# Transformation Factor from $CO_2$ Net Assimilation to Dry Matter in Crop Plants


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Although crop plants consist of more than 10 elements, carbon, hydrogen and oxygen are predominant components, amounting to, for instance, 99.4% in corn plants[1]. Since these three elements are incorporated into plants through photosynthesis, it can be said roughly that it is the photosynthesis that brings about plant growth. In fact, in a discipline of research so-called "growth analysis", factors relevant to photosynthesis such as net assimilation rate, leaf area index, and solar radiation are regarded to be most important. However, no quantitative relationship based on experimental evidences that can answer following questions has not been clarified yet. "How much of $CO_2$ is required to be photosynthesized to get 1 g of dry matter?" or conversely "how much of dry matter can be expected to increase when 1 g of $CO_2$ is assimilated?" Conversion factors so far used are all based on various assumptions and the most popular one is 0.61, which means that 0.61 g of dry matter is produced when 1 g of $CO_2$ is assimilated. This value was originated from the ratio of molecular weight of starch to that of $CO_2$ assimilated, ie, $C_6H_{10}O_5/6CO_2 = 0.61$, based on an assumption that all of $CO_2$ photosynthesized will be assimilated into starch. With starch crops such as rice, potato or sweet potato, this value may be regarded as reasonable. But this value may not be applied to oil and protein crops, because element composition of oil and protein is quite different from that of starch.

Therefore, the author attempted to determine the value of transformation factor for peanut (var. Azumahandachi) and soybean (var. Norin No. 2) in comparison with a starch crop, rice (var. Nihonmasari).

Transformation factor is defined in the present study as follows, and the value for each growth stage was calculated.

$$\text{Transformation factor} = \Delta W \ (\Delta C \times CO_2/C)^{-1} \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

where $\Delta W$ is dry matter increase of a whole plant (including dead portions) observed during a period of $t_1$–$t_2$,

$\Delta C \times CO_2/C$ expresses amount of $CO_2$ assimilated by that whole plant during the same period, that is $CO_2$ net assimilation in the period, and is calculated by multiplying the increase of carbon in the plant ($\Delta C$ in weight) determined by chemical analysis, by the ratio of $CO_2$ to C ($CO_2/C$ in weight). The ratio $CO_2/C$ is 3.667.

Plants were grown in pots, and 5–10 plants were sampled every 2 weeks after sowing to measure dry weight and carbon content of whole plants. For carbon analysis, the method of Mitsui and Kurihara (1958)[2] was used.

## Changes of carbon content in plants according to growth

Since the transformation factor is a ratio between dry matter increase and carbon increase in plants, it is naturally dependent on the change of carbon content of plants according to growth. As shown in Fig. 1, the change of carbon content differed fairly among crops. In the vegetative stage and early reproductive stage, however, the dif-

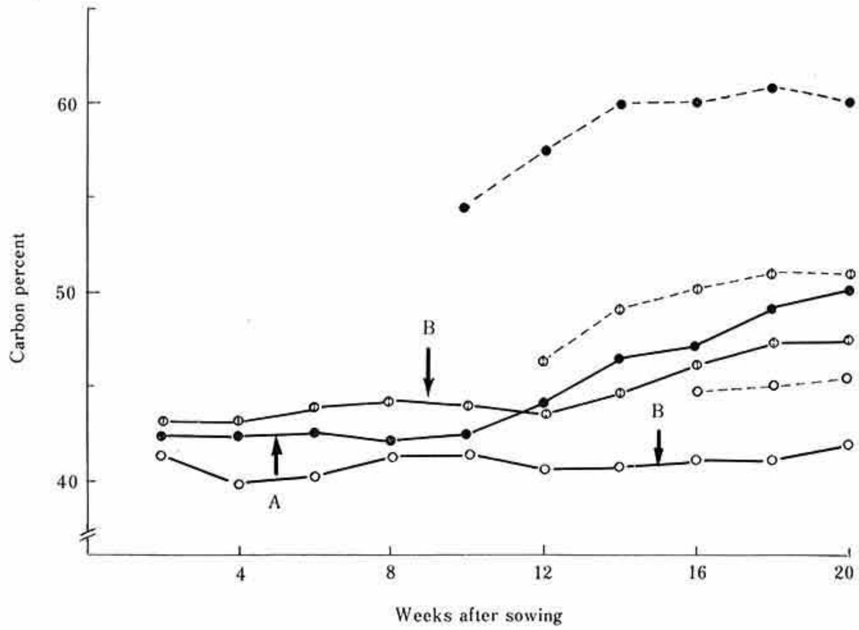


Fig. 1. Trend of carbon percentage in a whole plant and in seeds according to growth. ○ rice ⊘ soybean ● peanut —— whole plant …… seed The arrows indicate the date of beginning of flowering(A) or those of full blooming(B).

ference was small, being within a range of 40–44%. These percentages are slightly lower than the carbon percentage in starch, 44.4%. The lower percentage shown by rice plants is considered to be due to accumulation of silica in plants. Peanut seeds containing a large amount of oil and protein, both rich in carbon, showed the highest carbon percentage, amounting to as high as 60%. Carbon percentage of a whole peanut plant, therefore, increased markedly with an increasing proportion of seed dry weight in a whole plant, reaching 50% at the time of maturity. Soybean seeds were also rich in protein and oil, and showed a high percentage of carbon, 51%, at the full ripening. Carbon percentage of a whole plant of soybean also increased with the progress of seed ripening up to 47%.

On the contrary, rice seeds (brown rice), mostly composed of carbohydrate, showed a low carbon percent (45%), which was only slightly higher than that of vegetative organs. Therefore, carbon percentage of a whole plant was almost constant throughout the whole growth period.

## Changes of transformation factor according to growth

By utilizing values of carbon percentage in plants, as shown above, the transformation factor was calculated with all the combinations of $t_1$ and $t_2$ by the equation (1). The result is shown in Table 1, in which even numbers of week after sowing were taken as $t_1$ and $t_2$ ($t_1 < t_2$). It can be recognized as a general tendency that the factor became smaller when $t_2$ was taken from later growth stage, and when the interval between $t_1$ and $t_2$ was shorter, as indicated by figures in the table decreasing rightwards and downwards. As expected from the trend of carbon percentage, the factor for rice plants was stable throughout the whole growth period within a range of 0.57–0.69. In most cases it was 0.66 or 0.67. These figures indicate that dry matter increases calculated by the use of the factor, 0.61, might have been underestimated by nearly 10%. The factor for soybean plants ranged from 0.40 to 0.63, depending on the

**Table 1. Transformation factors of rice, soybean and peanut as affected by the combination of $t_1$ and $t_2$.**
**R: rice, S: soybean, P: peanut**

| $t_1$ (Weeks after sowing) \ $t_2$ | crop | Weeks after sowing 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | R | 0.69 | 0.68 | 0.66 | 0.66 | 0.67 | 0.67 | 0.67 | 0.66 | 0.65 |
| | S | 0.63 | 0.62 | 0.62 | 0.62 | 0.62 | 0.61 | 0.59 | 0.58 | |
| | P | 0.64 | 0.64 | 0.65 | 0.64 | 0.62 | 0.59 | 0.58 | 0.56 | 0.55 |
| 4 | R | | 0.68 | 0.66 | 0.66 | 0.67 | 0.67 | 0.67 | 0.66 | 0.65 |
| | S | | 0.62 | 0.62 | 0.62 | 0.62 | 0.61 | 0.59 | 0.58 | |
| | P | | 0.64 | 0.65 | 0.64 | 0.62 | 0.59 | 0.58 | 0.65 | 0.54 |
| 6 | R | | | 0.65 | 0.66 | 0.67 | 0.67 | 0.66 | 0.66 | 0.65 |
| | S | | | 0.62 | 0.62 | 0.62 | 0.61 | 0.59 | 0.58 | |
| | P | | | 0.65 | 0.64 | 0.61 | 0.58 | 0.57 | 0.55 | 0.54 |
| 8 | R | | | | 0.66 | 0.67 | 0.67 | 0.67 | 0.66 | 0.65 |
| | S | | | | 0.62 | 0.62 | 0.61 | 0.59 | 0.57 | |
| | P | | | | 0.62 | 0.60 | 0.56 | 0.56 | 0.53 | 0.52 |
| 10 | R | | | | | 0.68 | 0.67 | 0.67 | 0.66 | 0.65 |
| | S | | | | | 0.62 | 0.61 | 0.58 | 0.56 | |
| | P | | | | | 0.59 | 0.54 | 0.54 | 0.52 | 0.50 |
| 12 | R | | | | | | 0.66 | 0.66 | 0.66 | 0.64 |
| | S | | | | | | 0.57 | 0.51 | 0.50 | |
| | P | | | | | | 0.46 | 0.51 | 0.48 | 0.46 |
| 14 | R | | | | | | | 0.65 | 0.66 | 0.63 |
| | S | | | | | | | 0.40 | 0.43 | |
| | P | | | | | | | 0.55 | 0.48 | 0.46 |
| 16 | R | | | | | | | | 0.66 | 0.62 |
| | S | | | | | | | | 0.45 | |
| | P | | | | | | | | 0.39 | 0.36 |
| 18 | R | | | | | | | | | 0.57 |
| | S | | | | | | | | | |
| | P | | | | | | | | | 0.29 |

choice of $t_1$ and $t_2$, so that a definite value can not be proposed. But during the period before ripening stage, the factor 0.62 can be applied. For peanut plants, the factor ranged from 0.29 to 0.65, a largest variation among three crops, but in this case also values 0.64 or 0.65 can be proposed for the period before active ripening of seeds.

## Two major factors causing variations of transformation factor

As stated above, transformation factor varys not only with the kind of crops but also with growth stage. What will be the factors that bring about these variations?

Carbon atoms of $CO_2$ assimilated are found in carbohydrates immediately after they are photosynthesized, but gradually they are incorporated into substances which are being vigorously synthesized in plants. The first factor, therefore, is the carbon percentage of the substances vigorously synthesized, and the distribution ratio of assimilate to the substances. When the substances rich in carbon (oil for instance) are synthesized, the factor becomes low. Carbon percents of peanut seeds, soybean seeds, and brown rice were 60, 51, and 45, respectively as mentioned before. From these figures, weight of seeds corresponding to 100 g of $CO_2$ can be calculated to be 45 g for peanut, 53 g for soybean and 61 g for rice. In this case, the calculation is based on an assumption that all of $CO_2$ assimilated is used for production of seeds.

The second factor is the change of weight that occurs when reserve substance is utilized to produce seed components. Seeds of crops are generally richer in carbon than starch, a major reserve substance, because seeds contain oil and protein. So that the weight tends to decrease when reserve substance, generally starch, is converted into seed components. For example, starch loses 42% of its weight when it is converted to oleic-acid (representative fatty acid in peanut seeds), even though the quantity of carbon was kept unchanged, as shown in Table 2. Transformation factor at the late ripening stage of peanut shown in Table 1 is lower than 0.45, the value to be obtained when all the assimilate is utilized to produce seeds. Similar phenomenon is recognized with soybean. Thus, it is clear that the weight loss associated with chemical conversion of reserve substance to seed components influences transformation factor.

**Table 2. Weight loss due to the transformation of starch into oleic acid**

| | starch → $3(C_6H_{10}O_5)_n$ | oleic acid $(C_{18}H_{34}O_2)_n$ |
|---|---|---|
| carbon (%) | 44.4 | 76.5 |
| sum of A. W. or M. W. | 486 | 282 |
| ratio | 100 | 58 |
| weight loss (%) | | 42 |

## Relationship between transformation factor and ratio of dry matter distribution to seeds

As the extent of transformation of reserve substance to seed components depends on the

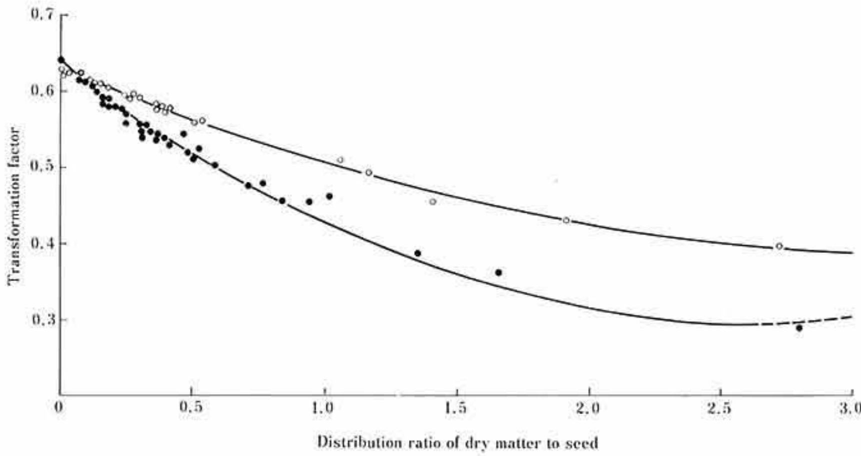


Fig. 2. Relationship between transformation factor and ratio of dry matter distribution to seed in ripening stage. ∘ soybean • peanut. Empirical equations for the curves are shown in the text

ratio of dry matter distribution to seeds, the latter acts as a common denominator of the above two factors. In view of this, relationship between the distribution ratio of dry matter and the transformation factor was examined.

The relationship in peanut and soybean plants is shown in Fig. 2. The transformation factor decreased as the distribution ratio increased. The decrease was more with peanut than with soybean. The relationship can be expressed by empirical equations, calculated by the method of least squares. They are

$$Y=0.049X^2-0.258X+0.640 \quad \cdots\cdots(2)$$

for peanut plant

$$Y=0.021X^2-0.141X+0.625 \quad \cdots\cdots(3)$$

for soybean plant

where X is the ratio of dry matter distribution to seeds during a period of $t_1$–$t_2$ and Y is the transformation factor in the same period.

When X = O, Y indicates the transformation factor in the period before the ripening stage. Therefore, the equations cover the whole growth period. However, when X exceeds 2.63 in the equation (2), and 3.36 in (3), Y begins to increase. This may not be expressing the actual situation. So that the equations can be valid within the range of $0 \leqq \times < 2.63$ for (2) and $0 \leqq \times < 3.36$ for (3).

Ratio of dry matter distribution to seeds varys with varieties and cultural conditions. Figures given in Table 1 are, therefore, to be regarded as an example. On the contrary, the equations (2) and (3) can be used universally in calculating the transformation factor by estimating the ratio of dry matter distribution. The varieties of peanut and soybean used in this experiment are moderate in content of oil and protein. For varieties with extremely high content of these components, slight modifications of numerical coefficients will be necessary. Details were reported in the original papers[3),4),5)].

## Conclusion

Transformation factors during the ripening stage of oil or protein crops were smaller than that of a starch crop. Value of the factor decreased as the growth stage advanced and it was dependent on the ratio of dry matter distribution to seed. Weight loss associated with the synthesis of seed components from reserve substance must be taken into consideration in estimating the dry matter increase of oil or protein crops from $CO_2$ net assimilation.

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