Drought

Drought Stress (left) and Non-stress (right) plots.
Note differences in plant height, width, and color between treatments

Due to the unpredictable nature of rainfall during the growing season, field screening of common bean for drought tolerance can be difficult as unpredictability reduces the efficiency of the selection program for drought tolerance. The amount and distribution of rainfall can vary between growing seasons, which results in stress during different stages of development of the bean plant. In general, low rainfall sites are selected where a reproducible stress occurs annually and evaluation sites with sandy soils that have a low water holding capacity can be used to increase the likelihood that the plants will experience water stress. The effect of soil heterogeneity or topography can increase drought stress and contributes to the uneven application of irrigation water (White and Singh, 1991). As a result breeders may choose indirect screening methods in the greenhouse or lab to reduce variability encountered in the field (Ludlow and Muchow, 1990).

Intermittent and terminal drought are the two distinct kinds of drought associated with limited rainfall that can be distinguished. Intermittent drought is due to climatic patterns of sporadic rainfall that causes intervals of drought and can occur at any time during the growing season (Schneider et al., 1997) or when farmers have the option of irrigation, but the supply is occasionally limited. In contrast, terminal drought occurs when plants suffer lack of water during later stages of reproductive growth or when crops are planted at the beginning of a dry season (Frahm et al., 2004). An example of terminal drought occurs when beans are planted during a short period of precipitation (Postrera or second planting in Honduras) or toward the end of the rainy season without the option of irrigation. In general, the lack of water interferes with the normal metabolism of the plant during flowering time and pod-fill, as these are stages when drought causes the greatest yield reduction. Intermittent drought usually occurs in highland regions, whereas terminal drought is a lowland phenomenon. It is important that breeders have clear assessment of the kind of drought that occurs in a particular production region, since the genotypic response and mechanisms to resist or tolerate terminal or intermittent drought can differ in beans. Breeders in the tropics can often take advantage of dry seasons to screen beans for drought resistance in the field. Supplemental irrigation can be used to manage the level and timing of the water stress. The drought stress imposed in the nursery should resemble the type of drought expected in the target environment.

The CIAT drought screening nurseries at Palmira, Colombia are grown with a single irrigation after planting to insure uniform germination. The bean plants in the nursery depend on residual soil moisture and sporadic rains (50-100 mm) during the remainder of the growing season (White and Singh, 1991). In drought screening trials conducted over a three-year period in Palmira, Singh (1995) provided bean plants with adequate moisture until flowering. After flowering, the water-stress plots received an average of 20 mm of water whereas the control plots received an average of 80 mm of water. In Honduras, Rosas et al. (1991) suspended irrigation before flowering in drought screening nurseries planted in the dry season. The control plots receive three additional irrigations for a total of 300 mm of water whereas the water stress treatment receives 200 mm of water during the growing season. The actual amount of water needed to produce stress varies greatly, since higher temperatures and coarse textured soils can aggravate drought stress. Bean plants receiving less than 400 mm of total precipitation would be considered to be under drought stress.

Bean breeders are most interested in drought resistance that involves performance not necessarily drought tolerance *per se*. Drought resistance is defined as relative yield of a genotype compared to other genotypes subjected to the same drought stress (Ramirez and Kelly, 1998; Subbarao et al., 1995). The direct measurement of seed yield is the most practical way to screen for drought resistance (Acosta-Gallegos and Adams, 1991; Terán and Singh, 2002; White and Singh, 1991). To reduce variability stress nurseries should have sufficient soil fertility so that root growth is not limited and attempts to control both root and foliar pathogens should be considered. Bean root health is an essential component in managing drought stress as root pathogens aggravate problems of water and nutrient acquisition by restricting root systems. Improving the levels of root rot resistance is a key element in the successful development of drought tolerance in beans. For example, *Macrophomina* is a major problem under conditions of terminal drought (Frahm et al., 2004), whereas *Rhizoctonia and Fusarium* are major root pathogens in the regions where intermittent drought occurs (Navarrete-Maya et al., 2002). Cultivars such as Pinto Villa with resistance to intermittent drought that occurs in the Mexican highlands are also recognized for resistance to root rot (Acosta et al. 1995), suggesting that selection for drought tolerance under local conditions may enhance root rot resistance. Likewise BAT 477 with resistance to terminal drought is also recognized as a source of resistance to *Macrophomina* (Olaya et al., 1996; Review, Miklas et al., 2005)

Since drought resistance is a quantitatively inherited performance based trait, selection needs to be practiced with advanced generation lines in replicated trials over years and locations (Schneider et al., 1997; White et al., 1994). Drought resistance can only be estimated by comparing the performance of breeding lines under stress and non-stress (irrigated) conditions. Using data from the two water treatments, breeders can calculate drought intensity index for the experiment and the different susceptibility indices and means to assist in selection of drought resistant genotypes.

The drought intensity index (DII) can be used to compare the stress between two or more experiments, the higher the value the greater the drought stress

$$DII= (1-Xs/Xi)$$ (Ramírez-Vallejo and Kelly, 1998)

where Xs is the mean experiment yield of all genotypes grown under stress, and Xi is the mean experiment yield of all genotypes grown under non-stress conditions. Values exceeding 0.7 would indicate severe drought.

Schneider et al. (1997) showed the geometric mean (GM) of seed yield to be the best predictor of bean genotype performance in stress and non-stress environments. They recommended a breeding strategy that involved genotypic selection based first on GM, followed by selection based on seed yield in the stress environment. The GM is calculated as follows:

$$GM = \sqrt{(Ys * Yi)}$$

where Ys is the mean seed yield of a line under drought stress and Yi is the mean seed yield of the line grown under non-stress. The square root of the product (Ys * Yi) from two treatments is used to calculate the GM for an individual genotype. The GM can be calculated for multiple locations. The geometric mean from three locations would be the cube root of the product of the means of the three environments (White and Singh, 1991). Ramírez-Vallejo and Kelly (1998) also concluded that the most effective approach to breed beans for resistance to drought would be based first on selection for high geometric mean seed yields followed by selection for low Fischer Maurer drought susceptibility index values. The Fischer and Maurer drought susceptibility index (DSI) is calculated as follows:

$$DSI=(1-Ys/Yi)/DII$$ (Fischer and Maurer, 1978)

Genotypes can be evaluated across locations and time using DSI index since the DII is calculated for every experiment. Caution in using this index is advised as certain genotypes with the lowest DSI rankings had the lowest overall yield potential (White and Singh, 1991). Small yield differences between the stress and non-stress treatments produce low DSI values even though the potential yield of the line is low (see numeral example below).

Possible misinterpretations in the selection of drought resistance genotypes

Genotype	Stress Value - Ys	Non-stress Value - Yi	Arithmetic mean	% Reduction	DSI Index*	Geometric mean (GM)
A	100	150	125	33	0.98	123
B	110	140	125	21	0.63	124
C	90	130	110	31	0.90	108
D	120	150	135	20	0.59	134¶
E	80	200	140*	60	1.76	126
F	50	60	55	17†	0.49‡	55
Mean	**91.7**	**138.3**	**115**	**30.3**	**0.89**	**111.7**

Drought Intensity Index for the experiment; DII= (1-Xs/Xi) = 0.34

* Arithmetic means are more influenced by high values for yield under non-stress and poor performance under stress.

† Low percent reduction between treatments but low yield under stress and non-stress conditions.

‡ Low DSI value but low yield under stress and non-stress conditions.

¶ Highest value and preferred genotype in this example. Stable and high yield under stress and non- stress conditions.

The effect of drought can vary when it occurs during different stages of development of the plant. In general, drought has the greatest impact on bean seed yield when it occurs during reproductive development. Morphological and phenological traits such as plant type, root systems and early flowering play a major role in adaptation on plants to specific drought conditions. For example the bean cultivar 'Pinto Villa' has broad adaptation and yield stability in the semiarid highlands of Mexico (intermittent drought) partially due to phenotypic plasticity and the ability to continue to fill seed at low night temperatures (Acosta-Gallegos et al., 1995). Beaver and Rosas (1995) found that selection for earlier flowering, a greater rate of partitioning and a shorter reproductive period permitted the selection of small red bean breeding lines having one week earlier maturity without sacrificing yield potential. Lines with earlier maturity would be less vulnerable to terminal drought, but caution needs to be exercised, as an association between early maturity and lower yields exists. Kelly (1998) suggested using differences in growth habit to indirectly select for root architecture as superficial root systems of type III genotypes are better suited to intermittent drought where as the deep tap root of type II genotypes sustains plants through short periods of drought by mining the lower soil profiles for moisture. The grouping of genotypes by maturity class and growth habit lowers the experimental error of trials under drought stress and the stronger the stress the higher the CV. Therefore, with trials under stress more replicates are needed.

Few studies have attempted to use a marker-assisted approach to breeding for drought resistance. Schneider et al. (1997) used marker-aided selection to increase drought resistance of a bean population grown in Michigan under severe water stress. However, marker-assisted selection (MAS) was ineffective in Mexico under moderate water stress. The effectiveness of MAS was found to be inversely proportional to the heritability of the trait under consideration.

Table 1. Sources of resistance to drought in different seed classes.

Name or number	Seed color / type	Reference
Negro Vizcaya, L88-63, B98311	9 / Black	Acosta et al. (2001), Frahm et al. (2003)
	1 / White	
SEA 5, SEA 10, SEA 13	2 / Cream	Singh et al. (2001)
Pinto Villa	2M / Pinto	Acosta-Gallegos et al. (1995)
Matterhorn	1 / Great Northern	Kelly et al. (1999)
	7 / Purple	
RAB 651, RAB 655	6 / Small red	CIAT, 2002
Viva, G 13637 (Apetito)	5 / Pink	
	2R / Cranberry	
San Cristobal 83, ICA Palmar	6M / Red mottled	White and Singh (1991), Rosales et al., 2004
	5K / Light red kidney	
	1 / Snap	
LEF 2RB, AC 1028	Miscellaneous	Schneider et al. (1997)


Beans intercropped with prickly pear cactus in Mexico

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