LEAF OSMOTIC POTENTIAL AND MORPHOLOGICAL TRAITS OF 43 COTTON VARIETIES GROWING IN A RAINFALL GRADIENT FROM SOUTHWEST TO CENTRAL TEXAS – AN UPDATE

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Abstract

Drought tolerance strongly influences the growth, development and production of cotton under both dryland and irrigated systems. With the rapid release of new cotton varieties, up-to-date information on the fundamental relations between leaf morpho-physiological traits and drought tolerance is needed for both cotton farmers and researchers. We measured leaf osmotic potential at full turgor and leaf dry matter content for 43 cotton varieties in southwest and central Texas and found that increased investment of carbon in leaf construction in cotton varieties grown under a dryland production regime were associated with an increased, not decreased, lint yield, which was in contrast to the trend displayed in the irrigated production regimes. This suggests that the relationship between drought tolerance leaf traits and lint yield in current cotton varieties is environment dependent. Specifically, for better yield performance, leaf osmotic potential and leaf dry matter content in cotton genotypes may be selected in different directions depending on whether the target environment is a dryland or irrigated production system.

Introduction

To produce one kilogram of dry matter, plants may lose several hundred kilograms of water through transpiration (Black, 1968). The high rate of water loss in daytime hours usually cannot be balanced by root water uptake, and this can lead to severe dehydration for plant leaves (Schulze et al. 1987). Plants rely on two main mechanisms to delay leaf wilting: one is to reduce osmotic potential by accumulating solutes in cells, and the other is to increase cell wall elasticity by increasing carbon investment in cell wall construction (Cheung et al., 1975; Robichaux et al. 1986). Both mechanisms are shown to be strongly correlated in natural vegetation (Monson & Smith, 1982; Dong & Zhang, 2001) and simple, rapid methods have been developed to estimate these parameters (Bartlett et al., 2012; Griffin-Nolan et al., 2019; Petruzzellis et al., 2019). However, data are relatively limited to characterize cultivated crop genotypes growing in water limited regions (Mart et al., 2016).

Cotton has a high capacity to survive and thrive in dry and hot environments. Yet, the growth, development and production of cotton plants is strongly influenced by drought stress under both dryland and irrigated systems. The objectives of this study are: first, to test the usefulness of leaf water relations traits to explain cotton yield performance under drought stress conditions; and second, to identify cotton varieties with superior drought tolerance capacity. The insights gained from this study are expected to be useful for cotton improvement.

Materials and Methods

The study was conducted in conjunction with Texas A&M AgriLife Extension RACE cotton trial. Six cotton fields from four locations in southwest to central Texas were selected for field sampling. The mean annual precipitation of the four locations (Crystal City, Uvalde, Lytle, and Taylor) varies from 21 to 35 inches. The cotton field in Taylor was under dryland production, and the remaining fields were under irrigated management in the 2020 and 2021 growing seasons. Forty-three cotton varieties were used in the study (Tables 1 and 2). Most of the varieties were from the RACE trial planted in Lytle and Taylor. Some of the varieties were also planted at the Uvalde Research Center, as well as producer’s fields in Uvalde and Crystal City. All the cotton fields were planted from mid- to late April, except the Uvalde Research Center field, which was planted on May 5, 2020. Leaf area growth from all fields was measured once every two weeks in both 2020 and 2021. The measurement was done non-destructively using an optical sensor (LI-2000 Canopy Analyzer).

Leaf samples were collected twice: first at the early bloom and second at the peak bloom stage in 2020 and at peak bloom and late bloom stage in 2021 (Figure 1). On each sampling, one leaf was cut off at the base of the petiole from the 4th node counting from the top of a representative plant. Then the petiole of the leaf was immediately submerged in distilled water in a bucket, while the leaf was exposed to the air. On the same day of leaf sampling, the collected leaves were stored in a laboratory over night with the top of the bucket covered with aluminum foil to maintain a high humidity condition in the interior of the bucket filled with leaves whose petioles were submerged in a thin layer of distilled water. The next day, water drops from the surfaces of the leaf was blotted using tissue paper and prepared for physiological measurement. One 8-mm leaf disc was punched off each of the sampled leaves, wrapped in aluminum foil, frozen in liquid nitrogen, and then stored at a -80 ºC freezer awaiting osmotic potential measurement. Immediately after punching, the leaf was measured for saturate mass and area, then dried at 65 ºC to measure dry mass. Leaf osmotic potential was measured using a 5520 VAPRO Vapor Pressure Osmometer following Bartlett et al. (2012). Leaf dry matter content (LDMC) was determined as the ratio of dry mass and saturate mass. On each sampling, three leaves were collected from each cotton variety. In 2020, a total of 924 leaves were collected for the measurement of cotton leaf traits. In this study, the measured leaf osmotic potential at full turgor was used as a proxy of leaf water potential at leaf turgor loss point (Bartlett et al/, 2012; Petruzzellis et al., 2019), and the measured leaf dry matter content was used to indicate the cell wall elastic properties.

Cotton yield was measured by harvesting the entire plots at Lytle (each plot 6 rows 1205 ft in 36-inch row spacing) and Taylor (6 rows 1050 ft in 38-inch row spacing). The Lytle site was harvested with a cotton picker whereas the Taylor site was harvested with a cotton stripper. At the Uvalde Center field, plots were hand harvested. Sub-samples of the plots were ginned on a 20 saw Centennial Gin for turnout and lint samples were then used to obtain fiber quality. Although fiber quality was measured, this paper will only focus on the relationship between lint yield and leaf water relations traits. Linear regression was employed to depict the relationship between cotton lint yield and water relations traits, and the slopes of different regression lines were compared using the procedure of the Generalized Linear Model (GLM). Analysis of Means (ANOM, ±=0.1) was used to compare differences in measured lint yield and water relations traits among cotton varieties. Data analysis was carried out using Minitab 17.

Table 1. A list of cotton varieties used in the study in 2020.

ID	Variety	Site	ID	Variety	Site	ID	Variety	Site
1	19R132 B3XF	T	16	DG 3421 B3XF	UR,T	31	NG 4936 B3XF	L, UR, T
2	19R237 B3XF	T	17	DG 3615 B3XF	L, UR	32	NG 5007 B2XF	UR
3	20R 734 B3XF	T	18	DP 1044 B2RF	UR	33	NG 5711 B3XF	U2
4	20R 741 B3XF	T	19	DP 1646 B2XF	L, UR, T	34	PHY 340 W3FE	UR
5	20R 743 B3XF	T	20	DP 1725 B2XF	UR	35	PHY 400 W3FE	L, T
6	20R 749 B3XF	T	21	DP 1820 B3XF	T	36	PHY 480 W3FE	L, UR
7	20R 750 B3XF	T	22	DP 1845 B3XF	T	37	ST 4550 GLTP	L, T
8	20R 752 B3XF	T	23	DP 1865 B3XF	C, U1	38	ST 4848 GLT	UR
9	BX 2116 GLTP	T	24	DP 1948 B3XF	T	39	ST 4949 GLT	UR
10	BX 2141 GLTP	T	25	DP 2020 B3XF	L, T	40	ST 4990 B3XF	L, UR, T
11	BX 2191 B3XF	T	26	DP 2044 B3XF	T	41	ST 5600 NR B2XF	T
12	BX 2192 B3XF	T	27	FM 1953 GLTP	UR	42	ST 5610 B3XF	T
13	BX 2193 B3XF	T	28	FM 2398 GLTP	T	43	ST 5707 B2XF	L, T
14	BX 2194 B3XF	T	29	FM 4480 B3XF	T			
15	CG 3885 B2XF	UR	30	NG 4098 B3XF	L, UR, T			

C-Crystal City; L-Lytle; T-Taylor; UR-Uvalde Research; U1-Uvalde farmer field #1; U2-Uvalde farmer field #2

Table 2. A list of cotton varieties used in the study in 2021.

ID	Variety	Site	ID	Variety	Site	ID	Variety	Site
1	DP 2012 B3XF	T	16	DG 3421 B3XF	UR	31	NG 4936 B3XF	L, UR, T
2	20R732 B3XF	T	17	DG 3615 B3XF	L, UR	32	NG 5007 B2XF	UR
3	20R 734 B3XF	T	18	DG 3402 B3XF	T	33	NG 5711 B3XF	U2
4	21R 739 B3XF	T	19	DP 1646 B2XF	L, UR, T	34	PHY 332 W3FE	L, UR, T
5	21R 626 B3XF	T	20	DP 1725 B2XF	UR	35	PHY 400 W3FE	L, T
6	21R 632 B3XF	T	21	H 959 B3XF	L, T	36	PHY 480 W3FE	UR
7	DP 1851 B3XF	T	22	DP 1845 B3XF	T	37	ST 4550 GLTP	T
8	DP 1845 B3XF	T	23	DP 1865 B3XF	C, U1	38	ST 4848 GLT	UR
9	NG 5150 B3XF	L	24	NG 5150 B3XF	L, T	39	ST 4949 GLT	UR
10	PHY340W3FE	UR	25	DP 2020 B3XF	L, T, UR	40	ST 4990 B3XF	UR, T

11	BX 2295 B3XF	T	26	FM 1730 GLTP	T	41	ST 5091 B3XF	T
12	BX 2296 B3XF	T	27	FM 1953 GLTP	UR	42	ST 4993 B3XF	T
13	BX 2297 B3XF	T	28	FM 2398 GLTP	T	43	ST 5707 B2XF	T
14	BX 2298 B3XF	T	29	FM 2498 GLTP	T			
15	CG 3885 B2XF	UR	30	NG 4098 B3XF	UR			

C-Crystal City; L-Lytle; T-Taylor; UR-Uvalde Research; U1-Uvalde farmer field #1 (UJ); U2-Uvalde farmer field #2 (UN)

Results and Discussion

As seen in Figure 2, the measured values of leaf osmotic potential at full turgor (LOPFT) and leaf dry matter content (LDMC) were strongly negatively correlated, but the values from the irrigated and dryland fields were described by different regression lines: LOPFT = – 0.139 – 6.451 LDMC (R^2=53.4%, Irrigated), LOPFT = –1.122 – 2.282 LDMC (R^2=8.2%, Dryland). The slopes of the two regression lines are highly significantly different ($p<0.0005$). This means that for the same values of osmotic potential, cotton leaves from dryland tended to invest more carbon in leaf construction than those from irrigated fields. From panels (A) and (B) of Figure 3, we can see that leaf osmotic potential was positively related to lint yield in irrigated, but not in dryland management in 2020. In panels (C) and (D) of Figure 3, we can see that dry matter content had positive, or marginally positive, linear relationship with lint yield in dryland fields in both sampling stages in 2020; however, the relationship for irrigated fields was significantly negative in the early bloom stage, but not in the peak bloom stage. This suggest that under dryland production, a high carbon investment

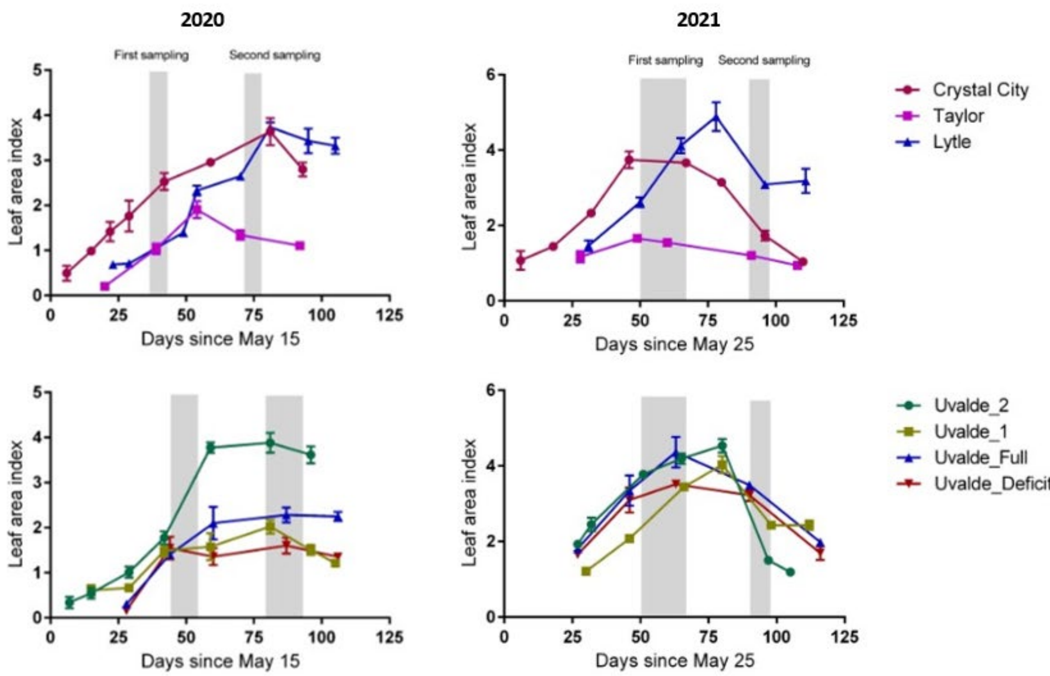

Figure 1. Seasonal trends of leaf area index measured at different cotton fields in the 2020 and 2021 growing seasons. Error bars indicate standard errors of the means (n = 3-5). The shaded bars indicate the first sampling and second sampling of cotton leaves used for leaf drought tolerance traits measurement.

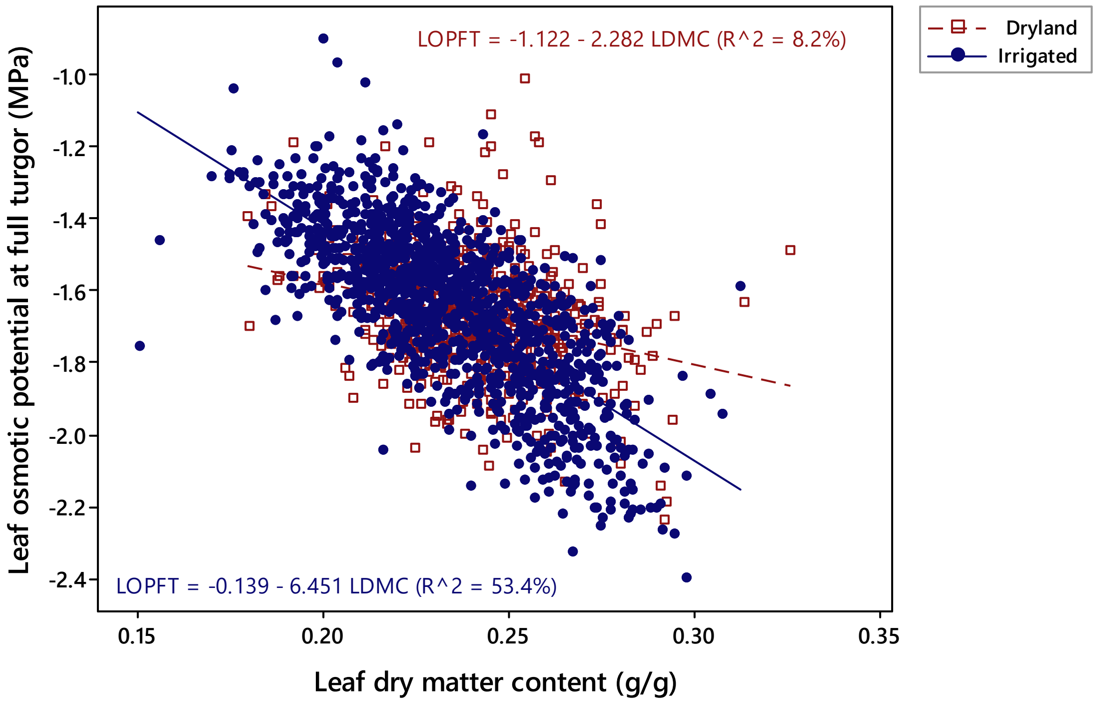

Figure 2. Relationship between leaf osmotic potential at full turgor (LOPFT) and leaf dry matter content (LDMC) for 1740 cotton leaves measured in 2020 and 2021.

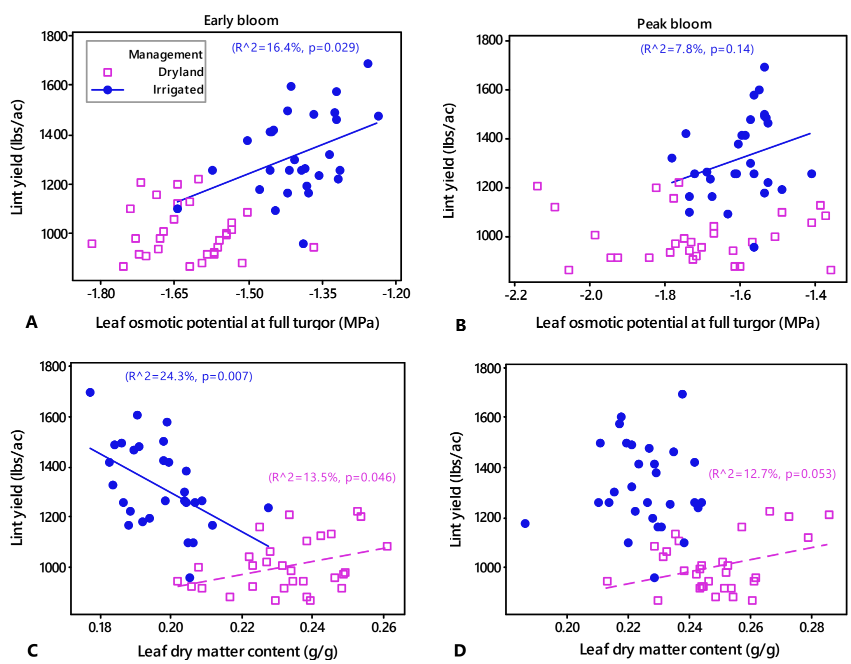

Figure 3. Relationships between cotton lint yield and leaf water relations traits under dryland and irrigated production regimes in 2020.

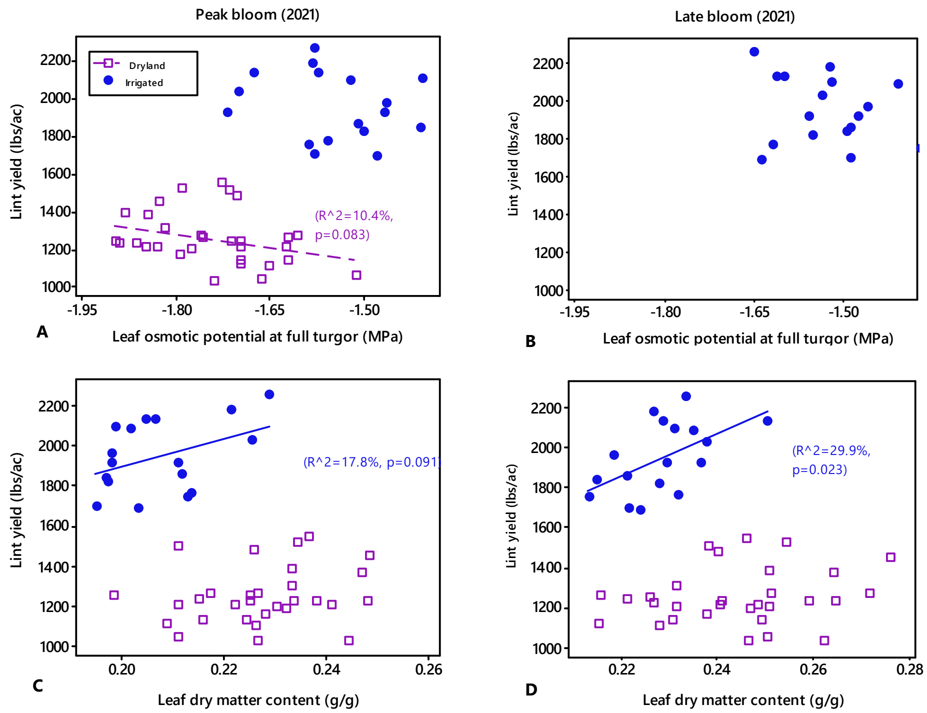

Figure 4. Relationships between cotton lint yield and leaf water relations traits under dryland and irrigated production regimes in 2021.

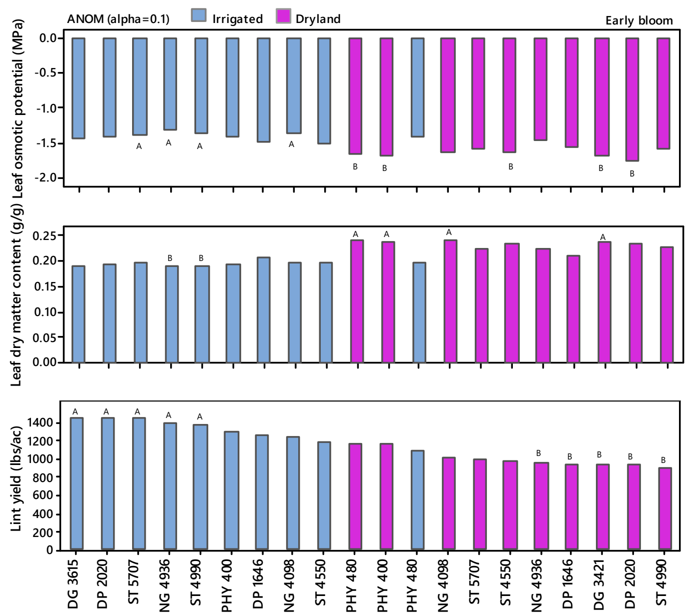

Figure 5. Leaf water relations traits and lint yield for 13 cotton varieties planted under dryland and irrigated production regimes in 2020.

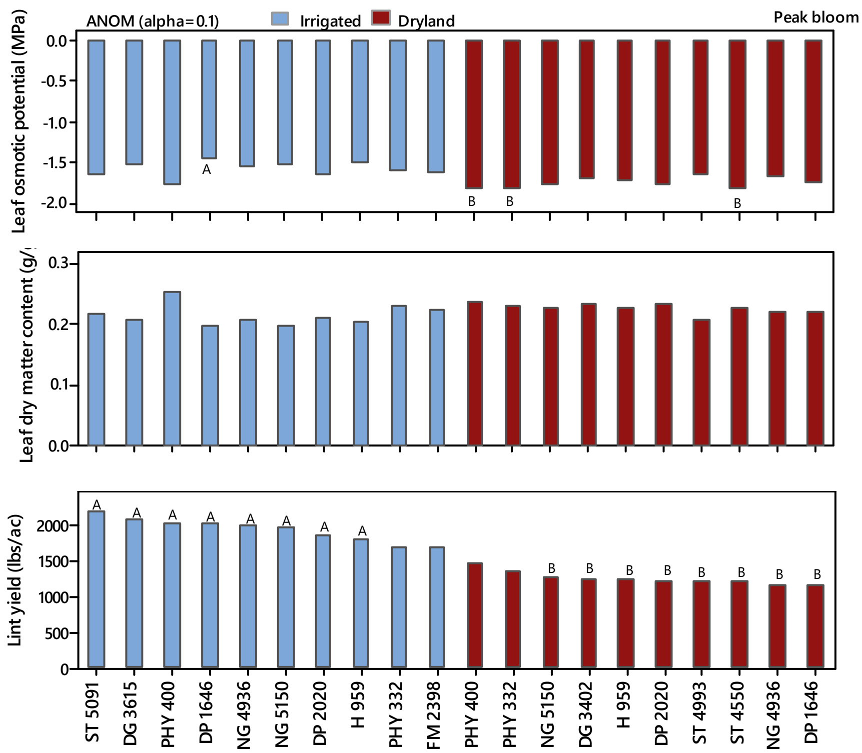

Figure 6. Leaf water relations traits and lint yield for eleven cotton varieties planted under dryland and irrigated production regimes in 2021.

in cotton leaves was associated with an increased lint yield, which is different from the situation of irrigated production.

In 2021, the results between lint yield and two leaf drought tolerance traits were different from those in 2020. As seen in Figure 4 panels of (A) and (B), the lint yield was not significantly related to leaf osmotic potential, except the marginal negative correlation found at the peak bloom stage for the dryland production. The correlation between lint yield and LDMC was only significantly in the irrigate production (Figure 4 panels (C) and (D)).

In Figure 5, the lint yields for 13 cotton varieties planted under irrigated and dryland fields in 2020 were ranked and compared using Analysis of Means (ANOM). Different capital letters indicate significant differences in lint yield from the mean yield. The data for leaf osmotic potential and dry matter content are also shown for the respective varieties. We can see that the lint yield for two PhytoGen varieties (PHY 400 and PHY 480) under dryland production was comparable with several varieties grown under irrigated management. These two PhytoGen varieties also had a lower osmotic potential and a higher leaf dry matter content, suggesting high drought tolerance. Five varieties (DG 3615, DP 2020, ST 5707, ST 4990, and NG 4936) displayed good performance under irrigated production, and ST 4990 and NG 4936 also showed leaf traits indicative of low drought tolerance and fast growth.

The similar relations in 2020 (in Figure 5) were also found in the data of 2021, as seen in Figure 6. While several varieties achieved high yields with low drought-tolerant and potentially fast-growing leaf traits under irrigated production, two PhytoGen varieties, PHY 400 and PHY 432, achieved a high yield under dryland production, along with more drought-tolerant leaf traits, such as a more negative osmotic potential. These results provide implications for cotton breeding aiming at improving drought tolerance.

Our data indicate that cotton varieties that showed good yield performance under irrigated production regime may not equally do well under dryland production, and vice versa, suggesting the existence of different mechanisms in the current cotton varieties for coping with water stress (Claeys & Inzé, 2013; Skirycz et al., 2011). Yet, different from the dichotomy of surviving vs. exploitive resource use strategy in natural vegetation (Dong & Zhang, 2001; Wright et al. 2004), in agricultural crops, the economic yield becomes an indispensable part of the trait-performance relationship.

Conclusions

Based on measured leaf water relations traits of 43 cotton varieties, we show that increased investment of carbon in leaf construction in cotton varieties growing under dryland production was associated with an increased lint yield, which was in contrast to the trend displayed in irrigated production regime. This suggests that the trait-yield relationship is environment-dependent. Specifically, for a better yield performance, leaf osmotic potential and leaf dry matter content in cotton genotypes may be selected in different directions depending on whether the target environment is dryland or irrigated production. Under dryland production, a higher leaf dry matter content appears to be important, while under irrigated production, a higher osmotic potential is an important trait to look for. We must note that there are inconsistences in the lint yield-leaf trait relationships found in 2020 and 2021. Additional data collected from multiple years are needed in order to obtain more conclusive results.

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