Production and Distribution of Dry Matter as a Basis of Sugar Beet Yields

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Crop yields are determined by the accumulation of various influences to which the crops are exposed during their growing seasons. From this viewpoint, so-called growth analysis seems to be very useful for investigating variations of crop yields.[7] Many studies by the growth analysis method on sugar beet have so far been reported.[5,6,8] However, many of them dealt with the total dry matter as a final object in general, without extending the analysis to the agricultural yields, which have a practical implication.

In the present study, the author attempted to introduce a concept of distribution rate into the system of growth analysis, in order to deepen our understanding on crop yielding. The distribution rate refers to the ratio of dry matter distributed and accumulated in the harvesting portion of the crop to the total amount of dry-matter produced in a given period during the growing season. As the harvesting portion of sugar beet is the root, the distribution rate expresses the movement of dry matter toward the roots.

When the distribution rate (DR) is used together with crop growth rate (GR), net assimilation rate (NAR), and leaf area (LA), i.e., three factors of the usual growth analysis, the growth rate of sugar beet roots (GR-r) can be expressed as follows:

$$\text{GR-r} = \text{GR} \times \text{DR} = \text{LA} \times \text{NAR} \times \text{DR}$$

By using this relationship, variations in sugar beet yields caused by varieties and various cultural conditions were analyzed.[3]

Basic pattern of sugar beet growth

At an initial growth stage, sugar beets showed a markedly high NAR, but due to a small LA its dry matter production was kept low. After mid-July, the dry matter production increased to a high level with the increase in LA (Figs. 1 and 2). As to the top and roots, it was observed that the top grew at the initial stage, while dry matter accumulation in roots began after mid-July.

This relationship between the total dry matter production and the dry matter accumulation in roots was clearly expressed by the trend of DR, which was very low at the initial stage, but gradually increased around July, reaching a level of about 50% in the period from August to September. Namely, nearly the same amount of dry matter was used for the growth of top and for the accumulation in the roots, during the period of high dry

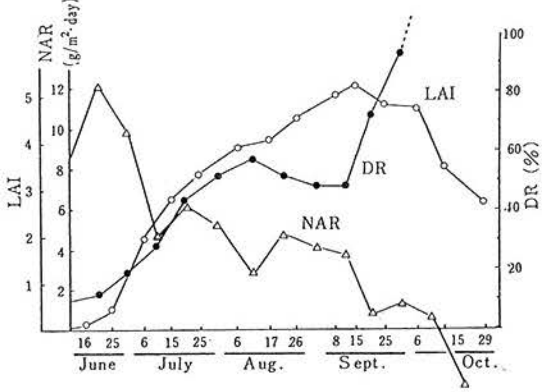

Fig. 1. Seasonal changes of leaf area index (LAI), net assimilation rate (NAR) and distribution rate (DR)

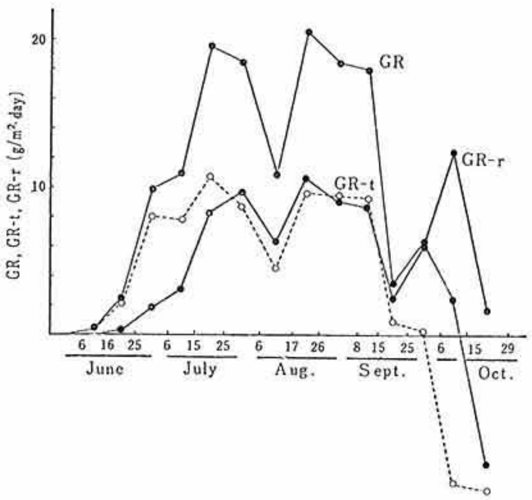

Fig. 2. Partitioning of total growth rate (GR) into growth rate of top (GR-t) and root (GR-r)

matter production.

After mid-September, NAR declined with the decrease in LA due to die-back and fall of lower leaves, and to lowering air temperature. As the result, dry matter production was markedly reduced, but the dry matter in roots showed an increase due to translocation from the top.

Individual leaves, constituting the top, showed seasonal changes in morphological and physiological characteristics according to the growth of the crop. It was made clear that these changes are closely related to the seasonal trend of dry matter distribution shown above.

Yielding ability of sugar beet varieties

A remarkable variation in yields observed among sugar beet varieties can not be explained only by the difference in dry matter production, because the variation in the total dry matter was relatively small among varieties, and the values of the total dry matter weight were not necessarily in parallel with the root yields.

The small varietal difference in the total dry matter is explained by the fact that, although there is a varietal difference in LA, there exists a negative correlation between LA and NAR, and that the contribution of these factors to dry matter production is different in different stages of the plant (Table 1). The non-parallel relationship between the total dry matter weight and the root yield is caused by the difference in DR among varieties. It was made clear that DR is the factor most closely related to the final root dry weight out of the various characteristics influencing the root yield (Table 2).

Table 1. Correlation between LAI and NAR, LAI and GR, and, NAR and GR at successive stages of growth

Growth stage	Correlation coefficient		
	LAI : NAR	LAI : GR	NAR : GR
I	−0.528	0.958**	−0.282
II	−0.800**	0.191	0.413
III	−0.391	0.658*	0.432
IV	−0.382	0.134	0.862**
V	−0.051	0.174	0.971**

Growth stage I : Emergence–12/July, II : 12/July–1/Aug., III : 1/Aug.–31/Aug., IV : 31/Aug.–29/Sept., V : 29/Sept.–31/Oct.
* Significant at 5% level
** Significant at 1% level

Table 2. Correlation of final root dry weight to several attributes of varieties

Attribute	Growth stage				
	I	II	III	IV	V
LAI	0.557	0.401	0.127	−0.081	−0.213
NAR	0.073	−0.126	0.303	0.075	0.814**
GR	0.647*	0.506	0.362	0.052	0.749**
DR	0.680*	0.716**	0.440	0.697*	0.649*
GR-r	0.836**	0.635*	0.559	0.381	−0.573

Growth stage I : Emergence-12/July, II : 12/July–1/Aug., III : 1/Aug.–31/Aug., IV : 31/Aug.–29/Sept., V : 29/Sept.–31/Oct.
* Significant at 5% level
** Significant at 1% level

The value of DR showed a tendency to be specific to each variety and was related to varietal characteristics such as the number of leaves developed and the size of individual leaves, etc.

Table 3. Effect of planting date on final root yield, sugar content, sugar yield and dry weight

Planting date	Growing term (days)	Total effective temperature (°C)	Root yield (t/ha)	Sugar content (%)	Sugar yield (t/ha)	Dry weight (t/ha)		
						Root	Top	Total
April 22	171	2863	42.1	15.74	6.63	9.20	6.96	16.16
May 27	141	2484	30.5	15.21	4.64	6.64	6.72	13.36
June 27	112	2023	17.1	13.74	2.35	3.52	6.40	9.92
July 27	85	1495	7.5	10.05	0.75	1.28	4.48	5.72

Effect of planting date on root yields

The difference in planting date causes a remarkable change in root yields of sugar beet. When the planting was made over the period from April to July with one-month intervals, and the harvesting was made in October, the resulted difference in root dry weight was far greater than the difference in the length of growing period, or in accumulated temperature (Table 3). Such a great difference can be explained by different responses of dry matter production and DR to growing time.

Namely, NAR did not show a definite seasonal change,[6] which has so far been thought to occur, but it changed according to the change of LA in each plot differing in planting date. Thus, GR in each plot showed the highest value when the number of leaves reached 20–30, irrespective of planting dates. However, it was also influenced by climatic conditions, so that its value became higher at the time nearer to late-July (Fig. 3). The leaf area index at the stage of 20–30 leaves was 3.5–4.0. This value is close to the optimum leaf area index hitherto reported.[1,2,4]

On the other hand, the size of individual leaves was hardly influenced by planting dates, so that the top growth of the plants at the stage showing the same number of leaves was almost the same, irrespective of planting dates. Consequently, the early-planted sugar beet, which has already terminated its top growth before the summer season (which allows high dry matter production) is able to distribute and accumulate a large amount of dry matter in roots. On the contrary, late-planted sugar beet is still utilizing a large amount of dry

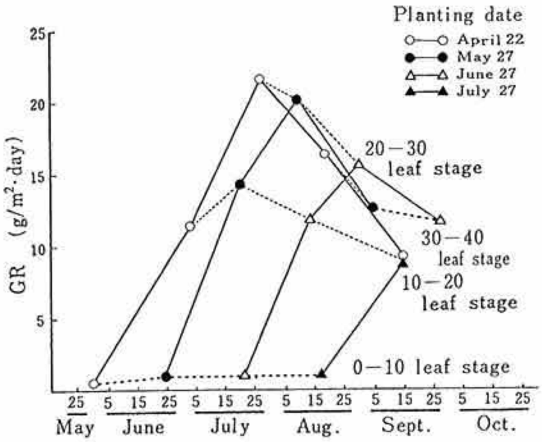

Fig. 3. Growth rate (GR) of plants as related to different planting dates

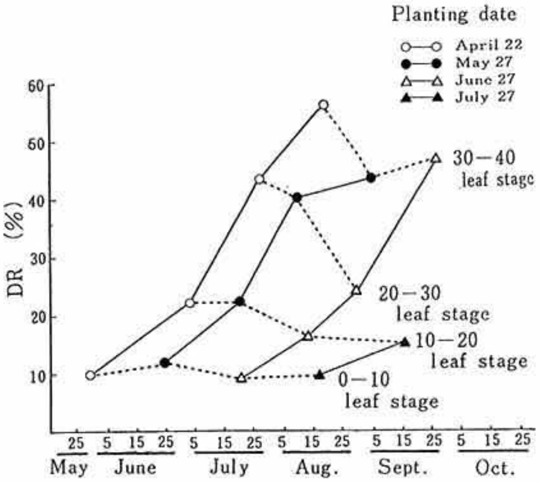

Fig. 4. Seasonal changes of distribution rate (DR) as related to different planting dates

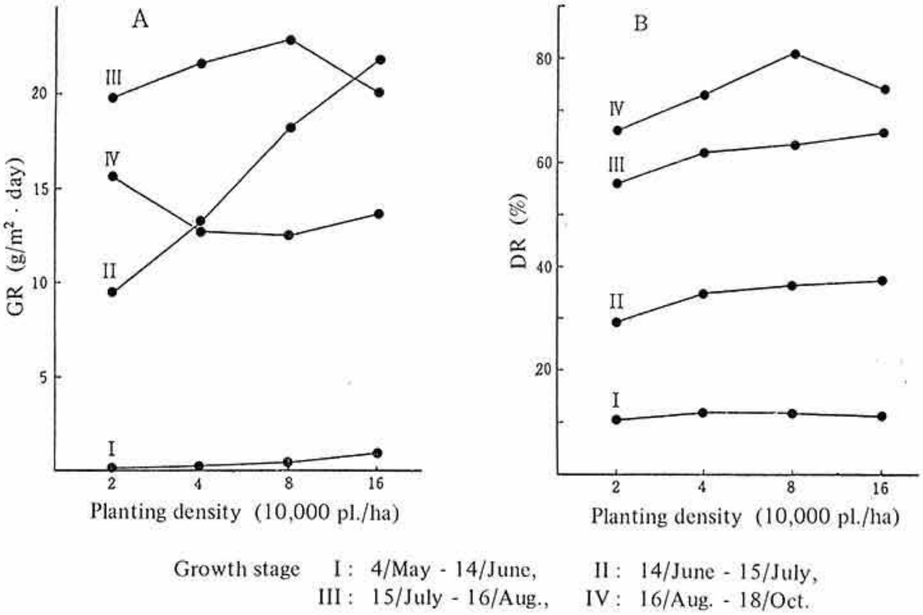

Fig. 5. Effect of planting density on growth rate (GR) and distribution rate (DR)

matter for the top growth in the summer season, leaving only a small amount to be distributed into roots (Fig. 4). Such differences in dry matter production and DR are the major cause for the marked difference in root yields due to different planting dates.

Root yield as influenced by planting density

At the initial growth stage, the leaf area index depends on the planting density, because plant growth is not influenced by the planting density. As the growth advances, the higher the planting density the more the effect of it on growth, and, therefore the leaf area index tends to reach a certain level, irrespective of the planting density. On the other hand, it was observed that the lower the planting density the higher was NAR during the period from June to July, but no appreciable difference in NAR occurred in other periods. As the result, the higher the planting density, the greater the dry matter production during the period before mid-July, i.e., the period showing a great difference in

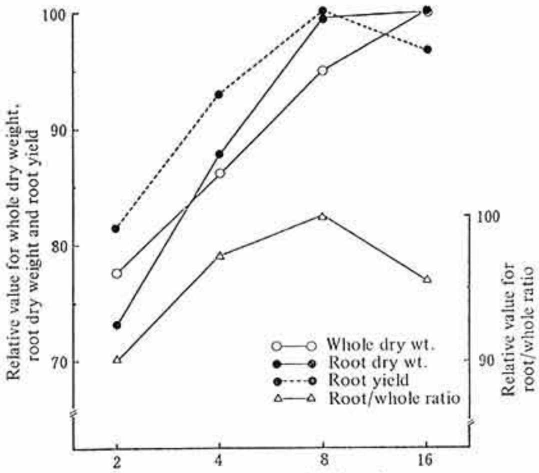

Fig. 6. Schema showing the effect of planting density on sugar beet root yield

the leaf area index. However, no large difference in dry matter production was observed in the later period (Fig. 5-A).

The DR showed a tendency to increase with the increase in planting density, except at the initial growth stage, but at the excessively high planting density the DR was decreased in the later growth period (Fig. 5-B). It was made clear that such a variation in DR caused by different planting densities is attributable to the development of crowns of sugar beet under a low planting density and the development of leaf petioles under an excessively high planting density.

The effect of the planting density on root yields can be explained by a synergistic effect of changes in dry matter production and DR as described above (Fig. 6).

Application of DR to individual selection of sugar beet

The above results indicate an important role of DR in determining root yields. To know the possibility of applying DR to sugar beet breeding, the individual selection using DR as a selection index was attempted. The criterion for the individual selection is shown in Table 4, and yield tests of lines derived from each of the 3 groups were made. The result showed that the lines derived from mother plants with high DR gave higher yields than the original population, irrespective of high or low mother root weight. On the contrary, yields of lines derived from mother plants selected only for mother root weight showed no appreciable difference from the yield of the original population, i.e., an effectiveness of individual selection was hardly recognized (Table 5). It is known from this result that the mother root weight does not express an intrinsic yielding ability, because it is being influenced by environmental conditions, particularly the competition, and that DR can effectively be utilized for the breeding.

Table 4. The criterion for individual selection

Dry matter distribution	Mother root weight	
	Large	Not necessarily large
High	Group U	Group V
Not necessarily high	Group W	——

Table 5. Average values of root yield, sugar content and sugar yield in selected lines

Name of line	Root yield (t/ha)	Sugar content (%)	Sugar yield (t/ha)
Group U	57.3 (112)*	15.83 (100)	9.06 (112)
Group V	55.6 (109)	15.88 (100)	8.83 (109)
Group W	51.3 (100)	15.64 (99)	8.01 (99)
Control**	51.1 (100)	15.86 (100)	8.10 (100)

* Relative value to the control

** Unselected progeny of original population

Discussion and conclusion

It was made clear that the yield of sugar beet depends not only on dry matter production, but also on DR. As to the relation between dry matter production and DR, there is a problem whether or not an increase in DR may cause a reduction in top growth, and result in a decreased dry matter production. However, as shown by the planting date experiment, it is possible to increase both dry matter production and DR at the same time, if the cultivation is made with good timing. It is also possible to increase dry matter production in consistent with an increase of DR, by suppressing the development of non-photosynthetic portions of the top, such as petioles or crowns.

Although one of the most remarkable changes in the characteristics of crops during their history of improvement is the development of the useful portions, such a development seems to result unintentionally. When an intentional attempt is made to increase the distribution of dry matter to the useful portion, it would be possible to get crops with increased agricultural yields.

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