Kor. Turfgrass Sci., 10 (4), 331～339, 1996

The Dynamical Models of the Life Action on the Assimilation and Dissimilation in the Ecosystem

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생태계에 있어서 동화 · 이화작용에 관한 동력학적 모델

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ABSTRACT

The mass action on the assimilation and dissimilation of a living system from bio-molecules to bio-spheres has been demonstrated by the theoretical models as the bio- and trophic-functions. From the viewpoint of this bio-mechanics, the general principle on the pre-equilibrium of the bio-molecular system is found.

Key words: Mass action, Living system, Bio-molecule, Bio-sphere, Bio- and trophic function.

INTRODUCTION

There are many ways to study the life but certainly the one, that must be the final arbiter, is the study of the kinetics of the life action. An enormous amount of information can be obtained from such studies, but only if we understand the subtle nuances of the theory involved, we can properly set up and carry out the necessary experiment. The mathematical expression of the basic model was found in Michaelis - Menten kinetics and own conception, and then was constructed as an original concept.

Expansion of this basic concept was carried out in order to obtain other new derivative models. The validity of the models has been found to be consistent with experimental data reported in literature. Therefore, the kinetics of the life action was abstracted as a theoretical models expressed in the language of mathematics.

BASIC CONCEPT

An organism can be considered as one macromolecular system which has a very multiple

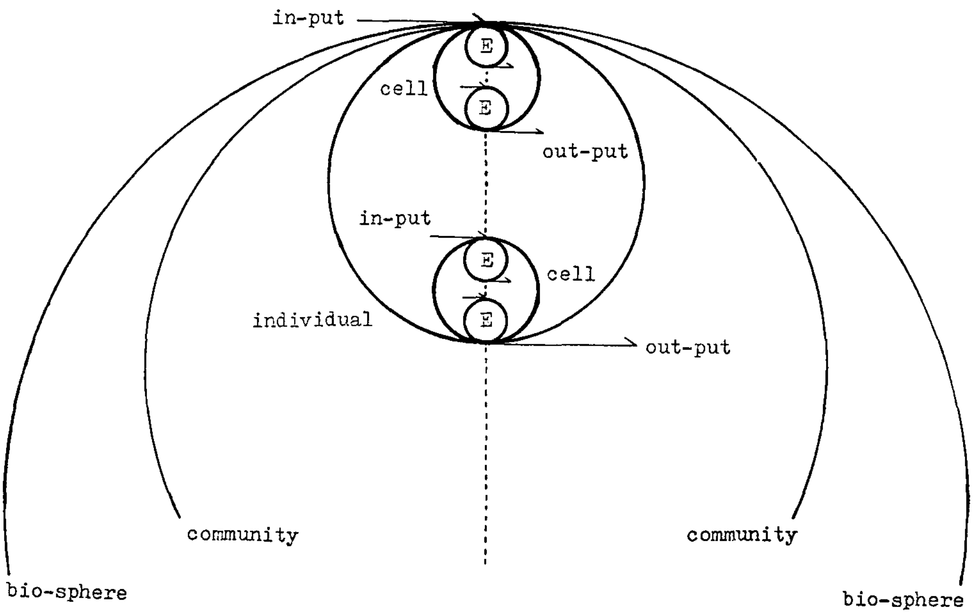

Fig. 1. The diagram of the basic concept from enzyme molecules to a bio-sphere.

structure. From this point of view, the metabolic action of one organism is interpreted by the same mass action as one molecular enzyme has. The basic diagram of this concept from bio-molecules to a bio-sphere on earth is shown in Fig. 1.

The brief concept of the kinetics of the mass action in the plant, which has more process of the assimilation than the animal, should serve to establish the theoretical basis of the dynamical model in the living things. The inverse relationship between the assimilation and dissimilation in the plant is

Light or energy	———	Assimilation $\longrightarrow$	———	Organic matters	
CO_2	———	Plant	———	O_2	············(1)
H_2O	———	$\longleftarrow$			
Nutrients	———	Dissimilation	———	H_2O	

in which the possible mechanistic equations involve the plant as the reactant which is converted reversibly to product.

KINETIC EQUATIONS

1. Assimilation

According to the basic concept, the plant b first reacts with the substrate s to form the plant-substrate complex bs, which then breaks down in a second step to form a free plant and the product p ;

$$b + s \underset{k_2}{\overset{k_1}{\rightleftharpoons}} bs \xrightarrow{k_3} b + p \quad \cdots\cdots (2)$$

In this reaction, k_1, k_2 and k_3 are specific rate constants for the assimilation designated. In the following derivation, Cb represents the organism concentration for the assimilation, and Cbs is the concentration of the substrate-organism complex. The concentration of the substrate is Cs and Cp represents the product concentration.

Since the velocity p of the assimilation of the organism is proportional to the concentration of the bs complex, we can write

$$p = \frac{dCp}{dt} = \frac{k_3 CbCs}{k_p + Cs} \quad \cdots\cdots (3)$$

where the constant k_p which replaces the term $k_2 + k_3/k_1$ can be called the same relationship as the Michaelis - Menten constant.

We shall consider that the organism has multiple independent catalystic sites existing in only one active system such as a chloroplast, a mitochondrion, a cell, an individual, a community, an ecosystem and a bio-sphere. When the substrates such as light, CO_2, H_2O and mineral nutrients are expressed by m variables which are the trophic-function of p, we shall conclude the equation (3) with a consideration of the same mechanisms, which require a great number of substrates to produce a complex rate equation :

$$p = \frac{dCp}{dt} = k_{3m} Cb \prod_{i=1}^{m} \frac{Csi}{k_{pi} + Csi} \quad \cdots\cdots (4)$$

where $k_{3m}Cb$ represents the asymptotic value P_m of the assimilation. Therefore, the equation (4) is given by

$$p = \frac{dCp}{dt} = P_m \prod_{i=1}^{m} \frac{Csi}{k_{pi} + Csi} \quad \cdots\cdots (5)$$

2. Dissimilation

From the equation (1) in any sequence involving two or more reactions, separate kinetic equations of the dissimilation must be written for each step in the mechanisms.

$$b + p \underset{k_5}{\overset{k_4}{\rightleftarrows}} bp \xrightarrow{k_6} b + s \quad \cdots\cdots (6)$$

In this reaction, k_4, k_5 and k_6 are specific rate constants for the dissimilation of the organism. The velocity r of the dissimilation can be expressed by

$$-r = -\frac{dCs}{dt} = -\frac{k_6 CbCp}{k_r + Cp} \quad \cdots\cdots (7)$$

where k_r replaces the term $k_4 + k_5/k_6$, and Cp expresses the product concentration of the assimilation which is the substrate of respiration.

When products such as organic matters, O_2 and H_2O are expressed by m variables of the trophic-function of r, we shall conclude the equation (7) with a consideration of the same mechanisms as the assimilation process, which require a great number of substrates to produce a complex rate equation as follows :

$$-r = -\frac{dCs}{dt} = -k_{6m}\, Cb \prod_{i=1}^{m} \frac{Cpi}{k_{ri} + Cpi} \quad \cdots\cdots (8)$$

Therefore, the equation (8) is rewritten by

$$-r = -\frac{dCs}{dt} = -Rm \prod_{i=1}^{m} \frac{Cpi}{k_{ri} + Cpi} \quad \cdots\cdots (9)$$

where Rm is the asymptotic value of the dissimilation.

3. Asymptotic values *Pm* and *Rm*

Asymptotic values Pm and Rm are changed by the environmental factors. Let the environmental factors affecting assimilation and dissimilation activities of the organism be a set of the variables of the bio-function. The best estimates of Pm and Rm are the bio-function defined in the environmental factors such as climate, soil conditions, relief, organisms and time. Chang(1975) has reported that the organism takes the mass action of the normal distribution in response to the environmental factors. According to this result, Pm and Rm could be shown by the normal curves, respectively. These characteristic functions are now written by

$$Pm = \frac{Pmn}{\sqrt{2\pi}} \prod_{j=1}^{n} \frac{1}{\sqrt{\varphi_j}} \exp\left[-\frac{(x_j - \eta_j)^2}{2\varphi_j}\right] \quad \cdots\cdots (10)$$

and

$$Rm=\frac{Rmn}{\sqrt{2\pi}}\prod_{j=1}^{n}\frac{1}{\sqrt{\psi_j}}\exp\left[-\frac{(x_j-\gamma_j)^2}{2\psi_j}\right] \quad\cdots\cdots(11)$$

where φ and ψ are the coefficients of the assimilation and dissimilation, x represents the variables of the bio-function, and η and γ express the abscissa values at the maximum levels, Pmn and Rmn, of Pm and Rm, respectively.

4. Dynamical models of assimilation and dissimilation

The assimilation equation given by the equations (5) and (10) is now more fully obtained by

$$p=\frac{Pmn}{\sqrt{2\pi}}\prod_{j=1}^{n}\frac{1}{\sqrt{\varphi_j}}\exp\left[-\frac{(x_j-\eta_j)^2}{2\varphi_j}\right]\prod_{i=1}^{m}\frac{Csi}{k_{pi}+Csi} \quad\cdots\cdots(12)$$

The dissimilation equation derived from the equations (9) and (11) is represented by

$$-r=-\frac{Rmn}{\sqrt{2\pi}}\prod_{j=1}^{n}\frac{1}{\sqrt{\psi_j}}\exp\left[-\frac{(x_j-\gamma_j)^2}{2\psi_j}\right]\prod_{i=1}^{m}\frac{Cpi}{k_{ri}+Cpi} \quad\cdots\cdots(13)$$

the equations (12) and (13) involve the double vector systems of the bio- and trophic-functions, and demonstrate two directions of the life action of the organisms. It is important that the variables of the trophic-function are alternated with the bio-function.

When the variables of the trophic-function have the definite values, p and r are expressed by the bio-function. In the case of a certain state of the bio-function, p and r are the trophic-function. Therefore, the author considers that the equations (12) and (13) are the basic equations of bio-mechanics which metabolism, photosynthesis, growth, productivity, net production and yield as the mass action of the organism are determined by.

The kinetic equation of photosynthesis which is the assimilation of light, CO_2 and H_2O is derived from the equation (12). The photosynthetic equation, which presents the relationship between photosynthetic rate and light intensity, was obtained by Tamiya(1951) and conformed to Monsi and Saeki(1953). Under the environmental condition of a certain state except for light irradiation, Tamiya's equation coincides with the equation (12). Kinetic models have been presented by Rabinowitch(1951) to account the rate of photosynthesis as a function of incident radiation, and these various models which are led to quadratic equations are equivalent to a part of the equation (12). The effect of light intensity on net photosynthesis by various species at 30℃ and 300 ppm CO_2 in air (Chang, 1975; Hesketh, 1963; Hesketh and Moss, 1963) has shown the same curves in comparison with the equation (12). Moss(1963), Hofstra and Hesketh(1969), Murata and Iyama(1963), Decker(1959), Hesketh(1967) and Joliffe and Tregunna(1963) reported the effect of temperature on net photosynthesis in single leaves of maize, bermuda grass, tobacco, and wheat at 300 ppm of CO_2 in air high illuminance, respectively. These results agree with a quadratic tendency to data of sunflower leaves (Chang, 1975) and with the case of a bio-function of the equation (12). The equation (12) corresponds to all reports on the photosynthesis - light, the photosynthesis - CO_2 and the photosynthesis - H_2O curves of the plant.

In the case of all reports, the asymptotic value of respiration rate as a bio-function of air temperature could not be found in the range from 15℃ to 45℃ but should be shown in 45℃ and over. These results are in accord with the front part of the bio-function of the equation (13). The curves of the equation (13) agree with all data which have been reported by the papers on the effect of O_2 concentration on respiration of the plant and animal.

5. Net production and yield

The sum of the mass action of the assimilation and dissimilation is the net production p_n of the organism.

$$p_n = p - r \tag{14}$$

When the equations (12) and (13) are substituted in the equation (14), the net production from a cell to a community are determined.

In the case of the sum of the assimilation and dissimilation, the mechanism into the convenient closed - loop type of geometric array may be arranged by the King's method. Therefore, the total of the equations (2) and (6) could be rewritten by

$$
\begin{tikzcd}
 & s \uparrow \{\text{out-put} & \\
 & + & \\
\text{in-put}\} \; s + & b \arrow[r, shift left, "k_1"] & bs \arrow[l, shift left, "k_2"] \arrow[d, "k_3"] \\
 & bp \arrow[u, "k_6"'] \arrow[r, shift right, "k_5"'] \arrow[d] & b+p \arrow[l, shift right, "k_4"'] \\
 & p_1+b \arrow[r, shift left] \arrow[u, phantom] & bp_1 \arrow[l, shift left] \arrow[u] \arrow[d] \\
 & bp_2 \arrow[u] \arrow[r, shift left] \arrow[d] & b+p_2 \arrow[l, shift left] \\
 & \vdots & \vdots \arrow[u]
\end{tikzcd} \tag{15}
$$

The basic figure in the equation (15) is a square form. The equation (15) suggests that the net production does not allow for any reverse reaction between the assimilation and dissimilation.

When the sample area is the limit as a point region, the concentrations of raw materials for the assimilation and dissimilation of the plant are nearly constant, and the variables of the bio- and trophic-functions except for time t are very nearly constant, too.
Consequently, p and r are given by the bio-function of time. The equation (14) consists of

$$p_n = p(t) - r(t) \cdots\cdots (16)$$

The equation of yield y of organic matter at an interval in time 0 to t is given by

$$y=\int_0^t p_n dt=\int_0^t p(t)dt - \int_0^t r(t)dt \cdots\cdots (17)$$

Therefore, standing crop, and productivity at a certain interval are estimated by the equations which are fitted to the equation (17).

If respiration rate is modified by a certain constant r, the equation (16) becomes

$$p_n=\frac{Y}{\sqrt{2\pi\omega}} \exp\left[-\frac{(t-\sigma)^2}{2\omega}\right] - r \cdots\cdots (18)$$

where Y, ω, t and σ equal to $Pm(n-1)$, $\varphi_{(n-1)}$, $x_{(n-1)}$ and $\eta_{(n-1)}$, respectively.

From the equation (18) of the net production, the yield equation is found to be

$$\begin{aligned} y(t) &= \int_{-\infty}^t \frac{Y}{\sqrt{2\pi\,\omega}} \exp\left[-\frac{(t-\sigma)^2}{2\omega}\right] dt - \int_0^t r\,dt \\ &= \frac{Y}{2}\left[1+\Theta\left(\frac{(t-\sigma)}{\sqrt{2\omega}}\right)\right] - \mathrm{D} \cdots\cdots (19) \end{aligned}$$

wher $\Theta(t) \equiv \frac{2}{\sqrt{\pi}} \int_0^t e^{-u^2}\, du$ is the biological function and $\int_0^t r\, dt = D$ represents amount of respiration at an interval in time 0 to t ; the $y(t)$ is expressed by the sigmoid curve. This sigmoid equation is agreed with the results of growth experiments due to Robertson (1907), Mitscherlich(1919), Lotda(1925), Ditto(1926, 1956), Brougham and Glenday(1967), Fecklefs(1967), Monsi(1953), and Chang and Yoshida(1973a, b).

KINETIC INTERPRETATION OF LIFE

According to the kinetic reactions (2) and (6), when the reactions of a bio-molecular system are proceeding to the equilibrium, there are metabolism and a life. Before an organism is in equilibrium, the living system must be altered in order to maintain the life, and the bio-molecular system may be kept on a pre-equilibrium condition. Therefore, haploid gametes unite to form diploid cells in the process of fertilization, and micro-organisms conjugate each other.

If conditions of a living system of bio-molecules, initially at pre-equilibrium, are changed, the pre-equilibrium will shift in such a direction as to tend to restore the original conditions. This is the general principle applied to the mass action from a bio-molecular system to a bio-sphere.

Let us assume that a cytoplasm containing DNA at a certain concentration has half of its total DNA in the form of diploid cell.

If a sperm is added to an egg, the concentration of DNA is increased ; by the author's principle, the pre-equilibrium then shifts so as to use up some of the added DNA ; that is, so as to tend to bring the DNA concentration back to its initial value.

In Gurdon's experiments(Gurdon, 1968), diploid nuclei from differentiated cells of a frog were transplanted into unfertilized eggs whose haploid nuclei had been previously removed. The resulting genetically complete diploid eggs were then artificially induced to divide and grow, often to form adult organisms those chromosomal makeup derives entirely from clonal reproduction of donor nuclei.

적 요

본 연구를 통헤, 생물함수와 영양함수의 이론적 모델을 이용하여 생체물질로부터 전생물계에 이르는 생체의 동화와 이화작용을 이론화하였다.

이 생물역학의 관점에서 생물물질계의 전 평형화에 대한 일반적인 원리를 밝혀내었다.

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