Yield and Quality Response of Snap Bean (Phaseolus vulgaris L.) to P and S Fertilizers Application under Different Irrigation Regimes in Central Rift Valley of Ethiopia

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Abstract

Snap bean (Phaseolus vulgaris L.) is a leading exportable vegetable crop and it is a protein source for consumers in many parts of Ethiopia. However, its' current national productivity of 4.12 t ha^{-1} is lower than its' potential as a result of inadequate moisture and poor soil fertility. Therefore, the field experiment was conducted at Melkassa Agricultural Research Center during the dry season in 2017 and 2018 to evaluate the response of snap bean to phosphorus and sulfur fertilizers application under different irrigation regimes on yield and quality. 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, 21 kg P ha^{-1}, 30 kg S ha^{-1} and 21 kg P ha^{-1}+30 kg S ha^{-1}) were allocated to sub-plots. The analysis of variance revealed that the interaction effect of irrigation regimes and fertilizers application had a significant ($P \leq 0.05$) effect on first grade and total pod yield. The main effect of various irrigation regimes had a significant ($P \leq 0.05$) effect for all yield and quality parameters except, second grade pod yield and pod diameter. On the other hand, application of different fertilizers types had non-significant effect in all parameters. The highest marketable yield was recorded from the interaction effect of 100% ETc with different fertilizers types' application. The partial budget analysis indicated that the best treatments were 85 and 100% ETc without fertilizers application, which gave higher net benefits of 111,879.2 and 160,242.6 ETB ha^{-1}, respectively with an acceptable marginal rate of returns for snap bean production. Therefore, snap bean producers could consider 85% ETc without fertilizers application where scarcity of irrigation water is limiting and 100% ETc without fertilizers application where there are no water shortages, in the central rift valley of Ethiopia with similar soil properties.

Keywords: fertilizers, irrigation, plati, yield

1. Introduction

Snap bean (*Phaseolus vulgaris* L.) comprises a group of common bean that has been selected for succulent pods with reduced fiber primarily grown for its young edible and fleshly pods (Kenneth, 2012). It 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). Also, the most important for export with the highest share (94%) among all vegetables (Lemma, 2011).

Even though, snap bean is an important vegetable crop, its' productivity and quality remained low and poor in Ethiopia (Amberber, 2013). National productivity in Ethiopia was 4.12 t ha^{-1}, which is low (Tesfaye, 2017) compared to the world productivity of about 14.22 t ha^{-1} (CIAT, 2006) due to lack of water and nutrient management practices and improved varieties in Ethiopia (Girma, 2009). Among these constraints, inadequate moisture and low soil fertility have been the major constraints to bean production in Ethiopia (Katungi *et al.,* 2010).

Water stress that persists during flowering period can reduce snap bean yield by 40 to 50% due to decline in leaf water potential, stomata conductance, and photosynthetic rate (Barrios *et al*., 2005). Not only water stress, but also poor soil fertility is a major problem affect 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). In Ethiopia, the amount of available P in soils is largely insufficient to meet the demand of beans (Azmera and Pellegrino, 2017). P deficiency can reduce snap bean yield by 60 to 75% (Snapp *et al.,* 2002).

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). 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 under different irrigation regimes

on yield and quality of snap bean.
- ➢ To determine economically feasible phosphorus and sulfur fertilizers application and irrigation regime for snap bean production.

2. Materials and Methods
2.1. Description of the Study Area
The experiment was conducted at MARC in 2017 and 2018 during off-season. The site is found at 117 km South East of Addis Ababa with geographic co-ordinate of $8^o24'$N latitude and $39^o12'$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 13.8^0C, respectively.

2.2. 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, 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.

2.3. 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. 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. 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. Organic matter (%) was calculated by multiplying the OC% by a factor of 1.724. Total N (%) was determined by using Micro-Kjeldahl digestion. 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.

Estimation of soil water characteristics
Measurement of soil moisture
Moist soil weight (W) was determined by weighing the sample at the time of soil sampling and dry weight was obtained after drying the sample to a constant weight in an oven at 105^oC for 24 hrs (Hillel, 1980).

$$W = \frac{\text{Wet soil weight} - \text{Dry soil weight}}{\text{Dry soil weight}} * 100 \qquad \text{(Eq. 2.1)}$$

Estimation of crop water requirement
Initial soil water content for topsoil at the time of sowing was assumed to be close to field capacity due to pre-irrigation. Then, the proper amount of crop water requirement is the amount of daily ETo multiplied by Kc (Allen *et al*., 1998).

$$\text{ETc} = \text{ETo} * \text{Kc} \qquad \text{(Eq. 2.2)}$$

Reference evapotranspiration (ETo) was estimated from weather data using CROPWAT windows version 8. Drip irrigation was applied based on ETo (FAO, 2009a) value of the previous day. The RAW was computed from the following equation:

$$\text{RAW} = \text{p} * \text{TAW} \qquad \text{(Eq. 2.3)}$$

Where; RAW = readily available soil moisture in the root zone [mm], p = fraction for allowable soil moisture depletion for no stress, TAW = total available water [mm]
Net irrigation (IRn) was amount of irrigation water required to bring the soil moisture level in the effective root zone to field capacity (Michael, 2008).

$$\text{IRn} = \text{ETc} - \text{Pe} \qquad \text{(Eq. 2.4)}$$

Where; ETc = crop evapotranspiration [mm day^{-1}], Pe = effective rainfall [mm]

2.4. Data Collected

Yield and yield components

Number of pods plant[-1] was determined by counting number of pods of 5 plants randomly selected in each plot. Fresh and dry pod weights (g) were estimated from the mean weights of 5 randomly selected plants in each plot. Snap bean pod yield were classified in two grades (Sunripe company manual, 2013). In the first grade, pods should be turgid, easily snapped, very tender, straight, bright in color with a fresh appearance, and stringless. In the second grade, pod sizes were smaller and irregular in shapes. Total yield (t ha^{-1}) was harvested from three central rows in each plot and all pods included regardless of their qualities.

Pod quality parameters

Pod length (mm) was measured from the initial to the tip of the pods from the mean of 5 pods randomly selected in each plot using ruler. Pod diameter (mm) was determined from the mean of 5 pods randomly selected in each plot using sieve by inserting the pods into the appropriate hole best fitting for the pod size. Pod texture was determined at harvest maturity stages from the following five visual scales (1=very fine, 2= fine, 3=reasonably fine, 4=coarse/rough, 5=very coarse/rough). Pod appearance was recorded at harvest maturity stages from 5 visual scales (1=excellent, 2=good, 3=acceptable, 4=poor, 5=rejected). Pod curvature was recorded at harvest maturity stages from 4 visual scales (1=straight, 2=slightly straight, 3=curved, 4=re-curved) (Hussein *et al*., 2015).

2.5. Stastical Data Analysis

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

3. Result and Discussions

3.1. Physico-Chemical Properties of the Soil

Soil textural class and bulk density 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 indicated 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. 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

3.2. Yield and Yield Components

Number of pods per plant

Application of various irrigation regimes had brought significant $(P \leq 0.05)$ effect on number of pods plant[-1], but the use fertilizers and their interactions didn't showed significant effect on number pods plant[-1] in both years. The highest number of pods plant[-1] were obtained at 100% ETc, while the lowest pod numbers plants[-1] were recorded from 55% ETc (Table 3). Similar with Onder *et al*. (2006) reduction of number of pods plant[-1] due to water stress and associated with reduction in the photosynthetic chlorophyll pigments.

Table 3. Mean value of number pods plant^{-1} and 2nd grade pod yield parameters as influenced by different irrigation regimes and fertilizers applications on snap bean in 2017 and 2018.

Fertilizers types (kg ha^{-1})	Number of pods plant^{-1}			2nd grade pod yield (t ha^{-1})		
	2017	2018	Combined	2017	2018	Combined
Control	9.62	9.99	9.80	1.40	1.92	1.66
P21	9.51	9.28	9.40	1.32	1.64	1.48
S30	9.87	9.61	9.74	1.25	1.83	1.54
P21+S30	10.22	10.38	10.30	1.31	1.76	1.53
LSD(0.05)	NS	NS	NS	NS	NS	NS
CV (%)	22.73	21.94	19.77	17.94	15.46	19.44
Irrigation Regimes (%)						
55 ETc	7.81^b	8.29^b	8.64^b	1.19^c	1.67	1.42
70 ETc	9.90^{ab}	9.40^b	9.10^b	1.16^{bc}	1.71	1.43
85 ETc	9.93^{ab}	9.48^b	10.46^a	1.40^{ab}	1.71	1.56
100 ETc	11.53^a	12.10^a	11.02^a	1.53^a	2.07	1.80
LSD (0.05)	2.76	2.01	1.15	0.24	NS	NS
CV (%)	28.34	20.49	11.74	23.77	25.11	26.12

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

Fresh and dry pod weight
Irrigation regimes had brought significant ($P≤ 0.05$) effect on fresh and dry pod weights in both years. However, the application fertilizers and their interactions had non-significant effect on fresh and dry pod weights. The highest fresh and dry pod weight were obtained from 100% ETc, while the lowest fresh and dry pod weight were obtained from 55% ETc (Table 4). Agreement with Onder *et al.* (2006) under low irrigation regimes, fresh and dry pod weights of snap bean were decreased.

Table 4. Mean value of fresh and dry pod weight plant^{-1} parameters as influenced by different irrigation regimes and fertilizers application on snap bean in both 2017 and 2018.

Fertilizers types (kg ha^{-1})	Pod fresh weight plant^{-1} (gm)			Pod dry weight plant^{-1} (gm)		
	2017	2018	Combined	2017	2018	Combined
0	59.20	51.94	55.58	5.05	7.13	6.10
P21	51.11	46.93	49.02	4.20	8.56	6.40
S30	47.27	45.70	46.48	4.03	8.38	6.20
P21+S30	50.25	50.36	50.31	4.21	8.19	6.22
LSD (0.05)	NS	NS	NS	NS	NS	NS
CV (%)	24.21	27.74	18.91	22.41	20.03	23.52
Irrigation Regimes (%)						
55 ETc	45.74^b	37.63^b	41.68^c	3.89^b	7.06^b	5.5b
70 ETc	50.14^a	44.45^b	47.30^{bc}	4.40^a	8.08^{ab}	5.89ab
85 ETc	55.28^a	45.96^b	51.32^b	4.51^a	8.24^{ab}	6.25ab
100 ETc	56.70^a	66.88^a	61.09^a	4.68^a	10.03^a	7.28a
LSD (0.05)	11.32	14.84	5.57	1.32	2.04	1.8
CV (%)	27.30	30.50	15.06	27.83	25.36	22.63

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

First grade pod yield
Irrigation regimes and interaction effect had brought highly significant ($P ≤ 0.01$) effect on first grade pod yield. However, the application of fertilizers had non-significant on 1st grade pod yield. Higher 1st grade pod yield was recorded from interaction of 100% ETc with all fertilizers, whereas lower 1st grade pod yield was obtained from interactions of 55% ETc with S30 and P21+S30 kg ha^{-1} (Table 5). Similar with Gupta *et al.* (2017) who reported that under low irrigation regimes, stomata openings are closed by signals from roots leading to reduction in leaf gas exchange and the mechanism ultimately lead to decreased pod yield.

Table 5. Interaction effect of various irrigation regimes and fertilizers application on 1st grade pod yield and total pod yield of snap bean

| Irrigation regimes (%) | 1st grade pod yield (t ha^{-1}) | | | | Total pod yield (t ha^{-1}) | | | |
| | Fertilizers types (kg ha^{-1}) | | | | | | | |
	0	P21	S30	P21+S30	0	P21	S30	P21+S30
55 ETc	3.47^{fg}	4.46^{ef}	2.89^{g}	3.25^{g}	5.75^{gh}	7.41^{efg}	5.36^{h}	6.57^{gh}
70 ETc	5.61^{cd}	3.39^{fg}	5.37^{de}	5.00^{de}	8.93^{def}	7.00^{gh}	9.17^{cde}	7.25^{fgh}
85 ETc	6.58^{c}	8.39^{b}	6.04^{cd}	6.58^{c}	9.32^{cd}	10.98^{bc}	9.72^{cd}	9.99^{cd}
100 ETc	9.63^{a}	9.31^{ab}	9.19^{ab}	9.46^{ab}	13.75^{a}	12.53^{ab}	13.48^{a}	12.36^{ab}
LSD (0.05)	1.08				1.78			
CV (%)	10.51				11.32			

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

Total pod yield

Irrigation regimes and their interactions had a significant *(P≤0.05)* effect on total pod yield, but fertilizers non-significant effect on total pod yield. Higher total pod yield was recorded from interaction of 100% ETc with all fertilizers, whereas the lowest total pod yield was obtained from interaction of 55% ETc with S30 (Table 5). Similar with those Abdel-Mawgoud (2006) increasing irrigation regimes, increased total pod yield due to increased applied water, which improved moisture content in the soil.

4.4. Pod Quality Parameters

Pod length

Irrigation regimes had brought highly significant ($P \leq 0.01$) effect on pod length, but the application of fertilizers and their interactions non-significant effect on pod length. The highest pod length was recorded from 100% ETc in both years, while the lowest pod length was obtained from 55% ETc (Table 6). Similar with Hosny *et al*. (2015) low irrigation regime decrease pod length of snap beans, which is due to water stress conditions.

Pod diameter

Irrigation regimes, fertilizers and their interactions, didn't show any significant effect on pod diameter (Table 6). As irrigation regimes increases, pod diameter numerically increased. Contrast to this study Abdel-Mawgoud (2006) pod diameter increased with increasing irrigation level up to the full irrigation application.

Table 6. Mean value of pod length and diameter parameters as influenced by different irrigation regimes and fertilizers applications on snap bean in 2017 and 2018.

| Fertilizer types (kg ha^{-1}) | Length (mm) | | | Diameter (mm) | | |
	2017	2018	Combined	2017	2018	Combined
0	130.77	134.6	132.70	8.74	8.50	8.62
P21	130.65	133.6	132.13	8.81	8.29	8.55
S30	133.33	132.5	132.91	8.79	8.44	8.61
P21+S30	130.37	132.6	131.49	8.83	8.29	8.56
LSD (0.05)	NS	NS	NS	NS	NS	NS
CV (%)	3.60	4.68	2.73	3.56	4.64	2.69
Irrigation Regimes (%)						
55 ETc	126.94^{b}	127.87^{c}	128.51^{c}	8.64	8.19	8.50
70 ETc	129.15^{ab}	132.33^{bc}	129.64^{bc}	8.76	8.36	8.53
85 ETc	133.33^{ab}	133.77^{b}	133.55^{ab}	8.88	8.46	8.61
100 ETc	135.70^{a}	139.35^{a}	137.53^{a}	8.89	8.52	8.70
LSD (0.05)	5.9	4.82	4.60	NS	NS	NS
CV (%)	5.08	3.62	3.48	2.88	6.74	4.04

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

Pod texture, appearance and curvature

Pod texture, appearance, and curvature of snap bean were influenced by irrigation regimes. The highest fine pod texture, excellent pod appearance, and straight pod curvature was recorded from 100% ETc, whereas the highest coarse pod texture, less attractive pod appearance, and curved pod curvature was obtained from 55% ETc (Figure 2). Fit with Sezen *et al.* (2008) pod color brightness and appearance improve as the irrigation regime increased.
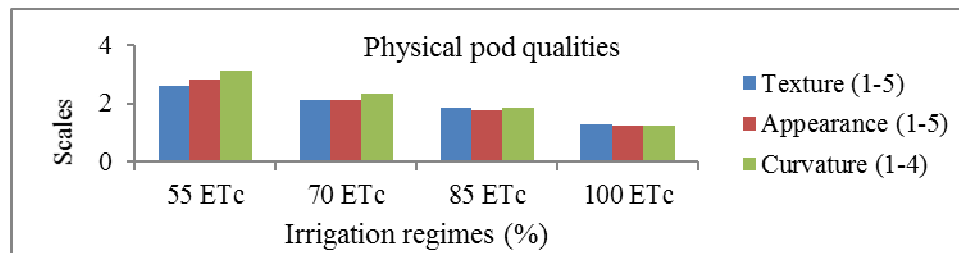
Figure 2. Mean of pod texture, appearance and curvature of snap bean influenced by irrigation regimes

4.5. Partial Budget Analysis

Partial budget analysis indicated that the best treatment was 100% ETc without fertilizers application, which gave highest net benefits 160,242.6 ETB ha^{-1} and also the second alternative recommendation from 85% ETc without fertilizers application, which gave 111,879.2 ETB ha^{-1} net benefits with an acceptable marginal rate of returns for snap bean production in table 7.

Table 7. Dominance analysis and marginal rate of returns of interaction effect of different irrigation regimes and fertilizers applications on marketable pod yield of snap bean

Treatments		T. variable cost (ETB ha^{-1})	Net benefit (ETB ha^{-1})	Dominance	Marginal cost (ETB ha^{-1})	Marginal benefits (ETB ha^{-1})	Marginal rate returns (%)
55% ETc	0	372.6	65372.4		-	-	-
70% ETc		474.2	105770.8		101.6	40398	39758.29
85% ETc		575.8	111879.2		101.6	6108	6011.61
100% ETc		677.4	160242.6		101.6	48363	47597.09
55% ETc	P21	882.1	83222.9	Dominated			
70% ETc		983.7	68176.3	Dominated			
85% ETc		1085.3	129864.7	Dominated			
100% ETc		1186.9	147853.1	Dominated			
55% ETc	S30	1299.6	55535.4	Dominated			
70% ETc		1401.2	92693.8	Dominated			
85% ETc		1502.8	107577.2	Dominated			
100% ETc		1604.4	154320.6	Dominated			
55% ETc	P21+S30	1689.1	71480.9	Dominated			
70% ETc		1790.7	82044.3	Dominated			
85% ETc		1892.3	110562.7	Dominated			
100% ETc		1993.9	151231.1	Dominated			

5. Conclusion and Recommendation

Snap bean is the most important exporting vegetable crop grown for young edible and fleshly pods. Snap bean production in Ethiopia has increased from year to year both for export and local markets, but their productivity is very low and poor quality due to inadequate moisture and soil fertility problems. Water stress at the critical stage can reduce snap bean yield and quality. On the other hand, a major problem of snap bean production in Ethiopia is poor soil fertility.

The interaction effect had brought significant effect on first grade yield and total pod yield. The main effect of irrigation regimes had a significant effect in all yield and quality parameters except, second grade pod yield and pod diameter. On the other hand; the main effect of fertilizers applications didn't showed significant effect in all parameters. Lack of response by the snap bean to the three fertilizer types could partially be attributed to the medium level of soil availability for both nutrients, P and S. Based on the current findings, 85 and 100% ETc without fertilizer applications, which gave higher yield and better quality. Therefore, snap bean producers could consider 85% ETc without fertilizer applications where irrigation water is a limiting factor and 100% ETc without fertilizer applications where there are no water shortages in the central rift valley of Ethiopia with similar soil properties.

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