Root growth of ten dry bean genotypes in relation drought tolerance

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Introduction

Dry bean ***Phaseolus vulgaris L is*** one of the pulse crops currently being promoted in Saskatchewan (Slinkard and Vandenberg 1993). Bean production in the province frequently suffers from soil moisture deficits that restrict crop growth and development. Experience in the province has shown that pinto bean cultivars differ markedly in their ability to withstand drought. However, the mechanisms involved have not been investigated.

Crop genotypes with deep penetrating roots apparently undergo reduced drought stress under rainfed conditions through extraction of moisture from deeper in the soil profile (Jordan and Miller 1980, Passioura 1983). The potential for deep and extensive root growth as a mechanism of drought tolerance has not been investigated in dry bean under Saskatchewan conditions.

Therefore the objectives of this study were to:

1) screen ten pinto bean genotypes for differences in rooting pattern under limited soil moisture and

2) determine the relationship between rooting pattern and seed yield under field conditions.

Materials and Methods

Experiment 1

A plant growth container with a volume of $0.008m^3$ was constructed fi-om a one metre long and 10 cm diameter polyvinyl chloride (PVC) sewer pipe. The containers were cut longitudinally along one side, the cut taped shut and then placed upright in a pit one metre deep, located at Preston plots, University of Saskatchewan.

A growth medium consisting of 50% medium grain sand and 50 % top soil was used. The growth medium held about 7.5% moisture at field capacity. Each plant container was filled with the rooting medium and seeded with three seeds of one of the ten pinto bean genotypes. The genotypes (Othello, Agate, GH196-2, 6315, 5325, Earliray, Fiesta, ISB82-354, UI 111 and Nodak) were chosen to represent the pinto bean material with acceptable maturity in Saskatchewan.

All plant containers were watered to field capacity prior to seeding. After emergence, only 33 mm of water in 1994 and 35 mm of water in 1995 was applied when gravimetric moisture determination indicated moisture levels close to wilting point. A rainout shelter was erected on top of the pit to divert rainfall The treatments were arranged in a split-plot design with bean genotype as the main plot and stage of sampling as the subplot. Four replications were used.

One plant container of each bean genotype in each replication was pulled out at the unfolding of the third trifoliolate leaf (V4), the opening of the first flower (R6) and early pod formation (R8). Each tube was held open with small cylinders at the previously lengthwise cut surface and small soil samples for moisture determination taken at depths of 10, 20, 30, 40, 50, 60, 70 and 80 cm. The soil core samples were cut into successive 10 cm sections and removed. Plant roots were extracted by carefully washing away the rooting medium. Root length of each portion was estimated by a modified version of Newman's (1966) line intersect method (Tennant 1975). Root weight was determined after drying the root material at 60^0C for 48 hours. The experiment was conducted in the summer of 1994 and repeated again in the summer of 1995. The data were subjected to the analysis of variance (ANOVA). The root data collected at the V4 stage of plant growth in 1994 and 1995 were combined and analyzed together. The data collected at R6 and R8 were combined over both growth stage and years and analyzed together.

Experiment 2

Six of the ten bean genotypes used in the first experiment (three deep-rooted lines: Othello, Agate, GH196-2; and three shallow-rooted lines: Earliray, Fiesta and ISB82-3540 were grown in the field under rainfed and irrigated conditions at Saskatoon in 1994 and 1995. A randomized complete block design was used. The bean genotypes were seeded at 55 plants/m' in plots 2.4 m long by 1.2 m wide. Galvanized tin strips were placed around irrigated plots. In 1994 irrigation plots received 50 mm of water at early pod fill in addition to 3 13 mm of rainfall received by the rainfed plots, whereas in 1995 the irrigation plots received 75 mm of water between early flowering and early pod fill in addition to 195.1 mm of rainfall received by the rainfed plots. Seed yield was measured in 1.44 m^2 bordered plots. Root samples were taken at physiological maturity of the bean plants at intervals of 10 cm (4 samples per plot) to a depth of 60 cm. The data were analyzed using the analysis of variance (ANOVA).

Results Discussion

Experiment 1

Bean genotypes did not differ in root length or root weight at the third trifoliolate leaf stage and at later stages of plant growth. Roots were mainly concentrated in upper soil layers hence root weight decreased with depth in the soil profile at third trifoliolate leaf stage (Table 1). At the later stages of crop growth (R6 and R8 combined) roots had grown deeper in the soil profile making the depth effect for root weight non-significant (Table 2).

The genotype x depth interaction for root weight was significant at the V4 stage of crop development and at later stages primarily due to varying root weight among bean genotypes at different depths (Tables 1 and 2). Differences among genotypes were more observable at R6 and R8 stages of crop development (Table 2) when Othello, Agate, 6315, 5325 and UI 111 had root systems higher in root weight compared to Earliray, Fiesta, ISB82-54 and Nodak at depths below 70 cm. While root length followed similar trends to root weight, the genotype x depth interaction for root length was not significant (data not shown). The method used to estimate root length (Newman's intersect method) has a disadvantage of overestimating smaller samples and underestimating bigger samples. It is possible that the range of genotypic variation for rooting length was underestimated due to the weakness pointed above.

Moisture was heavily depleted to greater depths by the last sampling stage. Due to their extensive root systems, Othello, Agate and GH196-2 extracted more moisture at greater depths than Earliray, Fiesta and ISB82-354 (data not shown). This may indicate a potential mechanism of drought avoidance through deep root growth.

Thus no significant genotypic differences for mean root length or mean root dry weight were observed in this experiment. However, bean genotypes differed in the ability to extend roots to greater depths where moisture was still available.

Experiment 2

Irrigated plots significantly outyielded rainfed plots in both years (Table 3). In 1994 the seed yield increase was apparently due to increase in seed weight in irrigation plots whereas in 1995 the seed yield increase was due to increase in the number of pods produced by individual plants in irrigation plots. The water level by genotype interaction for seed yield was not significant in either year meaning that the ranking of the genotypes did not change with the change in water level. Thus, bean genotypes with superior seed yield in irrigated plots also showed superior seed yield in rainfed plots.

Bean genotypes did not differ in mean root length, in root length at O-30 cm depth and in total root length (Table 4). However, bean genotypes differed significantly in root length at the 40-60 cm depth (Table 4). At this particular depth the bean genotype Othello, had a significantly longer root system compared to the other five genotypes. In general bean genotypes which showed extensive root systems at great depths in the first experiment (ie. Othello, Agate and GH196-2 were high yielding when grown in the field (Table 4). Irrigation did not change the root length at any depth. The interaction between genotype and water level for root length was not significant (data not shown).

Summary

Significant genotypic differences in rooting pattern were observed in container-grown plants and in field-grown plants. Some genotypes had more extensive root systems at greater depth than others. Genotypes with extensive root systems at greater depths extracted more soil moisture at those depths compared to genotypes with less extensive root systems. This may indicate a potential for drought avoidance through deeper root growth.

When grown in the field bean genotypes which showed extensive root systems at greater depth were superior in seed yield. However, the rooting pattern of bean genotypes were the same under either irrigation or rainfed conditions. Possibly, the drought stress experienced by the crop was not severe enough to alter the rooting pattern of the plants in the field.

Table 1 Root weight (g) of the ten bean genotypes at the V4 stage of crop development (1994 and 1995 data were combined and analyzed together)

Genotype	Depth in cm							
	O-10	IO-20	20-30	30-40	40-50	50-60	60-70	70-80
	Root weight (g)							
Othello	0.212	0.079	0.067	0.07 1	0.055	0.048	0.033	0.000
Agate	0.240	0.067	0.060	0.061	0.056	0.045	0.008	0.000
GH 196-2	0.229	0.069	0.059	0.070	0.052	0.024	0.02 1	0.000
6315	0.196	0.065	0.062	0.064	0.056	0.035	0.012	0.000
5325	0.253	0.076	0.069	0.073	0.07 1	0.030	0.006	0.000
Earliray	0.256	0.08 1	0.079	0.072	0.063	0.024	0.002	0.000
Fiesta	0.229	0.090	0.079	0.068	0.055	0.027	0.000	0.000
ISB82-354	0.256	0.060	0.090	0.066	0.048	0.014	0.000	0.000
UI 111	0.248	0.080	0.073	0.064	0.041	0.022	0.004	0.000
Nodak	0.190	0.057	0.068	0.058	0.040	0.017	0.002	0.000
Mean	**0.231**	**0.072**	**0.071**	**0.067**	**0.054**	**0.029**	**0.010**	**0.000**

Comparing	**S.E.(diff)**	**L.S.D.(0.05)**
' h o depths	**0.018**	**0.068**
Two depths for same genotype	**0.012**	**0.018**
Two genotypes at same depth	**0.025**	**0.041**

Table 2 Root weight(g) of the ten bean genotypes averaged over the R6 and R8 stages of bean plant development, (1994 and 1995 data were combined and analyzed together)

Genotype	Depth in cm: 0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80
	Root weight (g)							
Othello	**0.296**	**0.081**	0.058	0.066	0.066	0.070	0.068	0.091
Agate	0.319	0.081	0.070	0.070	0.073	0.060	0.054	0.078
GH196-2	0.285	0.079	0.069	0.069	0.060	0.061	0.053	0.079
6315	0.331	0.098	0.067	0.073	0.078	0.073	0.065	0.062
5325	0.347	0.084	0.080	0.082	0.076	0.071	0.063	0.075
Earliray	0.258	0.077	0.071	0.075	0.069	0.060	0.041	0.043
Fiesta	0.288	0.074	0.064	0.070	0.068	0.070	0.058	0.036
ISB82-254	0.265	0.062	0.057	0.061	0.059	0.056	0.059	0.028
UI 111	0.341	0.074	0.060	0.060	0.058	0.063	0.053	0.068
Nodak	0.208	0.062	0.055	0.061	0.064	0.055	0.047	0.042
Mean	0.293	0.077	0.065	0.069	0.067	0.064	0.054	0.059

Comparing	S.E.(diff)	L.S.D.(0.05)
Two depths	**0.020**	**0.089**
Two depths for same genotype	**0.013**	**0.019**
Two genotypes at same depth	**0.017**	**0.028**

Table 3 Effect of water level on yield components and seed yield of six bean genotypes grown in the field in 1994 and 1995

Treatment	Days to Maturity	Plant height (cm)	Number of pods/ plant	Number of seeds /pod	Biomass (g)	100 seed weight (g)	Seed yield (kg/ha)
1994							
Rainfed	88	53	4	3	800	31.1	1625
Irrigation	89	54	4	3	930	34.1	1856
Mean	**88.5**	**533.5**	**4**	**3**	**865**	**32.5**	**1740.5**
Signif.	**n.s.**	**n.s.**	**n.s.**	**n.s.**	**	**	*
L.S.D.(0.05)					**58.2**	**0.80**	**200.1**
1995							
Rainfed	94	55.2	4.5	4	1213	34.5	2771
Irrigation	96	67.9	6.0	4	1346	33.4	**3292**
Mean	**95.0**	**61.5**	**5.2**	**4**	**1279.5**	**33.9**	**3031.5**
Signif.	*	**	**	**n.s.**	*	*	**
L.S.D.(0.05)	**1.9**	**5.37**	**0.69**		**102.1**	**0.96**	**213.9**

** - significant at 0.01
* - significant at 0.05
n.s. - not significant

Table 4 Mean root length, root length at O-30 cm depth, root length at 30-60 cm depth, total root length and seed yield of the six bean genotypes grown in the field in 1994

Genotype	Mean root length (cm)/10 cm depth	Root length (cm) at O-30 cm depth	Root length (cm) at 30-60 cm depth	Totalroot length (cm)	Seed yield (kg/ha)
Othello	61.7	212	159	371	2057
Agate	51.6	205	105	310	1758
GH196-2	50.2	202	99	301	1775
Earliray	47.4	197	88	285	1251
Fiesta	55.3	206	126	332	2041
ISB82-354	41.5	187	60	249	1560
Mean	51.2	201.5	106.2	308	1740
Signif.	n.s.	n.s.	*	n.s.	**
L.S.D.(0.05)			56.7		370.6

** - significant at 0.01
* - significant at 0.05
n.s. - not significant

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