Simplified Potential Productivity

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I. Introduction

It is not so an unusual phenomenon today that many of the technologies expected to bring welfare to human beings have instead brought unhappiness. This has originated chiefly in the field of technological developments where the limits of resources and the environment have been neglected.

However extensive activity should be maintained in food production to meet increasing demands for food while at the same time trying to keep the demerits of these technologies at the lowest level possible.

Therefore, the resources-environment-technologies system should be studied as an inseparable unit.

Here, an interim report on the ongoing research on potential productivity is presented that will give one of the target of agricultural activities.

II. Potential Productivity

1. The Significance of Potential Productivity

The efficient utilization of the sun's energy is a fundamental requirement in agriculture. To a large extent, the physiological phenomena of a plant, e.g. transpiration, photosynthesis and respiration, depend on the energy available. When environmental factors are under control and nothing can restrict the growth of a plant, mass production can proceed at the optimum rate. Production under such favorable conditions is called Potential Productivity.

The achievement of this value everywhere in a given basin has the following effects.

1) Maximum possible productivity gives rise to the desired production level, namely, one of the targets of agricultural activities.
2) Maximum possible productivity results in the reconsideration of technologies used in regions with low production.
3) Maximum possible productivity helps decision makers to decide how land could be used most effectively.

The arrival at a potential value is essential to Japan because of the great shortage of land; crop production has been almost completely overtaken by the rapid development of technologies, yet what little land exists must be cultivated intensively in order to be able to provide enough food for such a dense population.

2. Production Factors

A vast number of factors participate in the production process overall, i.s. : solar radiation, plant temperature, CO_2 concentration, the assimilation and transpiration rates of the plant, leaf area and soil conditions, including chemical and physical properties of soil, topographic nature, soil water content and fertility, to name the main factors.

All these factors act together and contribute to the complicated process of mass production. The next equation can be formulated as the produc-

tion equation[1]:

$$S_p \approx F \ (L, \ R_n, \ \theta_p, \ C, \ \varepsilon, \ \gamma, \ B, \ M) \qquad\qquad (1)$$

where

S_p = mass production $\qquad$ L $\ $ = leaf area index

R_n = net radiation $\qquad\quad$ θ_p = temperature of plant

C $\ $ = CO_2 concentration $\qquad$ ε $\ $ = assimilation intensity

γ $\ $ = respiration intensity of the plant

B $\ $ = soil conditions including chemical and physical properties of the soil, topographic nature, soil moisture and fertility level.

M $\ $ = other miscellaneous factors.

In the equation (1), R_n, θ_p, C, B are the physical environmental factors of plant production and L, ε, γ are factors, mainly physiological, of the plant itself.

Therefore, the optimum conditions required for the achievement of maximum mass production can be obtained from investigation of the relationship between the physical and physiological factors. These relations are shown in Figure 1.
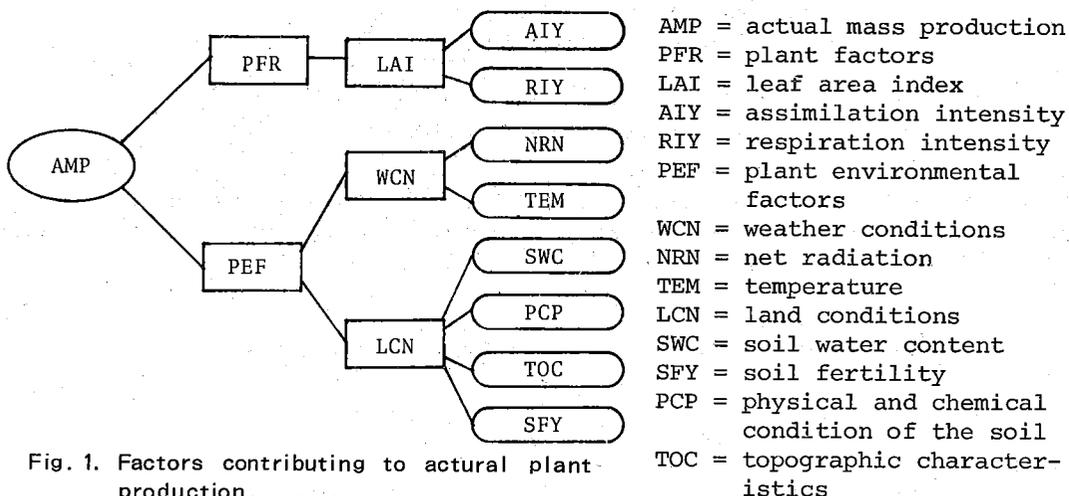

AMP = actual mass production
PFR = plant factors
LAI = leaf area index
AIY = assimilation intensity
RIY = respiration intensity
PEF = plant environmental
      factors
WCN = weather conditions
NRN = net radiation
TEM = temperature
LCN = land conditions
SWC = soil water content
SFY = soil fertility
PCP = physical and chemical
      condition of the soil
TOC = topographic character-
      istics

Fig. 1. Factors contributing to actural plant production.

3. Simplified Potential Productivity

The physiological investigation has shown that there is a close relation between assimilation intensity and net radiation and temperature, namely, that the assimilation intensity can be expressed by the function of net radiation and temperature:

$$\varepsilon \simeq f(R_n, \ \theta_p)$$

Respiration intensity is considered to be a simple function of only the temperature θ_p at present, namely:

$$\gamma \simeq f(\theta_p)$$

CO_2 concentration in the air is assumed to be constant though it changes with time of day and it has a tendency to increase from year to year

Equation (1) may then be reduced to the next equation by taking the above relations into account:

$$S_{p1} \simeq f(L, R_n, \theta_p, B) \tag{2}$$

This means present plant production under actual physical conditions.

When soil conditions B, including soil moisture and fertilizer are available to a sufficient extent, and technologies are well developed, then mass production can proceed at the potential rate. In this case, potential productivity can be expressed as follows:

$$S_{p2} \simeq f(L, R_n, \theta_p) \tag{3}$$

This equation represents present plant production under potential physical conditions. In this case, the relations between the factors can be shown as in Figure 2.
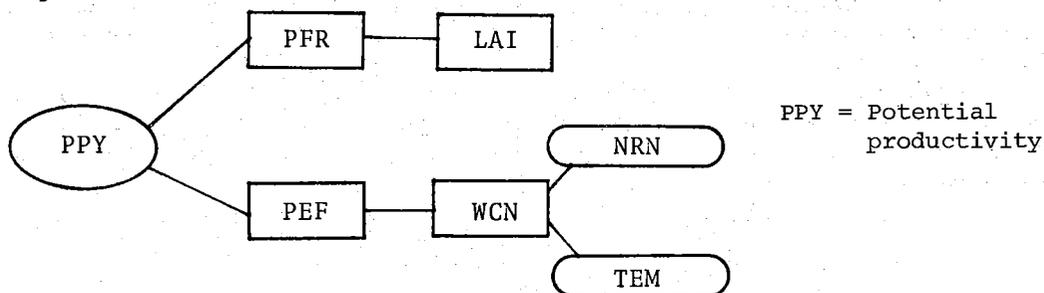

PPY = Potential productivity

Fig. 2. Factors cotributing to potential productivity.

In order to be able to calculate the value of potential productivity by means of equation (3), net radiation, temperature and leaf area index must be known.

Incoming Solar Radiation

Incoming solar radiation can be calculated according to the next equation:

$$R \simeq f(\delta, L_a, E_l, O_r, I_n, C_l) \tag{4}$$

where

δ = declination L_a = latitude

E_l = elevation O_r = orientation of the slope

I_n = incline of the slope C_l = cloudiness

This value is peculiar to the land itself and also has a close relation to production. Therefore this value is not only the main factor in production but also is considered to be "an integrated resource of the place concerned" including the land and climatic characteristics such as E_l, O_r, I_n, C_l, etc., themselves. It is therefore possible to classify land from the point of view of the so-called "integrated resources". Equation (3) is to be further simplified to $S_{p3} \simeq f(R_n)$ by assuming that the temperature θ_p is expressed in terms of net radiation ($\theta_p \simeq f(R_n)$) and that the leaf area is constant at an optimum value.

That is to say, L is the plant factor and suitable plant for a given

physical environment of net radiation and the temperature can be well chosen. However, net radiation and temperature are factors peculiar to the land it-self. Therefore, the potential productivity S_{p3} of the land itself can be expressed as follows:

$$S_{p3} \simeq f(R_n, \ \theta_p) \simeq f(R) \qquad\qquad (5)$$

This concept is especially important to the mountaineous countries such as Japan, Switzerland and the area of Austria known as the Tyrol, Where each location has its own orientation and decline, etc.

Leaf Area Index
   The productivity of a square unit is, of course, strictly restricted by the leaf amount and distribution. The acquisition of information on the leaf area (index) is of vital importance for the estimation of productivity by equations (2) and (3).
   This information can be obtained from field surveys or, under certain circumstances, from aeroplanes using remote sensor techniques.

Temperature
   Another factor necessary for the estimation of productivity is tempera-ture. This can be directly measured or taken by multi-spectral-scanners mounted onto aeroplanes.
   Thus, we have obtained three factors which contribute to the production function and this relation is shown in Figure 3.
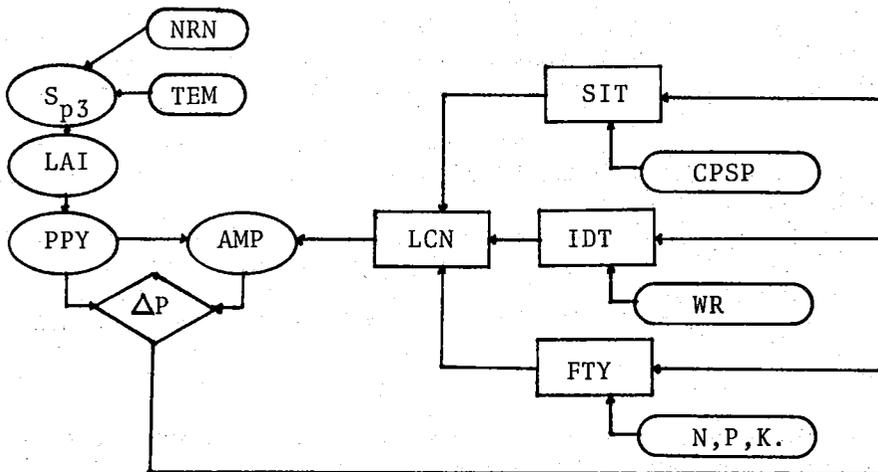

Fig. 3. Reconsideration loop to agricultural activity.

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SIT  = soil improvement technologies (including the technology
          of land-use)
CPSP = chemical and physical soil properties, topographic
          characteristics
IDT  = irrigation and drainage technologies
 WR  = water resources
FTY  = fertilizing technology
N.P.K.= Nitrogen, Phosphorus, Calcium, respectively.
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III. A Reconsideration of Actual Agricultural Activity

As mentioned above, potential productivity can be roughly estimated according to three items (or two main items), i.e. LAI, NRN and TEM and this results in one of the targets of agricultural activity.

Actual productivity, on the other hand, is modified by many factors and this value is always lower than that of potential productivity, i.e. the deficit productivity, is shown in Figure 4.
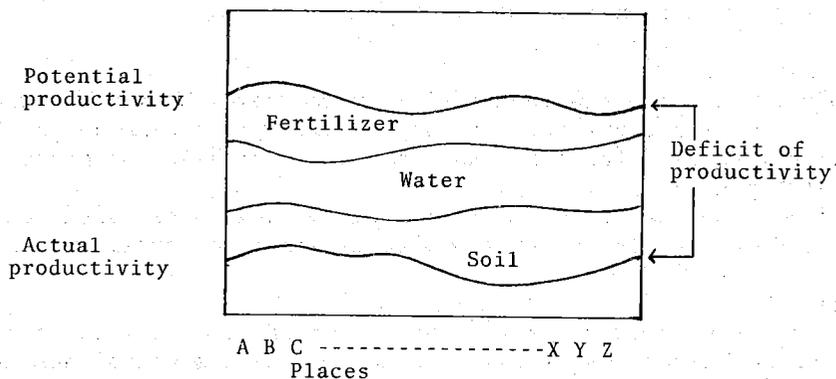
Fig. 4. The deficit of productivity.

The main components bringing about this deficit are the soil, water and fertilizer conditions and the relations between them are shown in the above diagram. The reconsideration of present technologies in each place must be done from these points.

The technologies of SIT, IDT and FTY have already been developed to quite an extent in Japan and so reconsiderations must be done according to the technological level of the region.

Thus the difference ΔP between PPY and AMP which is shown in Figure 3 is the main source of feedback to the present technologies employed. The difference ΔP must always be minimized by the improvement of technologies within economic limits. This is nothing other than reconsidering actual agricultural activity.

Reference
1. Matsuda, M. & Baumgartner, A. 1975: Ökosystematische Simulation des Nutzeffektes der Sonnenenergie für Wälder. Fostw. Cbl. 94:89-104.