

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

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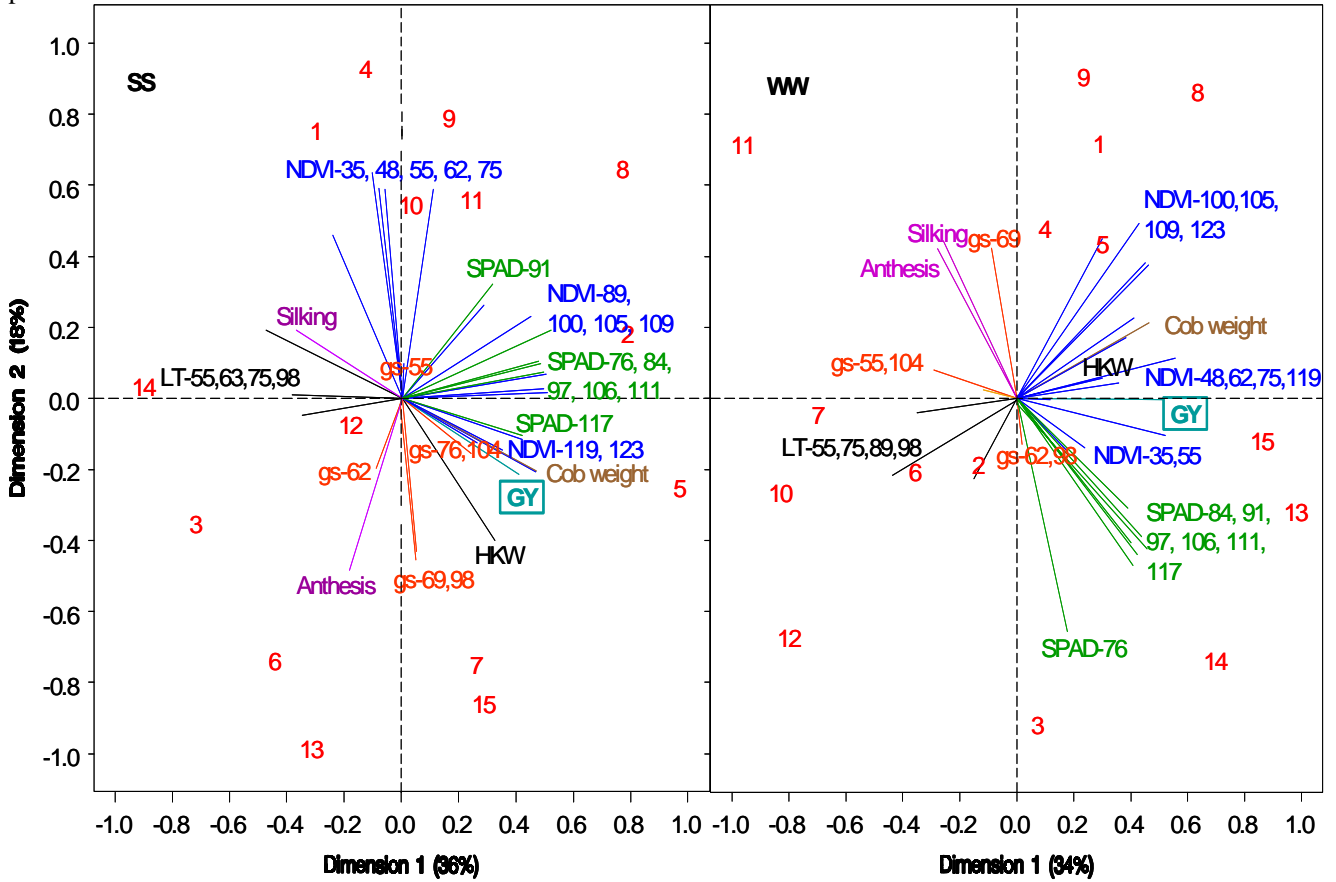
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Drought is the main abiotic stress limiting maize productivity in tropical and subtropical regions. A proper phenotyping may help to speed breeding advance. Plant water performance under drought, crop growth and leaf area duration are among the obvious secondary traits to search. 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 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, and irrigating once again at around 50% anthesis. Crop growth was assessed using a vegetation index (normalized difference 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 sensor and a porometer, respectively. 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.

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. 1 left). Under well irrigated conditions high biomass all along the crop cycle together with a low canopy temperature were associated with more grain yield (Fig. 1 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% genotypic differences in GY across hybrids (Table 1). Under 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. Methodological problems associated with measuring in very large canopies may explain the lesser performance of these traits in well watered hybrids. The above results along with the heritability of the traits and their genetic correlations with GY (data not shown) support the use of these secondary traits to evaluate genotypic performance under drought.

**Figure 1.** 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	
SS	LT89	0.40**	78.5	$GY = -28.3 \times LT89 + 4204.6 \times NDVI123 - 16.2 \times SPAD76 + 1068.8$	0.73***	52.7	
Lines	IS	$g_s19$	0.24*	180.3	$GY = 4.2 \times g_s19 + 4.5 \times g_s104 - 1200.4$	0.54**	141.3
WW	NDVI109	0.48**	562.7	$GY = 12198.9 \times NDVI109 + 105.6 \times SPAD106 - 9508.9$	0.71**	417.4	
SS	$g_s62$	0.33*	157.8	$GY = 2.9 \times g_s62 + 2591.8 \times NDVI89 - 2003.3$	0.48*	138.6	
Hybrids	IS	SPAD91	0.32**	497.2	$GY = 189.6 \times SPAD91 + 5.8 \times g_s55 - 7505.7$	0.53**	410.9
WW	SPAD91	0.34**	931.8	$GY = 230.7 \times SPAD91 - 1035.3$	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;  $g_s$ , 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.

\* $P < 0.05$ , \*\* $P < 0.01$ , \*\*\* $P < 0.001$ .