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BRIEF COMMUNICATION

Interrelationship between leaf gas-exchange characteristics, area leaf mass, and yield in soybean (*Glycine max* L. Merr) genotypes

Desiraju SUBRAHMANYAM

Plant Physiology Laboratory, G.B. Pant University of Agriculture and Technology, Hill Campus, Ranichauri-249 199, Uttarakhand, India

Abstract

Variability in leaf gas-exchange traits in thirteen soybean (*Glycine max* L. Merr) genotypes was assessed in a field experiment conducted at high altitude (1 950 m). Leaf net photosynthetic rate (P_N) exhibited a high degree of variability at all the growth stages studied. P_N and other gas-exchange parameters exhibited a seasonal pattern that was similar for all the genotypes. P_N rate was highest at seed filling stage. P_N was positively and significantly associated with aboveground dry matter and seed yield. The area leaf mass (ALM) exhibited a strong positive association with leaf P_N, aboveground dry matter, and seed yield. The positive association between ALM, P_N, and seed yield suggests that this simple and easy to measure character can be used in breeding programmes as a surrogate for higher photosynthetic efficiency and eventually higher yield.

Additional key words: area leaf mass; net photosynthetic rate; stomatal conductance; transpiration rate; water use efficiency.

Selection for higher photosynthesis has not always resulted in improved crop growth. Regular correlation between leaf P_N and yield has been very difficult to demonstrate in the field (Wilson 1984). Nevertheless, leaf P_N is one of the important attributes controlling the plant growth. Genotypic variation in leaf P_N per unit leaf area may be useful in increasing productivity of crop plants, but only if it can be demonstrated to be measurable and related to growth in the field stands (Mahon 1990). Variability in photosynthesis can be attributed to differences in g_s (Dornhoff and Shibles 1970, Peet *et al.* 1977, Hobbs and Mahon 1982). Increasing leaf P_N may improve seed yield in soybean. Selection for high specific leaf mass may increase P_N (Thompson *et al.* 1995). The objective of the present study was to assess the extent of variability in important leaf photosynthetic characteristics and to investigate their relationship with specific leaf mass and seed yield in some Indian soybean genotypes.

Seeds of thirteen soybean genotypes (PK 1133, PK 1135, PK 1024, PK 1109, PK 1137, PK 1134, PK 1092, PK 364, PK 327, PK 1042, SL 284, MACS 520, MACS 534) were obtained from Plant Breeding section of Hill Campus. They were planted in 3×2 m size plots in randomised block design with 4 replications in B-block of G.B. Pant University of Agriculture and Technology, Hill Campus farm. The farm is situated at an altitude of 1 950 m a.s.l. in the central Himalayan region. The experimental soil was silty clay loam with pH 5.3, organic carbon 1.05 %, available N 21.5 g m^{-2}, available P 0.92 $g(P_2O_5)$ m^{-2} and available K 36.0 $g(K_2O)$ m^{-2}.

P_N and related parameters of three randomly selected plants per each plot were measured on fully expanded leaves (leaf located on 2nd or 3rd node from top) between 10.00 and 13.00 h on cloudless days at four ontogenetic stages: V6 (plants have 6-7 nodes with completely unfolded leaves), R2 (full bloom stage), R3 (beginning of pod), and R5 (beginning of seed filling). Care was taken to sample the leaves from the same position for all measurements. P_N was measured with a *CIRAS-I* portable photosynthesis measuring system (*PP Systems*, Hitchin, U.K.) fitted with a broad leaf cuvette (exposed area 250 mm^2). The instrument was set up and calibrated

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Present address: ICAR Research Complex for Eastern Region, WALMI Complex, Phulwari Sharif P.O., Patna-801 505, Bihar, India; fax: +91-612-452232, e-mail: desiraju_subbu@yahoo.com
Abbreviations: ALM = area leaf mass; C_i = internal CO_2 concentration; E = transpiration rate; g_s = stomatal conductance; P_N = net photosynthetic rate; WUE = water use efficiency.

according to the manufacturer's instructions. Gas flow rate to the cuvette was set at 5 $cm^3 s^{-1}$, boundary layer resistance was determined to be 0.28 $m^2 s^{-1} mol^{-1}$ (H_2O), and leaf temperatures were estimated using the instrument's facility to calculate leaf energy balance. A transmission coefficient of 0.15 was used (following the instructions of the manufacturer). Immediately after the measurement of P_N, the leaf was excised and the leaf area was measured using a portable leaf area meter model *C-201* (*CID*, USA) with *C-201S* scan board. The leaf was dried at 60 °C for 48 h and the dry mass was determined for ALM measurement. At harvest, total dry mass and seed yields were also recorded. The variability amongst different photosynthesis traits was assessed by simple one-way *ANOVA*. The relationship between different photosynthesis traits was assessed by computing correlation coefficients. All the statistical analysis were carried out using statistical software developed by the Computer Center of G.B. Pant University of Agriculture and Technology, Pantnagar.

Table 1. Variations in leaf photosynthetic traits and other characters of soybean genotypes. Leaf net photosynthetic rate was measured on fully expanded leaves of the 2nd or 3rd node from the top. Three plants per plot/replication were randomly selected for measurement and the statistical significance was tested by simple one-way *ANOVA*. Each mean value represent the average of 13 genotypes ± standard deviation.

Parameter	Growth stage	Mean	Range	F-ratio
Net photosynthetic rate, P_N	V6	21.0±1.5	13.8 – 28.7	4.029
[μmol $m^{-2} s^{-1}$]	R2	25.8±3.6	18.5 – 50.6	3.362
	R3	30.8±3.9	25.6 – 40.5	2.068
	R5	37.1±4.3	28.9 – 44.9	4.499
Transpiration rate, E	V6	7.08±1.50	4.8 – 9.0	5.837
[mmol $m^{-2} s^{-1}$]	R2	4.97±0.90	4.0 – 6.8	5.817
	R3	7.52±0.60	6.6 – 8.1	5.548
	R5	7.39±0.90	6.1 – 8.6	10.111
Stomatal conductance, g_s	V6	397±64	215 – 611	4.358
[mmol $m^{-2} s^{-1}$]	R2	507±35	337 – 765	3.687
	R3	767±51	729 – 933	3.363
	R5	978±83	656 – 996	6.001
Internal CO_2 concentration, C_i	V6	391±30.4	376 – 424	2.775
[$cm^3 m^{-3}$]	R2	336±91.6	246 – 390	3.689
	R3	381±18.7	370 – 395	1.285
	R5	398±23.7	367 – 427	3.392
Area Leaf Mass, ALM	V6	21.0±8.2	8.4 – 30.0	6.965
[g(dry matter) m^{-2}]	R2	39.0±9.1	27.8 – 50.6	4.511
	R3	40.0±5.4	33.2 – 46.4	4.233
	R5	50.0±12.4	24.2 – 91.3	9.004
P_N/E	V6	3.00±0.67	2.55 – 3.73	2.775
	R2	6.20±2.60	3.56 – 5.56	3.689
	R3	4.10±0.66	3.45 – 4.90	1.285
	R5	5.20±0.77	4.27 – 6.05	3.392
P_N/g_s	V6	55.7±14.0	40.4 – 71.7	2.398
	R2	62.5±11.8	34.6 – 138.8	3.850
	R3	39.0±7.4	33.2 – 58.6	1.915
	R5	39.3±9.3	30.5 – 54.8	3.020
P_N/C_i	V6	0.05±0.01	0.035 – 0.078	3.840
	R2	0.15±0.08	0.042 – 0.203	1.139
	R3	0.08±0.01	0.065 – 0.815	1.009
	R5	0.09±0.01	0.065 – 0.105	3.415
Seed yield [g m^{-2}]		173.2±13.9	103.1 – 203.9	6.136

P_N and other related traits exhibited seasonal pattern, which was similar for all genotypes examined. P_N was highest at R5 stage with a mean of 37.1 and range of 28.9 to 44.9 $\mu mol(CO_2) m^{-2} s^{-1}$. Similarly, highest g_s and ALM were recorded at R5 stage with means of 978 mmol $m^{-2} s^{-1}$ and 51 g m^{-2}, respectively. Significant differences in C_i, P_N/E, and P_N/g_s were noticed at different growth stages (Table 1). Seasonal variation in P_N and other related traits were reported for different crops (Larson *et al.* 1981, Lugg and Sinclair 1979, Mythili and Nair 1996, Subrahmanyam and Rathore 1992, and others). The highest rates for both P_N and ALM at R5 stage are mainly due to the increased demand for photosynthates by the developing seeds during seed filling stage. Similar results were reported for different crops (Koller *et al.* 1970, Subrahmanyam and Rathore 1999).

High genetic variability was observed in all leaf gas exchange traits, total dry matter at harvest, and seed yield as indicated by the F-ratios which are highly significant (Table 1) at all the growth stages. However, the variability in C_i was non-significant at R3 stage. Similarly, the variability in P_N/E and P_N/g_s was non-significant at R3 stage. The variability in P_N/C_i was also non-significant at R3 and R5 stages. P_N was positively and significantly related to both E and g_s at all the four growth stages. ALM exhibited positive association with P_N at all the four growth stages (Table 2). However, the relationship was statistically non-significant at V6 and R2 stages. Genotypic variability in P_N and other characteristics was reported for different crops (Suresh *et al.* 1997, Kumar *et al.* 1998, Subrahmanyam and Rathore 1999, Jiang and Xu 2001, and many others). Variation in P_N can be associated with differences in g_s, chlorophyll content, leaf size, leaf area, and ALM (Dornhoff and Shibles 1970, Hesketh *et al.* 1981, Hobbs and Mahon 1982, Bhagsari and Brown 1986). The strong positive association between ALM and P_N, and between P_N and g_s indicates a possible role for these characters for the observed variability in P_N. Similar observations were made with other crops (Pearce *et al.* 1969, Gupta *et al.* 1989). Bhagsari and Brown (1986) suggested that the genotypic variation in P_N might be due to the differences in ALM. However, this relationship is dependent on species and may not hold true for all species and environments. ALM displays a strong positive association with leaf P_N in several crops and ALM can be used as an indirect selection criterion for higher photosynthesis (Dornhoff and Shibles 1970, Suresh and Nair 1997).

Table 2. Relationship between leaf photosynthetic characteristics and seed yield in soybean genotypes. The relationship was studied by computing Pearson Product Movement correlation coefficients. $^*p \leq 0.05$, $^{**}p \leq 0.01$, $n = 52$.

Relationship between		Growth stage V6	R2	R3	R5	Mean
P_N and	g_s	0.54^{**}	0.33^{**}	0.41^{**}	0.40^{**}	0.66^{**}
	E	0.59^{**}	0.31^{**}	0.39^{**}	0.42^{**}	0.73^{**}
	C_i	-0.39^{**}	-0.66^{**}	-0.75^{**}	-0.55^{**}	-0.31^*
	ALM	0.11	0.19	0.29^*	0.80^{**}	0.39^{**}
	total aboveground biomass at harvest	0.09	0.10	0.15	0.28^*	0.44^{**}
	seed yield	0.14	0.11	0.04	0.53^{**}	0.32^*
P_N/E and	P_N/g_s	0.82^{**}	0.97^{**}	0.59^{**}	0.35^{**}	0.84^{**}
	P_N/C_i	0.32^*	0.80^{**}	0.64^{**}	0.31^*	0.63^{**}
ALM and	total aboveground biomass	0.17	0.13	0.17	0.52^{**}	0.36^{**}
	seed yield	0.10	0.12	0.18	0.80^{**}	0.41^{**}

The short-term water use efficiency (WUE) was calculated as P_N/E and this ratio showed a positive and significant association with P_N/C_i, which is a measure of carboxylation efficiency of the leaf, and with P_N/g_s, which is an estimate of potential WUE at the g_s level (Table 2). The strong association between P_N/E and P_N/C_i or P_N/g_s suggests that these ratios determine the potential WUE of the leaf. Similar association was reported earlier for diffe-rent crops (Jacob *et al.* 1990, Subrahmanyam and Rathore 1999, Bunce and Sicher 2001).

A positive association was observed between the total aboveground biomass at harvest (TDM) and P_N. However, the relationship was statistically significant only at R5 stage. Nevertheless, the seasonal mean P_N showed positive and significant association with TDM (Table 2). At R5 stage similar positive and significant (p = 0.001) association was observed between P_N and seed yield. The seasonal mean P_N also exhibited significant ($p = 0.05$) positive association with seed yield. However, the relationship between P_N recorded at other stages and seed yield was non-significant. The seasonal mean ALM at R5 showed a strong positive association with both TDM at harvest and seed yield (Table 2). Positive association between TDM and P_N has been reported for different crops (Mythili and Nair 1996, Kumar *et al.* 1998, Subrahmanyam and Rathore 1999). Similarly a positive relationship between seed yield and P_N was reported for different crops (Peet *et al.* 1977, Buttery *et al.* 1981, Harrison *et al.* 1981, Babu *et al.* 1985, Reynolds *et al.* 1994, Kumar *et al.* 1998, and others).

The genotypes PK 327 and PK 1042 which showed high P_N, g_s, and ALM also displayed higher, though not the highest TDM and seed yield. Similarly PK 1135 and PK 1133 showed the lowest P_N and low g_s and ALM. The positive association between ALM, P_N, and seed yield suggests that this simple and easy to measure character can be used in breeding programmes to select for higher photosynthetic efficiency and eventually higher yield in soybean.

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