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Effects of Supplemental Irrigation on Physiological Parameters and Yield of Faba Bean (*Vicia faba* L.) Varieties in the Highlands of Bale, Ethiopia

[1]F. Girma and [2]D. Haile
[1]Oromia Agricultural Research Institute, Sinana Agricultural Research Center,
P.O. Box 208, Bale-Robe, Ethiopia
[2]Haramaya University, P.O. Box 138, Dire Dawa, Ethiopia

Abstract: Crop production is limited by environmental factors among which moisture deficit imposed at critical stages of crop growth is the most important one. Drought stress has become the major limiting factor on plant growth and yield. Supplemental irrigation at stress periods is, hence, important for improving yield of crops. Faba bean production in Southeast Ethiopia is limited by terminal drought imposed at anthesis and grain filling stages. An experiment was conducted at Sinana Agricultural Research Center, Southeast Ethiopia to evaluate faba bean varieties in response to yield and physiological parameters. Seven faba bean varieties were tested with two moisture regimes (rain fed and supplemental irrigation) on field and in pot. The varieties have showed significant difference in yield components. Degaga, Bulga-70 and Messay gave higher yield whereas Tesfa had a lower yield. Moisture susceptibility index was calculated to evaluate susceptibility of varieties to moisture stress. Based on the index, CS20-DK and NC-58 varieties were tolerant, Shallo, Degaga and Bulga-70 were moderately tolerant and Tesfa and Messay were relatively susceptible to moisture stress. Supplemental irrigation significantly improved yield components except harvest index and thousand seeds weight. Physiological parameters did not change among faba bean varieties indicating that the varieties perform similarly in these parameters. However, physiological parameters such as transpiration rate and internal CO_2 concentration were significantly improved by supplemental irrigation at anthesis whereas irrigation did not affect photosynthetic rate, water use efficiency and chlorophyll fluorescence ratio. Leaf temperature was decreased by supplemental irrigation showing a cooling effect on the crop canopy.

Key words: Drought stress, faba bean, moisture, physiological parameters, yield

INTRODUCTION

Faba bean (*Vicia faba* L.) is the most important pulse crop in the term of popularity, seed protein content and world's cultivated area. The leader producing countries are China, Italy, Spain, the UK, Egypt, Ethiopia, Morocco, USSR, Mexico and Brazil (Al-Suhaibani, 2009). Faba bean is regarded as a drought-sensitive crop and the major factor restricting its cultivation is the high year-to-year yield variability usually due to drought stress. Water deficit affects nearly all the plant growth processes. However, the stress response depends upon the intensity, rate and duration of exposure and the stage of crop growth (Thalooth *et al*., 2006; Edalat *et al*., 2009).

Faba bean (*Vicia faba* L.) is reported to be more sensitive to water deficit than some other grain legumes (Khan *et al*., 2010). That sensitivity is as a result of its maximum depth of rooting being relatively shallow, approximately 0.9 m and its disability to adjust osmotically to water stress. The early podding stage of development was the most sensitive to water stress, causing a reduction in faba bean yield by 50% (Ouda *et al*., 2010). Temporary water deficit may occur at almost any stage of growth wherever faba bean is grown and in many areas, especially Mediterranean-type climates, terminal drought occurs during reproductive development. Variation in the amount and distribution of rainfall is generally considered the major reason for variability in seed yield of faba bean (Khan *et al*., 2010). More land can become productive by using partial irrigation, under low rainfall condition at strategic times during growing season. This may be accomplished if a proper index of crop sensitivity to water deficit at various growing stages is used (Al-Suhaibani, 2009).

Plant growth is controlled directly by drought stress and only indirectly by soil and atmospheric drought stress (Kufa and Burkhardt, 2011). Under both natural and agricultural conditions, plants are constantly exposed to stress. It has been estimated that, because of physiological stress, the yield of field grown crops in the United States is only 22% of the genetic potential yield (Boyer, 1982). Investigation on the adaptation

Corresponding Author: F. Girma, Oromia Agricultural Research Institute, Sinana Agricultural Research Center, P.O. Box 208, Bale-Robe, Ethiopia

mechanisms of plants species is important to understand their ecological success and growth conditions (Kufa and Burkhardt, 2011; Pearcy *et al.*, 1981). Furthermore, characterization of drought patterns in major growing regions is an important step in designing strategies for improving crop drought responses (Khan *et al.*, 2010).

Reports showed positive significant correlations between drought period and reduction of plant height, leaf area and leaf dry weight. Drought stress affects nutrients absorption which may be due to the: (i) reduction of transport from soil to the rizosphere, (ii) selective absorption of ions by roots, (iii) changes in shoot and root minerals requirement, (iv) transport reduction of elements into the plants and (v) deficiency or association of ions that cause to metabolic disorders (Bahavar *et al.*, 2009). Drought stress reduces dry matter production, yield and yield components through decreasing leaf area and accelerating leaf senescence (Emam *et al.*, 2010). Greater leaf area is necessary to have superior yield and yield components in grain legumes (Kulsum *et al.*, 2007). Shoot biomass accumulation is considered an important trait to attain high seed yield in grain legumes (Emam *et al.*, 2010).

In Ethiopia, drought period is likely to occur when the crop is at flowering and at the grain filling stages resulting in premature drying of leaves which in turn result in reduced assimilatory capacity and lower grain yields much below the potential yield of the crop. It is reported that 30 to 65% of grain yield of wheat is reduced by terminal low moisture stress as compared to the irrigated yield potential. Although management practices can contribute towards higher yields in stressed environment, major progress is expected through genetic improvement by developing drought tolerant crop varieties. Irrigation is acknowledged in sub-Saharan Africa to improve food sufficiency. Water conserving irrigation scheduling is one of the strategic options for achieving sustainable agriculture (Abu and Malgwi, 2011). Improving water use efficiency is one of the strategies to develop varieties in drought areas (Boutraa, 2010).

Studies on the effect of moisture on growth and performance of faba bean are generally lacking. Therefore, the study was proposed with the objectives of studying growth and performance of faba bean varieties under rain-fed and supplemental irrigation conditions.

MATERIALS AND METHODS

The experiment was conducted for three years (2004-2006) at Sinana Agricultural Research Center (7°7'N and 40°10' E, with altitude of 2400 m above sea level) in Southeastern highlands of Ethiopia. The major soils of the area are cambisols and vertisols with clayey to sandy loam structure and a pH of 7.5 (1:2.5 Soil: H_2O ratio).

Table 1: Soil characteristics of the experimental and nearby sites of Sinana

	Experimental sites			
Parameters	Robe	Sinana	Agarfa	Gassera
Available P	6.38	5.22	2.39	11.90
Total N	0.12	0.13	0.17	0.22
Organic C	2.75	2.00	2.05	1.52
Soil type	Cambisols	Cambisols	Vertisols	Vertisols

Most of the soils are poor in total nitrogen, low in available phosphorus and high in exchangeable potassium (Table 1). The highland of Bale is characterized by bimodal rainfall pattern receiving peak amounts in April and September. Days are hotter in February and nights are cooler in December. The average temperature is 9.5°C, maximum mean temperature is 21°C and the average total annual rainfall of the experimental years is 960 mm.

The treatments included 7 faba bean varieties (Shallo, Degaga, Bulga-70, Tesfa, Mesay, NC-58 and CS20DK) and 2 moisture regimes (rain-fed and supplemental irrigation). Physiological parameters such as Transpiration Rate (TR), net Photosynthesis Rate (PR), internal CO_2 concentration, Stomatal Conductance (SC), Water Use Efficiency (WUE) and Leaf Temperature (LT) were measured using CO_2 Gas Analyzer (CI-301PS, CID Inc., 1996, USA). Chlorophyll fluorescence parameters were measured by portable fluorometer (Plant Efficiency Analyzer, PEA, Hansanthech Instruments Ltd. England) from leaves dark-adapted for 30 min. Drought susceptibility index (S) was calculated from genotype means by using the generalized formula of Fischer and Maurer (1978) for grain yield per plant as:

$$S = \frac{(1 - Y_d / Y_p)}{D}$$

where, S is the drought susceptibility index, Yd and Yp are mean yield of the genotypes under water deficit and well-watered condition, respectively and D is drought intensity index which is obtained as:

$$D = 1 - \frac{mY_d}{mY_p}$$

where, mYd is the mean yield of all genotypes under water deficit condition, mYP is the mean of yield of all genotypes under well watered conditions. The drought susceptibility index (S) was used to characterize each genotype in the stress treatment which represents different stress environments. Low values of S (S<1) are considered as indicators of high drought tolerance whereas high S values show drought susceptibility (Tesfaye *et al.*, 2008). Data were subjected to analysis using general linear model procedure of SAS and means were separated using Fisher's least significant difference.

Table 2: Effect of different varieties of faba bean on yield and yield parameters

Variety	Pht	FPP	PPP	SPP	PL	TSW	HI	SY	S
Shallo	87.4^{a}	67	12c^{d}	24^{b}	6.2^{a}	406.7^{a}	0.37^{bc}	2672.3^{b}	1.02
Degaga	89.6^{a}	62	18^{a}	36^{a}	5.7^{ab}	400.9^{a}	0.39^{ab}	3635.9^{a}	1.02
Bulga-70	87.4^{a}	61	16^{ab}	35^{a}	6.0^{a}	348.9b^{c}	0.41^{a}	3542.1^{a}	1.02
Tesfa	73.2^{b}	56	11^{d}	35^{a}	5.2b^{c}	324.8c^{d}	0.29^{d}	1757.4^{c}	1.23
Messay	83.6^{a}	68	15b^{c}	20^{b}	5.7^{ab}	354.6b^{c}	0.42^{a}	3269.4^{a}	1.38
NC-58	83.9^{a}	60	16^{ab}	33^{a}	5.1^{c}	294.6^{d}	0.34^{c}	2513.4^{b}	0.62
CS 20 DK	88.4^{a}	67	16^{ab}	34^{a}	6.1^{a}	381.9^{ab}	0.37b^{c}	2812.4^{ab}	0.60
Mean	84.8	63.0	15	31	5.7	358.9	0.37	2885.7	-
$LSD_{0.05}$	6.3	ns	3.3	6.3	0.5	45.0	3.9	827.4	-

$LSD_{0.05}$: Fisher's least significant difference at $p \le 0.05$, values with the same letter are not statistically different to one another, ns: Non-significant, Pht: Plant height (cm), FPP: No. of flowers plant^{-1}, PPP: No. of pods plant^{-1}, SPP: No. of seeds plant^{-1}, PL: Pod length (cm), TSW: Thousand seeds weight (g), HI: Harvest index, SY: Seed yield (kg ha^{-1}), S: Drought susceptibility index

RESULTS

Yield and yield components: The result of the field trial showed variation among genotypes in number of pods and seeds per plant, pod length, thousand seed weight, harvest index and grain yield (Table 2). Degaga, Bulga-70 and Messay are similarly high yielders compared to other varieties whereas Tesfa is the lowest yielder. Degaga is better in most of the yield parameters than the other varieties. Based on the moisture stress susceptibility index, genotypes were grouped in to relatively susceptible (S), moderately tolerant (M) and Tolerant (T). Varieties such as CS20-DK and NC-58 were relatively tolerant; Shallo, Degaga and Bulga-70 were moderately tolerant where as Tesfa and Messay were relatively susceptible to moisture stress. Moderately tolerant varieties were also better yielders while the tolerant ones were low yielders. The susceptible varieties have shown different yielding response to moisture stress. Messay gave high yield while Tesfa showed low yield. The high yield in Messay was probably attributed to its higher harvest index despite moisture susceptibility.

Variation also exists between moisture regimes (supplemental irrigation and rainfall) (Table 3). Supplemental irrigation during moisture stress periods significantly increased plant height, number of flowers, pods and seeds per plant, pod length and seed yield of faba bean over the natural rainfall condition. Grain yield and number of seeds per plant were the largely affected parameters during moisture stress. Thousand seed weight and harvest index were not affected by moisture stress. In similar experiment conducted in pot, supplemental irrigation significantly increased the entire yield parameters considered (Table 4). Seed yield per hectare, pods per plant, seeds per plant, pod length, leaf dry weight, pod weight, biomass yield and pod sink strength showed a significantly improved response by supplemental irrigation.

Table 3: Effect of supplemental irrigation on yield and yield parameters

	Treatments				
Parameters	Rain-fed	Supp. irrigation	Mean	$LSD_{0.05}$	CV (%)
Pht	74.8^{b}	94.8^{a}	84.8	***	6.3
FPP	55.5^{b}	70.5^{a}	63.0	***	17.2
PPP	11.0^{b}	19^{a}	15	***	18.7
SPP	23.0^{b}	39^{a}	31	***	17.2
PL	5.3^{b}	6.1^{a}	5.7	***	7.6
TKW	351.5^{a}	366.4^{a}	358.9	ns	10.6
HI	0.36^{a}	0.38^{a}	0.37	ns	8.8
SY	2123.0^{b}	3648^{a}	2886	***	19.1

***: Statistically significant at $p \le 0.001$, ns: Statistically non significant, means within a column followed by the same letter were not significantly different

Table 4: Effect of supplemental irrigation on yield and yield components (pot experiment)

	Yield parameters*							
Treatments	SY	PPP	SPP	PL	LDW	PW	BM	PSS
R	3785^{b}	12^{b}	29.0^{b}	5.75^{b}	20.0^{b}	22.1^{b}	63^{b}	2.0^{4b}
SI	6437^{a}	22^{a}	52.0^{a}	6.46^{a}	23.0^{a}	63.7^{a}	111^{a}	4.78^{a}
Mean	5111	17	40.5	6.11	21.5	42.9	87	3.41
$LSD_{0.05}$	***	***	***	**	*	***	***	****

R: Rain-fed, SI: Supplemental irrigation, SY: Seed yield (kg ha^{-1}), PPP: No. of pods plant^{-1}, SPP: No. of seeds plant^{-1}, PL: Pod length (cm), LDW: Leaf dry weight (%), PW: Pod weight (gm plant^{-1}), BM: Biomass yield (g plant^{-1}), PSS: Pod sink strength (g day^{-1} plant^{-1})

Physiological parameters: Faba bean varieties did not show significant difference in all physiological parameters indicating that all of the varieties tested have similar physiological activities (Table 4) performing similarly in both irrigated and rain-fed conditions. Supplemental irrigation during critical crop stage (anthesis) had significant effect on some physiological processes (Table 5 and 6). Net transpiration rate, internal CO_2 concentration, leaf temperature and Stomatal conductance were increased by supplemental irrigation. However, significant effect was not observed on the net photosynthesis rate, water use efficiency and variable to maximum chlorophyll 'a' fluorescence ratio due to supplemental irrigation. Stomatal conductance showed significant ($r = 0.32$, $p<0.05$) and positive correlation with grain yield whereas Leaf temperature ($r = -0.41$, $p<0.005$) had negative correlation with gain yield (data not shown).

Table 5: Effect of varietal difference on physiological parameters of faba bean

	Physiological parameters*						
Treatments	PR	TR	SC	CO_2 int.	LT	WUE	Fv/Fm
Varieties							
Shallo	8.40	1.85	324.00	260.40	16.80	3.70	0.81
Degaga	4.60	1.88	752.60	244.20	18.70	2.70	0.82
Bulga-70	17.40	1.90	679.80	198.50	18.40	10.90	0.79
Tesfa	11.70	1.81	956.10	221.20	18.30	7.50	0.79
Messay	23.90	2.00	595.00	227.30	19.20	11.50	0.75
NC-58	13.90	2.32	583.70	202.80	18.70	6.70	0.79
CS 20 DK	29.10	1.77	923.10	202.50	16.60	17.10	0.75
Mean	5.57	1.93	687.76	222.41	18.10	8.59	0.79
$LSD_{0.05}$	ns	ns	ns	ns	ns	ns	ns

*PR: Net photosynthesis rate (μmol m^{-2} sec^{-1}), TR: Net transpiration rate (μmol m^{-2} sec^{-1}), SC: Stomatal conductance (mmol m^{-2} sec^{-1}), CO_2 int.: Internal CO_2 concentration (ppm), LT: Leaf temperature (°C), WUE: Water use efficiency (PR/TR), Fv/Fm: Variable chlorophyll a fluorescence/maximum chlorophyll a fluorescence), ns: Statistically non-significant

Table 6: Effect of supplemental irrigation on physiological parameters of faba bean

	Treatments				
Parameters*	Rain-fed	Supp. irrigation	Mean	$LSD_{0.05}$	CV(%)
PR	14.20^a	16.90^a	15.55	ns	24.0
TR	1.70^b	2.15^a	1.93	*	33.2
SC	413.10^b	962.30^a	687.70	**	28.4
CO_2 int.	188.60^b	256.20^a	222.40	**	3.7
LT	19.90^a	16.30^b	18.10	**	14.1
WUE	8.90^a	8.30^a	8.60	ns	28.5
Fv/Fm	0.80^a	0.77^a	0.79	ns	5.7

**: Statistically significant at $p \leq 0.01$ and *: Statistically significant at $p \leq 0.05$

DISCUSSION

Yield and yield parameters: The field experiment showed significantly different response of faba bean varieties in yield parameters where they could be categorized under high, low and medium yielders. Degaga, Bulga-70 and Messay were high yielders; CS20DK, Shallo and NC-58 were medium yielders where as Tesfa was found to be a low yielding variety. The low yielder variety, Tesfa, had similar number of seeds per plant with the high yielding varieties. Its low yield was apparently contributed by less number of pods per plant combined with less thousand seed weight, short plant height (less biomass accumulation) and hence low harvest index. The high yielding varieties had superior advantages over Tesfa in the same parameters which indicate that plant height, numbers of pods per plant and harvest index are the major parameters that determine yield of faba bean. Plant height determines the biomass to be accumulated across the whole plant tissue while number of pods per plant is the most important yield determining component because it sets the number and weight of seeds to be obtained during grain filling periods. Research in rice (Seyoum *et al*., 2011) indicated that depending on the type of genotype, change in the number and size of yield components affected yield levels. Grain yield has been reported to be influenced by panicles per plant, grains per panicle and grain weight.

Varieties were also categorized under different moisture susceptibility indices (Table 2). The best choices are susceptible but high yielder varieties while those which are tolerant but low yielders are not selected in breeding programs for high yield in water limited areas. Degaga and Bulga-70 are moderately tolerant and high yielders while NC-58 and CS20DK are tolerant to moisture stress and medium yielding varieties. The two varieties Messay and Tesfa are susceptible but contrary in yield response. Messay is high yielder despite its susceptibility to moisture stress while Tesfa is the lowest yielder among the varieties because of moisture stress.

Supplemental irrigation considerably improved yield components compared to the rain-fed (stress) condition. Most yield components have been improved except harvest index and thousand seeds weight. Thousand seed weight and harvest index were not affected by moisture stress because they reflect the characteristics of the varieties. Tesfaye *et al*. (2008) found significant reduction in yield and its components of durum wheat due to moisture stress levels set during different growth stages of the crop. Thalooth *et al*. (2006) found that subjecting mung bean plants to water stress at vegetative stages of growth caused the highest reduction in all growth parameters except that of stress at pod formation stage of growth. According to the authors, subjecting plants to water stress at pod formation stages of growth caused the highest reduction in number of pods per plant, pods dry weight, number of seeds per pod, seeds dry weight per plant, seed index and seed yield. Edalat *et al*. (2009) concluded that, kernel number per ear, kernel weight per ear and biological yield of corn had significant considerable role on kernel yield under different irrigation treatments. Lemma *et al*. (2009) reported that Water stressed plants attained less number of branches, lower number of pods per plant and per unit area, smaller number of grains per pod, lighter grain weight, low leaf area index and reduced harvest index which consequently led to a significantly lower grain yield under the dry water regime. Pod number per plant in the dry treatment showed a reduction of 44%, while the reduction of the parameter per square meter was 37%.

The pot experiment showed significant increase of yield and yield components by supplemental irrigation (Table 4). Supplemental irrigation significantly increased pod weight by 65.3% compared to natural rainfall. Irrigation also increased sink strength of faba bean by 57.4% over the rainfed condition. The increase due to the same in seed yield per hectare, pods per plant, seeds per plant, pod length, Leaf dry weight and biomass yield was 41.2, 45.5, 44.2, 11, 13 and 43.2%, respectively. Leaf dry weight of common bean was similarly reported by Emam *et al.* (2010) to be increased significantly by increasing soil moisture availability.

Physiological parameters: Plant growth is a process of biomass accumulation and is a consequence of the interaction of the photosynthesis, long-distance transport, respiration, water relations and mineral nutrition processes. In our experiment, there were observed no significant difference among varieties of faba bean in response to physiological parameters. However, reported a significant difference between durum wheat varieties in response to water deficit treatments in experiment conducted in the area. According to the authors, variability for net photosynthesis rate, instantaneous water use efficiency and stomatal conductance were observed among genotypes at anthesis. However, in the same experiment, the authors explained that there was no significant difference among genotypes for transpiration rate. It can be concluded from the result that variety selection is not promising for obtaining difference in physiological performance of faba bean varieties that could imply improvement in yield. All varieties show similar response in their physiological performance and this phenomenon probably may not be the reason why difference exists in yield of crop varieties. Hence, considering physiological parameters as indirect selection criteria would not be wise to improve yield of faba bean.

Water deficit treatment at anthesis significantly affected the net transpiration rate and Stomatal conductance. Photosynthesis rate, stomatal conductance and transpiration rate were reduced by 30, 44 and 52% due to moisture stress as compared to the control treatment, respectively. Khan *et al.* (2010) pointed out that appropriate stomatal behavior may be useful for improving drought response in faba beans by reducing water loss and increasing transpiration efficiency.

CONCLUSION

In the experiment conducted, no significant difference was found between varieties in physiological parameters but difference existed for yield components. Hence, physiological traits are not promising indirect selection criteria for faba bean breeding programs. Supplemental irrigation had significant effect on yield components and physiological parameters in which it increased some of them and decreased others.

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