Phosphorus and Sulfur Effects on Growth and Physiological Parameters of Snap Bean (*Phaseolus vulgaris* L.) Under Different Irrigation Regimes on Andosol in the Central Rift Valley of Ethiopia

Melkamu Hinsermu [1*], Walelign Worku[2] and Edossa Etissa[1]
[1] *Ethiopian Institute of Agricultural Research, Melkassa Agricultural Research Center*
[2] *Hawassa University, College of Agriculture, School of Plant and Horticultural Sciences*
Melkamu Hinsermu, **Corresponding Author** *E-mail: melkamuhinsermu12@gmail.com*

Abstract

Snap bean is a leading exportable vegetable crop and an important source of nutrition for consumers in many parts of Ethiopia including the Central Rift Valley. However, it's growth and physiology parameters are very stunted and poor due to inadequate moisture and poor soil fertility effect. Lack of phosphorus and sulfur fertilizers and irrigation regime are stunted and poor growth and physiology of snap bean. Therefore; field experiment was conducted at Melkassa Research Center off season in 2017 and 2018 to evaluate the effect phosphorus and sulfur fertilizers application under different irrigation regimes on growth and physiology of snap bean. The experiment was laid out in split-plot design with three replications. Four drip irrigation regimes (100, 85, 70 and 55% ETc) were assigned to the main-plots. Four fertilizer types (0 kg both P and S ha^{-1}, 21 kg P ha^{-1}, 30 kg S ha^{-1} and 21 kg P ha^{-1}+30 kg S ha^{-1}) were randomly assigned to the sub-plots. The analysis of variance revealed that the interaction effect of irrigation regimes and fertilizers application had a significant ($P<0.05$) effect on LAI and CGR. The highest LAI of snap bean was recorded from interaction of 100% ETc with control and S30 kg ha^{-1} with 3.32 and 3.18, respectively. Whereas, the lowest LAI was obtained from interaction of 55% ETc with S30 kg ha^{-1} and control with values of 1.44 and 1.46, respectively. The highest CGR of snap bean was recorded from interaction of 100% ETc with S30 kg ha^{-1} (17.45 g m^{-2} day^{-1}) followed by the control (15.66 g m^{-2} day^{-1}) and with P21 kg ha^{-1}+S30 kg ha^{-1} (14.46 g m^{-2} day^{-1}). The lowest CGR was obtained from interaction of 55% ETc with control (3.33 g m^{-2} day^{-1}). The main effect of various irrigation regimes had a significant ($P<0.05$) effect on NDVI, IPAR and stomata conductance parameters. On the other hand, application of different fertilizers types had no significant effect on all the parameters. The best growth and physiological parameters of snap bean was recorded from the interaction effect of 100 and 85% ETc with different fertilizers types. Therefore; 85% ETc irrigation regime without P and S fertilizers where scarcity of irrigation water is limiting and 100% ETc irrigation regime without P and S fertilizers where there are no water shortages, in the rift valley area with similar soil properties.

Keywords: fertilizers, irrigation, snap bean, growth

Introduction

Snap bean (*Phaseolus vulgaris* L.) comprises a group of common beans that has been selected for succulent pods with reduced fiber primarily grown for its young edible and fleshly pods (Kenneth, 2012). Snap bean is a major source of carbohydrates (39.7%), protein (28.9%), fibre (22%), fat (0.88%), calcium (1.8%), and phosphorus (0.13%) (Ghonimy *et al.*, 2009). It is most important for export with the highest share (94%) among all vegetables in Ethiopia (Lemma, 2011). Even though, snap bean is an important vegetable crop, its' phenology and growth parameters of snap bean is very stunted and poor due to lack of water and nutrient management practices and improved varieties in Ethiopia (Girma, 2009). Inadequate moisture and low soil fertility have been the major constraints to bean production in Ethiopia (Katungi *et al.,* 2010).

Water stress can reduce plant height, number of leaves plant^{-1}, number of branches plant^{-1}, and total fresh weight for snap bean when the supplied water was decreased from 80 to 60% of ETC (Saleh *et al.,* 2018). Under water stress conditions, snap bean vegetative growth is stunted and reduced at photosynthetic rates (Suzuki *et al.,* 1987). Efficient use of irrigation water is becoming increasingly important for enhancing profitability and resource conservation.

Poor soil fertility is a major problem that affects snap bean production in Ethiopia (Tesfaye, 2017). Among the essential nutrients; P and S are limiting nutrients (Jamal *et al*., 2010; Khan and Mazid, 2011). Phosphorus is one of the most sufficiently determinants of plant growth (Wang *et al.*, 1998). It is an important for intensify root growth, which improves the water and other nutrients absorption and translocation to the growing parts of the plants, resulting in an increased photosynthetic process and then better production. P deficiency reduces plant growth and crop productions especially in arid and semi-arid areas with calcareous soils (Bargaz *et al.*, 2016).

Sulfur is limiting nutrient nowadays due to nutrient mining under zero application of sulfur fertilizer, increases crop residue removal, and poor management practices (Alemu *et al.,* 2016). Until recently, sulfur received a little attention due to conviction for many years, that fertilizers and atmospheric inputs supplied the soil with adequate amounts of sulfur (Jamal *et al*., 2010). However, nowadays arable soils in many areas are proved to be sulfur deficient (Goswam, 2014). Low soil S had effect on phenology, growth and yield and yield related parameters of snap bean. Similarly, various soil tests from sample collected in different farm fields and regions in Ethiopia showed that lack of sulfur nutrient (ATA, 2015). Thus, this experiment was carried out with the following objectives:

- To evaluate the effect of phosphorus and sulfur fertilizers application on growth and physiology of snap bean.
- To determine the effect of irrigation regimes on growth and physiology of snap bean.

Materials and Methods

Description of the study area

The experiment was conducted at Melkassa Agricultural Research Center in 2017 and 2018 during off-season. The site is found at 117 km South East of Addis Ababa with geographic co-ordinate of 8^{o}24'N latitude and 39^{o}12'E longitude. It situated at an altitude of 1550 m.a.s.l. The area receives mean annual rainfall of 763 mm. The mean annual maximum and minimum temperature of the site is 28.6 and 13.8^{0}C, respectively. The average bulk density of the soil is 1.13 g cm^{-3}. The soil is slightly alkaline ranging from 7.4 to 7.8 pH.

Experimental design and treatments

The experiment was laid out in split-plot design with three replications. Four drip irrigation regimes (100, 85, 70, and 55% ETc) were assigned to main-plots. Four fertilizer types (0 kg both P and S ha^{-1}, 21 kg P ha^{-1}, 30 kg S ha^{-1} and 21 kg P ha^{-1}+30 kg S ha^{-1}) were to sub-plots. The area of each plot was 12 m^2. Three central rows were harvested, 3 rows were used for distractive samples, and the marginal rows were used as border rows. Spacing between plots and blocks were 1.5 m used.

Experimental procedures

Snap bean "Plati" variety was used for experiment at a spacing of 50 and 10 cm between rows and plants, respectively. P and S fertilizers were applied at sowing in the form of TSP (46% P_2O_5) and K_2SO_4 (51% K_2O and 18% S), respectively. KCl (60% K_2O and 48% Cl) was used to balance the supply of K applied through K_2SO_4. Low-head drip irrigation system was used for the experiment. Irrigation treatment was applied based on weather data obtained from meteorological station. Irrigation treatment was carried out when plants reached the first two true leaves stage.

Soil samples collection and analysis

Composite soil samples were collected from representative 12 spots using diagonal sampling method by using auger at a depth of 0-20, 20-40 and 40-60 cm for physico-chemical soil analysis. Soil texture (%) was determined by using hydrometer method (Bouyoucos, 1962). Bulk density (g cm^{-3}) was determined from undisturbed soil using core sampler. Electrical conductivity (dS m^{-1}) was analyzed on a 1:2.5 soil: H_2O suspension using a conductivity meter

(Sahelemedhin and Taye, 2000). Soil pH was determined on a 1:2.5 soil: H_2O solution suspension using a pH meter. Organic carbon (%) was determined using wet oxidation method (Walkley and Black, 1934). Organic matter (%) was calculated by multiplying the OC% by a factor of 1.724. Total N (%) was determined by using Micro-Kjeldahl digestion (Jackson, 1973). Available P (mg kg^{-1}) was determined by Olsen's method (Cottenie *et al.,* 1982). Exchangeable K was determined by using flame photometer (Hesse, 1971). Available S (mg kg^{-1}) was estimated by turbidity (Tandon, 1986). Soil samples were analyzed at MARC and DZARC soil laboratory.

Data collected

Growth anaysis parameters

Leaf area index (LAI) was calculated at 32, 46, and 60 DAS using the following equation (Thomas and Winner, 2000).

$$LAI = \frac{Leaf \quad area}{Ground \quad area}$$

(Eq. 1.1)

Crop growth rate (CGR) was estimated at 46 and 60 DAS using the following equation (Hunt *et al*., 2002).

$$CGR = \frac{W2 - W1}{T2 - T1} = g\ m^{-2}\ day^{-1}$$

(Eq. 1.2)

Where; W1, W2 = subscripts 1 and 2 indicate W (plant dry weight) on two occasions (g m-2), T1, T2 = subscripts 1 and 2 indicate consecutive samplings at time T2 and T1.

Physiological parameters

Normalized difference vegetation index (NDVI) was determined using Green Seeker 505 (Hand-held Manual NTech Industries INC., USA) portable model instrument. It measured green biomass from harvested rows at 40, 54 and 68 DAS and was taken at 11:00 am to 2:00 pm (Dobos *et al*., 2012). Stomata conductance (mmol m^{-2} s^{-1}) was measured using steady state porometer (Model Sc-1, Decagon Devices, INC.). It was measured from the mean of 3 plants $plot^{-1}$ at 40 and 54 DAS from fully expanded leaf at 3rd leaf from the top and was taken at 9:00 to 11:00 am. Intercepted photosynthetically active radiation (IPAR) (µmol m^{-2} s^{-1}) was measured using Ceptometer (Model LP-80, Decagon Devices, INC. WA, USA) on harvested rows at 44 DAS and was taken at 12:00 am to 1:00 pm.

Stastical data analysis

All data were subjected to analysis of variance using GLM procedure of the SAS software version 9.0 (SAS, 2004). The assumptions of ANOVA for normality of distribution and homogeneity of variance were checked, and statistical analyses where the F-ratios was found to be significant, mean separation was performed using Fisher's protected LSD at the 5% probability level.

Results and Discussion

Physico-chemical properties of the soil

Soil textural class and bulk density at all soil depths was loam and low, respectively in Table 1. Soil pH was 7.40 at all soil depths and is moderately alkaline (Motsara and Roy, 2008). Electrical conductivity of soil tested was free of salinity. Organic carbon at all soil depths, which could be rated as medium. Organic matter (OM) at a depth of 0-20 and 20-40 cm, which showed that high rating. However, OM at a depth of 40-60 cm, which could be rated as moderating (Hazelton and Murphy, 2007). Total N from all soil depths, which showed that low rating. Exchangeable K from a depth of 0-20, 20-40 and 40-60 cm (Table 2) was rated as very high. Available P at a depth of 0-20 cm was rated as medium, while at a depth of 20-40 and 40-60 cm, which was rated as low (Edossa *et al*., 2014). Available S at a soil depth of 0-20, 20-40 and 40-60 cm could be rated as medium (Goswam, 2014).

Table 1. Physical soil properties of experimental field before sowing

Soil depth (cm)	Bulk density (g cm^{-3})	Particles size distribution (%)			Textural classes
		Sand	Clay	Silt	
0-20	1.01	31.25	21.25	47.50	Loam
20-40	1.07	41.25	18.75	40.00	Loam
40-60	1.06	41.25	18.75	40.00	Loam

Table 2. Chemical soil properties of experimental field before sowing

Soil depth(cm)	pH	EC (dS m^{-1})	OC (%)	OM (%)	TN (%)	Ava. P (mg kg^{-1})	Exc. K (cmol (+) kg^{-1})	Ava. S (mg kg^{-1})
0-20	7.25	0.27	2.96	5.11	0.09	13.53	2.26	16.43
20-40	7.35	0.33	2.57	4.44	0.08	8.81	2.37	15.35
40-60	7.58	0.27	2.50	4.30	0.07	5.66	2.54	14.26

Growth analysis

Leaf area index

Use of various irrigation regimes, fertilizers and their interactions had significant *($P\leq0.05$)* effect on leaf area index at 60 DAS. The highest leaf area index of snap bean was recorded from interaction of 100% ETc with control and S30 kg ha^{-1} with 3.32 and 3.18, respectively. Whereas the lowest leaf area index was obtained from interaction of 55% ETc with S30 kg ha^{-1} and control with values of 1.44 and 1.46, respectively (Table 3). Generally, as irrigation regimes decreased, leaf area index was decreased, which might be due to reduction of leaf growth and accelerated leaf senescence (Table 3). Similar with El-Noemani *et al*. (2010) and Mohammad (2013) under low irrigation regimes, shrinking of leaves, acceleration in yellowing and aging of older leaves caused reduced leaf area index and also rate of light absorption was reduced.

Table 3. Interaction effect of various irrigation regimes and fertilizers application on leaf area index and crop growth rate of snap bean

Irrigation regimes (%)	Leaf area index				Crop growth rate (g m^{-2} day^{-1})			
	Fertilizers types (kg ha^{-1})							
	0	P21	S30	P21+S30	0	P21	S30	P21+S30
55 ETc	1.46^{f}	2.04^{b-f}	1.44^{f}	1.98^{b-f}	3.33^{h}	8.26^{efg}	7.94^{efg}	6.16^{fgh}
70 ETc	2.14^{b-f}	2.00^{b-f}	1.64^{ef}	2.20^{b-f}	11.43^{b-e}	9.66^{c-f}	8.42^{efg}	9.47^{c-f}
85 ETc	1.83^{def}	2.67^{ab}	2.34^{b-e}	1.84^{c-f}	8.50^{efg}	9.11^{d-g}	13.2^{a-d}	9.22^{c-g}
100 ETc	3.32^{a}	2.63^{abc}	3.18^{a}	2.46^{bcd}	15.66^{ab}	13.64^{abc}	17.45^{a}	14.46^{ab}
LSD (0.05)	0.71				4.47			
CV (%)	19.17				24.28			

Means within each column with different letters are significantly different using LSD at P ≤ 0.05

Crop growth rate

Use of various irrigation regimes and their interactions had brought significant *($P \leq 0.05$)* effect on CGR at 60 DAS. However, the application of fertilizers had non-significant effect on CGR. The highest CGR of snap bean was recorded from interaction of 100% ETc with S30 kg ha^{-1} (17.45 g m^{-2} day^{-1}) followed by the control (15.66 g m^{-2} day^{-1}) and with P21 kg ha^{-1}+S30 kg ha^{-1} (14.46 g m^{-2} day^{-1}). The lowest CGR was obtained from interaction of 55% ETc with control (3.33 g m^{-2} day^{-1}) (Table 6). It indicated that as irrigation regimes increases, plants easily to take up minerals from the soil, then enhancing cell enlargement and elongation resulting in increases crop growth rate. Similar with El-Noemani *et al*. (2010); Ghassemi and Mardfar, 2008) low CGR was observed under low irrigation regime on common bean due to stomata closure, reduced minerals uptake by plants, and hence affected plant growth.

Physiological parameters

Normalized difference vegetation index

Irrigation regimes had brought highly significant ($P \leq 0.01$) effect on NDVI at 40, 54 and 68 DAS. However, application of fertilizers and their interactions had non-significant effect on NDVI at 40, 54 and 68 DAS. The highest NDVI was recorded from 100% ETc, while the lowest NDVI was obtained from 55% ETc at 40, 54 and 68 DAS (Figure 1). The highest irrigation regimes gave deep greener leaves, vigorous, and healthy plants with better biomass and pod yield. Similar with Nemeskeri *et al*. (2017)

NDVI was significantly lower under low irrigation regimes compared to those under optimal water supply condition due to retarded growth of snap bean.

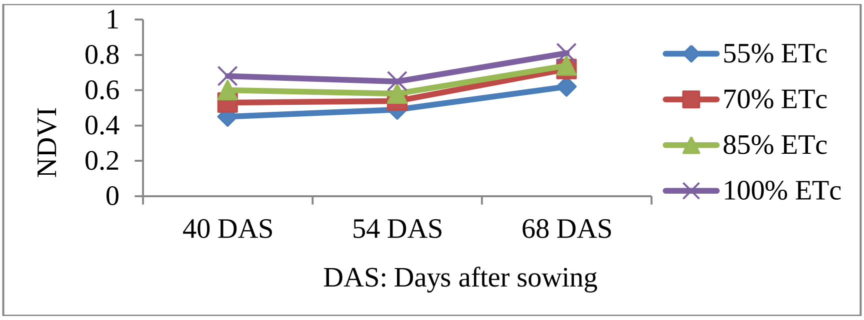

Figure 1. Normalized difference vegetation index of snap bean as affected by different irrigation regimes

Stomata conductance

Irrigation regimes had brought significant (P≤0.05) effect on stomata conductance at 40 and 54 DAS, but fertilizers and their interactions had non-significant effect on stomata conductance at 40 and 54 DAS. The highest stomata conductance was recorded from 100% ETc at both 40 and 54 DAS, while the lowest was obtained from 55% ETc in table 4. It indicated that at low irrigation regimes, stomata conductance was decreased. Similar with both Chaves *et al*. (2002) and Yokota *et al*. (2002) leaf stomata conductance decreases as soils get dry, either in response to drying of roots or leaves, or both and as result this decreased photosynthesis under mild to moderate water stress.

Table 4. Mean value of stomata conductance and IPAR parameters as influenced by different irrigation regimes and fertilizers applications on snap bean

Fertilizers types (kg ha^{-1})	Stomata conductance (mmol m^{-2} s^{-1})		IPAR (µmol m^{-2} s^{-1})
	40 DAS	54 DAS	44 DAS
0	386.32	192.02	950.25
P21	347.27	201.69	1141.58
S30	354.46	191.09	1057.83
P21+S30	337.09	222.05	1096.25
LSD (0.05)	NS	NS	NS
CV (%)	28.00	19.96	36.12
Irrigation Regimes (%)			
55 ETc	293.27^{b}	175.98^{b}	853.08^{b}
70 ETc	352.00^{ab}	187.18^{ab}	965.25^{b}
85 ETc	355.07^{ab}	205.17^{ab}	1015.50^{b}
100 ETc	424.88^{a}	239.33^{a}	1412.08^{a}
LSD (0.05)	83.34	40.21	210.48
CV (%)	23.42	20.04	19.52

Means within each column with different letters are significantly different using LSD at P≤0.05

Intercepted photosynthetically active radiation

Irrigation regimes had brought highly significant *($P \leq 0.01$)* effect on IPAR at 44 DAS. However, application of fertilizers and their interactions didn't show significant effect on IPAR at 44 DAS. The result disagrees with Mario *et al.* (2006) reported that application of phosphorus gave higher NDVI values than zero phosphorus treatment. The highest IPAR of snap bean was recorded from 100% ETc with 1412.08 µmol m^{-2} s^{-1}, while statistically similar lower IPAR were obtained from 55% ETc, 70% ETc and 85% ETc with 853.03, 965.25 and 1015.50 µmol m^{-2} s^{-1}, respectively (Table 4). This indicated that as irrigation regime increased; larger leaves were produced leading to higher interception of photosynthetic active radiation. Low irrigation regimes, reduced IPAR owing to reduced light interception and decreasing photosynthetic rate. Similarly, Flexas *et al.* (2004) under low irrigation regime, stomata closure and reduction in leaf internal CO_2 concentration are the main causes for reduced leaf photosynthetic rates.

Conclusion and Recommendation

Snap bean is the most important exporting vegetable crop grown for young edible and fleshly pods. Its' production in Ethiopia has increased from year to year, but their growth and physiological parameters is very stunted and poor due to inadequate moisture and soil fertility problems. Lack of phosphorus and sulfur fertilizers and irrigation regime are stunted and poor growth and physiology of snap bean. Therefore; field experiment was conducted at Melkassa Research Center to evaluate the effect phosphorus and sulfur fertilizers application under different irrigation regimes on growth and physiology of snap bean. The analysis of variance revealed that the interaction effect of irrigation regimes and fertilizers application had a significant ($P<0.05$) effect on LAI and CGR. The highest LAI of snap bean was recorded from interaction of 100% ETc with control and S30 kg ha^{-1} with 3.32 and 3.18, respectively. Whereas, the lowest LAI was obtained from interaction of 55% ETc with S30 kg ha^{-1} and control with values of 1.44 and 1.46, respectively. The highest CGR of snap bean was recorded from interaction of 100% ETc with S30 kg ha^{-1} (17.45 g m^{-2} day^{-1}) followed by the control (15.66 g m^{-2} day^{-1}) and with P21 kg ha^{-1}+S30 kg ha^{-1} (14.46 g m^{-2} day^{-1}). The lowest CGR was obtained from interaction of 55% ETc with control (3.33 g m^{-2} day^{-1}). The main effect of various irrigation regimes had a significant ($P<0.05$) effect on NDVI, IPAR and stomata conductance parameters. On the other hand, P and S fertilizers application had no significant effect in all parameters. Lack of fertilizer types response could partially be attributed to the medium level of soil availability for nutrients, P and S. Based on this current finding; 85 and 100% ETc without P and S fertilizers application, which gave better growth and physiology of snap bean. Therefore, 85% ETc without P and S fertilizers, where irrigation water is a limiting factor and 100% ETc without P and S fertilizer application, where there are no water shortages in the rift valley area with similar soil properties.

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