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Characteristics Related to Yield of Dry Bean (*Phaseolus vulgaris* L.) Under Water Stress Conditions

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Abstract. **The lack of knowledge about characters related to seed yield in dry beans under water stress, has been a major barrier to yield stabilization. The only advance in basic yield potential under water stress has been through direct empirical selection for yield, without prior nomination of their component characteristics. In trying to determine those desired combinations of characters, Principal Factor Analyses were performed on 27 traits of 11 dry bean genotypes arranged as a two factor factorial in a split plot design, in Michigan in 1986. This research indicated that better drought adapted bean cultivars can be developed by considering the following groups of characters: 1) Vigor and development, accomplished by delayed flowering with a heavy and deeply penetrating root system, 2) High yield, achieved by producing a heavy biomass at maturity, 3) Heavy biomass at anthesis, attributable to heavy stems, and 4) Sensitive stomata combined with the ability of the plant to increase root growth.**

Abstracto. **La carencia de conocimiento acerca de las caracteristicas relacionadas con el redimiento de grano en frijol bajo condiciones de stress de agua, ha sido una barrera grande en la estabilzación de el rendimiento. El unico avance en el potencial del rendimiento básico bajo stress de agua ha sido a través de selección empírica y directa por rendimiento, sin una anterior nominación de sus caracteres componentes. Tratando de determinar esa deseada combinación de caracteres, se llevaron a cabo Análisis de Factores Principales sobre 27 caracteristicas de 11 genotipos de frijol, arreglados en un factorial de dos factores en un diseño de parcelas divididas, en Michigan en 1986. Esta investigación indicó que cultivares de frijol mejor adaptados a sequía pueden ser desarrollados considerando los siguientes grupos de caracteres: 1) Vigor y desarrollo, establecido por una floración retrasada y un sistema radical pesado, profundo y penetrante, 2) Alto rendimiento, logrado produciendo una pesada biomasa en madurez, 3) Biomasa pesada al inicio de floración, atribuible a tallos pesados y 4) Estomas sensitivos combinados con la habilidad de la planta a incrementar el crecimiento radical.**

There has been little breeding or direct selection for specific drought resistant characters because the beneficial characters in stress environments have not been identified in dry beans. The purpose of the present investigation was to identify characteristics in a set of dry bean genotypes which relate to seed yield under water stress occurring during flowering and seed filling, these are the two most sensitive stages of plant development in dry beans (Robins and Domingo, 1956), snap beans (Millar and Gardner, 1972), soybeans (Sionit and Kramer, 1977), broad beans (El Nadi, 1969) and cowpeas (Turk et. al., 1980).

Materials and Methods

The trial was carried out at the Montcalm Research Farm, in Montcalm County, Michigan, during 1986. Eleven genotypes of dry beans of diverse origin and plant characteristics were grown; C20, Black Magic, N81017, LEF-2-RB, B76001, II-900-5-M, BAT-85, A-195, N80068, B82008 and San Juan Sel.

Water stress was created by covering the area with plastic 15 days before anthesis, and by permanently terminating irrigation. Irrigated treatments were well-watered. Rainfall and irrigation were recorded during the course of the experiment.

Data was collected on twenty seven traits during the growing season (Table 1). Six of the eleven genotypes were selected for detailed measurement; LEF-2-RB, B76001, II-900-5-M, BAT-85, N80068 and B82008. This selection was based on previous information regarding water stress tolerance. Stomatal resistance and water potential (ventilated diffusion porometer and pressure chamber (Fischer et. al., 1977), were taken at the end of bloom, on the 66th and 67th day after planting. Leaf water potential was taken in two days, on four plants, two plants per plot per day, between 11:00 AM and 3:00 PM, on completely developed trifoliate leaves from the top part of each plant. This measurement was done immediately after the stomatal resistance reading had been recorded.

The experimental units were arranged as a two factor factorial in a split plot design with two replications and consisted of four row plots, 6 m long with rows 50 cm apart. Water stress and irrigated conditions were the whole plot factor, while genotypes the split plot factor. The experimental plots were planted in a deep sandy soil (Montcalm sandy loam). The center two rows of each plot, eliminating plants at the row edge, were used for sample collection and final harvest. Principal Factor Analysis (Catell, 1965), (Veldman, 1967), and Stepwise Regression Analysis (Draper and Smith, 1980) were used to analyze the data.

Results

Rainfall was not sufficient during critical morphological stages flowering and pod filling (Figure 1).

Stomatal Resistance. There was a statistically non-significant difference between stressed and irrigated treatments (8.15 sec/cm^{-1} stress and 3.72 sec/cm^{-1} irrigated), and a significant difference between genotypes. In the stressed treatment (Table 2), the genotypes LEF-2-RB, B76001 and II-900-5-M had the higher resistances, while lower resistances appeared for the genotypes BAT-85, N80068, and B82008. for the irrigated plants, the genotype LEF-2-RB had the highest resistance; while lower resistance appeared for the rest of the genotypes.

Water Potential. There was a significant difference between stressed (−8.91 bars) and irrigated (−6.49 bars) treatments with significant difference between genotypes, and a significant interaction between genotype and water treatment. Genotypes II-900-5-M and N80068 showed the lowest values in the stressed treatment (Table 3); while genotypes LEF-2-RB, B76001, BAT-85, and B82008 had higher values under stress. Under irrigation all genotypes showed higher water potential values, compared to the stressed ones.

Stepwise multiple regression analysis, water stress. According to the equation calculated by the multiple regression analysis for dependent variable grain yield, when the primary yield components, #14: # of seeds, #22: yield efficiency, #23: harvest index and #26: weight of seeds, were excluded from variables going into the model, the best model selected included nine variables and gave a R^2 value of 1. Three variables accounted for almost 99% of variance. These variables were: #25: biomass at maturity, #7: weight of roots at anthesis and #10: weight of leaves at maturity, in decreasing order of importance according to the magnitude of the R^2 value. Table 4.

Factor analysis, water stress. There were three factors with a contribution greater than 15% to the total variance (Table 5). The first factor accounted for 30.79% of the total variation, after rotation. The variables with the highest loadings in the first factor were: #11: weight of roots at maturity and #1: days to anthesis. The variables with the highest negative loadings in this factor were #21: leaf/stem ratio at maturity and #19: top/root ratio at maturity. This is essentially a vigor (strength shown in development) and development (growth to become into a more complete state) factor. The second factor accounted for 19.89% of the total variation, after rotation. This factor was highly associated with #22: yield effficiency, #25: biomass at maturity and #15: grain yield. Consequently, this factor was named yield, because it identified itself with known yield characters. The third factor accounted for 16.01% of the total variation, after rotation. This factor was

Table 1. Measured and calculated characteristics and methods of measurement.

1: Days to anthesis, when 50% of the plants had one open flower.
2: Days to end bloom, 50% of the plants without flowers.
3: Days to physiological maturity, when one pod had a mature color on 50% of the plants.
4: Days to harvesting.
5: Dry weight of stems at anthesis, using 1m sample.
6: Dry weight of leaves at anthesis, using 1m sample.
7: Dry weight of roots at anthesis, using 1m sample.
8: IKI test in roots at anthesis. Using starch indicator solution (Adams et. al., 1978) made by using 0.3g iodine and 1.5 potassium iodide in 100 ml water. Treating freshly cut root tissues with IKI and visually ranking the briliant blue color development, the amount of starch was rated on a five-point scale, 1(least) to 5(most).
9: Dry weight of stems at maturity, using 1m sample.
10: Dry weight of leaves at maturity, using 1m sample.
11: Dry weight of roots at maturity, using 1m sample.
12: Dry weight of pod walls.
13: IKI test in roots at maturity.
14: Number of seeds in 20 pods, at harvesting time.
15: Grain yield, using one 5m length row.
16: Duration of flowering; difference between anthesis and end bloom.
17: Duration of seed filling; difference between beginning seed filling and physiological maturity.
18: Top/root ratio at anthesis; stems plus leaves divided by roots at beginning bloom.
19: Top/root ratio at maturity; stems plus leaves plus pods divided by roots at physiological maturity.
20: Leaf/stem ratio at anthesis; leaves divided by stems at beginning bloom.
21: Leaf/stem ratio at maturity; leaves divided by stems at physiological maturity.
22: Yield efficiency, grain yield in g/square m/day.
23: Harvest index, economic yield divided by biological yield.
24: Biomass at anthesis; leaves plus stems plus roots at beginning bloom.
25: Biomass at maturity; leaves plus stems plus roots plus pods (including seeds) at physiological maturity.
26: Weight of 100 seeds in grams.
27: Leaf growth rate in square cm, calculation by $a = .624 + .583(lxw)$; using length and width leaf.

Table 2. Analysis of variance for stomatal resistance of six dry bean genotypes grown under water stress and irrigation. Montcalm, 1986.

SOURCE	DF	M.S.
Replication	1	7.809
Water treatment	1	117.572
Error a	1	20.925
Genotype	5	30.047 **
Interaction	5	13.543
Error b	10	8.414

** Significant at $P \leqq 0.05$

MEAN STOMATAL RESISTANCE AS MEASURED WITH (sec/cm^{-1})

GENOTYPES	Signif. difference at $P \leqq 0.05$	
	STRESS	IRRIGATED
LEF-2-RB	11.66	7.20
B76001	12.45	3.90
II-900-5-M	11.61	2.52
BAT-85	6.18	4.09
N80068	4.43	2.15
B82008	2.60	2.51

**LSD at $P \leqq 0.05 = 18.49$

Table 3. Analysis of variance for water potential of six dry bean genotypes grown under water stress and irrigation. Montcalm, 1986.

SOURCE	DF	M.S.
Replication	1	0.602
Water treatment	1	26.042 *
Error a	1	0.282
Genotype	5	3.693 **
Interaction	5	5.973 ***
Error b	10	1.069

* Significant at $P \leqq 0.06$
** Significant at $P \leqq 0.05$
***Significant at $P \leqq 0.01$

MEAN XYLEM WATER POTENTIAL AS MEASURED WITH (−bars)

GENOTYPES	Significance at $P \leqq 0.05$	
	STRESS	IRRIGATED
LEF-2-RB	−8.10	−7.10
B76001	−8.90	−5.55 **
II-900-5-M	−10.80	−7.10 **
BAT-85	−7.70	−6.90
N80068	−10.40	−6.50 **
B82008	−7.60	−5.80

**LSD at $P \leqq 0.05 = 2.66$

highly associated with #24: biomass at anthesis and #5: weight of stems at anthesis. Therefore, this factor was called biomass at anthesis.

Analysis of variance of the economic yield. The analysis of variance revealed a significant genotypic effect, a significant water effect, and an interaction between both factors (Table 6). Four of the eleven genotypes had a significant reduction of economic yield under water stress; Black Magic, N81017, LEF-2-RB, and San Juan Sel, while only one cultivar, A-195 had a significant increase, for this trait under stress. The other seven genotypes did not show any significant difference between treatments, even though there was reduced yield (Table 9).

Discussion

Stomatal resistance and water potential. With respect to stomatal resistance, the genotype LEF-2-RB did not show differences between water treatments, this indicates that its stomata remained partially opened under both conditions.

Table 4. Stepwise regression analysis of data under water stress with grain yield as dependent variable.

Variable		Partial Regr. Coeff. (b)	F	Partial R^2
Intercept		−3.697		
#25:Biomass Maturity		0.696	486.42	0.9121
#7:Roots Anthesis		−1.741	28.27	0.0517
#10:Leaves Maturity		−0.344	13.48	0.238
Source	**DF**	**Mean Square**	**F**	
Regression	3	9168.78	186.56 **	
Error	7	49.14		
$R^2=0.9876$				

Table 5. Factor analysis results: water stress conditions.

	Rotated Factors		
Traits	1	2	3
1	**.8662**	.3765	−.1046
2	.6928	.1254	−.4941
3	.7618	.4648	−.2380
4	.7618	.4814	−.2484
5	−.2064	−.0647	**.9360**
6	−.3813	.0701	.7881
7	.4405	.1909	.1167
8	−.5120	−.0303	.4206
9	.7476	.4457	−.1225
10	−.4895	.6131	.2169
11	**.8937**	.2204	−.1479
12	.4423	.7219	−.0453
13	.3669	.3906	−.3411
14	−.3320	−.0921	−.0406
15	.2615	**.9206**	−.0152
16	.3375	−.0933	−.6015
17	.6732	.4695	−.2900
18	−.5753	−.1749	.5482
19	−**.8532**	.2339	.3368
20	−.0008	.2802	−.2714
21	−**.8472**	.1742	.3197
22	−0.526	**.9643**	.0936
23	.1885	.4807	−.0700
24	−.1840	.0845	**.9404**
25	.2622	**.9369**	.205
26	.1291	.3046	.3501
27	.7593	.0630	−.0297
% Variance	30.79	19.89	16.01
Cum. % Var.	30.79	50.68	66.69

Table 7. Weight of roots (g/m^2) at anthesis of 11 dry bean genotypes under water stress and irrigation. Montcalm, 1986.

Entry No.	Identification	Irrigated	Stress
1	C20	29.1	27.5
2	Black Magic	41.1	24.6 *
3	N81017	54.1	39.6 *
4	LEF-2-RB	21.4	27.8
5	B76001	29.2	44.5 *
6	II-900-5-M	30.3	32.1
7	BAT-85	25.3	21.5
8	A-195	32.1	29.4
9	N80068	30.5	26.8
10	B82008	38.3	32.2
11	San Juan Sel	29.4	20.5
	Mean	32.8	29.6

* LSD at P=0.1≦14.0
** LSD at P=0.05≦17.0
*** LSD at P=0.01≦23.3
C.V.=27.29%

Table 6. Analysis of variance for seed yield of 11 dry bean genotypes under water stress and irrigation. Montcalm, 1986.

SOURCE	DF	M.S.
Replication	1	119.19
Water treatment	1	25129.46 **
Error a	01	0.01
Genotype	10	8063.94 **
Interaction	10	3295.73 *
Error b	20	1432.09

* Significant at P≦0.05
** Significant at P≦0.01
C.V.=15.59%

However, regarding water potential B76001 exhibited higher values than 11-900-5-M. This difference could be explained by considering other characters like root weight and top/root ratio; B76001 exhibited under water stress, a significant increase of root weight at anthesis (Table 7), and a significant decrease of top/root ratio at anthesis (Table 8). On the other hand, the genotype II-900-5-M exhibited under stress, a significant reduction of root weight at maturity (Table 9), and a significant increase of top/root ratio at maturity (Table 10), i.e., this genotype was not able to extend its root system into new areas of the soil that may have a higher potential of water.

Therefore, this genotype exhibited the expected high water potential value under irrigation, and low water potential under stress, indicating its inability to conserve water under conditions of high evaporative demand.

The stomatal resistance of the N80068 genotype did not show differences between water treatments, indicating that its stomata remained open under both water conditions.

In general, the result obtained under both conditions indicated that water potential and stomatal resistance of the bean plants were sensitive to differential moisture regimes. Under water stress, the plants had lower values for water potential, and higher values for stomatal resistance, indicating a higher resistance to gas exchange which caused a reduction in plant growth and yield, and to transpiration which would affect leaf temperature.

Stepwise multiple regression analysis, water stress. The positive loaded variable biomass at maturity which, according to the R^2 value, explained 91% of the total variance was the

Table 8. Top/root ratio at anthesis for 11 dry bean genotypes under water stress and irrigation. Montcalm, 1986.

Entry No.	Identification	Irrigated	Stress
1	C20	3.119	2.770
2	Black Magic	2.771	4.242
3	N81017	2.571	2.722
4	LEF-2-RB	6.263	5.045
5	B76001	5.057	2.885 *
6	II-900-5-M	3.486	2.695
7	BAT-85	5.876	6.127
8	A-195	4.450	3.781
9	N80068	2.554	2.646
10	B82008	3.646	3.390
11	San Juan Sel	6.356	6.369
	Mean	4.195	3.879

* LSD at $P \leqq 0.1 = 2.167$
** LSD at $P \leqq 0.05 = 3.109$
*** LSD at $P \leqq 0.01 = 8.703$
C.V. = 27.06%

Table 9. Weight of roots (g/m^2) at physiological maturity of 11 dry bean genotypes under water stress and irrigation. Montcalm, 1986.

Entry No.	Identification	Irrigated	Stress
1	C20	19.4	17.3
2	Black Magic	22.3	17.2
3	N81017	24.0	26.6
4	LEF-2-RB	12.4	10.6
5	B76001	20.4	18.8
6	II-900-5-M	22.3	16.3 *
7	BAT-85	7.3	7.5
8	A-195	31.5	30.3
9	N80068	24.2	21.9
10	B82008	20.5	16.8
11	San Juan Sel	8.7	7.8
	Mean	19.3	17.3

* LSD at $P \leqq 0.1 = 5.2$
** LSD at $P \leqq 0.05 = 7.6$
*** LSD at $P \leqq 0.01 = 22.03$
C.V. = 12.78%

most important variable. This is interpreted to mean that successful bean production under water stress depends on plants which are able to effectively exploit photosynthesis in order to render a greater part of their biological yield as grain.

However, under irrigation its stomatal resistance was the highest among all the genotypes, but is was lower when compared to the one shown by itself under water stress, indicating a greater stomatal opening under irrigation. LEF-2-RB was able to exhibit the expected high water potential value, perhaps due to its ability to increase its stomatal resistance avoiding water loss during stress conditions.

With respect to the stomatal resistance of genotypes B76001 and II-900-5-M, they showed differences between water treatments, this indicates that these genotypes possess stomata sensitive enough to permit opening when water is abundant, and closing under high evaporative demand.

Factor analysis, water stress. The first factor, vigor and development, is so called because the development of the plant is reflected by the positive loading of days to anthesis (length of the vegetative cycle). Plant vigor is reflected by the negative loading of leaf/stem ratio at maturity, the positive loading of root weight at maturity, and by the negative loading of the top/root ratio at maturity. This indicates that because of the lack of soil moisture, it is important for the plant to develop a heavy dense penetrating root system to absorb adequate water from a greater volume of soil, or to extract water within a particular volume of soil more efficiently.

An explanation for the importance of the length of the vegetative cycle is that roots require assimilates from the shoot, while the shoot requires water and nutrients from the root system. A long vegetative cycle results in more total $C0_2$ fixed during growth, cycle, and this provides the required

Table 10. Top/root ratio at physiological maturity of 11 dry bean genotypes under water stress and irrigation. Montcalm, 1986.

Entry No.	Identification	Irrigated	Stress
1	C20	19.833	19.286
2	Black Magic	22.799	21.074
3	N81017	23.443	13.746 *
4	LEF-2-RB	57.125	51.710
5	B76001	22.193	23.461
6	II-900-5-M	21.497	31.983 *
7	BAT-85	60.929	46.126 **
8	A-195	15.801	17.992
9	N80068	24.470	20.453
10	B82008	25.748	23.543
11	San Juan Sel	68.383	41.968 **
	Mean	32.929	28.303

* LSD at P=0.1≦9.681
** LSD at P=0.05≦14.751
*** LSD at P=0.01≦47.959
C.V.=12.67%

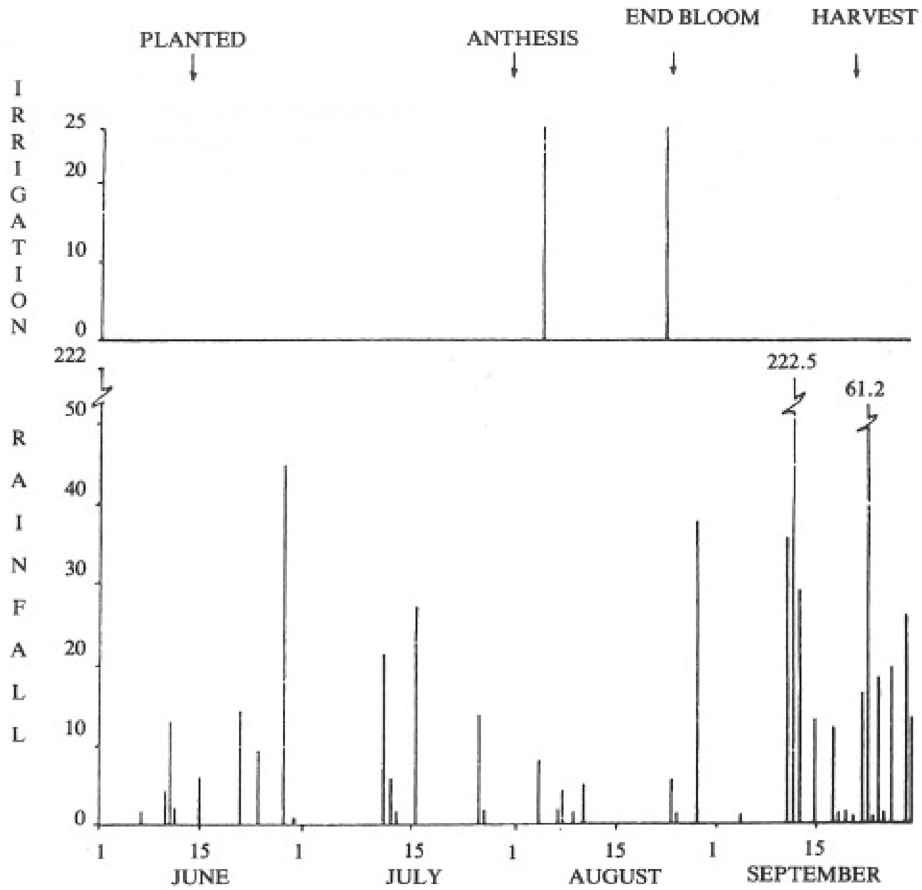

FIGURE #1. SUMMARY OF THE RAINFALL AND IRRIGATION (mm) FOR THE 1986 GROWING SEASON AT THE MONTCALM RESEARCH FARM.

assimilates to grow a well developed root system, and therefore, a vigorous and well developed plant.

The second factor, called yield, identified itself with yield characters: yield efficiency, biomass at physiological maturity, and grain yield. Any factor affecting photosynthetic activity is likely to affect its total dry matter content (biomass), and within broad limits, grain production.

Thus, high yielding genotypes are based on an effective exploitation of photosynthesis to translocate a great part of their heavy biomass at maturity, to grain. Increasing biomass at physiological maturity, would be the recommended way to increase grain yield under water stress. The combination of both characters require the maintenance of a high harvest index if yield increase is to be achieved.

The third factor, biomass at anthesis, its importance rests in part, upon the stem serving as a temporary storage site for assimilates which may be translocated to pods and seeds during the seed filling stage. During certain phases of development more assimilate is being produced than is being used in growth and development, and this excess, other than that portion lost in dark respiration or by leakage, can be directed to storage sites. During later phases (fruiting), when current photosynthesis is not able to furnish the assimilate requirements of yield sinks, storage compounds can be remobilized and moved to active sites, such as seed development. Therefore, reduced photosynthesis caused by water stress could be compensated for by enhanced translocation from the stem during the grain filling stage.

Conclusions

We can conclude that better adapted bean cultivars, under water stress imposed at the reproductive stage, can be developed by considering the following groups of plant characters: 1. Vigor and development, accomplished by delaying flowering, a heavy and deeply penetrating root system, and a high root/top ratio. 2. High yield, achieved by producing a heavy biomass at maturity. This combination results in a high harvest index. 3. Heavy biomass at anthesis, attributable mainly to heavy stems. 4. Sensitive stomata (able to close under drought), and the ability to increase root growth and decrease top/root ratio.

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