Stomatal Conductance of Eight Grain Sorghum Lines Varying in Transpiration Efficiency

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Introduction

Plant transpiration efficiency (TE), the ratio of total biomass or carbon assimilation to water transpired, influences crop productivity. Stomatal conductance (g_s) influences photosynthesis (A) and transpiration (T) rates. Does this influence alter transpiration efficiency? If so, do genotypes differ in these effects? Screening of 400 grain sorghum accessions (a micro-lysimetric method under greenhouse condition) indicated transpiration efficiency differed among genotypes (Xin and Aiken, 2006). Do these genotypes differ in stomatal conductance, with implications for transpiration efficiency?

Objective

Evaluate variation for assimilation, stomatal conductance and transpiration efficiency among grain sorghum lines which are expected to differ in TE.

Procedure

Gas exchange measurements of selected grain sorghum accessions were evaluated for differences in g_s, A, TE and Ci (leaf internal CO_2 concentration), under standard conditions.

Plant Material:

The following sets of sorghum lines were selected for the study, representing extremes in the range of TE from a greenhouse screening trial (Xin and Aiken, 2006).

Accession	Pedigree	Origin	Race	Working group
PI 257309	Mf.G.F.1228	Argentina	Guinea-bicolor	Nigricans-bicolor
PI 295121	CAPRICORN	Australia	Caudatum	Breeding materials
PI 586381	IS 27595	Cameroon	Guinea-caudatum	Sumac
PI 567933	ER HUANG JIN	China, Beijing	Bicolor	Nervosum-Kaoliang
PI 391652	T'so 1MS	China, Shaanxi		
PI 267532	IS 2879	India	Kafir-caudatum	Caffrorum-darso
PI 533946	MS385AXIS1008SA6473PB3R	India	Durra-bicolor	Durra-dochna
PI 584085	94USE9327	Uganda	Caudatum	Caudatum-nirican

Growth environment:

Differences in stomatal conductance, among the sorghum lines, were evaluated in two field studies.

Irrigated field

Sorghum lines were grown on a deep silt loam soil (Aridic Argiustolls) in four replicated (1.4m*5.6m) field plots with two levels of irrigation and recommended soil fertility level (Fig.1).

Field micro-lysimeters:

Sorghum lines were grown in four replicated micro plots (0.7m*0.07m). Seeds were placed in 1.3 L pots filled with potting mix and saturated with nutrient solution (Fig. 2). Evaporation was minimized by enclosing pots in gas-permeable plastic bags. When the seedlings reached second-leaf (V2) vegetative stage, pots were moved from greenhouse and were placed in a container which was buried in the soil to a depth equivalent to the soil surface. Water was added to the potting mix to maintain relative water content greater than 75%

Leaf gas exchange

Leaf gas exchange measurements (LI-COR LI-6400 portable photosynthesis system) supported the calculation of photosynthesis (A), stomatal conductance (g_s) and leaf internal CO_2 partial pressure (Ci). Standard measurement condition included CO_2 partial pressure (Ca) at 370 µmol mol^{-1}, temperature of 30 °C, photosynthetic photon flux density of 1200 µmol m^{-2} s^{-1} and vapor pressure deficit at 2.5-3.1 kPa. Measurements were made after the youngest mature leaf had adjusted to cuvette conditions, typically after 15 minutes. Measurements were completed for lines grown in field micro-lysimeters at the six-leaf ($V6_{FL}$) vegetative stage and at the six-leaf ($V6_F$) and the ten-leaf ($V10_F$) stage for lines grown in field study (data from irrigated treatment presented here).

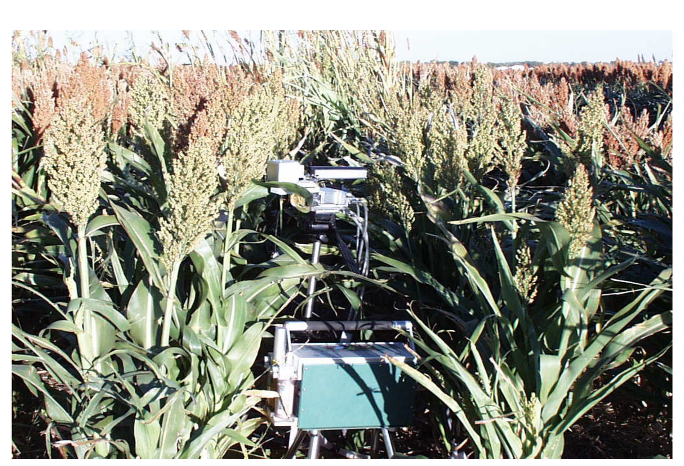

Figure1. Gas exchange measurement of sorghum grown in the irrigated field condition.

Figure 2. Gas exchange measurement of sorghum grown in micro-lysimeters under field conditions.

Analysis:

Intrinsic transpiration efficiency (Tanner and Sinclair, 1983) was calculated from diffusion equations for assimilation (1) and transpiration (2)

$$A = (Ca - Ci)\, g_{s\,CO2} \qquad (1)$$

$$T = (e_l^* - e_a)\, g_{s\,H20} \qquad (2)$$

Therefore, by dividing equation 1 by equation 2, and solving for the assimilation driving gradient, we obtain an expression for transpiration efficiency normalized by vapor pressure deficit (nTE),

$$k\,(Ca - Ci) = \frac{A\,(e_l^* - e_a)}{T} \qquad (3)$$

where k accounts for the ratio of stomatal conductance of CO_2 ($g_{s\,CO2}$) and H_2O ($g_{s\,H20}$), e_l^* is the saturation vapor pressure at leaf temperature, e_a is the ambient vapor pressure and (e_l^*-e_a) is the vapor pressure deficit.

Response variables were analyzed as randomized complete block design by SAS using Duncan's multiple range test for means comparison

Results

The following table represent the statistical comparison of $g_{s\,H20}$, A, Ci, and nTE for the lines measured at standard condition in $V6_{FL}$ and $V6_F$ and $V10_F$.

Table. Means of stomatal conductance, assimilation, leaf internal [CO2] and intrinsic transpiration efficiency for sorghum plants of four replicated plots at six-leaf stage in field lysimeters ($V6_{FL}$) and six- and ten-leaf stages in field ($V6_F$ and $V10_F$).

Stomatal conductance (mol m^{-2} s^{-1})

Sorghum Accession	6th leaf, field lysimeters ($V6_{FL}$)	6th leaf, field, irrigated ($V6_F$)	10th leaf, field, irrigated ($V10_F$)
PI 257309	0.1393 ab	-	0.1993 b
PI 295121	0.1618 ab	0.2400 a	0.1687 ab
PI 586381	0.1505 ab	0.2483 a	0.1498 ab
PI 567933	0.1250 a	0.1970 a	0.1460 ab
PI 391652	0.1688 ab	0.1737 a	0.1100 ab
PI 267532	0.1418 ab	-	0.0933 a
PI 533946	0.1970 b	0.2450 a	0.1652 ab
PI 584085	0.1680 ab	0.1733 a	0.0917 a
MEAN	**0.1586**	**0.2080**	**0.1401**
RMSE	**0.0365**	**0.0904**	**0.0540**
DMRT	**0.0613**	**0.1491**	**0.0907**

Assimilation (µmol m^{-2} s^{-1})

Sorghum Accession	6th leaf, field lysimeters ($V6_{FL}$)	6th leaf, field, irrigated ($V6_F$)	10th leaf, field, irrigated ($V10_F$)
PI 257309	21.5 ab	-	17.9 a
PI 295121	27.4 abc	25.9 a	27.4 b
PI 586381	24.2 abc	37.4 a	25.0 b
PI 567933	19.3 a	37.4 a	24.2 ab
PI 391652	28.6 bc	30.4 a	15.4 ab
PI 267532	25.0 abc	-	15.4 a
PI 533946	32.6 c	40.8 a	28.6 b
PI 584085	28.2 abc	28.7 a	15.6 a
MEAN	**26.4**	**33.0**	**21. 5**
RMSE	**4.6**	**12.1**	**5.7**
DMRT	**7.8**	**19.9**	**9.5**

Leaf Internal Carbon Dioxide (µmol mol^{-1})

Sorghum Accession	6th leaf, field lysimeters ($V6_{FL}$)	6th leaf, field, irrigated ($V6_F$)	10th leaf, field, irrigated ($V10_F$)
PI 257309	95.5 a	-	169.3 c
PI 295121	69.9 a	194.5 b	73.8 a
PI 586381	87.3 a	93.2 a	73.2 a
PI 567933	87.3 a	56.5 a	78.5 a
PI 391652	65.9 a	60.8 a	127.4 b
PI 267532	62.6 a	-	91.9 ab
PI 533946	71.6 a	67.2 a	61.8 a
PI 584085	72.1 a	73.1 a	75.6 a
MEAN	**75.23**	**84.13**	**91.48**
RMSE	**24.52**	**32.55**	**38.47**
DMRT	**41.12**	**53.70**	**64.62**

Intrinsic Transpiration Efficiency (A (e_l^* – e_a) /T)

Sorghum Accession	6th leaf, field lysimeters ($V6_{FL}$)	6th leaf, field, irrigated ($V6_F$)	10th leaf, field, irrigated ($V10_F$)
PI 257309	14.1 a	-	9.9 a
PI 295121	15.6 a	8.3 a	15.0 b
PI 586381	14.4 a	13.8 b	15.0 b
PI 567933	14.3 a	15.8 b	14.7 b
PI 391652	15.6 a	15.6 b	12.3 ab
PI 267532	16.0 a	-	14.4 b
PI 533946	15.3 a	15.0 b	15.6 b
PI 584085	15.3 a	15.1 b	15.2 b
MEAN	**15.15**	**14.32**	**14.13**
RMSE	**1.39**	**1.80**	**2.16**
DMRT	**2.34**	**2.97**	**3.63**

RMSE is the root mean square error.
DMRT is the critical value using Duncan's multiple range test and standard error for means comparison.

Stomatal conductance differed among lines in isolated cases. However, no consistent difference among lines in g_s was evident. In contrast, we observed consistent trends for Ci, A and nTE which differed for two lines. PI 257309 tended to have greatest Ci, least A and nTE while PI 533946 tended to have least Ci, greatest A and nTE.

Measurements combined across lines and environment illustrate a linear relationship between Ci and nTE. (see Fig. 3)

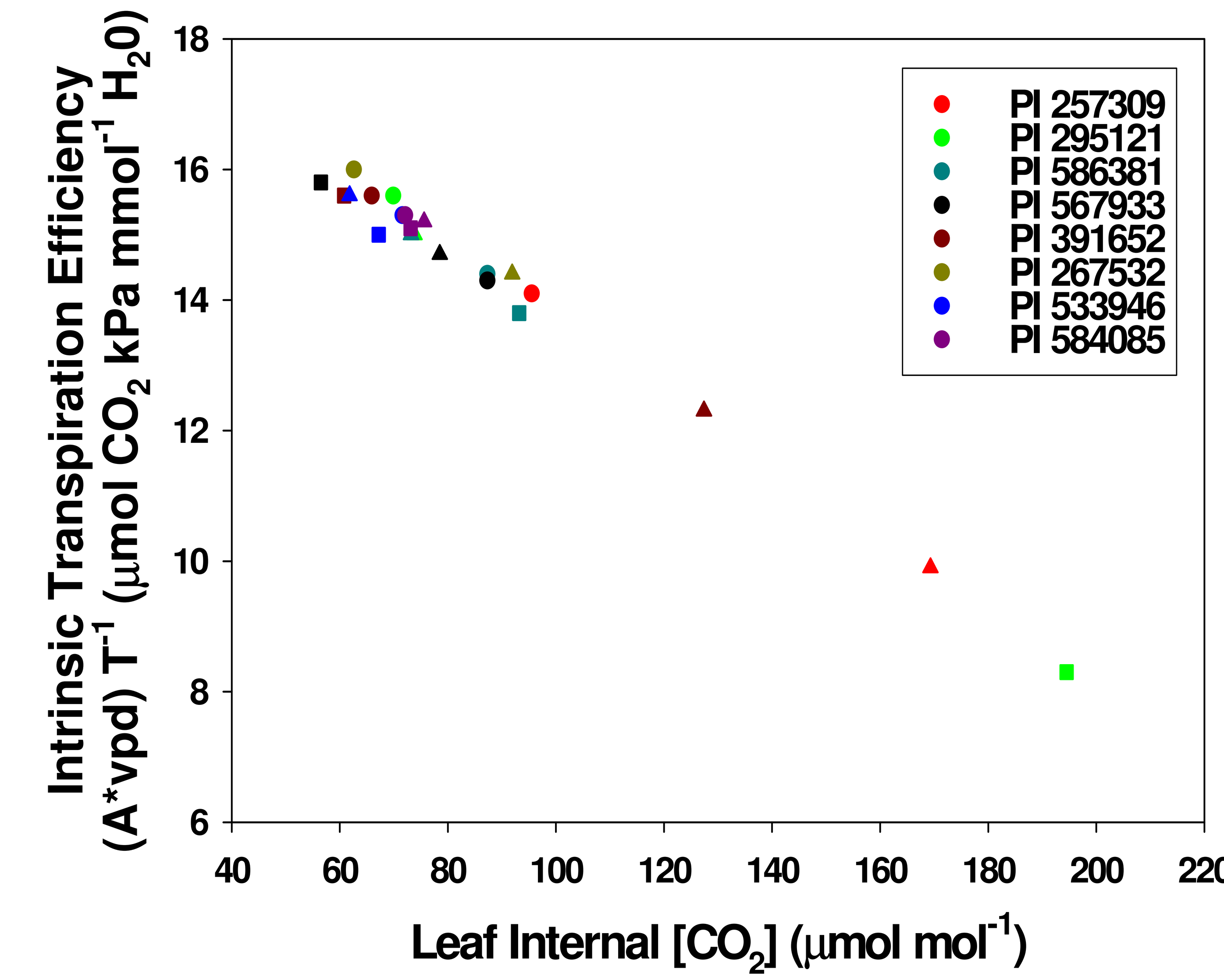

Figure 3. Intrinsic transpiration efficiency is plotted in relation to leaf internal CO_2 for selected sorghum lines, expected to differ in transpiration efficiency. Measurements, under standard conditions, represent means of four replicates, observed at $V6_{FL}$ (circles) $V6_F$ (squares) and $V10_F$ (triangles).

Discussion

Since the driving gradient (Ca-Ci) was similar among the lines, we attribute differences in assimilation to g_s as indicated in equation 1. Similarly, we expect differences in g_s to alter transpiration rates, as the driving gradient ($e^*_l - e_a$) was similar under standard measurement conditions. Under conditions of similar driving gradients, g_s accounted for differences in assimilation and is expected to account for the differences in transpiration.

However, when it comes to intrinsic transpiration efficiency, g_s disappears (equation 3). The ratio of stomatal conductances for CO_2 and $H_2$0 reduces to a constant (k) in our expression for intrinsic transpiration efficiency (nTE), similar to the result derived by Sinclair and Tanner (1983). Leaf internal CO_2, setting the driving gradient for assimilation, also drives nTE, as illustrated by the contrasting trends of PI 533946 and PI 257309.

The ratio of Ci/Ca observed in these studies (0.18 to 0.27 for all but three observations) was substantially less than that reported by Bunce (2005) for several C4 species (0.55), but near the lower range of values (0.27 to 0.50) reported for grain sorghum by Premachandra et al., (1994). We presume this indicates a greater degree of transpiration efficiency for these lines.

References

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