radiation.[3-4]

$$P = \frac{\alpha I P_{max}}{\alpha I + P_{max}} \tag{2}$$

In Formula (2), αand P_{max} are the parameters describing the light response characteristics of plant photosynthesis[5], where α is the slope of the light response curve of plant photosynthesis

under low light conditions, also known as the initial quantum efficiency[6-7]. $P_{max}$is the maximum net photosynthetic rate under the strong light (used as a fitting parameter in this paper). Parameter I is the photosynthetically active radiation reaching plant leaves.

2.2 Influence Function of Temperature and CO_2 Concentration

Temperature is a key factor affecting the photosynthesis of crops, since they need to withstand the temperature changes of the external environment (day and night, season) during their growth and development. The changing curve of the influence of temperature on crop photosynthesis generally shows a single peak. The increase of temperature at low temperature will promote the photosynthesis of plants, while the increase of temperature at high temperature will reduce the photosynthesis of plants, indicating that high temperature will have adverse effects on the photosynthesis of plants. The temperature corresponding to the peak value of the single-peak curve is the optimum temperature for photosynthesis of crops. Different crop varieties and growth conditions also change the optimum temperature for photosynthesis of the same crop with the change of seasons[8].

In Formula (3), F(T) is the influence function of temperature on leaf photosynthetic rate ($0 \leq F(T) \leq 1$). T is the temperature at which photosynthesis takes place; T_{max} is the temperature when F(T) reaches the maximum value 1.0; B is the temperature influence profile parameter in the temperature influence function[9].

$$F(T) = \frac{2(T+B)^2(T_{max}+B)^2-(T-B)^2}{(T_{max}+B)^4} \tag{3}$$

CO_2 is a necessary raw material for photosynthesis of crops, so the change of CO_2 concentration in the air can have a significant impact on the photosynthetic rate of crops. The response curve of photosynthetic rate of crop leaves to the increase of CO_2 concentration can be divided into proportional stage and saturation stage. The numerical model of the influence of CO_2 concentration on photosynthetic rate of plant leaves is shown as follows[8].

$$P_X = P_0\left[1 + \mu\, ln\left(\frac{C_X}{C_0}\right)\right] \tag{4}$$

In Formula (4), P_X is the photosynthetic rate when CO2 concentration is C_X, P_0 is the photosynthetic rate when C_0 is equal to CO_2 concentration of 340μmol•mol^{-1}. Goudriaan's study suggested that the influence of CO_2 concentration changes on photosynthetic rate of plants could be corrected according to the ratio of constantly changing CO_2 concentration to 340μmol•mol^{-1}. μ is the coefficient, which is different for C_3 and C_4 crops. It is generally believed that μ is around 0.8 for C_3 crops and 0.4 for C_4 crops . In Formula (5), F (C_X) is the influence function of CO2 concentration on photosynthetic rate. [10]

$$F(C_X) = \left[1 + \mu\, ln\left(\frac{C_X}{C_0}\right)\right] \tag{5}$$

2.3 The Leaf Photosynthesis Function Model

The primary task of plant respiration is to provide energy for the life activities of plants, while the photosynthates of plants cannot be directly used to provide energy and must be oxidized through respiration. Therefore, respiration can be considered as the reverse process of photosynthesis.

Respiratory rate R_d can be divided into growth respiratory$R_g$and maintenance respiratory R_m, so respiratory rate can be expressed as:

$$R_d = R_g + R_m \tag{6}$$

Maintenance of respiratory R_m is related to temperature, and some studies suggest that it can be expressed as a formula [9-10]:

$$R_m = r_m \cdot D_M \cdot Q_{10}\frac{T-T_m}{10} \tag{7}$$

In Formula (7), R_m is the respiration coefficient maintained by leaves at room temperature T_m. Q_{10}=2 is the temperature coefficient. D_M is the dry matter weight of leaves. Due to the lack of D_M observations, parameters r_{md} are introduced.

$$r_{md} = r_m \cdot D_M \tag{8}$$

$$\mathrm{R_m} = r_{m_d} \cdot Q_{10} \frac{T-T_m}{10} \tag{9}$$

Considering light, temperature, CO_2 concentration and respiration comprehensively, the leaf photosynthesis function model is established. A model expression based on a rectangular hyperbola can be expressed as a formula:

2.4 Light Intensity Model

Sunshine intensity is the amount of solar radiation per square meter of area. The unit is W/m^2. Taking 1 W/m^2 as the standard sunshine intensity, the actual sunshine intensity is less than 1 W/ m^2 most of the time. Factors affecting sunshine intensity:Influence of meteorological factors and azimuth effect of sunshine. In this paper, the sun exposure azimuth is defined as azimuth β affected by the earth's revolution. Dust storms and other meteorological factors have a great influence on sunshine intensity, and it is variable.

1) The effect of earth rotation on azimuth α of sunlight.

There are two kinds of azimuth α : one is affected by the rotation of the earth; The other is the included angle between the normal direction of the solar incident light and the receiving surface.

During the sunshine duration of a day, the sunshine azimuth α changes 180°, and the sunshine intensity changes with the change of α. At noon α=0°, the day light is the strongest, and the sunshine becomes weaker in the morning or afternoon with the increase of α. In this paper, the relative value of light intensity in different seasons is derived by using the measured data of photoelectric output.

2) The effect of earth revolution on azimuth β of sunshine.

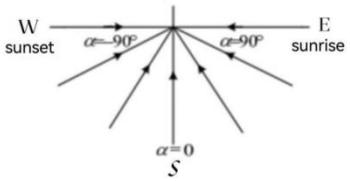


Figure 1. Angle changing

β is defined as the folding Angle based on the measured data. According to the above analysis, the range of α is 90°→0°→90°, and it changes in the east-west direction with a change period of one day. β, on the other hand, changes in the north-south direction over a one-year period. The variation range of β can not be measured directly, but can only be transformed by the variation of β on the influence degree of sunshine intensity and photoelectric output. The transformation method is: in the absence of meteorological factors, the variation range of β is marked by the inverse calculation of the gap between summer solstice and winter solstice photoelectric output value. When the northern hemisphere summer solstice, the sun is direct at 23.5° north latitude of the Earth, equivalent to β=0°, when the winter solstice, the sun is direct at 23.5° south latitude of the Earth, according to the measured data of photoelectric output β≈ arc cos (winter solstice output/summer solstice output), β changes with the geographical location of the measurement point and observation time.

In this paper, the absolute value of photoelectric output refers to the output power of photoelectric equipment P(W) or the daily power generation E(Wh). The absolute value of sunshine intensity and photoelectric output is affected by meteorological factors and sunshine azimuth α and β, which are changeable and inconvenient to study. Therefore, a relative value is introduced as a reference value for the study. Based on the maximum sunshine intensity at noon, the unit value (reference value) of light intensity at this time is set as 1, and the sunshine is weakest at sunrise in the morning and sunset in the evening. No matter what the specific value of light intensity is at this time, the unit value is set as 0. Similarly, at noon, when the solar light is the strongest, the photoelectric output is the largest, and the photoelectric output unit value is set as 1; the light is the weakest in the morning sunrise and evening sunset; when the absolute value of the photoelectric output is 0, the photoelectric output unit

value is set as 0. In this way, the variation trend of the unit values of photoelectric output and sunshine intensity is completely synchronized.

Take 30° north latitude, the summer solstice as an example. The sunshine duration is 05:30 -- 20:30(15 h), sunshine azimuth change 180°/15=12° per hour. The figure below shows the correspondence between sunshine intensity, photoelectric output unit value and sunshine hour, sunshine azimuth Angle α.

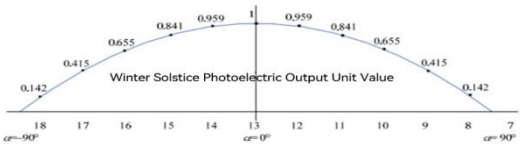


Figure 2. Winter solstic photoelectric output unit value

Take the winter solstice as an example, the sunshine duration is 07:30 -- 18:30(11h), and the azimuth of sunshine changes 180°/11=16.364° per hour. The figure below shows the correspondence between sunshine intensity, unit value of photoelectric output standard and sunshine time, and sunshine azimuth Angle α. There are at least three special points: α=90°(summer solstice 05:30, winter solstice 07:30), the unit is 0; α=0°(summer solstice 13:00, winter solstice 13:00) the unit value is 1; α=0~90°(summer solstice 20:30, summer solstice 18:30) the unit value is 0, and this trend is exactly the same as . This paper verifies the correctness of the theory by using the actual observation data of the experimental power station. The following figure shows the observed data:

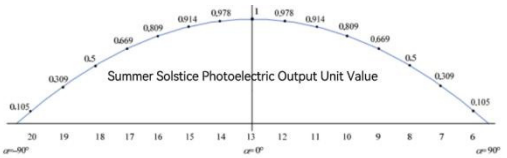


Figure 3. Summer solstic photoelectric output unit value

After fitting, the following equation can be obtained. The variation function of sunshine intensity at 30° north latitude on winter solstice with time is

$$\mathrm{I} = 0.0343t^2 + 0.8916t - 4.8142 \quad R^2 = 0.9975 \tag{10}$$

The variation function of sunshine intensity at 30° north latitude on summer solstice with time is:

$$\mathrm{I} = 0.0184t^2 + 0.4779t - 2.1254 \qquad R^2 = 0.9971 \tag{11}$$

2.5 Forest Carbon Sequestration

For a forest, we assume a growth cycle of m years for the main trees. Considering sustainable development, we assume that the maximum annual percentage of deforestation, k, is $\frac{1}{m}$, and that the annual carbon sequestration capacity of trees increases linearly from year to year during their growth cycle. If the annual carbon sequestration of the whole forest before logging is U, then F(I) is used to represent the annual carbon sequestration, which can be obtained as below:

$$F(1) = U_n(1-k) + \frac{1}{m}kU_n$$

$$F(2) = U_n(1-k) + \frac{1}{m}kU_n + \frac{2}{m}kU_n$$

$$F(3) = U_n(1-k) + \frac{1}{m}kU_n + \frac{2}{m}kU_n + \frac{3}{m}kU_n$$

……

$$F(i) = U_n(1-k) + \frac{1}{m}kU_n + \frac{2}{m}kU_n + \frac{3}{m}kU_n + \cdots + \frac{i}{m}kU_n = \frac{i^2+i}{2m^2}U_n$$

……

$$F(m) = (\frac{1}{m} + \frac{2}{m} + \cdots + \frac{m-1}{m})U_n = \frac{m-1}{2}U_n$$

The following is a classification discussion:

$m \leq 20$,the total carbon sequestration of the previous x year is

$$G(x) = \begin{cases} \sum_{i=1}^{x} F(i) & , x < m \\ \sum_{i=1}^{m} F(i) + (x-m)F(m) & , m \leq x < 20 \\ \sum_{i=1}^{m} F(i) + (x-m)F(m) - (x-20)C & , x \geq 20 \end{cases}$$

$m > 20$,the total carbon sequestration of the previous x year is

$$G(x) = \begin{cases} \sum_{i=1}^{x} F(i) & , \quad x < 20 \\ \sum_{i=1}^{m} F(i) + (x-m)F(m) - (x-20)C & , \quad x \geq 20 \end{cases}$$

$C = U_n \cdot m \cdot k \cdot \alpha, \alpha$ is the utilization rate of the wood, generally between 50% and 80%.

3. The Market Model Analyzing Management of Forest

3.1 Establishment of Measurement Indicators

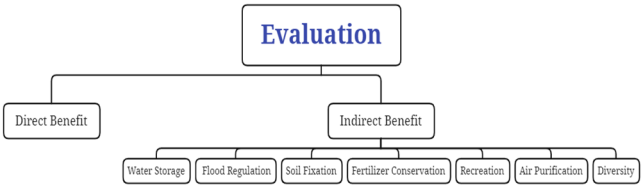


Figure 4. Evaluation indicators of forest ecosystem

The inherent characteristics of the forest determine its ecological, economic and social benefits. In this study, market simulation method is used to evaluate the ecological, economic and social benefits of the forest ecosystem, and the absorption capacity together with the support capacity of the forest ecosystem in the test area were analyzed.

Table 1. Direct economic benefits of forest ecosystems

Forest Type	Timber Value(yuan/hm^2·a)
Tropical Zone	30 152.59
Subtropical Zone	20 325.08
Temperate Zone	10 497.57
Frigid Zone	670.06

Water storage function and benefit analysis of forest ecosystem

Forest water storage converted to engineering amount, and then converted from engineering amount to engineering cost, multiplied by benefit input ratio, that is, forest flood control benefit. The calculation formula is:

$$V = \sum_{i=1}^{n} S_i i(F_i - F_0) b\beta \tag{12}$$

S_i is the area of category i forest; F_i Type is the i forest water storage; F_0 is the water storage capacity without forest land in this area; b: $1m^3$ flood storage construction expenses of dams ; β is the benefit/input ratio.

According to the data of Water Resources Department of Hunan Province, the average construction cost of dike is 0.52 yuan, and its service life is 50 to 100 years, so the average life is 75 years, and the ratio of flood control benefit and investment of water conservancy project is 13.1. Based on this economic and technical index, the benefits of water storage of various forest types are calculated.

Function and benefit analysis of water interception and flood regulation in forest ecosystem

When rainwater reaches a forest from the atmosphere, it is first intercepted by the forest canopy and tree trunks, and then partially intercepted by the ground cover, some of which evaporates and returns to the atmosphere as part of the hydro-logical process of the forest. According to the research, the interception capacity of forest canopy one-time precipitation is 37,000-65,000kg/hm^2. The interception capacity varies with forest type: cold zone is greater than tropical zone, mixed forest is greater than pure forest. Water absorption rate: tropical than cold zone, mixed forest than pure forest. This economic and technical index calculates the benefits of flood interception and diversion for various forest types.

Efficiency and benefit analysis of forest soil fixation

Forest soil is protected by forest canopy, forest cover, dead leaves and other multiple protections, which can reduce or even eliminate erosive rainfall, slow down, delay and weaken the formation and development of surface runoff and prevent soil erosion. The amount of soil erosion is different under different forest types. The benefit of forest soil fixation and sand control can be estimated by the following formula:

$$V = \sum K d_i G S_i \tag{13}$$

V benefits of forest soil fixation and sand prevention; K is the cost of digging up 1000kg sediment; d_i The amount of sediment loss in the forest of species i; G is the proportion of sediment quantity entering river reservoir to total loss; S_i is the area of forest i.

According to the bureau of water resources, the average cost of digging or intercepting 1000kg of sediment is 2.5 yuan as K value. According to Schultz's results, the sediment entering the riverbed reservoir accounts for 50% of the sediment loss with a G-value. The benefits of forest soil fixation and sand control can be calculated.

Function and benefit analysis of forest fertilizer conservation

The function of forest fertilizer conservation depends on the effect of forest soil fixation. The surface of forest soil contains a variety of nutrients. Soil nutrients vary with different forest types. N, P and K contents of organic matter in tropical and forest soils are the highest.

Due to the existence of forest fertilizer preservation mechanism, forest soil nutrient loss is reduced, compared with bare land, more organic matter, N, P, K are retained. It is converted into the corresponding amount of fertilizer, according to the price of various fertilizers to calculate the forest benefits of consolidating fertilizer.

$$V = \sum_i d_i s_i \sum_j r_j c_j p_j \tag{14}$$

V is forest fertilizer efficiency; d_i is the i forest topsoil loss reduction; s_i is the area of forest i. r_j is the content of JTH seed fertilizer; c_j is the j fertilizer conversion coefficient; p_j is the price of the j fertilizer. N is converted into ammonium bicarbonate, P converted into superphosphate and K is converted into potassium sulfate. The conversion coefficients c_j are 94/14, 506/62, 174/78

respectively. The price of the three fertilizers is 360 yuan/kg, 330 yuan/kg, 340 yuan/kg respectively. The economic benefits of keeping fertilizer can be calculated.

Forest air purification function and benefit analysis

Function and benefit analysis of air purification by forest filtration:

Forests absorb a lot of air in photosynthesis. American plant physiologists Saltz and Ross calculated that plants need to absorb 8 050kg of air to fix 1kg of carbon, about 6 222m^3. Dry wood carbon content of 450-500kg/1000kg, photosynthesis synthesis of 1kg of dry organic matter, can absorb 3622-4 025kg of air, that is, 2780-3 111m^3 of air filtration.

$$v = M \cdot d \cdot p \cdot (1+c) \cdot K \tag{15}$$

Where, M: forest growth; d: dry weight of wood; p: production of 1kg organic filter air volume; c is the percentage of annual root and branch growth to wood growth calculated by dry weight; K: Cost of filtering 10 000m^3 air. d is 0.45; c is 22.8%; K is 1 yuan; p for 290. This equation can be used to calculate the air filtration efficiency of coarse forest.

Function and benefit analysis of forest dust removal:

The forest structure is complex. Trees, with their dense foliage, block, filter and absorb dust from the air and act as air purifiers. The general pine forest can absorb 36400kg of dust per hm^2 per year, and the water green forest in the tropics can absorb 68000kg of dust. According to the average calculation, the annual forest dust can be 52000kg per hm^2, and the dust removal cost per 1000kg is 166 yuan.

$$V = S \cdot c \cdot p \tag{16}$$

Where, S: forest area (hm^2); C: Dust removal per hectare of forest (1000kg); P: Dust removal cost (yuan). The forest dust removal benefit can be calculated out.

Forest plants absorb a large number of harmful substances in the atmosphere. For example, 1 hm^2 camellia forest can absorb 7.9kg hydrogen fluoride per year. 1 hm^2 cryptomeria fortunei can absorb 720kg of sulfur dioxide per year.

$$V = S \cdot m \cdot p \tag{17}$$

Where, S: forest area; M: The amount of harmful matter absorbed per hectare of forest; P: the treatment cost of hazardous substances. The benefits of forest absorption of harmful substances can be calculated out.

Forest diversity and its benefit analysis

Forest diversity is rich in meaning, including biological species diversity, ecosystem diversity, genetic diversity, landscape diversity and so on. Forest diversity resources have their use value and non - use value. Value of use is the benefit they provide in the form of services for present or future biodiversity products. Non-use value is to leave a possible benefit to future generations through the efforts of present generations. Because of this, forest biodiversity resources can be directly or indirectly used by people to obtain economic benefits, with "utilization value", and can make contemporary people pay for ensuring future generations to use, so that future generations can obtain benefits and have "selection value", and not out of any utilitarian consideration, It is simply the "existence value" of willingness to pay because of the existence of forest biodiversity resources. Therefore, its value accounting method can not be unique, but should include a variety of methods.

Forest recreation function and benefit analysis

In 1960, the United States adopted the Regulation of Forest Multiple Utilization and Sustainable Production, which made outdoor recreation the primary goal of forest management. The Federal Forestry Law of the former Federal Germany formulated in 1975 also clearly stipulates that one of the main objectives of forestry operation is to protect the environment and provide rest places.

It is very difficult to calculate the economic value of forest recreation, because forest recreation is a "public commodity" without market exchange and price, and its market price information and consumption information are difficult to obtain. The quantitative study of its value is difficult to get in-depth and systematic development. According to relevant data, the average annual benefit of forest

recreation per hectare is 2.05 yuan /(hm^2·a), according to which forest recreation benefit can be obtained.

The results show that forest ecosystem not only provides direct product value to society, but also has huge indirect use value, and the contribution of such value to human beings is more significant than that of forest products. It should be noted that this is only an incomplete estimate, with the deepening of people's understanding of the ecological function of the forest, its ecological economic value will be more clear.

3.2 Implementation

Assume that the age of maturity of the tree is m year (m years count as old age), regardless of the death of the tree. Considering the sustainable development of the forest, the forest should be a stable population. The ratio of young: middle age: old is roughly 1:1:1, and the age level varies by 10% from upper to lower. Before maturity, the maximum value is 11:4 and the minimum value is 3:2.

Table 2. Forest benefit on solid fertilizer and so on

Forest Type /zone	Solid Fertilizer and Vacuuming(10 thousand yuan)	Tourism Benefit	Timber Direct Profit
Tropical	11 765	178	30 152
Subtropical	9 818	119	20 325
Temperate	8 409	61	10 498
Frigid	6 516	2	670

Considering that the forest should have certain social benefits, 10~15% of the area (K_0) should be used for tourism development, for tourists to play, after the development of the natural function of the forest will be reduced to a certain extent, to the original 80%.

Since the indirect economic effects of forest on water storage, soil fixation and diversity are far less than that of soil fixation and dust absorption, they can be ignored. The income of forest resources converted into money is:

$$M=(1-k)\ natural\ economic\ income + k\cdot direct\ timber\ income + k_0\cdot 0.8\cdot\ natural\ economic\ income \quad (18)$$

It can be seen that since the natural economic benefits of forests are far greater than the direct benefits of timber and tourism, the amount of forest felling should be the minimum value to ensure the stability of the population through linear programming:

$$k=\frac{1}{m}-\frac{1}{15} \quad (19)$$

Tourism development should be the minimum value within the range namely k_0 =10%.

If the mature age of trees is less than 15 years, they can be felled in the proportion of k=1/m - 1/15 per year. If the mature age of trees is more than 15 years, the annual felling ratio is 1/m~1/m+1/15. Specifically, dynamic regulation is needed to make the forest tree structure ratio in a healthy and reasonable range.

Our model includes direct economic benefits and indirect economic benefits. In order to ensure the stability of the population system, there must be corresponding harvesting. Different forests are distinguished according to different species. The type of tree determines the time to maturity, so the transition point for a management plan that is applicable to forests is the transition point for tree species in different forests. Forest species at different latitudes vary significantly, so it is necessary to investigate the change in the proportion of tree species at different locations (latitude and longitude) to determine the transition point between management plans.

4. Conclusion

In this paper, we first deal with the factors that affect the photosynthetic rate of plant leaves, such as temperature, light and carbon dioxide concentration, and establish a model of plant photosynthesis. Then, we build the light intensity model through simulation and data query. In the data section, we divide the world's forests into four broad categories and assume that they consist of different tree species in different proportions. By substituting them into our model according to different natural conditions, we can get the formula of photosynthetic rate of forest belt at different latitudes. We took specific forests and calculated their theoretical annual oxygen production based on their area and latitude. By comparing them with the actual values, the correction coefficients are determined. To obtain the maximum value for carbon sequestration, we assume that the forest grows at a constant rate each year. In this case, the maximum percentage of deforestation is only related to the growth cycle of the tree, so we can get a relationship between the maximum carbon sequestration of the forest and time. In determining management strategies, we take into account the need for the forest population structure to remain within a stable range.

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