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Identification of Critical Growth Stage for Export Type Common Bean (*Phaseolus Vulgaris* L.) to Moisture Stress

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Abstract

A study was conducted on the identification of critical growth stages to moisture stress of common bean, cultivar Chercher, at nine different growth stages[emergence of cotyledons (V1), development of primary leaves (V2), development of first trifoliate leaves (V3), development of third trifoliate leaves (V4), bud formation (R5), flowering (R6), pod formation (R7), pod filling (R8) and maturity (R9)] with irrigating at those different stages were made at Haramaya University Research site, Haramaya, during 2010 and 2011. The identification of sensitive growth stages to at different growth stages on the yield and yield components of common bean were determined. The effect of water stress showed significance effect on most parameters considered. But, water stress on the days of flowering and dry biomass was not showed significance difference. However, applying the water deficit at vegetative growth stages (V1 to V4) did not significantly affect the yield and yield components of common bean as compared to the reproductive growth stages (R5 to R9). The highest yield per plant (6.19 g) and lowest yield per plant (1.55 g) were recorded when irrigation was withheld at the development of cotyledon (V1) and at bud formation (R5) growth stages. As compared to the well watered control, the lowest (3%) and highest (76%) seed yield reductions were obtained when water deficit was imposed at V1 and R5 stages. As this finding it is concluded that the most critical growth stage of common bean, Chercher variety to water deficit is at bud formation (R5).

Keywords: common bean, growth stage, water stress, yield

Introduction

Common bean is one of the most important pulse crops predominantly grown from low land to mid highland areas in Ethiopia and it covers about 48% of the total cropped area (EARO, 2000). The national production is about 267,069 ha area with a total production of 329,775,000 kg with an average productivity of 1,235 kg/ ha (CSA, 2009). The amount and distribution of rainfall can vary between growing seasons and thereby causing stress during different stages of development of the crop. Due to the unpredictable nature of rainfall during the growing season, field screening of common bean for drought tolerance can be difficult. Drought stress is an endemic problem throughout the world and common bean production under water limiting conditions is very common (Munoz-Perea *et al*., 2007). It is known that in many regions, legume crops and pastures are grown on nutrient and water deficient soils and symbiotic nitrogen fixation is highly sensitive to drought, which results in decreased N accumulation and crop yield (Miklas *et al*., 2006). The effect of drought can vary with growth stage of a plant. In general, drought has the greatest impact on common bean seed yield when it occurs during the reproductive development (Brevedan, 2003).

Morphological and phenological traits such as plant type, root system and early flowering play a major role in adaptation of plants to specific drought conditions (Smartt, 1998). Lines with earlier maturity would be less vulnerable to terminal drought whereas, lines with late maturity are highly vulnerable to terminal drought (Frahm *et al*., 2004). There is a negative association between early maturity and low yields (Boutra and Sanders, 2001). In general, the lack of water during the reproductive stage interferes with the normal metabolism of the plant during flowering time and pod filling resulting in the greatest yield reduction as these are stages critically affected by drought (Abebe *et al.,* 1998). Common bean is susceptible to water deficits, especially in pre-flowering and reproductive periods which have considerable impact on seed yield (Kindie, 1997). However, among sub-stages of the reproductive period (R5-R9) the sensitivity to water deficit and its impact on the yield and yield components is different. The sensitivity varies with the degree of water deficit and type of variety. There is a need to determine the sensitive growth stages of the export type varieties of common bean variety, Chercher, to water deficit in order to optimize irrigation water supply without reducing the potential yield of the crop. Therefore, the current study were made to identify the sensitive growth stages of an export type common bean that are very susceptible to water stress; and its effect on the yield and yield components of common bean.

Materials and Methods

Description of the Study Area

The study was conducted in 2010 at Haramaya University Agricultural research site in the green house. Haramaya is situated at 9°26'N latitude, 42°03'E longitude with an altitude of 1980 masl, with an alluvial soil type. Common bean (*Phaseolus vulgaris* L.) variety known as chercher (STTT-165-96**)** which is a white seeded canning type variety was used (MoARD, 2006). The number of days required for the variety to reach flowering and maturity ranges from 50 to 55 days and 93 to 103 days, respectively.

Soil sampling and analysis

An alluvial soil sample was taken from rare experimental site of Haramaya University and air dried for a week. 120 round pots (20 cm x 24 cm) were used for the experiment and filled with equal amounts (5kg) of soil. Two healthy seeds (completely filled and not attacked by insects) were planted in each pot and the experiments was managed following all necessary agronomic procedures like timely weeding, controlling moisture level by adding the determined amount of water throughout the growing season. Fertilizer was applied in the form of Diammonium Phosphate (DAP) according to the recommended rates, 100 kg/ha

Representative disturbed soil samples were taken from the experimental site to determine the volumetric moisture content, bulk density and moisture contents at field capacity and permanent wilting point. The samples were taken at the depth of 0-15 and 15-30 cm, processed and analyzed in the soil laboratories of Haramaya University and Melkassa Agricultural Research Center, Ethiopia.

Soil moisture content

The soil samples collected were weighed and oven dry for 24 hrs at 105^{0}C for soil moisture determination, using the gravimetric approach as represented by equation 1.

$$\theta w = \frac{(Ww - Wd)}{Wd} * 100 \quad (1)$$

Where, Θ_w = moisture content on dry weight basis (%); W_w = weight of the wet soil (g) and

W_d = weight of the dry soil (g)

The volumetric water content (%) was calculated using gravimetric water moisture content (%) and bulk density (p_b) as shown in equation 2.

$$\theta v\ (\%) = (\theta w * pb) \quad (2)$$

Bulk density

From the oven dried soil samples described above the bulk density was determined as

$$Pb = \frac{\mathrm{Ms}}{Vt} \quad (3)$$

Where, P_b =bulk density (g/cm^3), Ms =dry weight of the soil (g), and Vt = total volume of the soil (g)

Soil moisture content at field capacity and permanent wilting point

The moisture content at field capacity (FC) and permanent wilting point (PWP) were determined after soil samples were saturated for one day (24hrs) by using the pressure plate apparatus at 0.33 bars and membrane plate apparatus at 15 bars respectively.

$$\mathrm{FC/PWP}\ (\%) = \frac{Wwet - Wdry}{Wdry} * Pb * Di \quad (4)$$

Where; Wwet. = Weight of wet soil in (g); Wdry. = Weight of dry soil in (g); P_b = bulk density of the soil in (g/cm^3); and Di = depth of the soil sample taken or root depth in (cm)

Treatment and experimental design

The experiment consisted of nine deficit irrigation treatments and one control. The treatments include water stress applied at different growth stages, namely, emergence of cotyledons (V1), development of primary leaves (V2), development of first trifoliate leaves (V3), development of third trifoliate leaves (V4), bud formation (R5), flowering (R6), pod formation (R7), pod filling (R8) and maturity (R9) and a non stressed control that received full irrigation at all growth stages.

The treatments were laid out in a completely randomized design (CRD) with three replications. Each treatment consisted of 12 pots and a total of 120 pots were used for the experiment. The water stress treatments were created by withholding irrigation water at each growth stage (without irrigation until one growth stages translated to the next growth stages). There are two plants per pot and eight plants per experimental unit. All the treatments were irrigated equally by applying irrigation to field capacity at planting. The irrigation treatments were started from date of sowing of the crop and continued until maturity following the growth stage of plants.

Tensiometer Calibration

The tensiometer was calibrated before soil moisture measurement, and based on the tensiometer calibration; crops were irrigated when the tensiometer reading reached 21 cbar throughout the growth stage except the growth stage that was deliberately stressed.

Data collection

Data was collected on days to flowering, days to physiological maturity, plant height, number of primary branches per plant, number of pods per plant, pod length, seed yield per plant, above ground dried biomass and harvest index. Five plants were tagged in all treatments for ease of representation.

Statistical analysis

The collected data was subjected to statistical analysis software (SAS) version 9.3 (2002). Where treatment means were significant the least significant difference (LSD) test was adopted for mean separation at 5% probability level.

Results

Effect of water stress on plant phenology

The result of water stress on phenological parameters of common bean is presented in Table 1. The days to flowering showed no significant difference with moisture deficit imposing at all growth stages. However, there was a significant difference on days to maturity ($p < 0.05$), with water stress applied at R5 taking longer time to reach maturity and R9 (maturity stage) recording the least time to reach maturity (Table 1)

Table 1. Influence of water stress at different growth stages on days to flowering maturity of common bean grown in 2010

Treatments	Days to flowering	Days to maturity
Control	46.33	93.67^{c}
V1	46.33	94.00^{c}
V2	46.33	94.67^{c}
V3	47.35	94.33^{c}
V4	49.67	94.33^{c}
R5	48.33	101.67^{a}
R6	46.33	98.67^{b}
R7	46.67	98.00^{b}
R8	46.67	92.00^{d}
R9	47.00	90.00^{e}
Mean	47.1	95.1
LSD(P<0.05)	NS	1.52
CV (%)	2.02	0.49

Means followed by the same letter within the columns are not significantly different from each other at 5% probability level. V = vegetative growth stages, R = reproductive growth stages.

Effect of water stress on growth parameters

The influence of water stress imposed at different growth stage of common bean growth parameters is presented in Table 2. The result showed a significant reduction in plant height at all growth stages (P <0.05) with the exception of R_5 (47.20cm) which recorded the tallest plant when compared to the control (no stress). The shortest plant heights was recorded when water deficit was imposed at R_6 (35.27cm). Branch number was also affected significantly, with the highest (5.67) and lowest (3.33) branch numbers obtained when water stress was imposed at R5 and R7 growth stages, respectively (Table 2).

Table 2. Influence of water stress imposed at different growth stages on plant height and branch number per plant of common bean in 2010

Treatments	Plant height (cm)	Branch number/plant
Control	44.93[ab]	4.33[b]
V1	42.60[ab]	4.33[b]
V2	40.73[ab]	4.33[b]
V3	38.73[bc]	4.00[c]
V4	39.07[abc]	4.33[b]
R5	47.20[a]	5.67[a]
R6	35.27[c]	4.00[c]
R7	37.13[bc]	3.33[c]
R8	36.93[bc]	4.00[b]
R9	36.07[c]	4.67[b]
Means	39.866	4.299
LSD (P <0.05)	7.48	0.98
CV (%)	11.02	13.42

Means followed by the same letter within the columns are not significantly different from each other at 5% probability level. V = vegetative growth stages, R = reproductive growth stages.

Influence of water stress on yield parameters

The result of the study showed that the water stress imposed at different growth stages significantly (p < 0.05) affected number of pods per plants, pod length and number of seeds per pod in all treatments (Table 3). Highest pod per plant was obtained with control (9.67) which was similar to when water stress was imposed at V1 and V2 growth stages, that is there was no significant differences between control (no stress), V1 and V2 stages.

Table 3. Influence of water stress imposed at different growth stages on yield components of common bean grown in 2010

Treatments	Pods per plant	Pod length (cm)	Seeds/pod (g)
Control	9.67[a]	7.87[a]	5.33[a]
V1	9.67[a]	7.73[a]	5.00[ab]
V2	9.67[a]	7.00[ab]	4.67[ab]
V3	6.00[bc]	6.47[ab]	4.00[b]
V4	7.00[b]	5.73[b]	4.00[b]
R5	2.00[d]	4.20[c]	2.33[c]
R6	6.33[bc]	5.93[b]	4.33[ab]
R7	4.00[cd]	6.07[b]	4.00[b]
R8	7.00[b]	7.03[ab]	4.33[ab]
R9	5.33[bc]	6.97[ab]	4.33[ab]
Means	6.667	6.500	4.232
LSD (P <0.05)	2.19	1.30	1.07
CV (%)	19.96	11.76	14.93

The values followed by the letter within the columns are not significantly different from each other at 5% probability level. R = reproductive growth stage, V = vegetative growth stage

The different growth stages exhibit a significant difference to moisture stress in the length of pod and number of seeds per pod. The result was similar to number of pods per plant where there was no significant difference between control, V1 and V2 recording 7.87, 7.73, and 7.00 respectively (Table 3). The shortest pod length was obtained when stress was imposed at R5. Lowest number of seeds per pod was also obtained with R5 (2.33), while the highest (5.33) seed number per pod was obtained with control (no stress).

The water stress imposed at different growth stages significantly (P < 0.05) affected the average yield per pot, and harvest index whereas above ground biomass of the crop for all the treatments indicated a non significance difference (P >0.05). (Table 4).

The analysis of variance result summary for all parameters is presented in table 5. Of all the parameters measured, only days to flowering and above ground biomass showed a non significance difference at all stages of growth.

Table 4. Effect of water stresss at different growth stages on yield per pot, above ground biomass and harvest index of common bean in 2010

Treatments	Y/pot (g)	AGB/plot (g)	HI
Control	31.80[a]	54.50	0.58[ab]
V1	30.93[a]	54.73	0.57[ab]
V2	21.93[ab]	46.38	0.57[ab]
V3	22.40[ab]	46.00	0.46[abc]
V4	25.50[ab]	48.33	0.51[bc]
R5	7.78[c]	45.00	0.17[c]
R6	20.40[b]	44.07	0.46[abc]
R7	18.30[b]	41.73	0.46[abc]
R8	17.50d[b]	43.43	0.46[abc]
R9	16.47[b]	50.43	0.33[b]
Means	21.22	47.46	0.447
LSD (P <0.05)	4.43	ns	0.15
CV (%)	12.28	16.49	13.41

The values followed by the same letter within the columns are not significantly different from each other at 5% probability level. YPP = yield per plant, AGB = above ground dry biomass per sampled treatment and HI = harvest index

Table 5. Summary of analysis of variance table for all parameters in 2010

	Source of variations				
Parameters	Treatment	df	Error mean square	F value	probability
DF	3.632	9	4.100	0.892[ns]	0.554
DM	34.831	9	0.800	43.541*	0.001
PH	47.090	9	19.330	2.440*	0.047
BN	1.070	9	0.330	3.212*	0.014
PPP	16.686	9	1.660	10.011*	0.001
PL	3.514	9	0.580	6.001*	0.004
SPP	1.932	9	0.400	4.820*	0.002
YPP	5.751	9	0.360	15.982*	0.001
AGB	60.660	9	61.270	0.993[ns]	0.500
HI	0.042	9	0.004	11.353*	0.001

ns = non-significance, * = significance at 5% probability level, DF = days to flowering, DM = days to maturity, PH = plant height, BN branch number, PPP = pod number per plant, PL = pod length, SPP = number of seed per pod, YPP = yield per plant, AGB = above ground dry biomass, HI = harvest index

Discussion

The result of this study established that applying water stress at different growth stages of common bean variety chercher significantly affects growth, yield and yield components of the crop. Water stress imposed at different growth stages varied days to flowering but significantly varied the days to physiological maturity of the crop. The longest days to maturity (102 days) was recorded when water stress was imposed at R5 growth stages indicating that vegetative growth of the crop extends to develop drought resistance. However, the application of water stress at R9 gave the shortest time for crop to reach maturity (90 days). Maturity of crop is hastened as a drought escape mechanism. Water stress imposed during the reproductive growth stages significantly reduced plant height while the stress imposed during vegetative growth stages did not show significant change when compared to control treatment. Foroud *et al*. (1993) had reported that moisture stress is related quadratically to plant height. According to him, genotypes that suffered a relatively greater reduction in plant height under stress tend to have lower grain yield and harvest index under water deficit. Similarly, Solomon (2002) indicated that the number of branches per plant was significantly affected by water stress imposed throughout the growth stages of common bean plants, decreasing at reproductive growth stages and increase at few vegetative growth stages. Sexton *et al*. (1997) also reported that water stress imposed at midseason growth stages did not affect number of branches per plant but significantly affected plant height at early and late growth stages. These findings all support the current study results.

The imposition of water stress at V1 and V2 growth stages did not significantly affect number of pods per plant when compared to the control (no stress) (Table 3). Moreover significant differences were not observed among V3, V4, R6, R8 and R9 in terms of the number of pods per plant. Solomon (2002) had reported that, number of pods/plant and seeds/pod were the most affected yield components by soil moisture stress. The number of pods per plant depends on the number of pod setting branches that produce well developed pods (Deproost *et al.,* 2004). In this study, plant height, branch number, pod length, pods per plant, yield/pot and harvest index were the most parameters significant affected by moisture imposed at different growth stages. Similarly, Kindie (1997) found significant reductions in the number of pods per plant of many common bean varieties due to the application of moisture stress at different growth stages in a glass house. The deficit imposed at late vegetative stages (V4) and early reproductive stages (R5 to R6) significantly reduced pod length compared to control. According to Kindie (1997), pod length was highly influenced when water stress was imposed at mid, early and late season growth stages respectively which agrees well with our findings. The lowest number of seeds per pod was recorded when water stress was imposed at R5 growth stage while the highest was recorded at V1 (vegetative) growth stage. Solomon (2002) reported a decrease in the number of seeds/pod which also agrees with our findings. Similarly, Nunez *et al.* (2005) indicated that the number of seeds per pod is significantly reduced when water deficit is imposed at different growth stages of common bean.

This study also established that average yield/pot was significantly reduced when subjected to water stress at R5 growth stage (Table 4). However, no significant difference was observed among V2, V3, R6, R7, R8 and R9 treatments in terms yield/pot. Applying water stress at development of cotyledon (V1) and development of flower bearing buds (R5) reduced the yield of common bean by 3 and 76% respectively compared to no stress imposed treatment. This means water stress applied during high water consumption of the crop significantly reduced the yield of the crop. Similar result was reported by Pimentel *et al*. (1999), Solomon (2002) that periods of water stress during the reproductive growth phase of common bean caused significant reduction in grain yield. Whereas reduction of above ground biomass was not significantly affected by water stress imposed at different growth stages of the crop, because the treatments that produce lower yield produced higher vegetative parts as in the case of R5 growth stage. Worku and Skjelvag (2006) reported similar findings but in contrast, Solomon (2002) reported a significant biomass yield difference at all growth stages due to water stress in common bean.

The lowest harvest index was recorded when water deficit was imposed at R5 (0.177g/g) growth stages while the highest were recorded at V1 and V2 (0.57g/g). This result indicates that water stress imposed at early growth stages was not significantly affect the harvest index as it imposed at late vegetative growth to reproductive growth stage of the common bean. Blum (1998) similarly reported that, harvest index was affected by water deficit at different growth stages, especially during the reproductive stage due to flower abortion and poor grain filling.

Conclusion and Recommendation

Based on the findings water stress at different growth stages had a significant effect on plant height, branch number, pod length, pod per plant seeds per plant and harvest index, with the exception of days to flowering and above ground biomass on the common bean variety studied. The imposition of water stress at late reproductive (R8 and R9) growth stages hastened the maturity of the crop. Hence, the results demonstrated that the variety used was susceptible to water stress at flower bearing buds (R5) growth stages. Therefore, sufficient amount of irrigation water should be applied especially at flower bud development stage, which has been identified as the critical period for the common bean variety.

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