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EFFECT OF PHOSPHOUS APPLICATION AND PLANT DENSITY ON YIELD AND YIELD COMPONENTS OF HARICOT BEAN (Phaseolus vulgaris L.) AT YABELLO SOUTHERN EHIOPIA

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***Abstract**: Haricot bean (Phaseolus vulgaris L.) is an important pulse crop in Ethiopia and the most important yield limiting factors in this crop are plant density and level of phosphorous in the soil. A field experiment was conducted at Yabello Pastoral and Dryland Agriculture Research Center, southern Ethiopia, from March to July in 2012, 2013 and 2014 to determine optimum plant density and level of phosphorous. The experiment was laid out in RCBD with (4*5) factorial arrangement. Four plant populations (125000 plants ha^{-1}, 148148 plants ha^{-1}, 190476 plants ha^{-1} and 250,000 plants ha^{-1} with five levels of phosphorous (0 kg P_2O_5 ha^{-1}, 35 kg P_2O_5 ha^{-1}, 46 kg P_2O_5 ha^{-1}, 58 kg P_2O_5 ha^{-1} and 69 kg P_2O_5 ha^{-1}) in three replications. Increasing phosphorous level and plant population has significantly reduced days to 50% flowering and physiological maturity while plant height and above ground dry biomass increased in this case. The highest plant density with no fertilizer has decreased number of braches per plant. The highest number of pod per plant, seed per pod and hundred seed weight were recorded at the lowest density and highest phosphorous level. Harvest index increased from (24.67 – 44.11) with increasing plant density from 125000 - 190,476 plants ha^{-1} and not consistent with phosphorous rate. The Phosphorous level and plant density had affected grain yield of common bean as the highest grain yield (3685 kg ha^{-1}) obtained at 46 kg ha $^{-1}$ Phosphorous and 190,476 plants ha $^{-1}$ and the lowest grain yield was recorded at the lowest 125,000 plant density and no Phosphorous application. Therefore, it can be concluded that, application of **46** kg Phosphorous ha^{-1} and plan population of **190,476** plants ha^{-1} (35 cm × 15cm) is recommended for better haricot bean production at Yabello and similar areas of Borana Zone, Southern Ethiopia.*

***Keywords**: physiological maturity, biomass, plant population, harvest index, interaction effect.*

INTRODUCTION

Common bean *(P. vulgaris* L.) is widely grown in low land and mid altitude areas. The crop also does well in some areas as low as 500 m and as high as 1900 m.a.s.l. that receive a well distributed average rainfall of 500 to 1500 mm throughout the growing season (Bulti, 2007). It is an important pulse crop occupying about 366,877 ha (19.69% of land area allocated to pulses) and producing about 463,008 tons of grain (16.83% of the total pulses production) (CSA, 2013). Average yield (1.26 t ha^{-1}) of common bean is low which is partly because phosphorus is deficient in about 70% of soils of Ethiopia (Mamo and Haque, 1991). The pulses serve as an important protein supplement in the cereal based Ethiopian diet and form significant export commodity group to fetch hard currency for the country. Common bean in Ethiopia is produced in almost all the regional states with varying intensity (A. Kamal; et.al.2003).

Phosphorus is a constituent of **nucleic acids**, phospholipids and ATP (Marschner, 2012). It is however less available for plant uptake in most tropical soils mainly because of its fixation with Ca in alkaline soils and Fe and Al in acidic soils. Even though addition of P fertilizer increases **grain yield** in many crops such as common bean (Kassa *et* *al*., 2014), soybean (Devi *et al*., 2012) and the application of excess P fertilizer has been associated with environmental pollution (Marschner, 2012). Only one plant density that is 250,000 plants ha^{-1} (40 cm × 10 cm) and no fertilizer is used for common bean production irrespective of various agro-ecological zones with different soil fertility status.

Therefore, the objective of this study was to determine the effect of plant density and phosphorous levels on growth parameters, yield components and yield of common bean.

2. MATERIALS AND METHODS

2.1. Description of the Study Area

Yabello is found in southern Ethiopian rift valley 570km away from Addis Ababa with an altitude of 1656masl. The area is characterized by erratic, low and unpredictable seasonal rain fall. Occasionally high temperature during the rainy season exacerbates soil moisture stress. As a result moisture deficit is the most pressing problem causing frequent crop failure in the area. Annual rain fall ranges from 500mm to 700mm. Main season rain fall starts in March and reaches its peak in April. Soil in this area is of diverse type, generally low in organic matter, poor in water holding capacity and Electrical conductivity hence drought prone contributing to periodic crop moisture deficit (fig. 1 - 3)

2.2. Experimental design and treatments

The experiment was conducted in Borana lowlands of southern Oromia at Yabello pastoral and Dryland Agriculture research Center, southern Oromia Ethiopia, from March to July in 2012, 2013 and 2014. **One** released Haricot bean variety (Hawassa-dume) was used and The experiment was laid out in RCBD with (4*5) factorial arrangement of four different plant populations (125000 plants ha^{-1}, 148148 plants ha^{-1}, 190476 plants ha^{-1}, and 250,000 plants ha^{-1}) and five levels of phosphorous (0 kg P_2O_5 ha^{-1}, 35 kg P_2O_5 ha^{-1}, 46 kg P_2O_5 ha^{-1}, 58 kg P_2O_5 ha^{-1} and 69 kg P_2O_5 ha^{-1}) in three replications. In this experiment, the plot size was 2.80m*4m from which 11.2m^2 and 7.6m^2 were the **gross** and **net** plot size respectively.

3.4. Experimental Procedure

The land was ploughed, disked, and harrowed by a tractor and two seeds were planted per hole at the specified intra and inter row spacing on 28th March 2012, 6th April 2013 and 3rd April 2014. Hand weeding and cultivation were started two weeks after planting in which one hoeing and two hand weeding were done to control weeds. Harvesting was done manually when the crop reached harvest maturity and the pods were picked from the net plots and allowed to air and sundry for six days.

3.5. Data Collected

3.5.1. Phenological parameters

Days to 50% emergence was recorded as the number of days from sowing to when 50% of the plants emerged in each plot. Similarly, days to 50% flowering was recorded as the number of days from planting to when 50% of the plants produced flower and 98% physiological maturity was recorded as the number of days from planting to when 98% of the plants showed yellowing of pods.

3.5.2. Growth and growth related parameters

Plant height was measured as the height of 10 randomly selected plants from the ground level to the apex of each plant at the time of physiological maturity from the net plot area.
Number of branches per plant was determined by counting of primary branches on the main stem from randomly selected 10 plants from the net plot area.

3.5.3. Yield components and yield

Number of pods per plant was determined by counting the number of pods per plant of 10 randomly selected plants from each net plot area at harvest. Similarly, number of seeds per pod was recorded from 10 randomly selected pods from each net plot at harvest.

Hundred seed weight was determined by taking the weight of 100 seeds randomly sampled seeds from the total harvest from each net plot area and adjusted to 12.5% moisture level.

Total above ground dry biomass (kg ha^{-1}) was determined by taking the total weight of the harvest including the seeds from each net plot area after sun drying the biomass to constant weight.

Seed yield (kg ha^{-1}) was determined after threshing the seeds harvested from each net plot. The seed yield was adjusted to 12.5% moisture level and converted to kg ha^{-1}.

Harvest index (HI) was computed as the ratio of seed yield (kg ha^{-1}) to total above ground dry biomass.

3.6. Statistical Analysis

The collected data were subjected to analysis of variance (ANOVA) appropriate to factorial experiment in RCBD according to the Generalized Linear Model (GLM) of SAS, 2004 and interpretations were made following the procedure described by Gomez and Gomez (1984). The means were compared using the least significant differences (LSD) test at 5 % level of significance.

4. RESULTS AND DISCUSSION

4.1. Effect on Phenological Parameters

4.1.1. Days to 50% emergence

There was no significant difference among the phosphorous levels and plant population densities on day to 50% emergence (Appendix table 1). This might be attributed to the availability of adequate soil moisture at the planting time. This result was in agreement with the work of Amato *et al.* (1992) where seed germination and establishment rate of faba bean were not affected by the plant density. Gebre (2006) who worked on sesame also reported non- significant effect of inter and intra-row spacing and their interaction on the days to 50% emergence.

4.1.2. Days to 50% flowering

The interaction effect of plant density and phosphorous was found highly significant ($P < 0.01$) on days of 50% flowering (Appendix Table 1). The plants at the highest level of phosphorous (69 kg p ha^{-1}) with the highest plant population density (250,000 plants ha^{-1}) flowered earlier (39 days) while plants at the lowest phosphorous level and lowest plant population (0 kg phosphorous at 125,000 plants ha^{-1}) flowered late (44.67 days). This might be due to the fact that the higher plant population and optimum phosphorous application hastened initial flowering, with flower formation thereby extended to 39-44.67 days. In agreement to this result, Turk *et al.* (2003) worked on lentil reported that denser plant population hastened the days to flowering. On the other hand, Kueneman and Wallance (2008) reported that, days to flowering were not significantly affected by increasing or decreasing plant density of dry beans. In contrast to this resul, Abubaker (2008) found no significant effect of plant population on days to flowering of common beans.

4.1.3. Days to maturity

The interaction effects of plant density and phosphorous rate were highly significant ($P < 0.05$) and the increased levels of both parameters led to the decrease in days to maturity till the optimum level (Appendix Table 1). Longer number of days (80.22days) to maturity was recorded for the lowest plant density (125, 0000 plants ha^{-1}) and (0 kg ha^{-1}) phosphorous while the earliest (74.44 days) to maturity was recorded at the heist plant density and the heist phosphorous rate (250,000 plants ha^{-1} and 69 kg ha^{-1} phosphorous ha^{-1}) (Table 1). The days to maturity was within the range (45 to 150) days reported by Singh (1982) for dry bean seed depending on type and location

The prolonged days to maturity with lowest population density or wider inter row and intra row spacing might be due to high availability of growth resources that promote luxurious growth and prolonged maturity. In contrast to this result, Oad *et al*. (2002) reported that the closer row and plant spacing increased maturity days of safflower, On the other hand, Holshouser and Joshua (2002) reported no significant effect of row spacing on maturity on soybean.

Table 1: Interaction effect of phosphorus and plant density on days to emergence, flowering and maturity of haricot bean

Phosphorous levels	Density (Plants ha^{-1})	Days to flowering		Days to maturity		Plant height	
0 kg ha^{-1}	250,000	44.00	abc	77.78	bcd	20.89	d
	190476	44.11	abc	78.67	abc	31.98	abc
	148148	43.56	bc	78.67	abc	32.2	abc
	125000	44.11	abc	**80.22**	a bc	33.71	ab
35 kg ha^{-1}	250,000	43.44	c	80.00	ab	29.04	c
	190476	43.44	c	78.56	abc	30.27	bc
	148148	44.00	abc	75.00	ef	30.58	abc
	125000	43.44	c	77.11	cde	33.09	abc
46 kg ha^{-1}	250,000	44.67	a	78.22	a	31.20	abc
	190476	44.56	ab	76.44	cdef	29.44	bc
	148148	44.11	abc	76.44	cdef	31.60	abc
	125000	44.00	abc	77.78	bcd	32.84	abc
58 kg ha^{-1}	250,000	39.00	d	78.44	abc	**34.91**	**a**
	190476	43.44	c	75.00	ef	33.71	ab
	148148	43.44	c	76.44	cdef	33.69	ab
	125000	43.89	abc	78.44	abc	33.47	abc
69 kg ha^{-1}	250,000	43.67	abc	74.44	f	19.56	cde
	190476	43.44	c	74.89	ef	15.07	bcde
	148148	43.44	c	75.67	def	14.16	bcdef
	125000	43.67	abc	76.89	cde	23.22	cd
LSD (0.05)		1.81		4.18		6.79	
CV (%)		2.6		3.3		29.0	

LSD = (0.05) Least Significant Difference at 5% level; CV% = Coefficient of Variation. Means in columns and rows followed by the same letter(s) are not significantly different at 5% level of Significance

4.2 Effect on Growth Parameters

4.2.1. Plant height at maturity

The analysis of variance showed that the interaction effect of plant density and phosphorous rate had highly significant ($P < 0.01$) effect on plant height at maturity (Appendix Table 1). The highest plant height (34.91) was recorded at the highest plant population density (250,000 plants ha^{-1}) and the second highest phosphorous level (58 kg ha^{-1}) (Table 1). This might be due to increase in the number of plants per unit area coupled with high plant competition and lower amount of light intercepted by a single plant resulting in increased inter node length caused in such variation in plant height. An optimal supply of Phosphorous in the early stage of plant growth is a vital factor for the full development of seeds and increased the carboxylation efficiency through stimulating the ribulose-1, 5-biphosphate carboxylase activity, resulting in an increased photosynthetic rate Jacob and Lawlor (1992) Phosphorous levels significantly influenced seed yield. In contrast to this study, Turk *et al*. (2003) and

Caliskan *et al*. (2004) worked on lentil and sesame, respectively, reported negative correlation of plant height with plant density.

4.2.2. Number of branches per plant

According to the result of Analysis of variance, the interaction effect of the two factors was found to be highly significant ($P < 0.01$) on number of branches per plant (Appendix Table 1). The highest number of branches per plant (6.22) was recorded at the lowest plant density (125,000 plants ha^{-1}) and 58 kg ha^{-1} phosphorous while the lowest number of branches per plant (4.44) recorded at the highest plant density (250000 plants ha^{-1}) and no fertilizer (0 kg ha^{-1}) phosphorous (Table 2). This might be due to the fact that, as plant density decreased the available growth resources and more interception of sunlight for photosynthesis as well as optimal supply of P in the early stage of plant growth enhanced the crop lateral growth. This result was in line with the findings of Mehmet (2008) who obtained increased number of branches at the wider plant spacing for soybean and which may have resulted in production of more assimilate for partitioning towards the development of more branches.

4.3. Above ground dry biomass (kg ha^{-1})

The analysis of variance revealed that, the interaction effect of Plant density and phosphorous had highly significant ($P < 0.01$) effect on above ground dry biomass of haricot bean (Appendix Table 1). The highest above ground dry biomass (10486 kg ha^{-1}) was recorded at the highest plant density, 250,000 plant ha^{-1} and the highest phosphorous level 69 kg ha^{-1} while the lowest dry biomass of 3344 kg ha^{-1} recorded at the lowest plant density of 125000 plants ha^{-1} and the lowest phosphorous level of 0 kg ha^{-1} (Table 2). The highest total dry biomass at the highest density and the highest level of phosphorous might be due to the more number of plants per unit area and more application of phosphorus fertilizer may have cushioned the competitive effects of haricot bean plants as population density was increased which might have led to efficient use of phosphorus fertilizer at higher plant population densities and improvement in fodder and grain yields ha^{-1}. In agreement with this study, Getachew *et al.*, (2006) reported increased dry biomass of faba bean with increased plant density.

4.4. Number of pods per plant

The interaction effect of Plant density and level of phosphorous showed that, significant ($P < 0.05$) effect on number of pod per plant (Appendix Table 1). The highest number pods per plant (23.22) was recorded at the highest phosphorous level 69 kg ha^{-1} and the lowest plant population density 125,000 pants ha^{-1} while the lowest number per plant recorded at the highest plant population density (250000 plants ha^{-1}) with the lowest phosphorous level 0 kg ha^{-1} (Table 2). The decrease in number of pods per plant with increase in plant density could be due to increased intra specific competition which eventually caused reduction in number of pods per plant. In agreement with this study, Yusuf *et al.*, (200) reported appreciable increase in pod per plant, grain and fodder yields ha^{-1} with application of phosphorus fertilizer applied in different population densities. Similarly, Abdel (2008) who worked on faba bean reported that the development of more and vigorous leaves on low plant density helped to improve the photosynthetic efficiency of the crop and supported large number of pods.

Table 2. Interaction effect of phosphorous and plant density on plant height, branch per plant, above ground dry biomass and pod per plant of haricot bean

Phosphorous level	Density (Plants ha^{-1})	branch per plant		above ground dry biomass		pods per plant	
	250,000	4.444	d	5406	cdef	**8.80**	**h**
0 kg ha^{-1}	190476	4.778	bcd c	4872	efg	14.80	bcde
	148148	5.667	ab	3748	gh	15.56	bcd

	125000	5.333	abcd	**3344**	**h**	16.33	bcd
35 kg ha^{-1}	250,000	4.667	cd	4433	fgh	10.77	fgh
	190476	5.000	bcd	5028	defg	13.93	cdef
	148148	5.111	bcd	4617	fgh	12.47	defgh
	125000	5.556	abc	6583	c	16.82	bc
46 kg ha^{-1}	250,000	5.556	abc	6195	cde	11.62	efgh
	190476	4.889	bcd	5517	cdef	12.87	defg
	148148	4.667	cd	4442	fgh	14.09	cdef
	125000	5. 89	abc	4680	fgh	16.38	bcd
58 kg ha^{-1}	250,000	4.778	bcd	9306	ab	14.47	bcdef
	190476	4.667	cd	5072	defg	15.20	bcde
	148148	5.556	ab	6361	cd	15.69	bcd
	125000	**6.222**	**a**	5178	cdefg	18.02	b
69 kg ha^{-1}	250,000	4.778	bcd	**10486**	**a**	9.56	gh
	190476	4.889	bcd	8226	b	15.07	bcde
	148148	5.111	bcd	6233	cde	14.16	bcdef
	125000	5.333	abcd	4978	defg	**23.22**	**a**
LSD (0.05)		0.92		2541.2		6.793	
CV (%)		1.59		27.4		29.0	

LSD (0.05) = Least Significant Difference at 5% level; CV= coefficient of variation; Means in column followed by the same letters are not significantly different at 5% level of Significances

4.5. Number of seeds per pod

According to the analysis of variance, the interaction effect of the two factors showed highly significant ($P < 0.01$) effect on number seeds per pod (Appendix table 1). The highest mean number of seeds per pod (4.33) was recorded at the lowest plant density of 125,000 plants ha^{-1} with the highest phosphorous level while the lowest mean number of seeds (3.00) per pod was obtained at the highest plant density, 250,000 plants ha^{-1} with no phosphorous application (Table 3). Decreasing plant population density has definitely increased number of seed per pod across all the treatments. This variation might be due to low plant density encountered less intra plant competition than high plant density and thus exhibited better growth that contributed to more number of seeds per pod. This result was in agreement with Abdel (2008) who reported that number of seeds per pod increased with decreased plant density in Faba bean.

4.6. Hundred Seed weight

The analysis of variance revealed that, the interaction effect of plant density and phosphorous levels showed that, highly positive significant ($P < 0.01$) effect on hundred seed weight of haricot bean (Appendix table 1). The highest hundred seed weight (29.50gm) was recorded at the lowest plant density (125,000) plants ha^{-1} and the second highest (58 kg ha^{-1}) phosphorous level while the lowest hundred seed weight (21.00gm) was obtained at the highest plant density (250,000) plants ha^{-1} with phosphorous application of 0 kg ha^{-1} (Table 3). The variation in hundred seed weight might be due to in wider spaced plants, the supply of assimilates to be stored in the seed improved and the weight of hundred seeds increased. In line with this result, Solomon (2003) reported that hundred seed weight decreased with increase in plant density on haricot bean. Moreover, Matthews *et al.* (2008) also reported that, hundred seed weight and plant density was negatively related on faba bean.

4.7. Grain yield (kg ha^{-1})

The analysis of variance revealed that, the interaction effect of Phosphorous and plant density showed highly significant ($P < 0.01$) effect on grain yield of common bean (Appendix Table 1). The highest grain yield (3685 kg ha^{-1}) was obtained at 46 kg ha^{-1} Phosphorous and 190,476 plants ha^{-1} (35 cm × 15cm), while the lowest grain yield (1487 kg ha^{-1}) was recorded at the lowest 125,000 plant density (40 cm × 20cm) and no Phosphorous application (0 kg ha^{-1}) (Table 3). Application of phosphorus fertilizer may have cushioned the competitive effects of Haricot bean plants as population density was increased which might have led to efficient use of phosphorus fertilizer at higher plant population densities and improvement in grain yields ha^{-1}. The result of this study was in line with Hamidi, et. Al., (2010) who reported Combined effects of plant density and fertilizer rate were positive and the increased levels of both parameters led to the increase in grain yield. In agreement with result, Ball *et al.* (2000) also reported that, increasing plant population reduced yield of individual plants but increased yield per unit area of common bean.

4.8. Harvest index

The analysis of variance showed that, the interaction effect of Phosphorous rates and plant population density was significantly ($P < 0.05$) affected harvest index of haricot bean (Appendix Table 1). The highest harvest index (44.11) was obtained at the plant density of 190,476 plants ha^{-1} with the phosphorous level of 46 kg ha^{-1} while the lowest harvest index (24.67) was obtained at the plant density of 250,000 plants ha^{-1} with the phosphorous rate of 69 kg ha^{-1} (Table 3). The higher harvest index implies higher partitioning of dry matter in to grain yield and the lowest harvest index at the highest plant density might be due to interplant competition for resources such as nutrients, water and solar radiation is low as compared to high plant density. This result was in line with Solomon (2003) who found that harvest index was reduced with increase in plant density on haricot bean.

Table- 3: Interaction effect of phosphorous and plant density on Seed yield ha^{-1}, Seed per pod, hundred seed weight and Harvest index of haricot bean

Phosphorous level	Density (Plants ha^{-1})	Seed per pod	hundred seed weight	Grain yield ha^{-1}	Harvest index
0 kg ha^{-1}	250,000	**3.000 e**	**21.00 g**	2066 cdef	40.22 abcd
	190476	3.556 cde	24.67 bcd	2271 cde	42.67 ab
	148148	3.889abcd	22.17 efg	2201 cdef	35.67 bcd
	125000	3.889abcd	25.50 bc	**1487 g**	35.33 bcd
35 kg ha^{-1}	250,000	3.556 cde	23.83 cde	1942 defg	37.89 abcd
	190476	4.00 abcd	23.67 cdef	2509 bc	41.44 abc
	148148	4.00 abcd	23.50 cdef	1781 efg	37.78 abcd
	125000	4.111 abc	24.50 cde	2134 cdef	32.67 de
46 kg ha^{-1}	250,000	3.444 de	22.67 defg	2839 b	39.67 abcd
	190476	4.111 abc	23.33 cdefg	**3685 a**	**44.11 a**
	148148	4.111 abc	25.50 bc	1707 fg	33.11 cd
	125000	4.222 ab	23.17 cdefg	1864 efg	39.33 abcd
58 kg ha^{-1}	250,000	3.778abcd	24.83 bcd	1825 efg	36.89 abcd
	190476	4.00 abcd	23.33 cdefg	2827 b	41.44 abc
	148148	4.222 ab	27.00 b	2255 cdef	38.89 abcd
	125000	4.222 ab	**29.50 a**	2205 cdef	38.44 abcd
	250,000	3.667 bcd	23.61 cdef	2111 cdef	**24.67 e**
	190476	4.222 ab	24.00 cde	2445 bcd	37.56 abcd

69 kg ha^{-1}	148148	4.222	ab	24.00	cde	1870	efg	34.56	bcd
	125000	**4.333**	**a**	21.33	fg	2110	cdef	34.67	bcd
LSD (0.05)		1.0835		2.372		949.7		14.565	
CV (%)		17.1		10.6		26.6		24.1	

LSD (0.05) = Least Significant Difference at 5% level; CV= coefficient of variation; Means in column followed by the same letters are not significantly different at 5% level of Significance

5. SUMMARY AND CONCLUSION

Common bean (*P. vulgaris* L.) is the most important food and export crop specially in lowlands of Ethiopia and it is the source of protein and cash for poor farmers. In view of this, an experiment was conducted to determine the effect of plant density and phosphorous levels on yield components and yield of haricot bean. A factorial experiment was conducted in RCBD with three replications. The experimental materials were one Haricot bean variety with four different plant densities (125000 plants ha^{-1}, 148148 plants ha^{-1} , 190476 plants ha^{-1}, 250000 plants ha^{-1}) and five different levels of phosphorous fertilizers (0 kg ha^{-1}, 35 kg ha^{-1} , 46 kg ha^{-1}, 58 kg ha^{-1} and 69 kg ha^{-1}). The interaction effect of plant density and phosphorous levels found highly significant ($P < 0.01$) on days of 50% flowering. The plants at the highest level of phosphorous (69 kg p ha^{-1}) with the highest plant population density (250,000 plants ha^{-1}) flowered earlier (39 days) while plants at the lowest phosphorous level and lowest plant population (0 kg P at 125,000 plants ha^{-1}) flowered late (44.67 days). Longer number of days (80.22 days) to maturity was recorded for the lowest plant density (125, 0000 plants ha^{-1}) and (0 kg ha^{-1}) phosphorous while the earliest (74.44 days) to maturity was recorded at the highest plant density and the highest phosphorous level (250,000 plants ha^{-1} and 69 kg ha^{-1} phosphorous ha^{-1}). The interaction effect of plant density and phosphorous rate had highly significant ($P < 0.01$) effect on plant height at maturity. The highest plant height (34.91) was recorded at the highest plant population density (250,000 plants ha^{-1}) and the second highest phosphorous level (58 kg ha^{-1}). the interaction effect of the two factors was again found to be highly significant ($P < 0.01$) on number of branches per plant. The highest number of branches per plant (6.22) was recorded at the lowest plant density (125,000 plants ha^{-1}) and 58 kg ha^{-1} phosphorous while the lowest number of branches per plant (4.44) recorded at the highest plant density (250000 plants ha^{-1}) and no fertilizer (0 kg ha^{-1}) phosphorous**.** The interaction effect of Plant density and phosphorous had highly significant ($P < 0.01$) effect on above ground dry biomass of haricot bean. The highest above ground dry biomass (10486 kg ha^{-1}) was recorded at the highest plant density, 250,000 plant ha $^{-1}$ and the highest level of phosphorous level 69 kg ha^{-1} while the lowest (3344 kg ha^{-1}) above ground dry biomass was recorded at the lowest plant density of 125,000 plants ha $^{-1}$ and the lowest (0 kg ha^{-1} **)** level of phosphorous. The interaction effect of Plant density and level of phosphorous showed that, significant ($P < 0.05$) effect on number of pod per plant. The highest number pod per plant (23.22) was recorded at the highest phosphorous level 69 kg ha^{-1} and the lowest plant population density 125,000 pants ha^{-1}. According to the analysis of variance, the interaction effect of the two factors showed highly significant ($P < 0.01$) effect on number seeds per pod (Appendix table 1). The highest mean number of seeds per pod was obtained at the plant density of 125,000 plants ha^{-1} with phosphorous application rate of 58 kg ha^{-1}. The interaction effect of plant density and phosphorous showed highly positive significant ($P < 0.01$) effect on 100 seed weight and the highest hundred seed weight was recorded at the lowest plant density (125,000) plants ha^{-1} and 58 kg of phosphorous ha^{-1} while the lowest was obtained at the highest plant density (250,000) plants ha^{-1} with no phosphorous application (0 kg) ha^{-1}. The effect of Phosphorous and plant density was highly significant ($P < 0.01$) on grain yield of common bean (Appendix Table 1). The highest grain yield (3685 kg ha^{-1}) was obtained at 46 kg ha $^{-1}$ Phosphorous and 190,476 plants ha $^{-1}$ (35 cm × 15cm), while the lowest grain yield was recorded at the lowest 125,000 plant density (40 cm × 20cm) and no Phosphorous application (0 kg ha $^{-1}$). The analysis of variance showed that, the interaction effect of the two factors was significantly ($P < 0.05$) affected harvest index of haricot bean. The highest harvest index (44.11) was obtained at the plant density of 190,476 plants ha^{-1} with the phosphorous rate of 46 kg ha^{-1} while the lowest harvest index (24.67) was obtained at the plant density of 250,000 plants ha^{-1} with the phosphorous rate of 69 kg ha^{-1}. Therefore, *from this study it can be concluded that*, application of **46** kg Phosphorous ha^{-1} and plant population of **190,476** plants ha^{-1} (35 cm × 15cm) is recommended for better haricot bean production at Yabello and similar areas of Borana Zone, Southern Ethiopia.

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APPENDICES

Appendix Table 1. Mean squares of ANOVA for crop phenology, growth, yield and yield components of haricot bean as affected by phosphorous application and plant density tested for three years

Parameter	Mean squares for source of variation with degrees of freedom								
	Block (2)	Year (2)	Phos (4)	Density (3)	Year×Pho (8)	Year×Den (6)	Pho×Den (12)	Year×Pho×Den(24)	Error (118)
Days emergence	0.017	0.01	0.08	0.06	0.02	0.01	0.08	0.04	0.05
Daysto flowering	2.02	772.93	78.74**	6.66**	4.58**	4.11**	10.68**	3.15**	1.25
Days to maturity	32.27	7973.36**	21.24*	86.35**	9.01	37.37**	12.31*	4.84	6.69
Plant height	45.72	631.07**	112.58**	122.95**	29.12	67.63*	61.34**	19.08	24.62
Branch per plant	10.9	1.42	2.33	2.58	0.91	3.33**	2.25**	1.28	0.982.02
Biomass	6013105	5611054	55275767**	46186541**	601068	1544725	15937552**	1761169	2470094
Pod per plant	5.34	125.95**	43.05	380.09**	13.13	79.38**	33.67*	11.01	17.65
Seed per pod	0.001	0.002	0.078*	0.037**	0.13	0.06	0.17**	0.043	0.096
Seed yield ha^{-1}	68945	746519	1423911**	3997640**	279252	1175328**	1948755**	321171	345011
Hundred seed weight	16.52	0.07	34.38**	24.90**	0.07	0.07	33.65**	0.07	6.46
Harvest index	148.62	67.27	241.04*	65.35	24.63	184.44*	167.34*	24.10	81.14

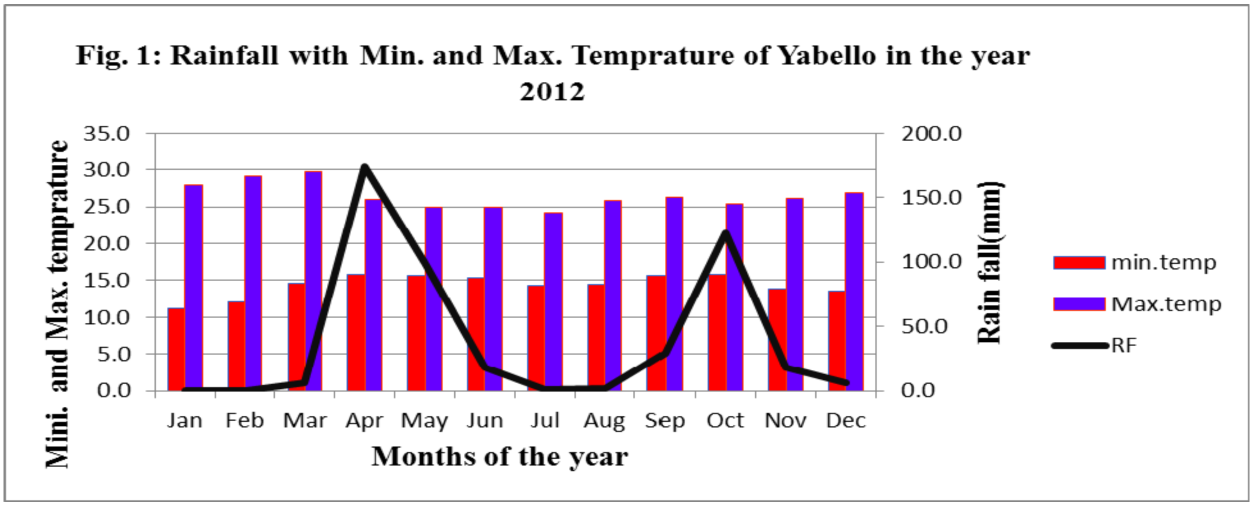
Fig. 1: Rainfall with Min. and Max. Temprature of Yabello in the year 2012
Mini. and Max. temprature
Rain fall(mm)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
200.0
150.0
100.0
50.0
0.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Months of the year
min.temp
Max.temp
RF

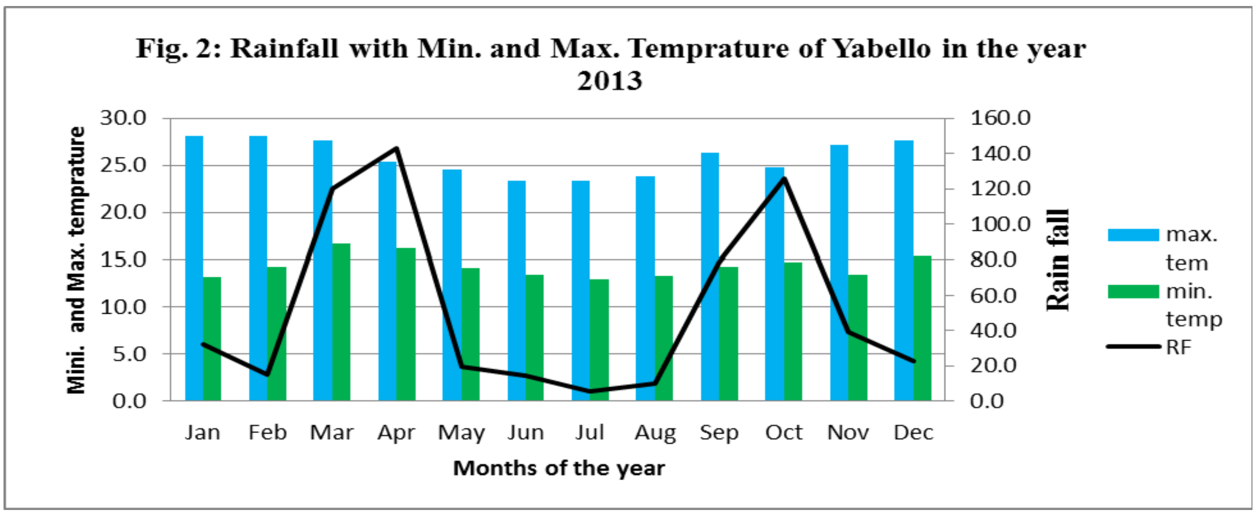
Fig. 2: Rainfall with Min. and Max. Temprature of Yabello in the year 2013
Mini. and Max. temprature
Rain fall
30.0
25.0
20.0
15.0
10.0
5.0
0.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Months of the year
max. tem
min. temp
RF

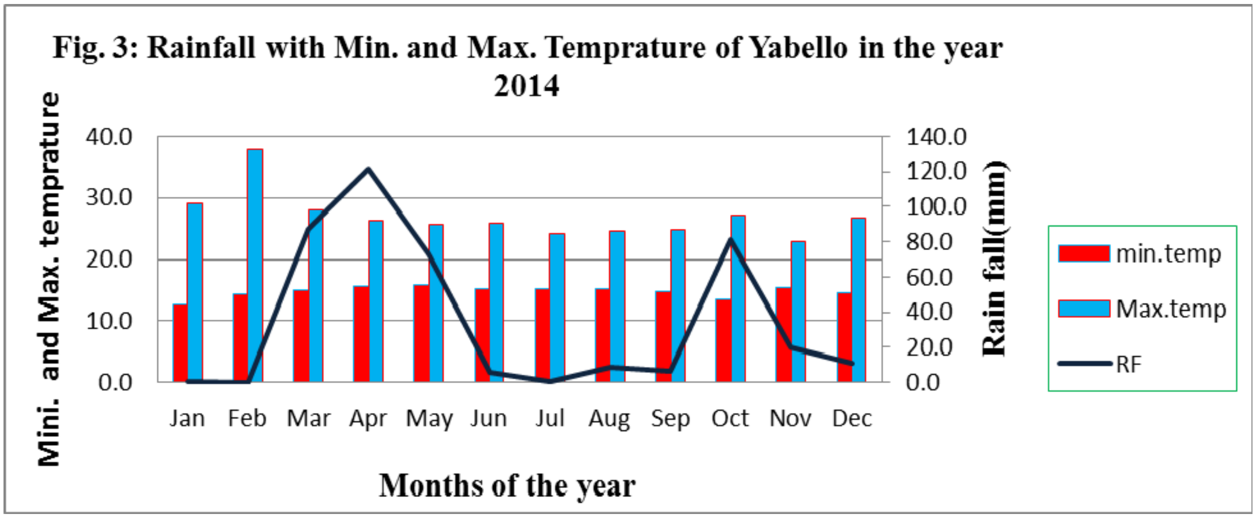
Fig. 3: Rainfall with Min. and Max. Temprature of Yabello in the year 2014
Mini. and Max. temprature
40.0
30.0
20.0
10.0
0.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Rain fall(mm)
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Months of the year
min.temp
Max.temp
RF