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EFFECT OF DIFFERENT PHOSPHORUS RATES TO SOYBEAN [G*lycine max* (L) Merril] VARIETIES IN YAYO DISTRICT ILUBABOR ZONE, SOUTHWESTERN ETHIOPIA

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ABSTRACT

Soybean [*Glycine max* (L) Merril] is among the most important legume crops produced in western Ethiopia. However, declining soil fertility as well as poor soil fertility management practices has limited its yields. A field experiment was conducted in Yayo District on a farmer's training centre to investigate the effect of phosphorus on yield and yield components of soybean varieties. The treatments included factorial combinations of six phosphorus rates (0, 11.5, 23, 34.5, 46 and 57.5 kg P2O5 ha^{-1}) and three soybean varieties [Clark-63k, Ethio-Yugoslavia and Jalale (AGS-217)]. The experiment was laid out in RCB design with three replications. Highly significant ($P<0.01$) variations in days to emergence, days to flowering, days to physiological maturity, plant height, number of nodules per plant, number of branches per plant, above ground biomass yield, stand count after establishment, stand count at harvest, number of seeds per pod, hundred grain weight, grain yield and harvest index were observed among the varieties. Similarly, days to flowering, days to physiological maturity, number of nodules per plant, number of branches per plant, above ground biomass yield, number of seeds per pod, hundred grain weight, grain yield and harvest index were highly significantly ($P<0.01$) affected by phosphorus rates whereas days to flowering, days to physiological maturity, number of nodules per plant, number of seeds per pod, grain yield and harvest index were highly significantly ($P<0.01$) influenced by the interaction effect of variety and phosphorus rates. Among the varieties, Ethio-Yugoslavia had the highest value for days to emergence (7.49), plant height (71.71cm), number of branches per plant (9.02), above ground biomass yield (7550 kg/ha) and hundred grain weights (14.3 g). Regarding the phosphorus rates, maximum responses were obtained at rate of 46 kg phosphorus ha^{-1} for plant height (62.26 cm), number of pods per plant (61.9) and hundred grain weight (13.97 g) whereas 57.5 kg phosphorus/ha resulted in the highest number of branches per plant (9.01) and above ground biomass (7734 kg/ha). Considering the interaction between phosphorus rates and varieties, application of 46 kg phosphorus ha^{-1} on variety clark-63k led to production of the highest number of nodules per plant (14.367), grain yield (2730 kg/ha) and harvest index (0.4) whereas, 11.5 kg phosphorus/ha on variety Jalale (AGS-217) resulted in the highest number of seeds per pod (2.63). Accordingly, the grain yield ranged from 2113.3 to 2406.7 kg ha^{-1} depending on phosphorus fertilizer rates and varieties. In conclusion, application of the highest rate of phosphorus (46 kg/ha) on variety Clark-63k resulted in the best performance in grain yields (2730 kg/ha) under the agro-ecology of Yayo district from among the three varieties and six phosphorus rates.

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INTRODUCTION

Soybean [*Glycine max* (L) Merrill] is a small erect and branching annual leguminous plant classified under the family Fabacae and sub family Paplionodeae (Sinclair *et al.,* 2001). Its germination is epigeal and the crop has a tap root system (Hymowitz, 1987). Soybean grows from sea level, up to 2000 metres above sea level; from latitudes ranging from the equator up to 55º north and 55º south. It grows under a wide range of temperature, but the optimum temperature for growth and development is 30ºC whilst for proper emergence of seedlings, a seedbed temperature of 25-33ºC is optimal. The

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crop requires 500-850 mm water during the growing season. Soybean has quantitatively highest protein content (37-42%) of all food crops and is second in terms of oil content (18-25%) among food legumes (Pal *et al.* 1983). These two products are used in thousands of ways for food, feed and industrial uses. It accounts for about 50% of the oil seed production in the World. Soybean oil consists of up to 85% of unsaturated fatty acids free from cholesterol. Generally, soybean produces balanced combination of protein, fat and carbohydrate to serve as valuable bio-feed stocks. In principle, soybean can be encouraged in smallholder based production systems in the tropics and subtropics to diversify production, generate income, and capture positive rotation effects that improve productivity of other crops being grown. Soybean is grown as a commercial crop in over 50 countries in the World. The largest producer of soybean in the world is North America, whose production stands at 70.5 million metric tons per annum followed by South America (44.8 million metric tons/annum). Africa produces 0.6 million metric tons in which the major producers are Kenya, Nigeria, Zimbabwe, Egypt, South Africa, Zambia, Malawi and Uganda (Nassiuma and Wasike, 2002). Soybean is grown as a commercial crop in over 22 countries of Africa. According to three-year (2006-2008) average data of FAOSTAT, 1.267 million hectares were allocated to soybean production in Africa and 1.361 million tons of grain were obtained. Among this (1.267 million ha's) data of FAOSTAT total area and production in Africa, Ethiopia is growing soybean 6826 ha and 6685 tons of grain was obtained. Soybean seed production may be limited by environmental stresses such as soil salinity (Ghassemi-Golezani *et al.,* 2009). Minimizing environmental stress will optimize seed yield (Mc Williams *et al.,* 2004).

Soybean was first introduced to Ethiopia in 1950`s because of its nutritional value, multipurpose use and wider adaptability in different cropping systems. In Ethiopia, soybean is adapted to diverse ecological niches and provided wider yield range (Amare, 1987). The most promising performance was recorded in areas where starchy root and tuber crops, cereals, enset (*Ensete ventricosum*) and coffee are dominant in the diet of the majority. Besides, it can also be used as oil crop, animal feed, poultry meal, soil fertility improvement and more importantly as income for the country. However, this provided only 10% of the soybeans required by the Ethiopian Nutrition Institute (ENI). According to Agricultural survey of CSA (2011), there are about 14198.20 hectares of land and produced 283459.26 tons produced. Since the oil content is high (16% and above) it also is used for edible oil production in Ethiopia. Soybean has a great potential for Ethiopia, as it has been duly recognized by many researchers and research organizations for its economic importance (IAR, 1982) and its domestic demand, for various uses is growing. Hence, production of soybean in Ethiopia is very essential to overcome malnutrition and partially compensate the expensive sources of animal proteins. This indicates that the local demand is increasing steadily (Assefa, 2008). Ilubabor Zone has an area of 25444 ha cultivated in 2013 by pulse crops, out of this 3783 ha used for soybean crops (Zone annual report). Accordingly, Yayo district is one of Ilubabor zone district growing soybean. Thus, the processing of protein rich soymilk, soy cheese, defatted soy flour and a number of traditional foods such as Injera (Ethiopian bread), Wot (sauce), Kitta (unleavened bread), Dabbo (bread), and Dabo kolo (cookie) and other products have been successfully produced from soybean and utilized by majority of households in Ilubabor Zone and around Yayo district (personal observation).Soybean is known for its wide adaptability coupled with its higher productivity per unit area compared to other grain legumes (Boyer, 1982). However, it is mostly cultivated in tropical and subtropical areas, where the soils are often deficient in phosphorus (P) and nitrogen due to intensive erosion, weathering, and P fixation by free Fe and Al oxides (Sample et al., 1980; Stevenson, 1986). Therefore, low P availability is often a major constraint to soybean growth and production (Vance et al., 2003). Phosphorus (P) deficiency can limit nodulation by legumes and P fertilizer application can overcome the deficiency (Carsky *et al.,* 2001). Phosphorus availability is of particular concern in the highly weathered soils of the humid tropics and sub tropics, where the crop productivity is severely compromised for lack of available P (Holford, 1997; Sanchez *et al*., 1997). The crop has great potential for Ethiopia as it has been dully recognized by many researcher and research organizations for its economic importance (IAR, 1982) and its domestic demand for various uses, Indigenous food processing industries using locally produced soybeans are highly expected to satisfy the vast growing interest of soybean based food stuffs. Among all the nutrients for soybean, the most significant are nitrogen and phosphorus. Under research, 46 kg phosphorus and 50 kg urea per ha are used for soybean [*Glycine max* (L) Merrill] around Ilubabor and Jimma (Getachew *et al*., 1987). However, the effect of phosphorus in soybean depends on numerous factors such as soil fertility, precipitation amount, genotypes, seed inoculation etc. Thus, there is a need to develop location specific recommendations of nutrient application. Thus, the objective of the study was to determine the effect of phosphorus on yield and yield components of soybean varieties.

MATERIALS AND METHODS

Description of the Study Area: The field experiment was conducted from September 2012 and mid April 2013 in Yayo District at Geci kebele, which is located in Oromia Regional State, Ilubabor Zone, southwestern Ethiopia. The site is located at 7° 50' N latitude and 36° 53' E longitude and altitude of 1675 m.a.s.l. at distance of 560 km from Addis Ababa and 36 km from the zonal town Mettu. The agro-climatic zone of the district is humid 'Weynadega' and humid 'kola' and altitude ranges from 1160-2200 m.a.s.l. The annual precipitation of the area ranges from 1191-1960 mm and the average maximum and minimum daily temperatures are 29^oC and 18^oC, respectively. In general, the Yayo district has mono modal rainfall distribution pattern with alternative wet and dry seasons with the major rain falling between March and November while being dry throughout the rest of the months. As a result, crop production by irrigation is not required between March and November because of sufficient amount of rainfall for crop production and the crop was done by fully irrigation.

Description of the Varieties: Three improved varieties were used in the study. High seed yielding soybean varieties named Clark-63k; Ethio-Yugoslavia and Jalale (AGS-217) were used as a seeding material. Their average yield per hectare obtained on the research and farmer fields in Ilubabor and around Jimma were recorded between 2.5 to 3.0 and 1.5 to 2.5 tons for clark-63k, 1.7 to 3.5 and 1.6 to 3.0 tons for Ethio-Yugoslavia 2.2 and 1.5 tons for Jalale (AGS-217), respectively, while Ethio-Yugoslavia is the late maturity type (145-154), Clark-63k a medium maturity type (120-134 days) whereas Jalale

(AGS-217) is early maturity type (120 days) to maturity (Asrat *et al.*, 2003). Variety Jalale (AGS-217) plant adaptation area altitude (m.a.s.l) and rainfall (mm) has 1300-1850 and 900-1300, respectively. The color of the seed coat and seed shape is generally yellow and round and smooth respectively. Variety Ethio-Yugoslavia has adaptation area altitude (m.a.s.l) and rainfall (mm) 1200-1900 and 1000-1200, respectively. The color of the seed coat and seed shape is generally yellow and round, respectively, while the Variety Clark-63k plant adaptation area altitude (m.a.s.l) and rainfall (mm) has 1300-2000 and 850-1250, respectively.

Treatments and Experimental Design: The treatments consisted of a factorial combination of three varieties and six rates of phosphorus fertilizer (0, 11.5, 23, 34.5, 46 and 57.5) kg ha^{-}. The treatments was laid out as randomized complete block design in a 6x3 factorial arrangement and replicated three times. Experimental gross plot size was 6 rows of 3m length and 2.4m width each line of each plot and the experimental net plot size was 4 rows of 3m length and 1.6m width each line of each plot. The gross and net plot was 6 x 0.4m x 3m (7.2 m^2) and 4 x 0.4m x 3m (4.8m^2), respectively, consisted of 30 harvestable plants for net plot with different rows and fertilizer rates spaced at 10cm between plants and 40cm between rows. The space between plots and blocks was 0.6 m and 1.2 m, respectively.

Experimental Procedures

Land preparation was done at the end of September 2012 by using local plough (*maresha*) according to farmers' conventional farming practices using oxen. At planting the experimental plots having fine seed bed was prepared and according to the design, field layouts were made and each treatment was assigned randomly to the experimental units within a block. Planting was done on December 25, 2012. The crop was done by fully irrigation without any germination and seedling establishment problem. The experimental field was weeded by hand three times during the growing period. Application of phosphorus as per the treatment was done by banding the granules at the depth of 5cm below and 5cm around the seed at panting. Urea (46% N) at rate of 50 kg ha^{-1} was applied by banding to all the plots five weeks after sowing as recommended by Jimma Agricultural Research Centre. Because of Urea is recommended and applied at five weeks to all the plots; at full bloom R3 (pods are 5 mm at one of the four upper most nodes on the main stem with a fully developed leaf) to R6 (pod at one of the four upper most nodes on the main stem contains green seeds that fill the pod cavity have been shown to benefit soybean growth) needs N supply in addition to fixation and for maximum soybean yield. Harvesting was done when the leaves of the soybean plants senescent and showed yellowing of leaves and pods start to open.

Soil Sampling and Analysis

An initial soil sample at a depth of 0-30 cm was taken from randomly selected 5 spots diagonally across the experimental field using hoe before sowing and composited and analyzed at Bako Research Centre Soil Laboratory section for selected chemical and physical soil properties, i.e. organic matter, total N, soil pH, available phosphorus, cation exchange capacity (CEC) and texture analysis. The soil samples were air dried ground and passed through a 2 mm mesh sieve for physico-chemical analysis. The particle size distribution (soil texture) was done by Bouyoucos hydrometric method; organic matter was determined based on the oxidation of organic carbon with acid dichromate medium following the Walkley and Black method as described by Dewis and Freitas *et al.* (1975) and Kjeldahl method (Dewis and Freitas *et al.,* 1975) was used to determine total N. Soil Cation Exchange Capacity (CEC) was determined by method described by Page *et al.* (1982). Besides, available soil P was determined according to the methods of Olsen and Dean (1965). The soil pH was determined in 1:2.5 (weight/ volume) soils: water dilution ratio using a glass electrode attached to a digital pH meter.

Phenological and growth parameters

Days to 50% emergence: Days to 50% crop emergence was recorded as number of days from date of sowing to the time when 50% of the seeds emerged in each plot from the ground.

Days to 50% flower initiation: Days to 50% flower initiation was recorded as the number of days from sowing to the time when one open flower appeared on 50% of the plants in a plot at any node on the main stem.

Days to physiological maturity: Days to 90% physiological maturity was recorded as the number of days from date of sowing to the date when 90% of the plants showed yellowing of leaves and pods and seed hardening in the pods.

Plant height (cm): Plant height was recorded from 10 randomly selected plants per net plot at physiological maturity from the base of plant to the tip of main stem in cm.

Number of effective and total nodules per plant: Bulk of the root mass of plants from the third and fourth rows of each plot were randomly sampled at 50% flowering from 10 plants from each plot were carefully uprooted for nodule count (Pal and Saxena, 1975). The number of effective nodules was determined by having cross section of nodules where nodules which showed a pink to dark red colour were considered as effective while those showing green colour were considered ineffective.

Number of primary branches per plant: Number of primary branches was determined by counting the average number of primary branches from the main stem of 10 randomly selected plants per plot area at physiological maturity.

Above ground dry-biomass per plot: The total above ground dry biomass of 10 randomly selected plants per net plot area was determined by harvesting close to the soil surface at physiological maturity by sun-drying to a constant weight. Finally the biomass yield per five plants selected was converted to per hectare and expressed in kg ha^{-1}.

Yield components and seed yield

Plant stand count: The number of seedlings was counted after establishment and at harvest from the net plot area and converted to per hectare basis.

Number of pods per plant: The total number of pods in 10 randomly selected plants from each net plot area was counted at the time of harvest and expressed as the number of pods per plant.

Table 1. Selected physico chemical properties of the experimental site soil before planting

Physical properties				Chemical properties				
Particle size distribution (%)			Textural class	pH (1:2.5 H_2O)	OM (%)	Total N (%)	Av. P (mg/kg)	CEC (cmol/kg)
Sand	Clay	Silt						
48	30	22	Clay loam	6.2	2.19	0.25	17.6	27.4

Where: OM = Organic matter; Av.P = Available Phosphorus; CEC = Cation Exchangeable Capacity

Table 2. Main effects of varieties and phosphorus rates on days to 50% seedling emergence of soybean

Treatments	Days to 50% seedling emergence
Variety	
Clark-63k	6.5^{b}
Ethio-Yugoslavia	7.5^{a}
Jalale (AGS-217)	6.0^{c}
LSD (5%)	0.07
Phosphorus rates (kg ha^{-1})	
0	6.68
11.5	6.66
23	6.7
34.5	6.7
46	6.68
57.5	6.69
LSD (5%)	Ns
CV (%)	1.5

Means within column for a factor followed by the same letter are not significantly different at 5% level according to LSD test, Ns = Non-significant

Number of seeds per pod: From the above counted pods per plants in all plots of randomly selected plants, the total number of seeds was threshed and counted and determined as the average number of seeds per pod.

Hundred seed weight (g): Hundred seeds were counted from the harvested bulk of seeds per net plot and their weight (g) was determined at seed moisture content 12.5% by using a sensitive balance.

Seed yield (kg ha^{-1}): Grain yield was measured after leaving the harvested plants in an open air for about 14 days to dry so that they attained constant weight. Finally from 120 plants yield per net plot area of each treatment was converted to per hectare basis and the average yield was reported in kg ha^{-1}.

Harvest index: The harvest index was calculated as the ratio of grain yield to total above ground dry biomass yield.

Statistical Data Analysis

All the collected data were subjected to analysis of variance following the procedure described by Gomez and Gomez (1984) using SAS at version 9.1 (SAS Institute, 2001). Least Significance Difference (LSD) test at 5% level of significance was used to separate the treatment means that showed significant differences.

RESULTS AND DISCUSSION

Some Physical and Chemical Properties of the Experimental Site Soil: The results of soil analysis revealed that the textural class of the surface soil is clay loam with a pH value of 6.2; available phosphorus of the soil is 17.6 mg/kg soil (Olsen); CEC is 27.4 cmol/kg soils, organic matter content of the soil is 2.19%; and total nitrogen content of the soil amounts to 0.25% (Table 1).Tekalign *et al*. (1991) described soils with available P<10, 11-31, 32-56, >56ppm as low, medium, high and very high, respectively. Thus, the soil of the experimental site is considered medium in available P. The available P of the experimental soil is 17.6 mg/kg. Ideally, the critical value should be determined for each soil type, crop and farming system. However, Olsen *et al.* (1954) reported that the values of available P lower than 50-55 mg/kg were likely to show the potential yield response to P applications. In general, the existence of low contents of available P is a common characteristic of most of the soils in Ethiopia (Tekalign and Haque, 1991; Yihenew, 2002; Wakene and Heluf, 2003).Likewise, according to Landon (1991), top soils having CEC greater than 40 cmol (+)/kg are rated as very high and 25-40 cmol (+)/kg as high, 15-25, 5-15 and < 5 cmol (+)/kg of soil are classified as medium, low and very low, respectively. Thus, the soil of the study site has high CEC (27.4 cmol (+)/kg). The cation exchange capacity (CEC) of the top soil profile (27.4cmol/kg) could be rated as satisfactory for crop production when fertilizers are used. In line with this, Landon (1991) rated CEC ranging between 25 and 40 cmol/kg as high and conducive for crop production. Berhanu (1980) classified soils with organic matter >5.20, 2.6-5.2, 0.8-2.6 and <0.8% as high, medium, low and very low, respectively in their organic matter status. Therefore, the organic matter content (2.19%) of the experimental soil is low. According to Landon (1991) soils having total N of greater than 1.0% are classified as very high, 0.5-1.0% high, 0.2-0.5% medium, 0.1-0.2% low and less than 0.1% as very low in total nitrogen content. Therefore, the soil of the experimental site has medium total nitrogen content (0.25%). Bruce and Rayment (1982) classified soils having pH with <4.5, 4.5-5, 5.1-5.5, 5.6-6 and 6.1-6.5 as extremely acid, very strongly acid, strongly acid, moderately acid and slightly acid, respectively in pH value content. The pH of the soil was analyzed to be 6.2 showing slightly acidic reach. FAO (2000) reported that the preferable pH ranges for productive soils to be from 6 to 7. Thus, the pH of the experimental soil was within the range for productive soils.

Phenological and Growth Parameters

Days to 50% emergence: Analysis of variance on crop phenology indicated that days to 50% emergence were highly significantly (P < 0.01) affected by the main effect of variety.

Table 3. Days to 50% flower initiation of soybean as affected by the interaction of varieties and phosphorus rates

Phosphorus rates(kgha^{-1})	Variety		
	Clark-63k	Ethio-Yugoslavia	Jalale (AGS-217)
0	55.20^{a}	54.97^{a}	54.00^{bc}
11.5	54.80^{a}	54.27^{b}	54.03^{bc}
23	54.10^{b}	54.27^{b}	54.03^{bc}
34.5	53.60^{cd}	50.60^{i}	52.63^{fg}
46	53.03^{ef}	48.83^{k}	51.33^{h}
57.5	52.17^{g}	47.70^{l}	50.03^{j}
LSD (5%) = 0.49			
CV (%) = 0.6			

Means for a factor followed with same letter within the table do not differ significantly at 5% level according to LSD test

Table 4. Days to 90% physiological maturity of soybean as affected by the interaction of varieties and phosphorus rates

phosphorus rates(kgha^{-1})	Variety		
	Clark-63k	Ethio-Yugoslavia	Jalale (AGS-217)
0	128.0^{f}	147.9^{a}	121.8^{l}
11.5	127.6^{g}	147.5^{a}	121.5^{l}
23	126.8^{h}	146.9^{b}	120.3^{m}
34.5	126.1^{i}	146.2^{c}	119.6^{n}
46	125.0^{j}	145.4^{d}	118.2^{o}
57.5	123.9^{k}	143.8^{e}	117.8^{o}
LSD (5%) = 0.407			
CV (%) = 0.2			

Means for a factor followed with same letter within the table do not differ significantly at 5% level according to LSD test

On the other hand, the effects of the different rates of phosphorus as well as the interaction were non-significant on days to 50% seedling emergence (Table 2). About 94% emergence was achieved regardless of the applied phosphorus, and seedlings from all plots, reached 50% emergence from 6-7.5days from the date of planting (Table 2). Favourable moisture condition at the sowing time and fine seed bed preparation might have contributed to the uniform germination across the treatment combinations. The present result was in agreement with that of Amato *et al.* (1992) wherein seed germination and establishment rate of faba bean was not affected by the phosphorus application. Small seed sized variety Jalale emerged 1.5 days earlier than large seed sized variety Ethio-Yugoslavia while variety Clark-63k emerged 1 day earlier than Ethio-Yugoslavia (Table 2). Late emergence of the variety Ethio-Yugoslavia might be attributed to the large seed size and Resistant to major termites and pests which might have taken more time to imbibe water for germination.

Days to 50% flower initiation: Days to 50% flower initiation was highly significantly ($P<0.01$) affected by the varieties of soybean, rates of phosphorus and their interaction. The variety Clark-63k at phosphorus rate of 0 kg ha^{-1} flowered late (55.20 days) while variety Ethio-Yugoslavia at phosphorus rate of 57.5 kg ha^{-1} flowered early (47.70 days) (Table 3). In general, the data obtained from the current investigation revealed that day to flowering was decreased with increment of phosphorus rates. The present result was in agreement with that of Acharya *et al*. (2007) who observed that phosphorus is important for enhancing flowering and seed formation of fenugreek (*Trigonella foenum-graecum* L.). Saleh (1976) also reported that phosphorus application encouraged flowering and fruiting of soybean varieties. FAO (1984) also reported that P played a great role to enhance flowering, seed formation and maturation.

Days to 90% physiological maturity: Days to 90% physiological maturity were highly significantly ($P<0.01$) affected by varieties, phosphorus rate and their interaction. The variety Ethio-Yugoslavia at 0 kg ha^{-1} of phosphorus took the longest duration (147.9 days) to reach physiological maturity while variety Jalale at 57.5 kg ha^{-1} of phosphorus matured earlier (117.8 days) (Table 4). In general, variety Jalale (AGS-217) was of the earliest in maturity while variety Ethio-Yugoslavia was the latest (Table 4)**.**With regards to phosphorus rates, the days required to reach physiological maturity was decreased in response to increasing rate of phosphorus. This shows that early-maturing crop varieties most probably have shorter periods of vegetative growth. The other reason for the faster senescence of leaves and pods could be due to the mobilization of leaf nitrogen and rubisco to the reproductive organs for development (Pandey *et al.,* 2001). Where the longer the crop duration, the greater would be the crop yield as observed for variety Clark-63k as compared to variety Jalale (AGS-217). This result was in agreement with that of FAO (1984) where deficiency of P resulted in delayed maturity. The effect of P on plant maturity might also be due to the influence of the nutrients on different plant hormones. In line with this, Mengel and Kirkby (1996) described that early senescence is due to depression of cytokinin synthesis whereas abscisic acid (ABA), which is closely related to carotinoids and mainly, produced in chloroplast, is influenced by P and is known for its effect to promote senescence.

Plant height (cm): The analysis of variance showed highly significant ($P<0.01$) differences among the soybean varieties and the plant height at physiological maturity was significantly ($P<0.05$) effected by phosphorus rates. However, the interaction effect of phosphorus rate and varieties was non-significant on plant height. The tallest plants (71.71 cm) were obtained from variety Ethio-Yugoslavia while the shortest (48.16 cm) ones were obtained from the variety Clark-63k (Table 5). However, differences in plant height between varieties Ethio-Yugoslavia and Jalale (AGS-217) as well as Clark-63k were statistically highly significant (Table 5).The increased plant height in variety Ethio-Yugoslavia may be attributed to its inherent genetic characters and better response to 46 kg/ha phosphorus rate and subsequent increase in all the nodulation parameters such as nodule number per plant and effective nodule per plant resulting in higher nitrogen fixation

Table 5. Main effects of varieties and phosphorus rates on plant height (cm) and number of primary branches per plant of soybean

Treatments	Plant height (cm)	Number of primary branches per plant
Variety		
Ethio- Yugoslavia	71.71[a]	9.02[a]
Jalale (AGS-217)	53.34[b]	8.51[b]
Clark-63k	48.16[c]	8.04[c]
LSD (5%)	3.937	0.428
phosphorus rates (kg ha^{-1})		
0	53.70[c]	7.74[b]
11.5	53.91[bc]	8.84[a]
23	59.79[a]	8.42[a]
34.5	57.41[abc]	8.5[a]
46	62.26[a]	8.63[a]
57.5	59.35[ab]	9.01[a]
LSD (5%)	5.567	0.606
CV (%)	10.1	7.4

Means within column for a factor followed by the same letter are not significantly different at 5% level according to LSD test.

Table 6. The interaction effect of varieties and rates of phosphorus on number of total nodules per plant

Phosphorus rates(kg ha^{-1})	Variety		
	Clark-63k	Ethio-Yugoslavia	Jalale (AGS-217)
0	2.7[i]	0.167[k]	1.237[j]
11.5	5.3[h]	2.9[i]	2.033[j]
23	8.5[e]	4.6[h]	7.9[ef]
34.5	13.25[b]	5.2[h]	9.7[d]
46	14.367[a]	7.2[fg]	9.433[d]
57.5	12.433[b]	6.6[g]	11.333[c]
LSD (5%) = 0.932			
CV (%) = 8.1			

Means for a factor followed with same letter within the table do not differ significantly at 5% level according to LSD test

and therefore, more plant growth. Applications of 46 kg phosphorus ha^{-1} gave the highest plant height (62.26 cm) whereas the control treatment gave the lowest (53.70 cm) (Table 5). Increasing phosphorus from 0 to 23 kg ha^{-1} increased plant height consistently. The decreased plant height at the highest level of 57.5 kg/ha phosphorus and more than recommendation might be due to the availability of more P nutrients in the soil (Table 1). As the evidence observed from 46 kg and 57.5 kg phosphorus ha^{-1}, application of P gave higher soybean plant height as compared to control (Table 5).

Number of primary branches per plant: The number of primary branches per plant was highly significantly (P<0.01) different among the varieties of soybean. Similarly, highly significant effect was observed due to application of different levels of phosphorus. However, the interaction effect of variety and phosphorus rate was non-significant on the number of primary branches per plant. The highest number (9.02) of primary branches per plant was obtained from variety Ethio-Yugoslavia while the lowest number (8.04) of primary branches per plant was obtained under the variety Clark-63k (Table 5). The variety Ethio-Yugoslavia took the longest days (147.9) to reach to physiological maturity than other varieties; as a result it might have beard number of primary branches per plant. This result is contrary to Singh *et al.* (1992) who reported absence of significant differences in number of primary and secondary branches due to P application on lentil. Similarly, regarding phosphorus rates, the highest number of primary branches per plant (9.01) was recorded under the highest phosphorus application rate of 57.5 kg ha^{-1} while the lowest (7.74) was recorded from control treatment (Table 5).Increasing phosphorus rates showed an increasing trend in number of primary branches except in between 11.5 and 23 kg phosphorus ha^{-1}. Similar investigation by Islam *et al.* (2004) on soybean indicated that the number of primary branches increased with inoculums and higher doses of phosphorus at 26 kg P ha^{-1}.

Number of effective and total nodules per plant: Nodule development in response to phosphorus rate was assessed through its effect on nodule color. Analysis of variance revealed non-significant difference between varieties and phosphorus rates in relation to the number of effective nodules per plant. Similarly, the effects of phosphorus rates and the interaction were also non-significant. This was in agreement with the results of Caldwell and Vest (1977) who reported the influence of host plant on symbiotic effectiveness (nodulation and nitrogen fixation). The number of total nodule was highly significantly (P < 0.01) affected due to varieties of soybean and different levels of phosphorus application. There were also highly significant differences in number of nodules due to the interaction effect of varieties of soybean and phosphorus rates. Data on the number of total nodules per plant are presented in Table 6. The highest number of nodules per plant (14.37) was obtained from 46 kg ha^{-1} of phosphorus for varietyClark-63k whereas the lowest number of nodules per plant (0.167) was obtained from 0 kg ha^{-1} of phosphorus in variety Ethio-Yugoslavia. This could be due to the positive impact of phosphorus application for better root development. Moreover, crop varieties are different in their nodulation capacity in response phosphorus applications. This result was in line with the findings of Taylor and Francis (2005) who reported significant differences among lentil varieties in their nodulation capacity. The application of higher rate of phosphorus favoured for increased number of nodules. The results obtained from this study showed the existence of variation in nodule number, size, and color among the varieties in response to phosphorus rate. Visual observation showed that nodules developed on variety Ethio-Yugoslavia at phosphorus rate of 57.5 kg ha^{-1} were larger in size than the other varieties. Phosphorus deficiency might have caused a negative effect on the processes of nitrogen fixation by decreasing nodule capacity to fix atmospheric N_2 as result of small nodule size.

Table 7. Main effects of varieties and phosphorus rates on the above ground dry biomass yield (kg ha^{-1}) of soybean

Treatments	Above ground biomass yield (kg ha^{-1})
Variety	
Ethio-Yugoslavia	7550^{a}
Clark-63k	6541^{b}
Jalale (AGS-217)	6393^{b}
LSD (5%)	166.4
Phosphorus rate (kg ha^{-1})	
0	6059^{e}
11.5	6216^{e}
23	6667^{d}
34.5	6987^{c}
46	7306^{b}
57.5	7734^{a}
LSD (5%)	235.3
CV (%)	3.6

Means within column for a factor followed by the same letter are not significantly different at 5% level according to LSD test.

Table 8. Main effects of varieties and phosphorus rates on plant stand count after establishment and at harvest, and number of pods per plant of soybean

Treatments	Stand count after establishment/ha	Stand count at harvest/ha	Number of pods per plant
Variety			
Clark-63k	220694^{a}	221389^{a}	57.9
Ethio-Yugoslavia	224167^{a}	223779^{a}	56.1
Jalale (AGS-217)	213264^{b}	213244^{b}	52.0
LSD (5%)	6551.4	6514.8	Ns
Phosphorus rate (kg/ha)			
0	223750	223657	49.2
11.5	215833	215766	54.0
23	217708	217569	55.7
34.5	219722	220978	53.0
46	222917	222743	61.9
57.5	216319	216111	58.0
LSD (5%)	Ns	Ns	Ns
CV (%)	4.4	4.4	17.2

Means within column for a factor followed by the same letter are not significantly different at 5% level according to LSD test, Ns = Non-significant.

The possibility of the appearance of few nodules and wide range of variation between varieties was also demonstrated by Nutman (1975) who reported as the variation is attributed to the proportional differences in the number of infected root hairs which is host controlled. Many authors also reported that, environmental factors (water stress) have demonstrated negative effect on nodule initiation, structure, development and nitrogenase activity (Sprent, 1972; Sheoron *et al.,* 1981) through their effect on survival and multiplication. Generally the number of nodules per plant increased with increase of phosphorus rate irrespective of variety. It might be because of the fact that phosphorus is essential for the development and function of the nodules. The present finding was in agreement with that of Jacobson (1985); Jones *et al*. (1997); and Tang *et al*. (2001) who observed that nodule number and nitrogenase activity increased with increase in phosphorus rates.

Above ground dry-biomass yield: The main effects of varieties and phosphorus rates were highly significant ($P<0.01$) on the above ground dry biomass yield. However, the interaction effect of varieties and phosphorus rates were non-significant. The highest biomass yield (7734 kg ha^{-1}) was obtained due to 57.5 kg P ha^{-1} application, while the lowest biomass yield (6059 kg ha^{-1}) was obtained from control treatment (Table 7). The effects P rates at control and 11.5 kg phosphorus/ha were not significantly different for above ground dry biomass yield. Comparable investigation reported by Zeidan (2007) and Erman *et al,* (2009) also indicated that increasing phosphorus levels from 0 to 60 kg P_2O_5 ha^{-1} increased the general biomass of lentil and field pea plants and decreased at 90 kg P_2O_5 ha^{-1} for field pea.

Regarding the variety, the highest above ground dry biomass yield (7550 kg ha^{-1}) was obtained for variety Ethio-Yugoslavia while the lowest above ground dry biomass yield (6393 kg ha^{-1}) was obtained for variety Jalale (AGS-217). The highest biomass yield for variety Ethio-Yugoslavia might be due to longer maturity which had more time for biomass accumulation than variety Jalale (AGS-217) which had shorter flowering and maturity days. However, except for variety Ethio-Yugoslavia all the varieties were not significantly different for above ground dry biomass yield.Phosphorus deficiency generally decreases plant biomass accumulation by limiting interception of photosynthetically active radiation (PAR) rather than reducing efficiency of conversion of PAR into dry matter. The varieties that also take shorter period to their vegetative growth time are more productive under limited resources and the reverses could probably have higher vegetative yield. Similarly, Khamparia (1996) reported that increasing rates of P in inoculated treatment increased biomass yield by 13.1 to 14.7% of soybean. The current investigation was in line with the findings of Yilmaz (2008) who pointed out that increasing phosphorus levels improved above ground biomass at harvest of vetch by as much as 18.5%.

Yield Components and Yield

Plants stand count after establishment per hectare: Stand count after establishment was highly significantly ($P<0.01$) varied among the soybean varieties. However, the effects of Phosphorus rates and the interaction were non- significant. Regarding to variety, higher establishment was recorded for variety Ethio-Yugoslavia (224167 plants ha^{-1}), whereas the

Table 9. The interaction effect of varieties and rates of phosphorus application on number of seeds per pod

phosphorus rate (kg ha^{-1})	Variety		
	Clark-63k	Ethio-Yugoslavia	Jalale (AGS-217)
0	2.28^{i}	2.42^{efgh}	2.323^{hi}
11.5	2.283^{i}	2.407^{fgh}	2.63^{a}
23	2.437^{defg}	2.36^{ghi}	2.547^{abc}
34.5	2.43^{defgh}	2.503^{bcdef}	2.52^{bcde}
46	2.6^{ab}	2.59^{ab}	2.51^{bcdef}
57.5	2.513^{bcdef}	2.46^{cdefg}	2.54^{abcd}
LSD (5%) = 0.11			
CV (%) = 2.7			

Means for a factor followed with same letter within the table do not differ significantly at 5% level according to LSD test

Table 10. Main effects of varieties and phosphorus rates on hundred grains weight (g) of soybean

Treatments	Hundred grain weight (g)
Variety	
Ethio-Yugoslavia	14.30^{a}
Jalale (AGS-217)	13.54^{b}
Clark-63k	13.09^{c}
LSD (5%)	0.278
phosphorus rates (kg ha^{-1})	
0	13.33^{b}
11.5	13.28^{b}
23	13.60^{ab}
34.5	13.76^{a}
46	13.97^{a}
57.5	13.93^{a}
LSD (5%)	0.392
CV (%)	3.0

Means within column for a factor followed by the same letter are not significantly different at 5% level according to LSD test.

lowest (213264 plants ha^{-1}) for variety Jalale (AGS- 217) (Table 8). However, except for variety Jalale (AGS- 217) all the varieties were not significantly different for stand count after establishment. This variation could be attributed to genotypic differences. Therefore, it could be assumed that the soil of the experimental site had optimum available P content for the requirement of the test crop. The highest number (223750 plants/ha) obtained from control treatment, while the lowest (215833 plants/ha) obtained from 11.5 kg Phosphorus ha^{-}. The difference between varieties at stand count after establishment might be due to differences in seed quality.

Plants stand count at harvest: Stand count at harvest was highly significant different (P<0.01) among the soybean varieties. However, non-significant difference was observed due to phosphorus rates and it's interaction with variety. The highest stand count was obtained for variety Ethio-Yugoslavia (223779 plants ha^{-1}) while the lowest (213244 plants ha^{-1}) was obtained for variety Jalale (AGS-217) (Table 8). However, except for variety Jalale (AGS-217) the other two varieties were not significantly different in stand count at harvest. This variation could be attributed to genotypic differences. On the other hand, variety Ethio-Yugoslavia is higher in vegetative (vigorous) growth on clay loam soil might be resist and to external factor and observed healthier looking plants in Yayo agro ecology than the other varieties. With regards to Phosphorus rates, the highest number of plant stand count at harvest (223657 plants/ha) was observed at control treatment while the lowest number of plant stand count at harvest (215766 plants/ha) was recorded from 11.5 kg phosphorus ha^{-} though statistically non-significant.

Number of pods per plant: The analysis of variance showed non-significant variation among the varieties of soybean in number of pods per plant. Similarly, the effects of phosphorus rates and the interaction were also non-significant. However, variety Clark-63k had the highest number of pods per plant (57.9) while variety Jalale (AGS-217) produced the lowest number of pods per plant (52) (Table 8). With regards to phosphorus rates, the highest number of pods per plant (61.9) was observed at phosphorus rate of 46 kg ha^{-1} while the lowest number of pods per plant (49.2) was recorded in unfertilized treatments. Similar result was also reported in soybean by Subramanian and Radhak (1981); and Jayapaul and Ganesaraja (1990) where the application of 80-120 kg P_2O_5 ha^{-1} of soybean increased the number of pods plant^{-1}.

Number of seeds per pod

The number of seeds per pod was highly significantly (P<0.01) affected due to varieties of soybean and different levels of phosphorus application. Moreover, the interaction effect of varieties and rates of phosphorus application was also highly significant on the number of seeds per pod. The highest number of seeds per pod (2.63) was obtained from 11.5 kg ha^{-1} of phosphorus for variety Jalale (AGS-217) whereas the lowest number of seeds per pod (2.28) was obtained from 0 kg ha^{-1} of phosphorus for variety Clark-63k (Table 9). Variety Jalale (AGS-217) showed little response to phosphorus rates whereas variety Clark-63k showed better response to phosphorus application. Zafar *et al*. (2003) also reported that there was a regulatory system through which it was possible to direct and concentrate available nutrients to permit development of more number of pods per plant and seeds per pod. This result was in line with the findings of Malik *et al*. (2006) and Shahid *et al*. (2009) who reported significant increase in number of seeds per pod of soybean by phosphorus fertilization. They also further pointed out that phosphorus aids in transferring photosynthesis from the stalks, leaves and other growing parts to the economically important organs like seed making them plump and bold.

Table 11. Grain yield (kg ha^{-1}) of soybean as affected by the interaction of varieties and phosphorus rates

phosphorus rate(kg ha^{-1})	Variety		
	Clark-63k	Ethio-Yugoslavia	Jalale (AGS-217)
0	2185^{e}	2105^{efg}	2050^{gh}
11.5	2400^{cd}	2189^{e}	2165^{ef}
23	2350^{d}	2098^{efg}	2188^{e}
34.5	2567^{b}	2327^{d}	2152^{ef}
46	2730^{a}	2495^{bc}	1995^{h}
57.5	2465^{c}	2418^{cd}	2075^{fgh}
LSD (5%) = 99.32			
CV (%) = 2.6			

Means for a factor followed with same letter within the table do not differ significantly at 5% level according to LSD test

Table 12. Harvest index of soybean as influenced by the interaction of variety and phosphorus rates

phosphorus rate(kg ha^{-1})	Variety		
	Clark-63k	Ethio-Yugoslavia	Jalale (AGS 217)
0	0.38^{abc}	0.31^{de}	0.36^{c}
11.5	0.39^{ab}	0.33^{d}	0.37^{abc}
23	0.37^{abc}	0.27^{g}	0.37^{bc}
34.5	0.38^{abc}	0.30^{def}	0.33^{d}
46	0.4^{a}	0.31^{def}	0.29^{efg}
57.5	0.33^{d}	0.29^{efg}	0.28^{fg}
LSD (5%) = 0.027			
CV (%) = 4.8			

Means followed for a factor with same letter within the table do not differ significantly at 5% level according to LSD test

Hundred Seed weight (g): Hundred seed weights were found to be affected highly significantly ($P<0.01$) by soybean varieties and Phosphorus application rates. However, the interaction effect was non-significant. The highest 100-grain weight (14.3 g) was recorded for the variety Ethio-Yugoslavia while the lowest (13.09 g) value of 100-seed weight was recorded by variety Clark-63k (Table 10). With regards to phosphorus rates, the highest 100 grain weight (13.97 g) was obtained under 46 kg ha^{-1} of phosphorus while the lowest (13.28 g) was obtained under 11.5 kg phosphorus ha^{-1} which was not statistically different from no fertilizer application. Chatterjee and Som (1991) reported increase in hundred seed weight due to the application of phosphorus up to 80 kg P_2O_5 ha^{-1}. In line with this result, Malik *et al.* (2006) reported that P fertilizer and seed inoculation having a significant influence on 1000-seed weight of soybean, with the highest value from 90 kg P_2O_5 ha^{-1} with *Rhizobium* inoculation which was statistically at par with 120 kg P_2O_5 ha^{-1} with inoculation. Zafar *et al.* (2003) reported that the effect of rates of phosphorus application was highly significant in affecting 1000-seed weight. This might be due to the influence of cell division, phosphorus content in the seeds as well as the formation of fat and albumin.

Grain yield (kg ha^{-1})

The main effects of phosphorus rates and varieties had highly significant ($P<0.01$) effects on the grain yield of soybean. Moreover, variety and phosphorus rate interaction was highly significant. Variety Clark-63k treated with 46 kg ha^{-1} of phosphorus produced the highest grain yield (2730 kg ha^{-1}) while variety Jalale (AGS-217) supplied with 46 kg ha^{-1} of phosphorus produced the lowest grain yield (1995 kg ha^{-1}) (Table 11). Variety Jalale (AGS-217) had little response to phosphorus applications and could be preferable variety when there is shortage of phosphorus fertilizers. Tomar (2001) revealed as that application of phosphorus influenced the seed yield of French bean *(Phaseolus vulgaris)* significantly up to 60 kg P_2O_5 ha^{-1}. Singh and Singh (2000) and Tewari and Singh (2000) also revealed significantly increased seed yield due to increased phosphorus application from 75 to 100 kg P_2O_5 ha^{-1}.

Among the soybean varieties, Clark-63k produced highest yield followed by Ethio-Yugoslavia while variety Jalale (AGS-217) produced the lowest seed yield (Table 11). Similarly, among the phosphorus rates, the highest grain yield of 2406.7 kg ha^{-1} was obtained in response to the application of 46 kg phosphorus ha^{-1} followed by 34.5 kg P ha^{-1} while the lowest yield was produced under control treatment. From these results, Variety Clark-63k was the better variety due to its feature or attractive of highest yield and early maturity than variety Ethio-Yugoslavia under the agro-ecology of Yayo district, south-western Ethiopia. Similarly, the investigation on soybean, Farani (1988) indicated that seed yield was increased with seed inoculation and varying phosphorus levels up to 26 kg P ha^{-1}. Similar results were also reported by Chatterjee and Som (1991) where seed yield of French bean and increased from 2276 to 2350 kg ha^{-1} due to increase in phosphorus fertilization from 40 to 80 kg P_2O_5 ha^{-1}.

Harvest index: Harvest index calculated as the ratio of grain yield to the above ground dry biomass weight was highly significantly ($P<0.01$) influenced by the main effect of variety, phosphorus rates as well as the interaction effect of variety and phosphorus rates. The application of phosphorus at 46 kg ha^{-1} resulted in the highest harvest index for variety Clark-63k (0.4) while the lowest harvest index (0.27) was recorded for variety Ethio-Yugoslavia at 23 kg ha^{-1} of phosphorus (Table 12). Among the rates of phosphorus application, the highest harvest index (0.36) was obtained with the application of 11.5 kg phosphorus ha^{-1} followed by 0 kg phosphorus ha^{-1} or control treatment which gave (0.35) while the lowest harvest index (0.30) was obtained from the application of 57.5 kg phosphorus ha^{-1}. Similarly, Ali (1993) reported that inoculation and phosphorus application exhibited significant effect on harvest index of various legume crops has decreased with increase in phosphorus application. In contrast to the current result, Zafar *et al*. (2003) found that values of harvest index showed an increasing trend in the harvest index values with application of Phosphorus. Salado-Navaro *et al.* (1993) working in soybean, found highly and significantly negative association of HI with days to physiological maturity. In addition, they also reported minimum harvest index from control plot as compared to fertilized. Among the varieties, Clark-63k gave the highest harvest index (0.4) while variety Ethio-Yugoslavia had the lowest harvest index (0.3). The lowest harvest index (0.3) obtained for variety Ethio-Yugoslavia might be due to its late maturity and more vegetative growth (Table 12). The higher harvest index of variety Clark-63k might be due to the higher grain yield obtained.

Summary and Conclusions

Ethiopia is among the countries with the highest rates of nutrient loss, mainly due to the low nutrient input and high biomass removal. Therefore, in the absence of chemical supplies, Phosphorus has crucial role in symbiotic relationships between legume crops and nitrogen fixing microorganisms. Its availability is important in maintaining the rhizobial population in the soil, facilitating the movement of bacteria towards root system and its subsequent infection. As a result nitrogen fixation and its potential contribution to tropical crop production systems have been limited due to uncorrected phosphorus deficiency. Therefore, the present study was conducted to investigate the effect rates of phosphorus on yield and yield components of soybean [*Glycine max* (L) Merrill] varieties on clay loam soil in Yayo District, south-western Ethiopia. The result of the analysis of soil samples showed that the soil of the experimental field to be clay loam in texture and had a pH of 6.2, 2.19% organic matter, 0.25% total N, CEC of 27.4 cmol/kg soil and available Olsen phosphorus of 17.6 mg kg^{-1}. It was observed that interaction of variety with phosphorus rates affected days to flower initiation, days to physiological maturity, number of nodules per plant, number of seeds per pod, grain yield and harvest index. All agronomic parameters were highly significant affected by variety except number of pods per plant. Similarly, phosphorus rate had highly significant effect on all parameters studied except on days to emergence, plant height, and stand count after establishment and at harvest and number of total nodules per plant, phosphorus use efficiencies. Accordingly, variety Jalale (AGS-217) was found to be early maturity (119.856 days), had higher number of seeds per pod (2.5) with harvest index (0.33) while variety Clark-63k gave higher number of nodules per plant (9.425), pods per plant (57.9) and grain yield (2730 kg/ha) with the interaction of phosphorus rate and high in P use efficiency. Variety Ethio-Yugoslavia was late maturity (146.29 days) and gave higher hundred grain weight (14.30 g).

As phosphorus rates increased, days to flower initiation and days to physiological maturity were decreased but above ground biomass were increased. In general, the application of higher rates of phosphorus (46 kg ha^{-1}) gave higher seed yield that was 2406.7 kg ha^{-1}. Variety Jalale (AGS-217) showed low response to phosphorus applications could also be preferable variety when there is shortage of phosphorus fertilizers. The highest number of seeds per pod (2.63) was obtained with the interaction of phosphorus rate of 11.5 kg $ha^{-1}$with variety Jalale (AGS-217).Accordingly, variety Clark-63k, as noticed from its performance on various growths and phenological characters including its response to phosphorus rates might be the best variety under the agro-ecology of south-western Ethiopia of Yayo District. Accordingly, application of higher rates of phosphorus (46 kg/ha) was found to be superior in most parameters recorded. The results also revealed further application of phosphorus rate might not give better yields around south-western Ethiopia of clay loam. However, to give a conclusive recommendation, it is important to repeat the study over varieties and seasons with consideration of economics of fertilizer use to reach at conclusive recommendations.

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