Maize phenotyping for drought adaptation: potential contribution of new physiological protocols

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Abstract

A proper phenotyping of critical secondary (i.e. other than yield) traits may speed maize breeding for drought conditions. One set of maize inbreds and another of hybrids were grown under three different water regimes: well irrigated and two different levels of water stress around flowering. Four different traits measured through the crop cycle were assessed: two of them, informing on the plant growth and senescence (vegetation index plus leaf chlorophyll content) and another two about the water status (leaf temperature and stomatal conductance). Under water stress conditions combination of one trait reporting on water status, plus another trait informing on the amount of green biomass - senescence contributed to explain a substantial portion of genotypic differences in grain yield. However for well irrigated conditions only traits related with green biomass – senescence were chosen and they explained far less of the genotypic differences in yield. .

Media summary

Proper phenotyping for secondary traits may help maize breeding for drought conditions

Key Words

Chlorophyll, grain yield, infrared thermometry, leaf temperature, NDVI, spectroradiometry, stomatal conductance,

Introduction

Drought is the main abiotic stress limiting maize productivity in tropical and subtropical regions. A proper phenotyping for critical traits other than the yield itself (which is the primary trait) may help to speed breeding advance. Beside different methodological requirements (low cost, easy to measure, etc) any secondary trait must to be genetically correlated with yield and to show heritability equal or larger than the yield itself (Bänziger et al. 2000). Plant water performance under drought, crop growth and leaf area duration are among the obvious secondary traits to search (Araus et al. 2002). Different techniques allow to measure in a fast and non destructive manner this kind of traits. For example growth and senescence may be assessed at the whole canopy level using vegetation indices such as the Normalized Difference Vegetation Index (NDVI) measured with an spectroradiometer (Aparicio et al. 2000; Araus et al. 2001). Senescence may be also evaluated at the leaf level using portable leaf meter as well. Water status of the leaves may be assessed indirectly by measuring leaf temperature (Sanguineti et al. 1999; O'Neill et al. 2006) and in a more direct way through the stomatal conductance measured with a low-cost fast leaf porometer (Sanguineti et al. 1999). This study reports on the combined use of these four characteristics assessing genotypic variability in inbreds and hybrids grown under different water regimes.

Methods

A set of 15 contrasting inbred lines from La Posta population, exhibiting a wide range of agronomical performance under drought while no differences in ASI, were grown during the 2007 dry season at Tlaltizapan (State of Morelos, Mexico). In addition another set of 18 single hybrids derived from the same population were also grown. Full irrigation (WW) and two different levels of water stress were assayed. Intermediate (IS) and severe (SS) water stress were imposed by stopping irrigation 2 weeks and 3-4 weeks prior anthesis, respectively, then resuming irrigating at around 50% anthesis for both SS and IS, and then just for IS irrigating two more times during grain filling. The ratio of total water input (rainfall plus irrigation) versus potential evapotranspiration for the whole crop season (December 2006 to April 2007) was 0.36, 0.62 and 1.62 for SS, IS and WW, respectively. Average maximum and minimum temperature during this period was 33.5 and 13.0 ºC, respectively. Crop growth and senescence was assessed using a vegetation index (NDVI) measured with a portable spectroradiometer and leaf senescence with a portable chlorophyll meter (SPAD). Plant water status was monitored by measuring leaf temperature (LT) and stomatal conductance (g_s), using an infrared thermometer and a porometer, respectively (Fig. 1). All four traits were measured several times through the crop cycle. The performance of these traits predicting genotypic differences in grain yield (GY) was assessed by principal component and multiple linear regression (stepwise) analyses. Heritabilities of these traits and their genetic correlations with yield were also calculated.

Figure 1. Different devices used in this study to evaluate plant growth, phenology and water status: Spectroradiometer with active sensor to measure NDVI (upper left), leaf chlorophyll meter (upper right), porometer to measure stomatal conductance (lower left) and infrared thermometer to measure leaf temperature (lower right).

Results

Traits performed differently depending on the trial growing conditions. Under stress, assessments during the second part of the crop cycle (from flowering onwards) of leaf and whole crop senescence (using SPAD and NDVI), measurements of stomatal conductance around flowering and canopy temperature all along the crop cycle were the best predictors of grain yield. Genotypes exhibiting higher late values of NDVI, SPAD and g_s and lower LT yielded the more (Fig. 2 left). Under well irrigated conditions high green biomass (NDVI) all along the crop cycle together with a delayed senescence (high SPAD values during flowering and grain filling) were associated with more grain yield (Fig. 2 right). Single measurements of LT, NDVI and SPAD explained in combination near 75% variability in GY among lines in the most stressed trial, while a combination of a single measurement of g_s and another of NDVI explained near 50% of genotypic differences in GY across hybrids also at SS (Table 1). At intermediate stress more than 50% of variability in GY was explained in the lines by g_s measured at two different times of the crop cycle, whereas for the hybrids it was the combination of SPAD and g_s. Under well watered conditions more than 70% of variability across lines was explained by the combination of single measurements of NDVI and SPAD, while for hybrids only a measurement of SPAD at flowering, which explained one third of the genotypic variability, was chosen in the analysis. Some measurements of these traits exhibited strong genetic correlation with grain yield and heritabilities larger than yield itself. The best performers were NDVI and SPAD in inbreds rather than in hybrids (data not shown). Methodological problems associated with measuring in very large canopies may explain the lesser performance of these traits in well watered hybrids. The above results support the use of these secondary traits to evaluate genotypic performance under drought.

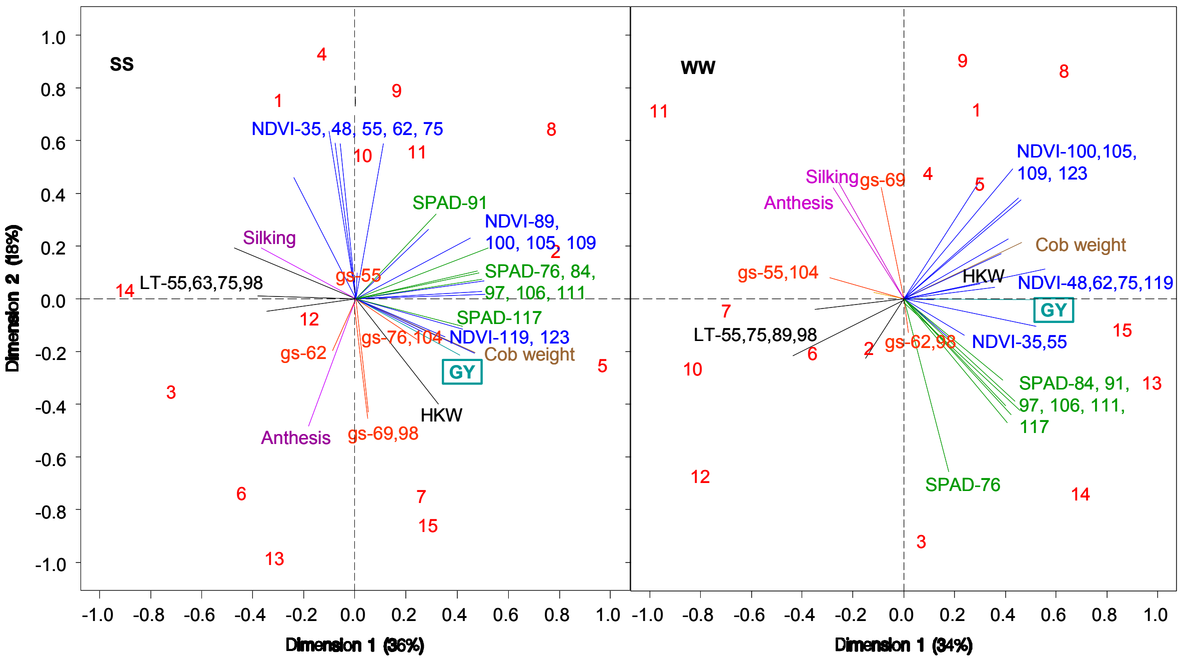

Figure 2. PCA analysis in maize lines (LPS) grown under WW, well-watered conditions, and SS, severe stress. GY, grain yield; g_s, stomatal conductance; LT, leaf temperature; NDVI, normalized difference vegetation index; SPAD, leaf chlorophyll,. SS, severe stress; WW well watered. Numbers following the trait acronyms (LT, g_s, NDVI and SPAD) refer to the days after sowing when measurements were performed.

Table 1. Multiple linear regressions (stepwise) to explain GY from physiological traits built from genotype means within each water treatment for both Lines and Hybrids.

	Water treatment	Initial Variable	Initial R^2	Initial MSE	Final Stepwise Model	Final R^2	Final MSE
Lines	SS	LT89	0.40**	78.5	GY = -28.3×LT89 + 4204.6×NDVI123 – 16.2×SPAD76 + 1068.8	0.73***	52.7
	IS	*gs*19	0.24*	180.3	GY = 4.2×*gs*19 + 4.5×*gs*104 – 1200.4	0.54**	141.3
	WW	NDVI109	0.48**	562.7	GY = 12198.9×NDVI109 + 105.6×SPAD106 - 9508.9	0.71**	417.4
Hybrids	SS	*gs*62	0.33*	157.8	GY = 2.9×*gs*62 + 2591.8×NDVI89 -2003.3	0.48*	138.6
	IS	SPAD91	0.32**	497.2	GY = 189.6× SPAD91 + 5.8×*gs*55 – 7505.7	0.53**	410.9
	WW	SPAD91	0.34**	931.8	GY = 230.7 × SPAD91 -1035.3	0.34**	931.8

SS, severe water stress; IS, intermediate water stress; WW, well-watered plants; Initial variable, first variable entering the model; Initial *R*2 and MSE, adjusted coefficient of determination (R^2) and mean square error after including the first variable in the model; final R^2 and MSE, adjusted R^2 and MSE obtained with the final stepwise model. GY, Grain yield; LT, Leaf temperature; *gs*, stomatal conductance; NDVI, Normalized Difference Vegetation Index; SPAD, Chlorophyll content measurement. Numbers following the name of each trait (LT, g_s, NDVI and SPAD) represent the data of measurement of each trait in days after sowing.
$^*P<0.05$, $^{**}P<0.01$, $^{***}P<0.001$.

Conclusions

The combination of at least two traits explains a substantial part of genotypic variability in grain yield. Nevertheless phenotypical traits perform poorer in large canopies and the traits chosen change with growing conditions. However some trends are evident. Thus under water stress conditions traits informing on both the water status plus the amount of green biomass - senescence contribute to explain genotypical differences in grain yield. Under well irrigated conditions only traits related with green biomass – senescence are chosen.

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