

Source and Sink Limitations to Soybean Yield

Suk Ha Lee* · Yeul Gue Seung** and Seok Dong Kim*

콩의 同化器官과 受容器官의 能力評價

李錫河* · 成烈圭** · 金奭東*

ABSTRACT : Improvement in potential crop yield could be achieved through either the improvement of source potential or sink capacity, but preferably both simultaneously. The field experiment was performed to evaluate the genotypic difference in partitioning of dry matter into each plant part in response to photosynthetic manipulation as well as to assess whether the soybean yield is source or sink-limited. Four soybean genotypes, which were "Baekunkong", "Suwon 168", and two local soybeans with black seed coat (hereafter referred to as the "black soybean", "Kangleungjae" and "Keumleungjae"), were grown in four different environments in which one or two layers of shading net during grain filling and two different planting densities (55,000 and 110,000 plants ha⁻¹) were applied to manipulate photosynthesis. Significant effects of genotype (G), photosynthetic manipulation (P), and G*P were shown in top and grain dry weight. Relative grain to top dry weight was the lowest in soybean plants grown at 110,000 plants ha⁻¹ and covered with two layers of shading net during grain filling. Evaluation of dynamic changes in shoot harvest index in response to photosynthetic manipulation treatments revealed that sink was more limited in local black soybeans than Suwon 168 and Baekunkong, indicating that the availability of photosynthate during grain filling did not limit the grain yield in local black soybeans when compared to Baekunkong and Suwon 168.

Key words : Source potential, Sink capacity, Partitioning, Photosynthetic manipulation

Crop yield is determined by the interaction between source potential supplying photoassimilates and sink capacity for storage (Kokubun and Asahi, 1984). However, it is difficult to determine exactly which part in plants is regarded as sink or source because shift changes from sink/source to source/sink are occurring in relation to plant developmental stage. In spite of these difficulties, many experiments have been

done to assess photosynthetic limitation to crop yield by altering source-sink ratios.

To alter the source potential or sink capacity, several workers have manipulated source or sink organs mechanically or through management. Source potential have been manipulated by altering radiation (Evans and Wardlaw, 1976; Satterlee and Koller, 1984) or CO₂ concentration (Hardman and Brun, 1971; Kramer, 1981;

* 作物試驗場 (Crop Experiment Station, RDA, Suwon 441-100, Korea)

** 忠南農村振興院 (Chungnam Provincial RDA, Taejeon 305-313, Korea)

(94. 1. 27. 接受)

Kimball, 1983 ; Gifford, 1977). In general, removal of ear or pod, or prevention of pollination have been used to change sink capacity in plants. Substantial reduction in photosynthesis was recorded after ear removal in wheat (Evans, 1975). Many manipulations of source-sink ratio led to the conclusion that sink demand affected photosynthetic rate in source leaves. It is evident that sink and source depend on each other, and are limiting to yield. And also, environments that were modified to increase photosynthesis often also increased yield (Nelson, 1988).

The availability of photoassimilates during grain filling limits the crop yield. Gifford et al (1973) proposed a method for assessing photosynthetic limitation to grain yield in a field crop that source limitations were analyzed during grain filling with techniques of shading and carbon dioxide enrichment to alter photosynthesis. Source limitations, which were estimated by change in grain storage and growth divided by changes in total dry weight increase of plants, should be useful predictive index of estimating the source or sink limitation to crop yield.

Local black soybean, widely and traditionally used for cooking with rice in Korea, had relatively low ratio of seed to pod-shell dry weight, suggesting the incomplete seed filling (Kim et al, 1993). In the previous self- and reciprocal-grafting study among local black soybeans and two other soybean genotypes (Lee et al, 1994), we have found out that shoot genotypes controlled the incomplete seed filling in local black soybeans. Related to that, incomplete seed filling was thought to be due to the insufficient photosynthates supply from the top rather than poor uptake of nutrient and water from the root system.

Though incomplete seed filling in local black soybeans was primarily dependent on the top characters, little is known on the relative importance of source and sink in determining yield of local black soybeans. The present study was undertaken 1) to evaluate the genotypic difference in partitioning of dry matter in response to

photosynthetic manipulation in which shading during grain filling and different planting densities were applied, and 2) to determine whether the local black soybean yield was limited by source potential or sink capacity.

Materials and Methods

Baekunkong, Suwon 168, and two local black soybeans, Kangleungjarae and Keumleungjarae, were selected for this study. Two local black soybeans showed the relatively smaller size of grain to pod at harvest than Baekunkong and Suwon 168, indicating the incomplete seed filling of local black soybeans.

Seeds of four selected soybean genotypes were sown on May 11, 1993, and grown at the Crop Experiment Station, RDA, Suwon in Korea. Fertilizer was applied to the field at the level of 40, 70, and 60 kg ha⁻¹ N, P₂O₅, and K₂O before planting, respectively. One week after emergence, seedlings were thinned to be one plant per hill. Row spacing was 0.6 m, and plot size was 4 rows × 2.4 m.

Four photosynthetic manipulation treatments were imposed by combining two levels of planting density (55,000 and 110,000 plants ha⁻¹) and shading with vinyl net during grain filling. The treatments were: 1) The planting density was 55,000 plants ha⁻¹ without shading (H), 2) 110,000 plants ha⁻¹ without shading (C), 3) 110,000 plants ha⁻¹ with one layer of shading (S₁), and 4) 110,000 plants ha⁻¹ with two layers of shading (S₂). Factorial experiment with 4 soybean genotypes × 4 photosynthetic manipulation treatments was laid out in a randomized complete block design with three replications.

At physiological maturity, ten plants in the middle of plot were harvested, separated into grain and shoot, oven-dried, and weighted. Source limitation was approximated on the basis of change in grain dry weight divided by that in top dry weight in response to photosynthetic manipulation treatments, as proposed by Gifford et al (1973).

Results and Discussion

Local black soybean genotypes, Kangleungjaræ and Keumleungjaræ, were characterized by greater grain dry weight (GDW) and top dry weight (TDW) than Suwon 168 which was early in maturity and used primarily for vegetable (Table 1). There were significant effects of photosynthetic manipulation treatments on GDW and TDW, indicating that the energy, originated from sunlight, played a great role in dry matter production. Sparse planting density (H), which gave soybean plants enough light for photosynthesis, increased GDW and TDW simultaneously, regardless of soybean genotypes. Significant interaction effects between genotypes and photosynthetic manipulation treatments were found in GDW ($P < 0.05$) and TDW ($P < 0.01$).

The partitioning of photosynthetic product between grain and the rest of soybean plant has been of primary importance. Harvest index (HI) can be defined as the ratio of economic yield to total dry weight including root part. However, shoot HI is commonly used in agronomic sense due to the difficulties assessing the root dry weight in the field. Shoot HI of local black soybeans was relatively lower than that of Baekunkong and Suwon 168. This suggests that smaller shoot HI of local black soybeans was closely related to the poorer partitioning of current photosynthate to the grain. There was significant difference ($P < 0.01$) in shoot HI among photosynthetic manipulation treatments. Of specific interest, when averaged across the four soybean genotypes, was no difference in shoot HI among three photosynthetic manipulation

Table 1. Genotypic difference in plant dry weight and shoot harvest index as affected by photosynthetic manipulation

Genotypes	Photosynthetic manipulation				Mean
	H	C	S ₁	S ₂	
	Grain dry weight (GDW) (g)				
Beakunkong	54.0	43.6	24.7	15.0	34.3 ^b
Suwon 168	21.5	18.3	13.2	7.9	15.2 ^c
Kangleungjaræ	75.3	46.2	49.8	24.0	48.8 ^a
Keumleungjaræ	82.6	51.9	46.1	31.1	52.9 ^a
Mean	58.4 ^a	40.0 ^b	33.4 ^b	19.5 ^c	
	Top dry weight (TDW) (g)				
Beakunkong	103.1	90.2	52.4	32.0	69.4 ^b
Suwon 168	34.8	32.2	22.7	13.5	25.8 ^c
Kangleungjaræ	166.6	109.0	109.7	65.3	112.7 ^a
Keumleungjaræ	189.2	119.9	102.4	81.9	123.4 ^a
Mean	123 ^a	87.8 ^b	71.8 ^c	48.2 ^d	
	Shoot harvest index (Shoot HI)				
Beakunkong	0.524	0.483	0.471	0.469	0.467 ^b
Suwon 168	0.618	0.568	0.581	0.585	0.588 ^a
Kangleungjaræ	0.452	0.424	0.454	0.368	0.425 ^c
Keumleungjaræ	0.437	0.433	0.450	0.380	0.425 ^c
Mean	0.508 ^a	0.477 ^a	0.489 ^a	0.451 ^b	

treatments(H, C, and S₁). These data clearly demonstrated that soybean plants grown under S₁ photosynthetic manipulation treatments, which is altered by relatively dense planting(110,000 plants ha⁻¹) and one layer of shading net to reduce their radiation to plants, maintained a very similar balance of dry matter between grain and top to those grown under sparse planting density(H : 55,000 plants ha⁻¹). On the contrary, soybean plants grown under S₂ had fairly low partitioning of dry matter to grain.

The GDW against SDW per plant in response to photosynthetic manipulation treatments is in Fig. 1 for the four soybean genotypes. The points for each genotype were fitted fairly well to the straight line. The minimum SDW to obtain GDW, which is the intercept on X-axis, is greater in local black soybeans than that in Baekunkong and Suwon 168.

On the basis of source limitation analysis proposed by Gifford et al(1973), the approximate source limitations(Sa), which represent the slopes of straight lines in Fig. 1, are estimated for the four soybean genotypes(Table 2). The estimated source limitations of Baekunkong and Suwon 168 are 0.61 and 0.54, respectively, where as those of the local black soybean are about 0.5. From the fact that Sa is near 0.5 in local black soybeans it could be concluded that yield should be improved by enhancing both photosynthesis

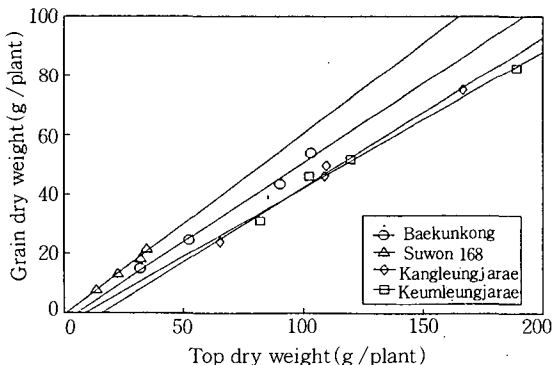


Fig. 1. Grain yield plotted against top dry weight as affected by photosynthetic manipulation.

Table 2. Source limitations to which the availability of photosynthate during grain filling limits the grain yield

Genotypes	Source limitation	T-value
Baekunkong	0.61	18.02**
Suwon 168	0.54	12.47**
Kangleungjarae	0.50	16.45**
Keumleungjarae	0.46	13.10**

and sink capacity simultaneously.

Considering that Sa under estimates the real source limitation(S) except when S=0(entirely sink-limited) or S=1(entirely source limited) due to the fact that root dry weight was not included in evaluating Sa, S of local black soybeans should be less than 0.5. This suggests that yield of local black soybeans is more sink-limited than source-limited, and additional photoassimilates during grain filling do not seem to be utilized in local black soybeans because of sink limitation. Sink limitation should be a result of the integrated effect of many physiological processes such as inferior translocation of assimilates immature growth of pod size, and sink inability to pull assimilates. However, in local black soybeans, potential pod size should not be a limiting factor to soybean yield, reduced from the greater relative pod to grain size when compared to other soybean varieties(Lee et al, 1994). Apparently, translocation studies with radio isotope-labeled compound should be further conducted to help explain the sink limitation to yield in local black soybean.

摘要

콩의 수확량에 대한 광합성 기관(source)과 광합성 산물 수용 기관(sink)이 미치는 영향을 살펴 보자. 꼬투리의 크기에 비하여 종실 건조물 축적이 불량한 수직검정콩인 강릉재래 및 금릉재래, 꼬투리의 비대가 충실한 백운콩 및 수원 168호를 시험하였다. 두 수준의栽植密度(ha당 55,000, 110,000 개체)와 開花期 이후 登熟期間 중 차광막을 설치하여 광합성 능력에 관여하는 환경要因을 변화시킴으로써 나타나는 乾物重分配 및 個體收量 反應을

分析한 결과를 요약하면 다음과 같다.

1. 地上部 및 種實乾物重의 品種間 광합성능력 변화를 위한 栽植密度 및 遮光幕 處理間 유의적인 차이가 인정되었고 품종 및 처리간 유의적인 相互作用 效果도 있었다.
2. 地上部 總乾物重에 대한 種實乾物重 比率은 품종간 차이가 인정되어, 수원 168호가 가장 높았으며, 광합성 능력을 변화시키기 위한 처리 가운데 극히 광이 부족한 S₂를 제외한 나머지 세 처리간 차이는 없었다.
3. 登熟期間中에 收量을 위한 source와 sink 능력을 광합성 기관 制限程度(source limitation value)에 의하여 품종간 비교하여 보면, 꼬투리에 종실이 충분히 蓄積되는 수원 168호는 source가, 수집검정콩인 강릉재래나 금릉재래는 sink의 기능이 수량에 있어서 制限要因으로 作用하였다.

References

1. Evans, L.T. and I.F.Wardlaw. 1976. Aspects of the comparative physiology of grain yield in cereals. *Advances in Agron.* 28:301-359.
2. Gifford, R.M., P.M.Bremner, and D.B.Jones. 1973. Assessing photosynthetic limitation to grain yield in a field crop. *Aust. J. Agric. Res.* 24:297-307.
3. Gifford, R.M. 1977. Growth pattern, carbon dioxide exchange and dry weight distribution in wheat growing under differing photosynthetic environments. *Aust. J. Plant Physiol.* 4:99-110.
4. Hardman, L. L. and W.A.Brun. 1971. Effect of atmospheric carbon dioxide enrichment at different developmental stages on growth and yield components of soybeans. *Crop Sci.* 11:886-888.
5. Kimball, B.A. 1983. Carbon dioxide and agricultural yield: an assemblage and analysis of 430 prior observations. *Agron. J.* 75:779-788.
6. Kim, S.D., Y.H.Kim, E.H.Hong, and E.H. Park. 1993. Seed characteristics of black soybean collections in Korea. *Korean J.Crop Sci.*38(5):437-441.
7. Kokubun, M. and Y. Asahi. 1984. Source-sink relationships between the main stem and branches during reproductive growth in soybeans. *Japan J.Crop Sci.* 53(4):455-462.
8. Kramer, P.J. 1981. Carbon dioxide concentration, photosynthesis, and dry matter production. *Bio Science* 31:29-33.
9. Lee, S. H., Y. G. Seung, Y. H. Kim, and E. H. Hong. 1994. Root vs. shoot genotype effects on growth characters and seed to pod-shell dry weight ratio in grafted soybean plants. *Korean J. Crop Sci.* in press.
10. Nelson, C. J. 1988. Genetic associations between photosynthetic characteristics and yield: review of the evidence. *Plant Physiol. Biochem.* 26(4):543-554.
11. Satterlee, L.D. and H.R. Koller. 1984. Response of soybean fruit respiration to changes in whole plant light and CO₂ environment. *Crop Sci.* 24:1007-1010.