

# Design and Examination of Soybean Ideotypes

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Yield improvement of soybeans in the future requires the breeding of high-yielding cultivars with the adaptability to higher planting rates and narrower row widths<sup>3,12,13</sup>). The objectives of this research were, 1) to identify physiological yield determinants of soybeans in terms of source-sink relationships so as to design high-yielding plant models, "ideotypes<sup>2)</sup>", 2) to examine the yielding ability of the designed ideotypes under various growing conditions, and 3) to evaluate the productivity of existing cultivars in comparison with the ideotypes and with wild *Glycine* species. The results would help not only understand yield-determining processes of soybean but breed high-yielding soybean cultivars through ideotypes. All the experiments of this study were conducted at Tohoku National Agricultural Experiment Station, Japan, with the exception of the experiments concerning interspecific differences in productivity among *Glycine* species, which were done at CERES<sup>11)</sup> of CSIRO, Australia. This paper summarizes the experimental results, some of which have been previously reported in detail<sup>4-10)</sup>.

## Identification of yield determinants and designing of ideotypes

### 1) Dry matter production and its relation to seed yield

The contribution of dry matter production at various growth stages to seed yield was evaluated. Seed yields were positively correlated with crop growth rates (CGR) and leaf area indices (LAI) at all the growth stages, particularly with CGR during late flowering to early pod growth. The distribution ratio of dry matter to pods during that time was

positively correlated with net assimilation rate (NAR), but negatively with LAI (Fig. 1), bearing negative correlation between LAI and NAR. Therefore, increasing soybean seed yield needs increasing LAI from earlier growth stage, and also reducing the decline of NAR with increasing LAI.

### 2) Yield determinants in terms of source-sink relationship in plant community

The processes limiting the yield of field-grown soybeans were identified in terms of source-sink relationships during reproductive stage. Shading treatments given at successive 10-day intervals showed that the decreased source ability during flowering to early seed development significantly reduced the number of pods and seed yields (Fig. 2) because of a decrease in dry matter production and/or dry matter partitioning to pods. Manipulation of the number of pods (by ir-

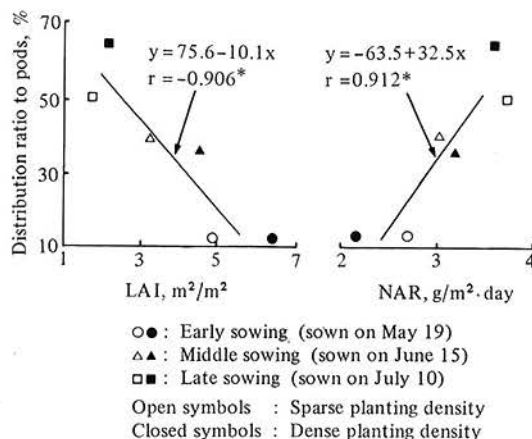


Fig. 1. Relation between distribution ratio of dry matter to pods and mean LAI or NAR for a month from flowering time

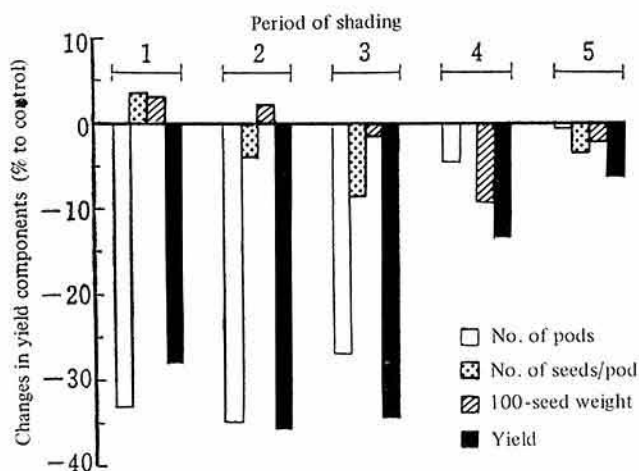


Fig. 2. Changes in yield components and yields as affected by shading at successive 10-day intervals during reproductive stage of soybeans

Periods of shading:

No.	Period*	Growth stage
1	3-13	flowering
2	13-23	pod elongation
3	23-33	seed development
4	33-43	
5	43-53	

\* Days after flowering time.

rigating or depodding) under shaded or unshaded conditions showed that seed yields were primarily determined by the number of pods regardless of cultivar or the amount of solar radiation, and that the change in 100-seed weight in response to the decreasing number of pods was greater under shaded conditions than under unshaded conditions. The data suggest that the yield of field-grown soybeans is primarily determined by the source ability during flowering to early seed development, but later by the sink ability during seed development.

### 3) Yield determinants in terms of source-sink relationship in a plant

Seed yields of soybeans depend upon photosynthesis and translocation of assimilate to seeds. The 3rd leaf (L-3), the 9th leaf (L-9), or the leaves on a branch which had emerged from the 13th node of a main stem (BL-13) (leaves were all numbered from the terminal node of a main stem downward) were al-

lowed to assimilate  $^{14}\text{C}$  at early pod-filling. The major sinks for L-3 were the pods of upper and middle nodes in the canopy. L-9 exported its labelled assimilates to many plant parts: stem of lower nodes, pods of the fed axil, roots, and branches. Most of the  $^{14}\text{C}$ -assimilate incorporated from BL-13 was retained in the pods of the fed branch. These facts indicate that there exist two major source-sink units in the soybean plant during early pod-filling: upper and middle sections of a main stem as one unit, and lower section of the main stem, roots and branches as the other. Clearly, branches are dependent on their main stem for photosynthates.

Effects of debranching of soybean plants on the distribution and utilization of  $^{14}\text{C}$ -assimilate were studied. Leaves at different positions in the canopy were allowed to assimilate  $^{14}\text{C}$ , either at early flowering, at early pod growth, or at early pod-filling stage. The debranched plants had the leaves of higher assimilatory efficiency and delayed

senescence (Table 1). A greater portion of  $^{14}\text{C}$ -assimilate fixed by the lower leaves of the debranched plants was present at pods and stem+petioles of the lower section, in contrast to those of control plants which exported some of the assimilate to branches. Lower leaves of the debranched plants remained active even during pod growth stage, and a

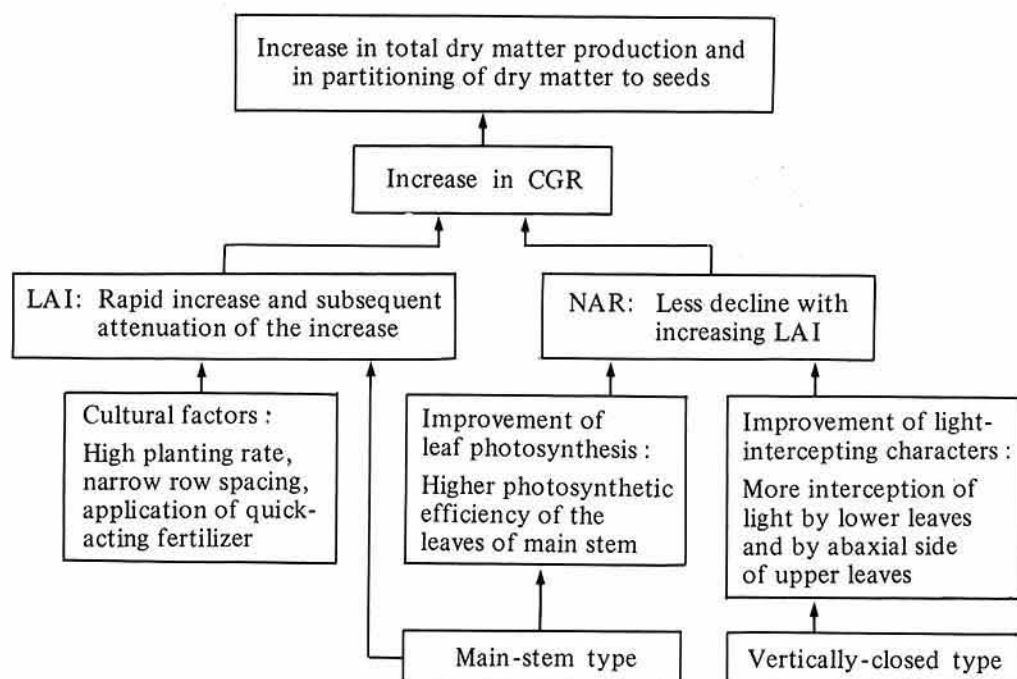
part of the fixed  $^{14}\text{C}$  was translocated slowly into the root. As a result, debranching increased pod-setting and dry weight at lower section of the main stem. The pattern of distribution and utilization of assimilate in debranched soybeans may lead to the designing of the main stem type as an ideotype which has an adaptability to higher planting rates.

**Table 1. Assimilation efficiency and translocation rate for control and debranched soybean plants after 24 hr following  $^{14}\text{CO}_2$  assimilation by specific leaves at three growth stages**

Treatment	Fed leaf*	Assimilation efficiency			Translocation rate		
		Fl.	Pg.	Pf.	Fl.	Pg.	Pf.
		$\times 10^3 \text{ dpm/cm}^2$			%		
Control	L-3	48.0	125.8	68.1	70.8	68.0	74.3
	L-8	30.0	40.3	50.4	83.3	46.3	40.5
	B L-13(8)	15.7	41.1	47.5	45.1	61.9	76.7
Debranched	L-3	60.9	124.8	84.0	69.4	60.8	66.1
	L-8	28.5	58.9	59.9	62.8	68.5	34.5
	L-12	—	37.6	11.4	—	39.0	68.1

Fl.: Early flowering, Pg.: Early pod growth, Pf.: Early pod-filling.

\* Numbered from the terminal node of a main stem downward.



**Fig. 3. Idealized flow chart for increasing the total dry matter production and the partitioning of dry matter to seeds of field-grown soybeans**

#### 4) Designing of ideotypes

From these analyses, attributes essential to soybean ideotypes were identified, leading to designing ideotypes with the adaptability to higher planting rates. Fig. 3 shows the idealized flow chart for increasing soybean yields using the designed ideotypes.

### Examination of the yielding ability of the designed ideotypes under various growing conditions

#### 1) Ideotype A: A plant type with upper leaves vertically closed

The effect of plant type alteration on yields and yield components at various reproductive stages was examined. Soybeans were grown at two planting rates in two row spacings for two years. As illustrated in Fig. 4, a plant type was artificially altered by transparent tapes and steel posts to keep upper leaves and petioles vertically erected which led to an increase in illumination on the lower leaves. By the alteration treatment, light penetration into the inter-row space increased greatly while decreased a little in the intra-row space, resulting in a positive effect on the yield at a high planting rate in a narrow row spacing. The yield of the altered plants increased sharply with increasing LAI, and the differ-

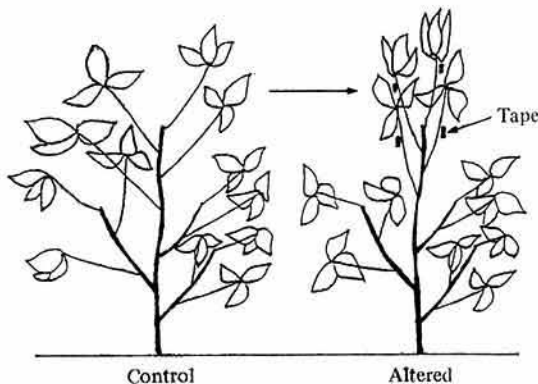


Fig. 4. Comparison of plant shape of the control and altered soybean plants

Plant shape was artificially altered by transparent tapes and steel posts to make upper leaves and petioles vertically closed.

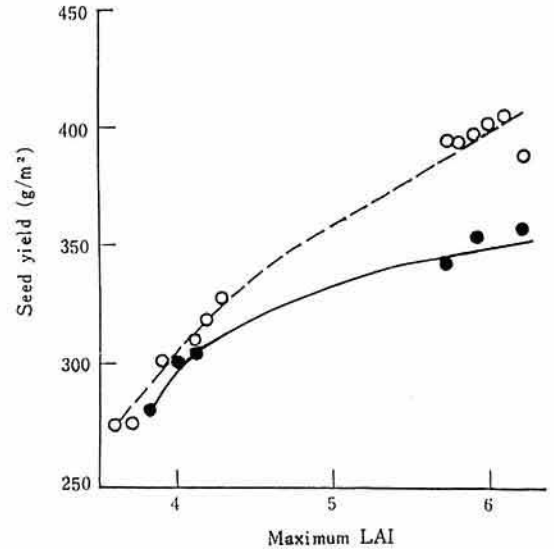


Fig. 5. Differences in grain yield between the control and altered soybean plants as a function of maximum LAI

Each point represents a treatment.

● : Control, ○ : Altered.

ence in yields between the altered and control plants was greater as LAI increased (Fig. 5). The effect of plant type alteration was significant during flowering time when LAI reached its maximum to cause mutual shading of the leaves, but it was negative at a later stage when LAI decreased gradually. The alteration treatment increased CGR during flowering, depending on NAR, not on LAI. The positive effect of plant type alteration was greater in a year with a decreased amount of solar radiation.

#### 2) Ideotype B: Main-stem type

Contrasting types of soybean plants, which were artificially created by removing branches (main-stem type) or by pinching the apical bud of the main stem (branch type), were compared under various planting patterns and rates. Fig. 6 illustrates the contrasting plant shapes. With the main-stem type, LAI became greater at a high planting rate and the decrease in NAR with increasing LAI was less than the branch type. As a result, CGR of the main-stem type increased with increasing LAI, while CGR of the branch type did

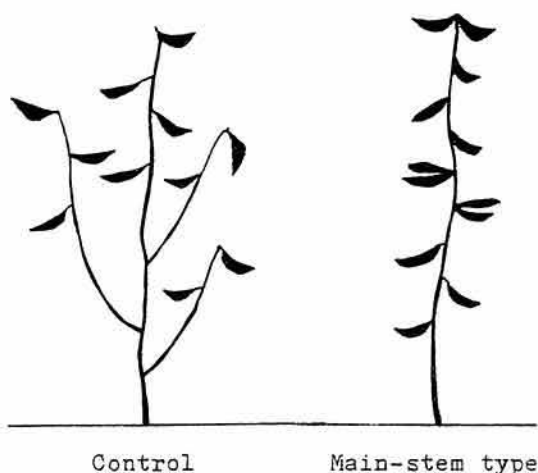


Fig. 6. Comparison of distribution of pods on the stem for the control and main-stem type of soybeans

not increase with increasing LAI. The number of pods increased with increasing LAI up to about 5.5 in all plant types, but did not increase at LAI exceeding about 5.5 except in the main-stem type. Thus, the main-stem type appears to have a potentiality to partition dry matter to pods efficiently, thereby to attain consistently higher yields at higher planting rates in narrower row spacings (Fig. 7).

## Evaluation of differences in productivity among cultivars or species

### 1) Specific differences in adaptability to planting rates

Nine cultivars of diverse yielding ability were compared at three planting rates for three years. Adaptability to planting rates was evaluated from the slopes of regression lines calculated from the data of the relationship between logarithms of seed yield per plant and planting rates. The three cultivars: Kitahomare, Harosoy and Okushirome bore easier slopes, giving higher maximum seed yields at higher optimum planting rates, than the respective control cultivars of similar maturity. Similarly, the calculation of the relationship between LAI and logarithms of total dry weights or seed yields revealed that the above three cultivars gave higher maximum values of total dry weights or seed yields at higher optimum LAI than the respective control cultivars (Table 2). The plant shape of the three cultivars became similar with the ideotype A when grown at higher planting rates. Thus the high-yielding cultivars possessed higher efficiency of dry matter production per leaf area, and the efficiency seemed to be associated with the plant shape with the upper leaves vertically-closed.

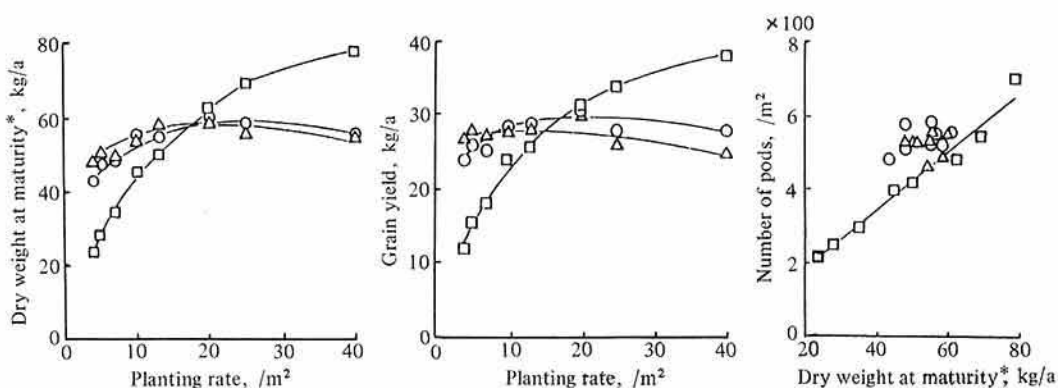


Fig. 7. Changes with planting density in top dry weights and grain yields, and relation between top dry weights and the number of pods for contrasting plant models of soybeans

\* Top dry weight excluding fallen leaves and petioles.

○: Control, □: Main-stem, △: Branch type.

**Table 2. Relationship between mean LAIs (L) during late flowering to pod growth and logarithms of seed yield (y) divided by the LAI for nine soybean cultivars grown at three planting rates**

Cultivar	Correlation coefficient	Regression equation $\log y = bL + \log k$	Optimum LAI <sup>1)</sup>	Maximum seed yield <sup>2)</sup>
Tokachinagaha	-0.890**	$\log y = -0.098L + 2.305$	4.44	330
Toyosuzu	-0.859**	$\log y = -0.089L + 2.303$	4.89	362
Kitahomare	-0.875**	$\log y = -0.071L + 2.247$	6.09	396
Harosoy	-0.902**	$\log y = -0.094L + 2.355$	4.62	384
Shiromenagaha	-0.926**	$\log y = -0.111L + 2.385$	3.93	351
Fukunagaha	-0.917**	$\log y = -0.127L + 2.422$	3.43	334
Norin No. 2	-0.946**	$\log y = -0.111L + 2.265$	3.90	264
Okushirome	-0.953**	$\log y = -0.090L + 2.269$	4.85	332
Nanbushirome	-0.955**	$\log y = -0.117L + 2.390$	3.70	334

\*\* Significant at 1% level. 1):  $-1/2.303b$ , 2):  $LK10^{bL}$ , g/m<sup>2</sup>.

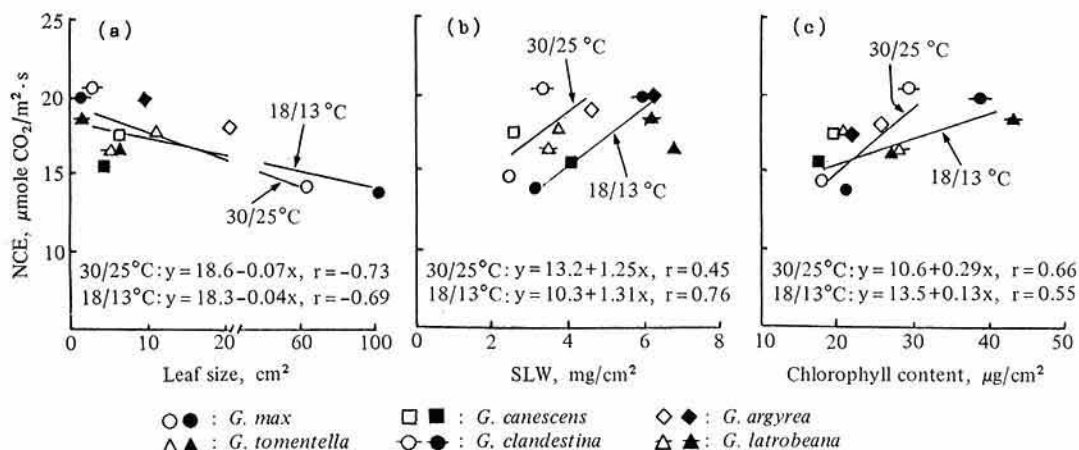


Fig. 8. Relation between net CO<sub>2</sub> exchange rate (NCE) and (a) leaf size, (b) specific leaf weight (SLW), and (c) chlorophyll content/leaf area for six *Glycine* species grown at 30/25 (open symbols) or 18/13°C (closed symbols)

## 2) Specific differences in the dry matter accumulation in seeds

Processes of dry matter accumulation in seeds and their relation to seed yields were examined for the nine cultivars grown in the field. The processes of seed growth were divided into three phases; T<sub>1</sub>: a period from flowering time to the initiation of T<sub>2</sub>, T<sub>2</sub>: a period when the growth rate is linearly high, T<sub>3</sub>: a period from the end of T<sub>2</sub> to physiological maturity. Durations of T<sub>1</sub> and T<sub>1</sub>-T<sub>3</sub> were positively correlated with final seed yields/m<sup>2</sup>.

The growth rate of individual seeds at T<sub>2</sub> bore a positive correlation with 100-seed weight but no correlation with final seed yields/m<sup>2</sup>, while the growth rates of seeds/m<sup>2</sup> bore a positive correlation with final seed yields/m<sup>2</sup>. The durations of T<sub>1</sub> were positively correlated with T<sub>1</sub>-T<sub>3</sub> and with the growth rates of seeds/m<sup>2</sup>. The results suggest that the longer the initial phase (T<sub>1</sub>) is, the more the numbers of pods and seeds/m<sup>2</sup> are, bearing an increase in the growth rates of seeds/m<sup>2</sup> as well as final seed yields/m<sup>2</sup>.

### 3) *Interspecific differences in productivity among Glycine species*

Characters relating to productivity of five wild *Glycine* species of diverse geographic origin<sup>1)</sup> were compared with those of the cultivated species (*G. max*) under a range of temperature regimes, ranging from 9/4 to 36/31°C (day: 8 hr/night: 16 hr). With all the species examined, net CO<sub>2</sub> exchange rates (NCE) appeared to have an optimum growth temperature in the range of 18/13–30/25°C with little variation over this range. Across the species, NCE was correlated negatively with leaf size, but positively with specific leaf weight (SLW) or chlorophyll content/leaf area (Fig. 8). Most of the species revealed optimum temperature for relative growth rate (RGR) at 30/25 or 33/28°C. Across the species and growth temperatures, RGR was correlated more closely with relative leaf area growth rate (RLAGR) than with NAR. *G. max* tended to, over a wide range of temperature, express the greatest potential for leaf growth, leading to greater matter production at the expense of photosynthetic efficiency/leaf area. The results suggest that increasing assimilatory efficiency/leaf area through improving the plant type is essential to maximizing soybean productivity while retaining its superior potential of leaf area production.

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