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The Development of Leaves in *Amaranthus retroflexus* and *Chenopodium album* Represented by the Plastochron

I. The Derivation of the Plastochron Index

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Plastochron에 의한 *Amaranthus reroflexus*와 *Chenopodium album*의 잎의 성장해석

I. Plastochron Index의 유도

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ABSTRACT

The plastochron index (PI) provides possibility on studies of the effects of various environmental factors on morphological and physiological development of plants. The PI of Erickson and Michelini(1957) could be used merely when leaf n is longer and leaf $n+1$ is smaller than the reference length at any time. If both the lengths of leaf n and $n+1$ are smaller or longer than the reference length, it could not estimated. In this study, the PI of Erickson and Michelini was complemented and the linear patterns according to leaf arrangement was represented. Namely when both the lengths of leaf n and $n+1$ are smaller than the length of reference, PI is $n-(\ln LR-\ln L_n)/(\ln L_n-\ln L_{n+1})$. And when both the lengths of leaf n and $n+1$ are longer than the length of reference, PI is $n+1+(\ln L_{n+1}-\ln LR)/(\ln L_n-\ln L_{n+1})$. Where PI represents plastochron index, n is the serial number counting from the base, LR is the reference length, L_n is the length of leaf n, and L_{n+1} is the length of leaf $n+1$. The linear model of PI is changed by the various environmental factors and the linear patterns are different according to leaf arrangement. According to leaf arrangement, the equation of the general regression lines is $Y_{in-(i-j)}=a-(n-1)(q_1+\cdots+q_{i-1})-(q_1+\cdots+q_{j-1})+rt+\varepsilon$. Where Y : the logarithmic of the leaf length in question, i : leaf number hang on the one node, n : the node number counting from base, q : spacing on the Y-axis, j : 0, 1, 2, ⋯, r : slope, t : time, ε : error.

INTRODUCTION

The PI was proposed by Erickson and Michelini in 1957. They defined plastochron as the time interval between initiation of any two successive leaves. More broadly, it can also be defined as the time interval between corresponding stages of development of two successive leaves at various vegetational stages (Maksymowch, 1973).

The PI has been scarcely used in the physiological studies. Michelini (1958) demonstrated the utility of the plastochron index by following fresh weight, dry weight, chlorophyll content and respiration for *Xanthium* leaves.

In studies of morphological and physiological development of whole organs of plants, results are often plotted against chronological age.

With respect to the physiological development, though the same chronological age there are great variability. Plants with morphological similarity may have quite different chronological ages (Lamoreaux *et al.*, 1978).

Freeman (1984) used plastochron age for *Grapevine* leaf development in relationship to potassium concentration, leaf dry weight and density. The use of PI has been extensively reviewed by Lamoreaux *et al.* in 1978.

They concluded the use of PI in investigations of hormonal regulation of plant growth and in studies of the affects of various environmental factors on developmental processes in crops were very useful.

The age of trees at any time could be determined, but the age of herbaceous plants could not. The use of PI resolved indirectly the problems. Nevertheless this model has never been applied broadly in ecological studies and particularly it has never been applied in Korea.

The objective of this study was to complement the plastochron index of Erickson and Michelini, and to represent the linear patterns which are different according to leaf arrangements.

THEORETICAL BACKGROUND OF THE PLASTOCHRON INDEX

The Fig. 1 is the expected growth curve of leaf lengths versus time.

The Fig. 1 showed that the three assumptions were produced; i) the growth in length of the young leaves is exponential, ii) the family of these lines are parallel, and iii) approximately equally-spaced in time.

Under these assumptions the following formula for the plastochron age of the plant was derived.

As shown in Fig. 2, if the length of leaf n is longer than the reference length (LR) and the length of leaf $n+1$ is smaller than the LR at time (t_3), the plastochron age of plant is $n+bc/bd$. Triangles ***abc*** and ***edc*** are similar and $bc/bd=ac/ae$. Since longarithms of leaf lengths are used, $ac=\ln L_n-\ln$

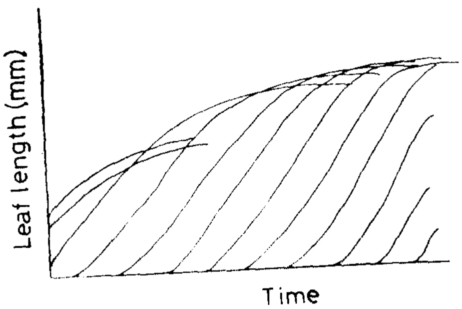

Fig. 1. The expected growth curve for the any species.

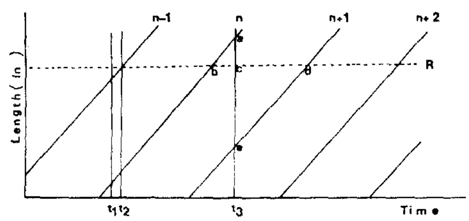

Fig. 2. The theoretical linear model of the plastochron. At a time when n-leaf length is longer than the reference length and $n+1$ leaf length is smaller than the reference length.

LR, $ae=\ln L_n-\ln L_{n+1}$. The fractional plastochron is now $\mathrm{PI}=n+(\ln L_n-\ln LR)/(\ln L_n-\ln L_{n+1})$, $(L_n>LR>L_{n+1})$ (Erickson & Michelini, 1957). Where PI represents plastochron index, n is the serial number counting from the base, L_n is the length of leaf n, and L_n+1 is the length of leaf $n+1$.

Here the reference length must be chosen in the range of exponential growth, i.e., in the linear portion of the plot of ln length versus time for estimating. According to the PI of Erickson & Michelini, the value of plastochron age can not be obtained at the time before t_2 in Fig. 2. And then the index must be complemented as shown in Fig. 3.

In Fig. 3, since the value of PI is n when the time is t_2, now the PI is $n-dc/bg$ at any time(t_1). Triangles bdc and fgb are similar and $dc/bg=bc/bf$. Since the lines of n and $n+1$ are parallel $bc/bf=ad/de$, and $ad=\ln LR-\ln L_n$, $de=\ln L_n-\ln L_{n+1}$. So the fractional plastochron is now $\mathrm{PI}=n-(\ln LR-\ln L_n)/(\ln L_n-\ln L_{n+1})$, $(2L_n-L_{n+1}>LR)$.

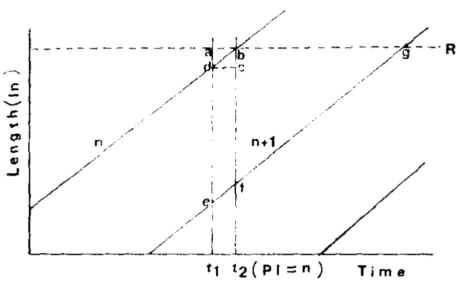

Fig. 3. The theoretical linear model of plastochron. At a time when n and $n+1$ leaf length are smaller than the reference.

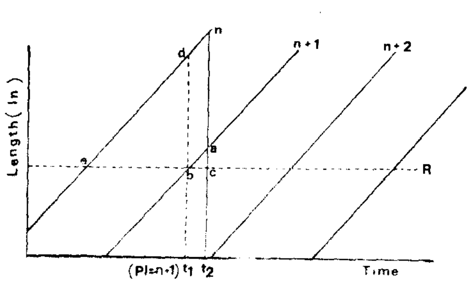

Fig. 4. The theoretical linear model of the plastochron. At a time when n and $n+1$ leaf length are longer than the reference.

If both the lengths of leaf n and $n+1$ are longer than the reference length, the PI at that time also will be changed.

In Fig. 4, because the value of PI is $n+1$ when the time is t_1, the PI will be $n+1+bc/eb$ at any time(t_2). So triangles deb and abc are similar and bc/eb equal to ac/db. As same as previous equations, $ac=\ln L_{n+1}-\ln LR$ and $db=\ln L_n-\ln L_{n+1}$. Now then the fractional plastochron index is $n+1+(\ln L_{n+1}-\ln LR)/(\ln L_n-\ln L_{n+1})$, $(2L_{n+1}-L_n>LR)$.

THE LINEAR MODEL OF THE PLASTOCHRON ACCORDING TO THE VARIOUS LEAF ARRANGEMENTS

Applying least squares techniques, the regression line for the PI was estimated.

$Y_n=a-(n-1)q+rt+\varepsilon$.

where, Y : the logarithmic of the length of leaf
a : Y-intercept of the first leaf
n : serial number counting from the base
r : slope
t : time
q : the ln of L_n/L_n+1
ε : error

According to the species and environmental conditions, the regression lines and plastochron ages

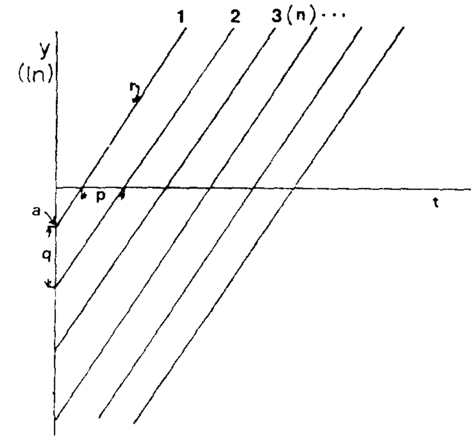

Fig. 5-a. Theoretical linear model according to the leaf arrangement. The model indicates a single leaf is sited on each node.

have different values. Regression equation varied with the leaf arrangements.

As shown in Fig. 5-a, if a single leaf attached on the one node (i.e., alternate leaf position), the numbers of values of plastochron and the ln of the plastochron ratio (q) are one. This parameter can be viewed as the relative rate of leaf growth per plastochron. In this case, the regression equation is the general equation. While if the two leaves hang on the one node (i.e., opposite leaf position), the numbers of the value of the plastochron and q are two.

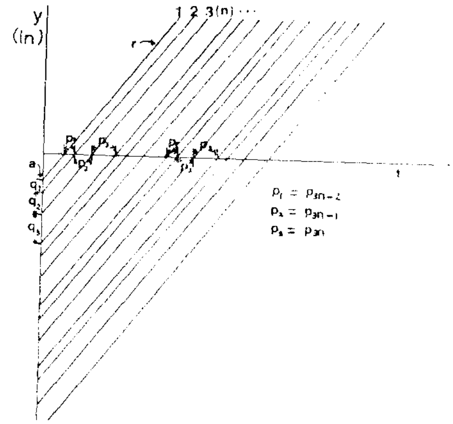

Fig. 5-b. The model indicates two leaves are sited on each node.

As shown in Fig. 5-b, although the occurance of the two more leaf hang on the one node, the time of the occurance is not same exactly. It has a little time interval between the leaves. And so the number of the regression lines and equations is two:

$$Y_{2n-1}=a-(n-1)(q_1+q_2)+rt+\varepsilon.$$

$$Y_{2n}=a-nq_1-(n-1)q_2+rt+\varepsilon.$$

Namely, the family of two regression lines and the values of two plastochron (p_1, p_2) replicately will be continued.

If the three leaf hang on the one node, as shown in Fig. 5-c, the regression equations were calculated by the following equations.

$$Y_{3n-2}=a-(n-1)(q_1+q_2+q_3)+rt+\varepsilon.$$

$$Y_{3n-1}=a-nq_1-(n-1)(q_2+q_3)+rt+\varepsilon.$$

$$Y_{3n}=a-n(q_1+q_2)-(n-1)q_3+rt+\varepsilon.$$

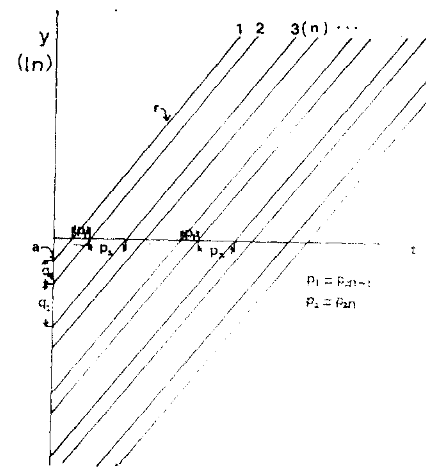

Fig. 5-c. The model indicates three leaves are sited on each node.

The general equation was determined by the following equation.

$$Y_{in-(i-j)}=a-(n-1)(q_1+\cdots+q_{i-1})-(q_1+\cdots+q_{j-1})+rt+\varepsilon.$$

where Y : the logarithmic of the leaf length in question
- i : leaf number hanged on the node
- n : the node number counting from base
- q : spacing on the Y-axis
- j : 0, 1, 2, 3, ······
- r : slope
- t : time
- ε : error

The linear model can be applied to the leaf growth data to determine environmental effects on the growth and development. It provides a more logical approach for formulating the test of differences resulting from population and temperature treatments (Vailejos *et al.*, 1983).

The research about the availability of applying the PI to the leaf development of *Amaranthus retroflexus* and *Chenopodium album* will be presented in next paper.

摘 要

plastochron이란 用語는 1957年 Erickson과 Michelini에 의해 提案되어, 계속적으로 出現하는 두 개의 잎들 사이의 時間 間隔으로서 定義된다.

Plastochron index(PI)는 植物의 生理的 形態的 측면에서의 成長에 影響을 미치는 環境的 要因과의 硏究를 하는데 有用하다.

Erickson과 Michelini의 index는 주어진 時間 때의 n번째 잎의 길이가 reference 길이 (LR) 보다 크고, $n+1$번째 잎의 길이가 LR보다 작을 때만이 計算 可能하였다.

따라서, 주어진 時間때의 n과 $n+1$번째 잎의 길이가 모두 LR보다 작거나 클 때의 PI는 구할 수 없었다. 본 硏究에서는 그와 같은 問題點을 補完하여 n과 $n+1$번째 잎의 길이가 모두 LR보다 큰 경우 ($2L_{n+1}-L_n>LR$)의 PI는

$$\mathrm{PI}=n+1+\frac{\ln L_{n+1}-\ln LR}{\ln L_n-\ln L_{n+1}}$$

LR보다 작은 경우 ($2L_n-L_{n+1}>LR$)의 PI는

$$\mathrm{PI}=n-\frac{\ln LR-\ln L_n}{\ln L_n-\ln L_{n+1}}$$

으로서 計算되어 질 수 있었다.

또한 plastochron index에 의한 linear model은 環境的 要因들에 의해 多樣해지며 특히 葉序形態에 따라 그 pattern이 달라짐을 알 수 있었다.

우리는 그 直線에 대한 equation만을 알면 우리가 원하는 時間때의 草本 植物의 相對的인 年齡을 決定할 수 있다.

多樣한 葉序에 따른 plastochron의 linear model은 least square method에 의해 다음과 같은 回歸 直線式을 얻을 수 있었다.

$$Y_{in-(i-j)}=a-(n-1)(q_1+\cdots+q_{i-1})-(q_1+\cdots+q_{j-1})$$

여기서, Y : 문제되는 잎 길이의 對數的인 값

i : 한 개의 node에 달려 있는 잎의 數

n : node의 數(基部로부터 세어)

q : Y-축의 spacing

j : 0, 1, 2, 3, ……

r : slope

t : 時間

ε : error

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