Assessment of Drought Tolerance in Dry Bean Cultivars Under Dryland and Irrigated Conditions in the Northern Plains

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Abstract

One of the main limitations for dry bean (*Phaseolus vulgaris* L.) production and other crops worldwide is water availability. In North Dakota for example, it is becoming more important given that dry bean production is being pushed from the fertile, non-irrigated Red River Valley located in the eastern part of the state, towards the central and western regions of the state, where drought stress frequently occurs. Most commercial cultivars show low tolerance to these adverse environments. Even more, there are few studies of drought tolerance of dry bean for this region. Over the past two decades, dry bean variety trials had been conducted at the Carrington Research and Extension Center (REC) under dryland and irrigated conditions simultaneously. This historic data gives the opportunity to obtain a preliminary assessment of how different cultivars and market classes of dry bean perform under drought conditions. Data from several studies show that dry bean grown under water stress conditions produced up to 60% less seed yield than those grown under non stress conditions. These differences are more dramatic if individual market classes are analyzed. Results showed that on average, seed yield can be reduced by 35%. Yields in black bean cultivars can be reduced as much as 36% under dryland compared to irrigated conditions followed by navy and pinto beans respectively. These results will help to design strategic plans towards the genetic improvement for drought tolerance in dry bean for the region.

Objectives

The main objective of this study was to assess the differences in seed yield due to drought stress within each one of the main market classes grown in the region (pinto, navy, and black). The second objective was to estimate the genetic gain and progress over time due to the use of improved dry bean cultivars.

Introduction

Drought stress is a limitation worldwide not only for dry bean production, but also for any crop, especially now when water resources are becoming more scarce (Muñoz-Perea et al., 2006). In 2006, for example, more than 60% of the country was abnormally dry or had drought conditions, including the Dakotas, Minnesota, Montana, and Wisconsin (MacPherson, 2006). The central and northern Great Plains of the USA. account for more than 70% of the total dry bean production in the country with North Dakota, Minnesota, Nebraska, and Colorado being the largest producers. Most commercial cultivars are showing low tolerance to these harsher environments. Declining ground water and diminished surface water supplies have exacerbated yield losses due to drought across the inter-mountain west and Great Plains over the past six years. In dry bean, reductions in seed yields can be as high as 90% depending on the cultivar and the severity of the drought (Ramirez-Vallejo and Kelly, 1998; Muñoz-Perea et al., 2006; Singh, 2007).

Dry bean is more sensitive to drought during pre-flowering and flowering stages causing excessive abortion of flowers, pods, and seed (Singh, 2007). The extent and duration of both intermittent and terminal drought stress in common bean are directly associated with yield and their effects are amplified by interactions with high temperature, disease, and soil type (Ramirez-Vallejo and Kelly, 1998). Genetic improvement of drought tolerance depends on effective methods for selection of superior genotypes and on the understanding of the genetics of the trait. In common bean, seed yield was found to be the most reliable measure of drought tolerance (Ramirez-Vallejo and Kelly, 1998).

In a two-year study conducted at three locations in Idaho under drought stress and non-stress conditions, the average seed yield reduction for all genotypes ranged between 32 to 88%; the mean seed yield of pink and red market classes were higher than the pinto and great northern (Singh, 2007). Muñoz-Perea et al. (2007) also reported that mean seed yield in the cultivars from the red market class was slightly higher than cultivars from the pinto market class. Among the pinto cultivars, Othello showed to be the most resistant to drought stress. In Nebraska, Urrea et al. (2007) reported yield reduction up to 48%. Their results showed that Matterhorn (great northern) had a 44% yield reduction whereas Bill-Z, a pinto bean, had 37% yield reduction. The drought intensity index (DII) and drought susceptibility index (DSI) gives estimates of the cultivar performance grown under drought conditions. DII values exceeding 0.7 usually indicate severe drought conditions. DII values of ~0.49 indicate moderate drought conditions. In Nebraska, DII was 0.9 and 0.8 for great northern and pinto bean, respectively (Urrea et al., 2007). Ramirez-Vallejo and Kelly (1998) reported a yield reduction from 22 to 71% in a study conducted in East Lansing, MI. The plant material studied included Sierra Pinto bean and Seafarer navy bean, as well as breeding lines adapted to the semiarid highland of Mexico. In 1998, DII was severe (0.78) and moderate in 1990 (0.63). There are no specific studies on drought tolerance for dry beans in North Dakota. However, most of the selection process made within the NDSU breeding program is on dryland conditions. Therefore, genes for drought tolerance are expected to be present in ND genotypes via indirect selection. The present study will contribute to understand the response of dry bean cultivars under drought stress in our region, and will also help to design future breeding strategies.

Table 1. Anova table of dry bean variety trials at Carrington REC across 24 years.

Source of variation	df	Type III SS	Mean square	F value	Pr > F
Year	23	30253714	1315379	1.11	0.4046
Conditions	1	30157427	30157427	25.45	<.0001
Year x Conditions	22	26070020	1185001	32.23	<.0001
Class	2	1014340	507170	13.79	<.0001
Class x Conditions	2	54214	27107	0.74	0.4814
Error	88	3235851	36771		

Materials and Methods

Dry bean variety trials have been conducted under dryland and irrigation conditions at the NDSU Carrington Research and Extension Center (REC) in North Dakota since 1981. This brings an excellent opportunity to look at a long-term trial under two conditions. Carrington (Foster county) represents the Central ND region, the new expansion of dry beans production, and an important region for certified seed production of dry bean. On every year, the field design was an RCBD with four replications. On average, 3 black, 7 navy, and 9 pinto varieties were included each year within the variety trials. Trials were planted at different fields with close proximity (<500 m) within Carrington REC through the years, according to crop rotation and similar soil type. Soil series at Carrington is a complex of coarse-loamy, mixed Udic and Pachic Udic Haploborolls. The seasonal (May-Sept.) average precipitation for that area is 327 mm.

To assess the effect of drought on yield, data from these trials for three market classes (black, navy, and pinto) was analyzed by market classes using the mean of each line planted on both conditions (dryland and irrigated) per year. Statistical analysis was conducted using proc GLM from SAS (SAS Institure Inc, 2004). Drought intensity index (DII), drought susceptibility index (DSI) and percentage reduction (PR) due to drought stress were calculated for each market class according to Fischer and Maurer (1978): $DII=[1-(Y_D/Y_I)]$, where Y_D and Y_I are the mean seed yield of all 3 market classes under dryland and irrigated conditions, respectively. $PR=[1-(Y_{Dm}/Y_{Img})\times100]$, where Y_{Dm} and Y_{Im} are the mean seed yields in dryland and irrigated respectively, for each market class. DSI=PR/DII.

Genetic gain was estimated according to Falconer and Mackay (1996), and using the broad-sense heritability (H) calculated from the ANOVA. In order to have a contrast, data from trials of the first 10 years and the last 10 years was used to estimate genetic gain. The first set would represent the earlier varieties from the 1980's, meanwhile the second set would contain modern varieties.

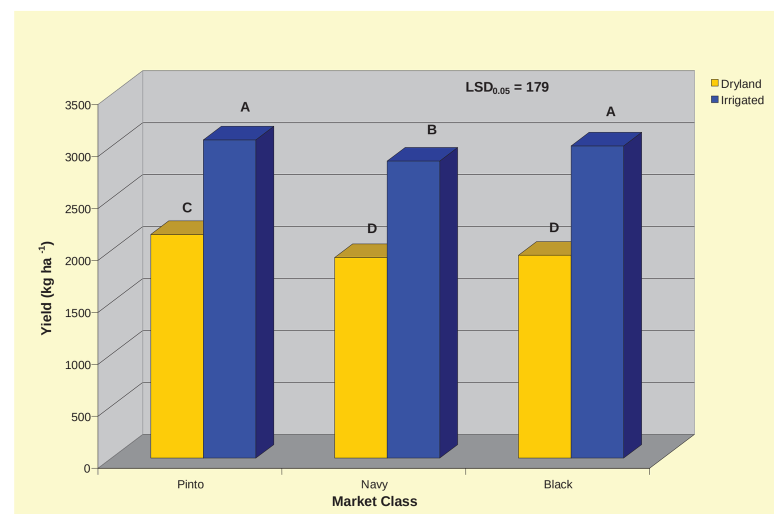

Figure 1. Mean yield of dry bean variety trials conducted at Carrington REC, classified by market class (pinto, navy, and black) in two conditions (dryland and irrigated), and averaged across 24 years.

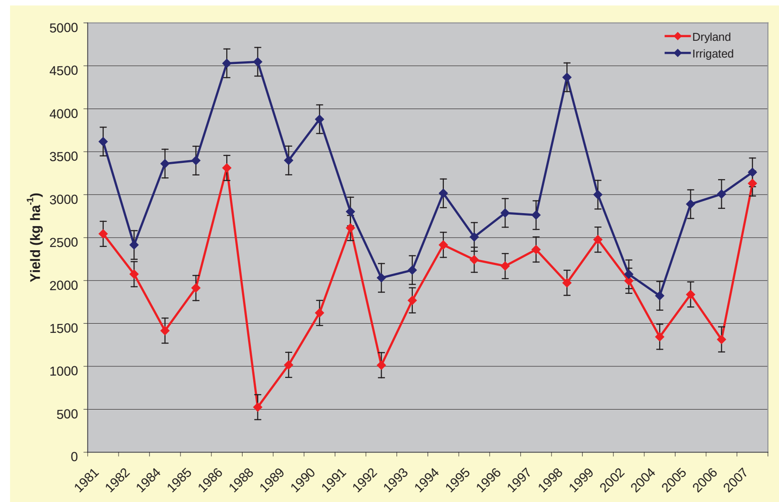

Figure 2. Dry bean seed yield grown under dryland and irrigated conditions from 24 years at Carrington REC.

Table 2. Drought intensity index (DII), drought susceptibility index (DSI), and percentage reduction (PR) due to drought stress calculated for each market class.

Market class	DII	PR	DSI
Black	0.30	35.0	1.09
Navy	0.32	32.5	1.01
Pinto	0.35	29.7	0.93

Table 3. Highest and lowest yielding cultivars within each market class under dryland conditions at Carrington REC.

Market class	Variety	Yield (kg ha^{-1})
Black	Black Knight	1842
Black	Eiben	2349
Navy	Seahawk	1146
Navy	Arthur	2719
Pinto	Rally	1513
Pinto	Lariat	3835

Table 4. Estimates of genetic gain (ΔG) for dryland conditions on two sets of varieties belonging to the first 10 years of trials (Early) versus the last 10 years (Modern), and grouped by market class.

Market Class	Cultivar group yield (kg ha^{-1})		ΔG† (kg ha^{-1})
	Early	Modern	
	-----------------------kg ha^{-1}	-----------------------	-----------------------
Pinto	1965.92	2240.72	137.40
Black	1760.15	2056.66	148.26
Navy	1688.46	1984.77	148.16
Mean	1804.84	2094.05	144.60

† $\Delta G = H(\mu_{Modern} - \mu_{Early})$, where H is the broad-sense heritability (0.50).

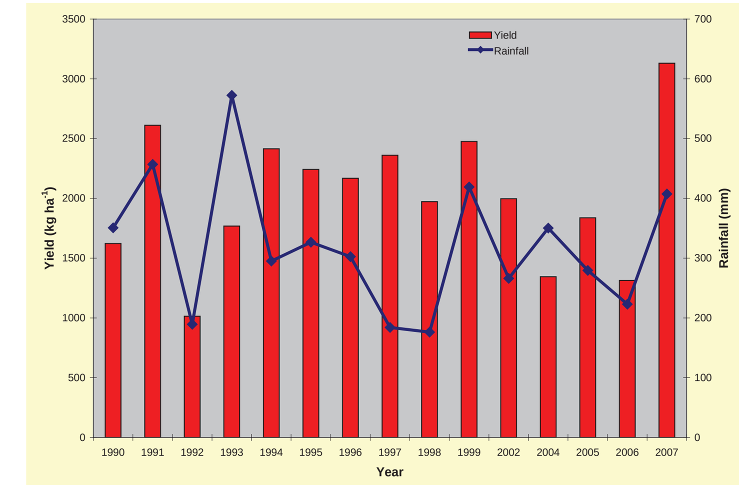

Figure 3. Comparison between mean seed yield and annual precipitation across market classes under dryland conditions at Carrington REC from 1990 to 2007.

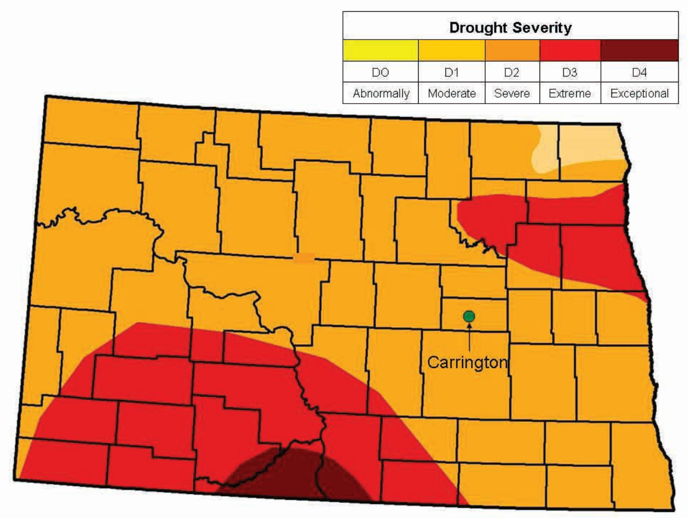

Figure 4. Drought severity map of North Dakota during the second week of August 2006
Source: Drought Monitor. http://drought.unl.edu/dm/

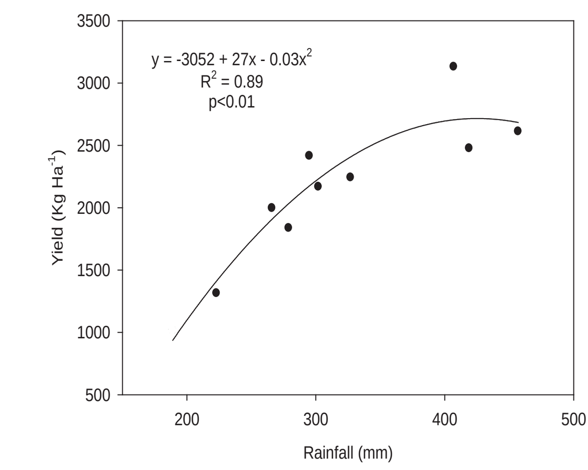

Fig 5: Relation between yield and rainfall in dryland conditions (market class combined)

Results and Discussion

Significant differences were found between stress condition (irrigated or dryland), market class, and the year x condition interaction (Table 1). Triple and quadruple interactions were not significant (data not shown). Results showed that depending on stress conditions, yield can be reduced up to 35.3% (1082 kg ha^{-1}) across all three market classes (data not shown). Black beans were the most affected by drought stress with a yield reduction of 36.3% (1131 kg ha^{-1}), followed by navy and pinto beans with reductions of 35.5 and 32.4% (1045 and 1012.6 kg ha^{-1}), respectively (Figure 1). Data shows that among the three market classes, pinto beans resulted to be the less affected by drought stress. These results were expected since pinto beans belong to the race Durango, which has been previously reported as tolerant to drought due to the environmental conditions of its geographic origin (Brick and Grafton, 1999). Dry bean genotypes belonging to the race Durango are usually more adapted to drought conditions than those belonging to other races. Pintos, great northerns, as well as North American reds and pinks belong to this race. On the other hand, navy and black beans belong to the Mesoamerican race. Race Durango was domesticated in the semiarid and arid northern highlands in Mexico (Brick and Grafton, 1999). Dry beans that belong to the race Durango have dark and small leaves and most of the time does not produce any guides. Lower internodes are short and provide good ground cover, helping to reduce evapotranspiration and conserving soil moisture. These characteristics will increase tissue water-retention capacity and facilitate the seed filling for a longer period of time (Muñoz-Perea et al., 2006; Singh, 2007). Results showed that black and navy beans are more sensitive to drought; this is expected since they belong to race Mesoamerica, which have been reported to be more sensitive to drought compared to Durango race (Muñoz-Perea et al., Singh, 2007). Differences in yield among years can be also attributed to other factors, such as disease pressure, changes on fertility, temperatures, and distribution of precipitation during the growing season (Figure 2). As expected, a good correlation was observed between rainfall and yield under dryland conditions. In some years, even with an adequate rainfall, varieties did not perform as expected in dryland conditions. This can be explained in part by the distribution of rainfall across the season. In North Dakota, rainfall distribution is widely varied and it is not unusual to have heavy rain during the spring followed by long dry periods often resulting in drought stress during the critical periods (Figure 3). For example, during August of 2006, Carrington was under severe drought (Figure 4), which correlates very well with the low yields obtained on that year. Figure 5 shows a regression analysis, in which, 89% of the variation in seed yield can be explained by precipitation. After 400 mm of precipitation, yields reached a plateau; if rain feed increase, yield could decrease considerably. This may be due to an increase in disease pressure caused by excess of moisture around the plants.

Black beans showed the highest drought susceptibility index (1.09), followed by navy and pinto beans with index of 1.01 and 0.93, respectively (Table 2). The DII were lower than 0.4 for all market classes, which indicates that were grown under moderate drought conditions across years. Looking at each one of the lines included in the variety trials from 1998 through 2007 under dryland conditions, the highest yielding pinto variety was Lariat, meanwhile the pinto variety Rally obtained the lowest yield. For navy beans, Arthur was the top yielding variety during this period, and Seahawk was the lowest. In the case of black beans, Eiben obtained the highest yield and Black Knight yielded the lowest (Table 3).

Estimates of genetic gain showed an average yield increase of 145 kg ha^{-1} for all market classes (Table 4). However, ANOVA showed no significance between the two variety groups (first 10 years vs. last 10 years), which suggests that genetic progress to increase dry bean seed yield has been slow in the last 24 years. These results are contrasting with observations made in other crops such as corn and soybeans, among others. On the other hand, the small yield increase allow growers to obtain ~$100 more per ha (assuming $0.70 per kg).

Conclusions

- According to the historic data obtained at the Carrington REC, an average yield reduction of 35.3% (1067 kg ha^{-1}) was observed in all market classes due to drought stress.
- Significant differences were found among the pinto, navy, and black market classes analyzed in this study. Black bean was the most affected, with 36.3% (1131 kg ha^{-1}) yield reduction, followed by navy and pinto beans with reductions of 35.5 and 32.4% (1045 and 1013 kg ha^{-1}), respectively.
- Pinto bean was more adapted to drought conditions, being less affected by the lack of water availability, followed by navy and black beans.
- All three market classes fell into moderate drought conditions based on the DII, DSI, and PR values.
- Genetic gain for seed yield has been slow when compared to other crops. However, yield gains of 145 kg ha^{-1} on average have been attained.

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