Influence of Water Availability on Photosynthetic Characteristics of Diverse Soybean Genotypes

Brett L. Naylor[1], and Felix B. Fritschi[1]

[1]Division of Plant Sciences, College of Agriculture, Food and Natural Resources, University of Missouri, Columbia, MO 65211

INTRODUCTION

The concept of water use efficiency (WUE) has been proposed as a physiological trait to select for when plants need to conserve water and withstand periods of water scarcity. Variation for WUE has been demonstrated in a variety of important crop species with some limited work in soybean. When genotypic variation for WUE is revealed in soybean it is important for plant breeders to know whether the differences are due to greater stomatal regulation, or from non-stomatal restrictions once CO_2 enters the leaf. Plant introductions (PI) 416997 and 398198 have been identified to have a higher WUE in well watered and water deficit conditions compared to PI's 398965 and 567201D in both greenhouse and field environments. The contribution to differences in WUE, whether from stomatal factors, or non-stomatal factors (i.e mesophyll or enzyme limitations), or perhaps a combination of both was unclear. Gas exchange measurements were conducted in the field to examine which photosynthetic characteristics may lead to differing WUE.

METHODS

Field Management: Four soybean (Glycine max) plant introductions were grown under a rainout shelter in the summer of 2013 and 2014 at the Bradford Research Center near Columbia, MO, USA . PI416997 and PI391198 were selected for low carbon isotope discrimination (CID) while PI398965 and PI567201D were selected for high CID based on data from a multi-environment study conducted 2009 through 2012. Seeds were planted in mid-May in four-row plots measuring 7.46 m^2. Three water treatments were imposed using drip irrigation and included well-watered (WW), moderate stress (MS), and severe stress (SS). Initially all plots were maintained well-watered, receiving the same amount of precipitation and irrigation water until first flower (R1 growth stage). From R1 to full seed (R6) the rainout shelter was moved over the plots when a precipitation event occurred and the only water applied to the plots was from drip irrigation. The WW treatment was irrigated every 3 to 5 days to maintain soil moisture near field capacity. The MS treatment received one re-watering of approximately 12mm at R3 and the SS treatment received no irrigation for over 40 days until R6 was reached.

Data Collection and Statistical Analysis : Leaf gas exchange measurements were carried out with a LI-6400 Photosynthesis Measurement System between 10:00 and 14:30 from growth stage R1 until R6 on the uppermost fully more expanded trifoliate. One LI-6400 was used to conduct $A_N \setminus C_i$ response curves at high PPFD (2000 µmol m^{-2} s^{-1} PPFD) to determine the response of A_N to c_i while simultaneously a second LI-6400 was used to conduct light response curves exposing leaves varying PPFD starting at 2000 to 0 PPFD with 8 varying levels in between. During the same time window, SPAD readings were taken to estimate chlorophyll levels and porometer readings were conducted to determine stomatal conductance. Sensitivity calculations and estimates were performed according to Jones (1985). All measured photosynthetic parameters, SPAD values, and porometer readings were analyzed using the PROC GLM procedure in SAS. Watering treatment and genotype were considered fixed effects while year and replication were considered as random variables. Means were separated using the Tukey-Kramer means comparison test.

ACKNOWLEDGMENTS

We would like to thank the United Soybean Board for the funding of this project and the Fritschi lab members who contributed to this project.

RESULTS

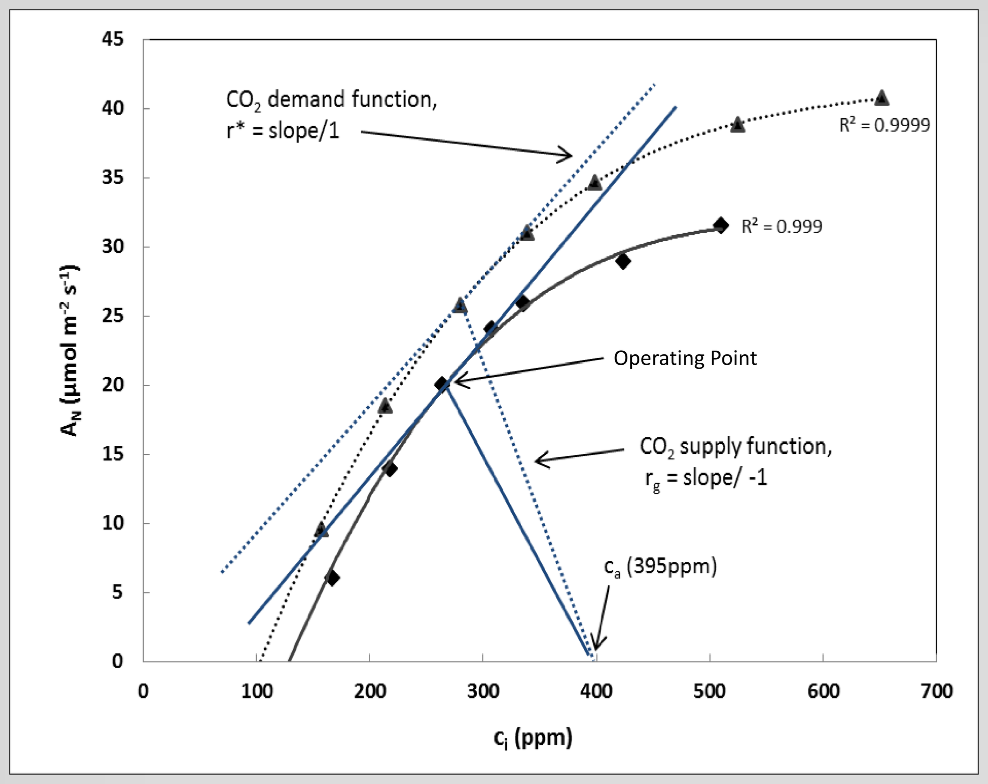


Figure 1. (above) Actual A_N/C_i curve from two different genotypes grown in well-watered conditions (solid line represents PI416997, dotted line represents PI398965). Gas and non-gas phase resistances (r_g and r*), were calculated using the slopes of the CO_2 supply demand functions at the operating point as shown above for all genotypes.

Figure 2. (right) Response of stomatal conductance (g_s), net photosynthesis (A_N), and leaf internal CO_2 concentration (c_i) from light response curves. Each line represents the mean of two genotypes (PI416997and PI398198 for high WUE, PI398965 and PI567201D for low WUE). Dotted lines represent the mean of the stress and drought treatments.

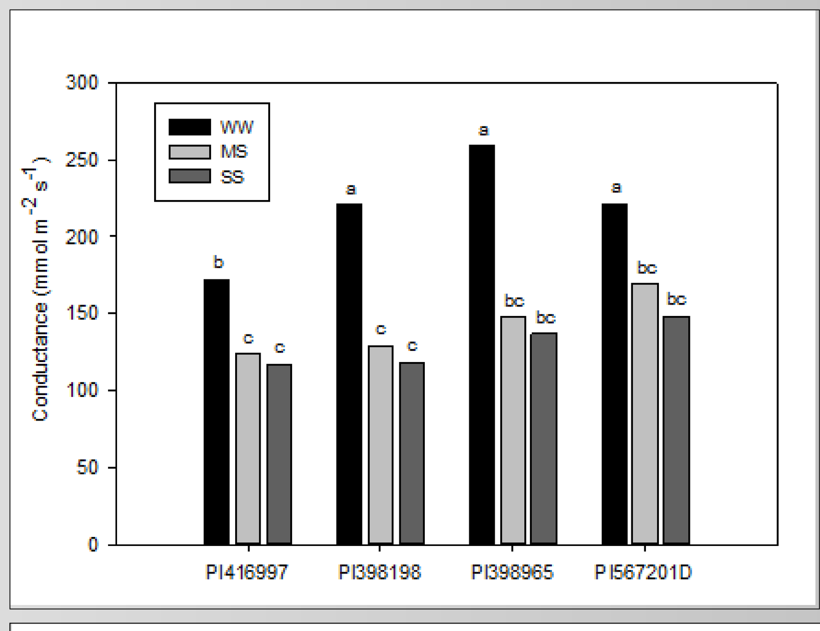
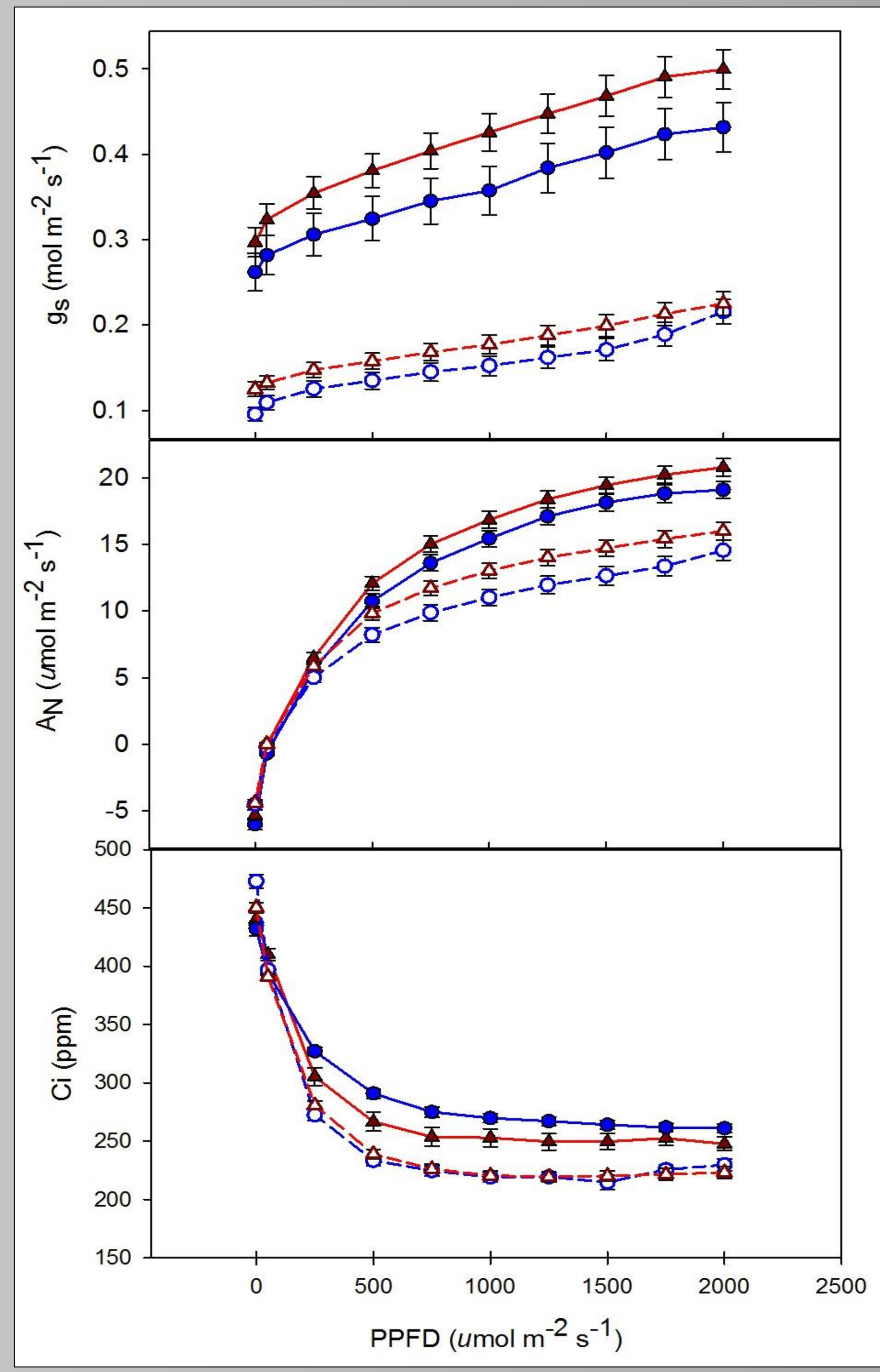


Figure 3. (above) Stomatal conductance measurements taken for each genotype by treatment using a porometer (Decagon Devices) during the 2013 and 2014 growing season. There was no significant difference between years. (n=100)



	Genotype				Treatment			Year		Grand Mean
	PI416997	PI398198	PI398965	PI567201D	WW	MS	SS	2013	2014	
A_N (µmol $m^{-2}s^{-1}$)	17.0^C	18.19^{BC}	19.25^{AB}	20.59^A	21.97^A	17.42^B	16.82^B	16.55^B	19.72^A	18.76
C_i (ppm)	234.5	246.1	246.5	245.7	262^A	235^B	231.3^B	254.8^A	244.3^B	243.2
g_S (mol $m^{-2}s^{-1}$)	$.242^C$	$.276^{BC}$	$.296^{AB}$	$.334^A$	$.404^A$	$.238^B$	$.218^B$	$.229^B$	$.311^A$	0.287
g_M (mol CO_2 $m^{-2}s^{-1}$)	0.076	0.078	0.079	0.088	0.085	0.078	0.079	0.083	0.08	0.081
Φ CO_2	$.010^B$	$.012^{AB}$	$.012^{AB}$	$.014^A$	$.014^A$	$.012^B$	$.010^B$	0.011^B	0.013^A	0.012
Vpd (kPa)	2.28^A	2.09^{AB}	2.12^{AB}	1.98^B	1.85^B	2.24^A	2.26^A	2.7^A	1.8^B	2.12
t_l (°C)	32.4	32.3	32	32.1	31.5^B	32.4^A	32.7^A	34^A	31.1^B	32.2
w_a (mmol mol^{-1})	28.13	29.2	28.14	29.55	29.23	28.43	28.6	29.9^A	27.9^B	28.75
WUE_i (mmol mol^{-1})	4.65	4.64	4.3	4.49	4.33	4.62	4.61	4.32^B	4.98^A	4.52
A_N/g_s (µmol mol^{-1})	85.8	81.4	79.7	81	71.2^B	88.2^A	86.9^a	91.1^A	81^B	81.9
T (mmol)	4.1^B	4.41^B	4.88^A	5.18^A	5.82^A	4.23^B	3.85^C	3.55^B	5.12^A	4.64
r_g (m^2 s mol^{-1})	16.41^A	15.86^A	11.62^B	10.13^B	8.34^B	15.5^A	16.8^A	16.9^A	12.04^B	13.5
r* (m^2 s mol^{-1})	20.61	22.24	18.03	16.06	15.1^B	20.26^A	22.45^A	23.47^A	17.4^B	19.2
l_g	$.421^A$	$.383^B$	$.386^B$	$.386^B$	$.345^B$	$.413^A$	$.425^A$	$.358^B$	$.409^A$	0.394
L_g (m^2 s µmol^{-1})	$.0399^A$	$.0373^A$	$.0292^B$	$.0255^B$	$.0207^B$	$.037^A$	$.0416^A$	$.0403^A$	$.0298^B$	0.0329
L^* (m^2 s µmol^{-1})	0.0569	0.0594	0.0501	0.0402	$.0384^B$	$.0627^A$	$.0538^{AB}$	$.0641^A$	$.0463^B$	0.0516

Table 1. (above) Means for A_N (photosynthetic rate), C_i (leaf internal CO_2 concentration), g_s (stomatal conductance), g_M (mesophyll conductance), Φ CO_2 (quantum yield of CO_2 fixation), Vpd (vapor pressure deficit), t_l (leaf temperature) w_a (sample chamber water concentration), WUE_I and A_N/g_s (intrinsic water-use efficiency), T (transpiration rate), r_g (total gas phase resistance to CO_2 diffusion), r* (total non-gas phase resistance to CO_2 diffusion), l_g (relative gas phase resistance), L_g (absolute gas phase limitation to photosynthesis), and L^* (absolute non-gas phase limitation to photosynthesis).

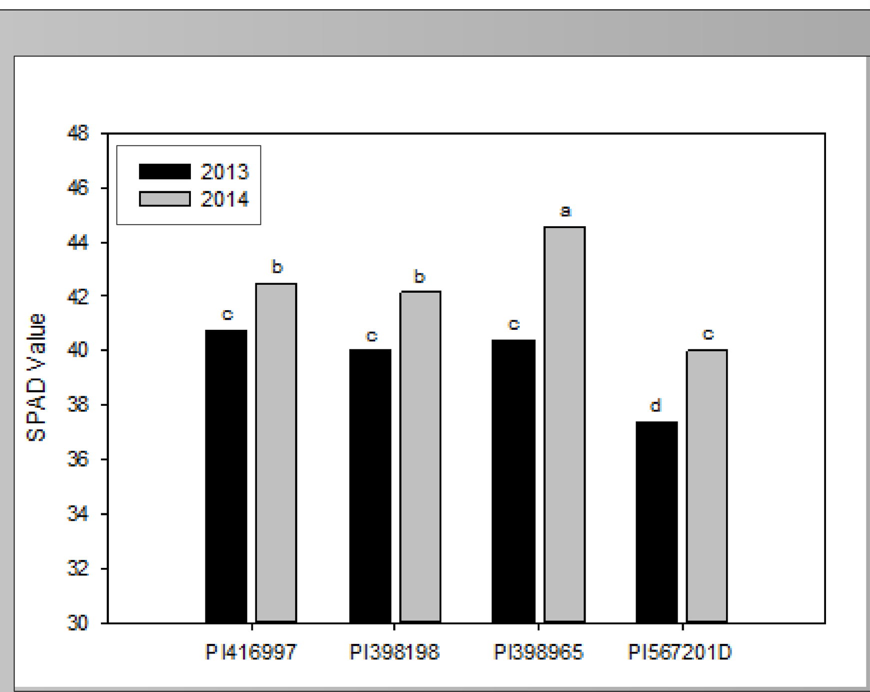


Figure 4. (above) SPAD values taken for each genotype during the 2013 and 2014 growing seasons. There was no significant difference between treatments. (n=150)

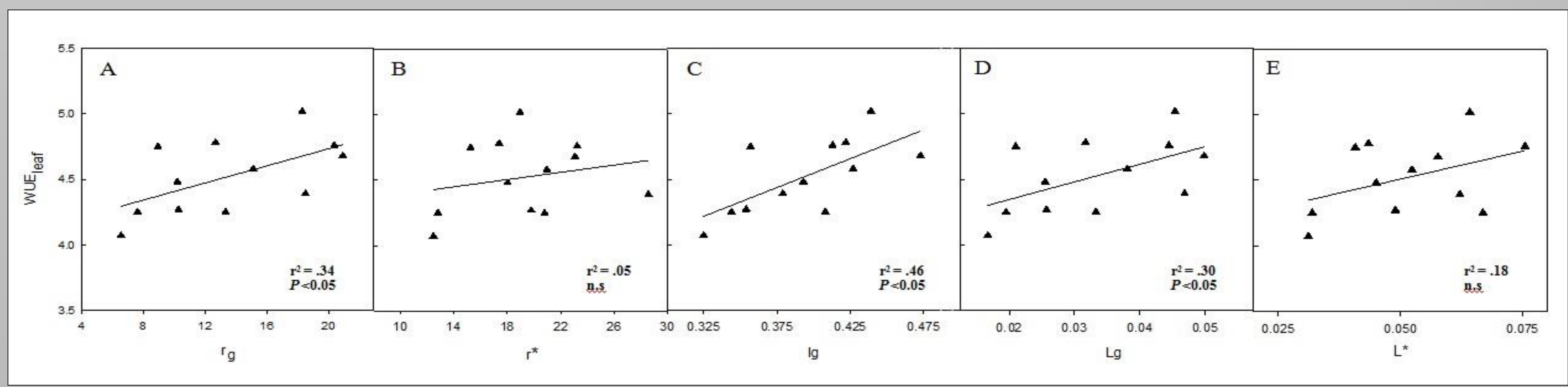


Figure 5. (left) Relationship between leaf level water-use efficiency (WUE_I) and r_g (total gas phase resistance to CO2 diffusion)(A), r* (total non-gas phase resistance to CO2 diffusion)(B), l_g (relative gas phase resistance)(C), L_g (absolute gas phase limitation to photosynthesis)(D), and L^* (absolute non-gas phase limitation to photosynthesis)(E).

CONCLUSIONS

- The moderate stress and severe stress treatments each significantly reduced photosynthesis, stomatal conductance, intercellular leaf CO2 concentration, mesophyll conductance, and transpiration rate while increasing intrinsic leaf level WUE.
- Higher WUE genotypes were observed to have approximately a 17% lower stomatal conductance, 15% lower transpiration rate, but only an 11% lower photosynthetic rate, and no significant difference in intercellular leaf CO_2 concentration.
- Higher WUE genotypes were observed to have approximately a 6% higher leaf level WUE, which was lower than expected, but could lead to distinct differences over a full growing season.
- Higher WUE genotypes did not exhibit higher or lower estimated chlorophyll content from SPAD values, but did have a lower stomatal conductance measured by the porometer. This was consistent with gas exchange measurements, but differences were less pronounced
- Leaf level WUE was significantly correlated with total gas phase resistance to CO_2 diffusion, relative gas phase resistance, and absolute gas phase resistance, but neither non-gas phase resistance, or absolute non-gas phase resistance.
- Higher WUE genotypes were observed to have significantly higher stomatal limitations. From this study it appears stomatal limitations contribute mostly to varying genotypic WUE(whole plant and leaf level) with non-stomatal limitations playing a smaller role, but still possibly a limiting factor in certain genotypes and environments.