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Effect of Nitrogen and Sulphur Application on Yield Components and Yield of Common Bean (*Phaseolus Vulgaris* L.) in Eastern Ethiopia

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A field experiment was conducted at Haramaya and Hirna to study the effect of nitrogen and sulphur application on yield components and yield of common bean during the 2012 main cropping season. The treatments consisted of three nitrogen rates (0, 23, 46 kg N ha^{-1}) and four sulphur rates (0, 20, 40 & 60 kg S ha^{-1}). The experiment was laid out as a randomized complete block design with three replications. The main effect of nitrogen had a significant influence on days to flowering, days to physiological maturity, plant height, leaf area index, number of pods per plant aboveground dry biomass, grain yield and harvest index. The main effect of sulphur had no significant effect on all of the parameters except a number of effective nodules per plant at both locations. Grain yield was significantly higher at Hirna than at Haramaya. Significantly higher grain yield was obtained in response to the application of 23 and 46 kg N ha^{-1} at Hirna, which resulted in the production of grain yields of 6.5 and 6.7t ha^{-1}, respectively. However, at Haramaya, the highest grain yield(6.7t ha^{-1}) was obtained in response to the application of 23 kg N ha^{-1}. Grain quality was not altered by nitrogen and sulphur application, except the total phosphorus, which was significantly affected by nitrogen application. In conclusion, the results revealed that nitrogen at moderate rates led to significant enhancements in yield components and grain yield. It could, thus, be deduced that application of nitrogen markedly increases the productivity of the crop in the region.

Keywords: Nitrogen, Sulphur and common bean

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INTRODUCTION

The common bean (*Phaseolus vulgaris* L.) was assumed to have been introduced into Ethiopia in the 16th century by the Portuguese (Imru, 1985). Common bean (n = 11) belongs to the order *Rosale*s, family *Fabaceae* (CIAT, 1986a). Areas, reported to be suitable for bean production in Ethiopia are those with altitudes between 1200-2200metres above sea level, mean maximum temperature of less than 30-32 ^{0}C, mean minimum temperature greater than 10-12^{0}C and annual rainfall ranges from 350-700 mm but well distributed throughout the growing season (Amare and Haile, 1989). It has been known as an export crop for a long period, contributing to the foreign exchange earnings. It is also grown as a food crop. Common bean is consumed in traditional dishes. The crop produces more for consumption than export. Dry beans are mostly prepared as ‘*nifro’* (boiled whole grains), mixed with sorghum or maize and ‘*wat’* (local soup) and also with ‘*kocho’*. Fresh beans (mature, the whole non-dried grain) are popular for their taste and crackability (MoARD, 2009).

It is well known that the dry seeds represent an affordable and inexpensive source of proteins despite being deficient in sulphur amino acids (Angela *et al*., 2010). Although the crop has been cultivated in different parts of the country, the major common bean production region is central, eastern, and southern parts of the country (CSA, 2000). In the semi-arid to sub-humid highlands of the Hararghe region, including the area where this study was conducted, the common bean is grown mostly intercropped with sorghum (*Sorghum bicolor* L), chat (*Catha edulis* Forsk.) and maize (*Zea mays* L.) and seldom as a sole crop (CSA, 2000).

The low yield of common bean is attributed to various constraints related to drought, lack of improved varieties, poor cultural practices, low soil fertility, disease and pests and environmental degradation (IAR, 1990). Maintenance of field S fertility is often overlooked, and its deficiency symptoms in crops are sometimes confused with P or N deficiencies or Al toxicity. Since concentrated fertilizers with a low S content are now widely used, S deficiency problems appear more often (Hitsuda *et al*., 2005).

Therefore, significant improvement in yield obtained under sulphur fertilization seems to result from increased concentration of sulphur in various parts of cluster bean that helped to maintain the critical balance of other essential nutrients in the plant and resulted in increased metabolic processes in plants (Sharma and Singh, 2005).

In Ethiopia, research on bean has mainly focused on varietal selection and other methods of genetic manipulation aimed at improving yield. However, little research has been done to investigate the effect of fertilizers on yield of the crop. What is more, given the low sulphur content of most Ethiopian soils due to the low status of the organic matter, and the importance of sulphur to the yield and quality of portentous crops like beans, there is a need for research to be conducted on the influence of the nutrients on the productivity of the crop. This research was, therefore, initiated with the objective of investigating the effect of nitrogen and sulphur fertilizer application on growth and seed yield of common bean.

MATERIALS AND METHODS

Description of the Experimental Site

The experiment was conducted during the 2012 main cropping season under rain-fed conditions at two locations *viz*., Main campus and Research sub-station Hirna of Haramaya University. The research site on the main campus of the university is situated at 9^0 26' N latitude, 42^0 3' E longitudes and at an altitude of 1980 m above sea level. The rainfall distribution of the area is bimodal with an average annual rainfall of 780mm (Tekalign, 2005) the seasonal rainfall during the experiment was 538.3 mm. The mean maximum and minimum annual temperatures are 23.4 ^{0}C and 8.25 ^{0}C, respectively. The soil of the experimental site is well drained deep alluvial with a sub-soil stratified with loam and sandy loam. The soil test results from the laboratory revealed that the soil has organic carbon content of 1%, total nitrogen content of 0.13%, available phosphorus content of 19.14 mg kg^{-1} soil, exchangeable potassium content of 0.49 cmol kg^{-1} soil, available sulphur content of 106.6 mg kg^{-1} soil, pH of 8.10, and composition of sand, silt and clay contents were 33, 22 and 45%, respectively.

Hirna is located at 9 ^{o}12' N latitude, 41 ^{o}4' E longitude and at an altitude of 1870 m above sea level at a distance of about 175 km to the west of Haramaya. The area receives mean annual rainfall ranging from 990 to 1010 mm. The average temperature of the area is 24.0 ^{0}C. The soil of Hirna is vertisol with the organic carbon content of 1.75 %, total nitrogen content of 0.18%, available phosphorus content of 32.2 mg kg^{-1} soil, exchangeable potassium content of 0.68 cmol kg^{-1}soil, available sulphur content of 44.63 mg kg^{-1} soil, pH of 7.09, and composition of sand, silt and clay contents were 27, 28 and 45%, respectively.

Treatments and Experimental Design

The treatments included three levels of nitrogen (0, 23, and 46 kg N ha^{-1}) and four levels of sulphur (0, 20, 40, and 60 kg S ha^{-1}). The experiment was laid out as a randomized complete block design (RCBD) in a factorial arrangement and replicated three times. There were, thus, twelve treatment combinations, which were assigned to each plot randomly.

Experimental Procedures

The experimental fields were plowed and harrowed using a tractor and plots were leveled manually. The size of each plot was 2.4 m x 3 m (7.2 m^2). The blocks were separated by a 1m wide open space, whereas the plots within a block were separated by a 0.5 m wide space. The seed of common bean variety ‘Gofta' (G-2816), that is type III in growth habit having bold seeds with a cream color was used in this experiment. This variety is adapted to Hararghe highlands, having altitudinal ranges of 1500-2000 m above sea level with an annual rainfall of 500-

1200 mm. The fertilizers as per the treatments were drilled in rows 40cm apart. The source of nitrogen was urea (46% N) while potassium sulphate (54% K_2O and 18% S) was used as a source of sulphur. Muriate of potash (62 K_2O and 48% Cl) was used to balance the supply of potassium applied through potassium sulphate as per the treatments. Both nitrogen and sulphur fertilizers were applied in splits whereas muriate of potash was applied as a basal dressing. Half doses of both nitrogen and sulphur were applied at planting and the remaining half dose of each nutrient was applied at a pre-flowering stage. The planting was done at an inter- and intra-row spacing of 40 cm and 10 cm, respectively, on July 16 at Haramaya while at Hirna it was done on 14 July 2012. Each plot had six rows of which one row on both sides of each plot and 30cm on both ends of each row served as a border to avoid edge effects. The four central rows were considered for various data recording. Thus, the net plot size was 1.6m x 2.4m (3.84 m^2). All the other recommended management practices were uniformly followed for raising the crop. Harvesting was done on 16 and 20 October 2012 at Hirna and Haramaya, respectively.

Soil sampling and analysis

Soil sampling and analyses were done before sowing the crop. Before sowing, the soil samples from the entire experimental fields of the study sites were taken randomly in a W-shaped pattern from the whole experimental plots. Ten samples were taken using an auger from each arm of the W-shaped lines of the field to a depth of 0-30 cm. Thus, 30 soil cores were taken from the whole experimental fields and thoroughly mixed. From this mixture, a sample weighting 1 kg was taken and replicated 3 times for analysis. Before analysis, the sample soil was air-dried, sieved through a 2-mm sieve mesh. The composite soil samples were analysed for selected physicochemical properties mainly textural analysis (sand, silt and clay), soil pH, total nitrogen (N), sulphur (S), organic matter, content, available phosphorus (P), cation exchangeable (CEE) capacity, and exchangeable potassium using the appropriate laboratory procedures.

Data Collection and Measurements

Days to flowering: This refers to the actual number of days required by the plants from emergence to a stage when 50% of the plants in the plot produced flowers. This was determined by counting.

Days to physiological maturity: This was recorded as the number of days from emergence to the time when about 90% of the plants in a plot had mature pods in their upper parts with pods in the lower parts of the plants turning yellow.

Plant height: The height from the base to the apex of 10 randomly taken plants from the central rows was measured using a ruler at the time of 50% flowering.

Leaf area and leaf area index: Three randomly taken plants from a net plot area were taken and leaf area of each plant was determined just before flowering. Leaf area index was calculated as the ratio of total leaf area to the ground area covered by the canopy.

Number effective of nodules: Bulked roots of 5 randomly taken plants were carefully exposed at flowering and uprooted for nodulation study. Roots were carefully washed under gently flowing tap water on a screen and nodules were separated and counted. The effectiveness of the nodules was checked by cutting the nodule for color judgment as a percentage of the pink being effective and the cream (white) ineffective.

Dry biomass (kg/ha): This refers to the dry biomass of the whole aboveground plant at physiological maturity. The total fresh biomass of 10 randomly selected plants were taken and dried in a forced draft air oven at 65^0C until constant weight was obtained.

A number of pods per plant: Pods of ten randomly taken plants from central three rows were counted during harvest to calculate the mean number of pods per plant.

Grain yield (kg): This was recorded from each net plot area. The grain moisture content was determined for each treatment and adjusted to 10.5% moisture content using the formula**.**
Adjusted grain weight (g) = Recorded grain weight x 100-M/100-D
Where M is the measured moisture content in grain and D is the designated moisture content.

Harvest index (HI): It was computed as the ratio of seed yield (kg ha^{-1}) to total dried aboveground biomass.

DATA ANALYSIS

The data were subjected to analysis of variance (ANOVA) according to the Generalized Linear Model using SAS version 9.0 (SAS, 2004). Differences between treatment means were separated according to the least significant difference (LSD) test at 5% level of significance.

RESULTS AND DISCUSSION

Days to flowering

At Hirna the number of days required for 50% flowering was significantly ($P < 0.05$) influenced by the main effects of nitrogen and sulphur application. However, their interaction and at Haramaya the main effect of nitrogen, sulphur and their interaction did not influence this parameter (Appendix Table 3 & Table 5).

At Hirna nitrogen application prolonged the days to 50% flowering. When the rate of nitrogen application was increased from nil to 23 kg N ha^{-1}, the days to 50% flowering remained statistically the same. However, when the nitrogen supply was increased to 46 kg N ha^{-1}, the days to 50% flowering was prolonged significantly. Thus, bean plants grown at the rate of 46 kg N ha^{-1} had their days to 50% flowering is delayed by about 3% (Table 1).

The delay in days to flowering due to the increased rates of nitrogen supply may be attributed to the positive role that nitrogen plays in promoting vegetative growth. This is in line with the results of Arya *et al*. (1999) who reported that common bean plants supplied with a higher dose of N (50 kg ha^{-1}) took more days to reach 50% flowering. This result is corroborated also by that of Tewari and Singh (2000) who reported common bean crop supplied with nitrogen (160 kg N ha^{-1}) required significantly more number of days to reach the growth stage of 50% flowering.

However, sulphur application significantly hastened the days to flowering of the bean plants at Hirna. Thus, plants grown without sulphur had days to 50% flowering prolonged by about 3% compared to plants grown with sulphur at the rate of just 20 kg S ha^{-1}. Unlike plants were grown at Hirna (which responded to sulphur application), those grown at Haramaya did not respond to the application of the nutrient (Table 1). This may be attributed to differences in environmental conditions between the two location

Table 1.The main effects of nitrogen and sulphur on days to flowering, physiological maturity and plant height at Haramaya and Hirna during the 2012 main cropping season

Means with the same letter are not significantly different at $P > 0.05$; CV = Coefficient of Variation NS = Not significant

Days to physiological maturity

The number of days required to reach physiological maturity of common bean was significantly ($P < 0.05$) affected by the main effect of nitrogen at both locations. However, the main effect of sulphur and their interaction with nitrogen did not affect this parameter at both locations (Appendix Table 3 & Table 5).

Bean plants grown at Hirna matured earlier than those grown at Haramaya (Table 1). The earlier maturity under the Hirna environment could be linked to the relatively higher growing temperature than the Haramaya (Appendix Table 2). The suitable areas for common bean cultivation in Ethiopia are those with a mean maximum temperature of less than 30-32^{0}C, mean minimum temperature greater than 10-12^{0}C. (Ohlander, 1977; Imru, 1985; Amare and Haile, 1989). Thus, the mean Hirna's temperature during the growing season falls within this range, whereas that of Haramaya falls below this range (Appendix Table 2).

Application of nitrogen resulted in significantly delayed physiological maturity at both locations. Increase in nitrogen application rate from 0 to 46 kg N ha^{-1} led to a significant increase in the number of days required to reach physiological maturity (Table 1). The result clearly indicated that days to maturity were prolonged in response to the increased levels of nitrogen. This may be attributed to the role that nitrogen plays in promoting vegetative growth. This is in line with the results of Gupta and Sharma (2000) who reported that nitrogen promoted vegetative and lush growth thereby delaying plant maturity. This indicates the nutrients taken up by plant roots from the soil will be used for increased cell division and synthesis of carbohydrate, which will predominantly be partitioned to the vegetative sink of the plants, resulting in plants with a luxurious foliage growth (Marschner, 1995). This is further corroborated by the results of Huerta *et al*. (1997) who reported delayed physiological maturity due to nitrogen fertilization up to 80 kg ha^{-1} in common bean. The application of sulphur had no significant effect on the days to maturity at both locations (Table 1).

Plant height

The analysis of variance showed significant ($P < 0.05$) differences in plant height due to the main effects of nitrogen application at both locations. However, there was no interaction effect on plant height at Haramaya and Hirna (Appendix Table 3 & Table 5). Plants grown at Hirna were significantly taller than those grown at Haramaya by about 14.9%. This may be attributed to differences in soil and weather conditions at the two locations whereby Hirna had probably more conducive environmental conditions for growth and development of common bean than Haramaya. This may most probably be the temperature, which was warmer at Hirna than at Haramaya. This is consistent with the suggestion of Blackshaw *et al*. (1999) who reported that higher temperatures are more favourable for growth and yield of common bean. With the increase in nitrogen application rates, there were increases in plant height. At Haramaya when the rate of nitrogen was increased from 0 to 23 and

Table 2. The main effects of nitrogen and sulphur on days to flowering, physiological maturity and plant height at Haramaya and Hirna during the 2012 main cropping season

	Days to 50% flowering		**Physiological maturity**		**Plant height(cm)**	
Nitrogen (kg N/ha)	**Haramaya**	**Hirna**	**Haramaya**	**Hirna**	**Haramaya**	**Hirna**
0	37	34b	98b	88b	98b	114.7b
23	37	34b	103.3a	88b	103.3a	119.5a
46	36	35a	106.8a	89a	106.8a	122.7a
LSD(5%)	Ns	0.78	6.94	1.1	6.94	4.1
Sulphur (kg S/ha)						
0	36	35a	99.9	88	99.9	118.7
20	36	34b	104.2	89	104.2	117.8
40	36	34b	103.7	86	103.7	120.1
60	37	34b	104.1	88	104.1	119.1
LSD (5%)	NS	0.91	NS	NS	NS	NS
CV%	3.9	2.6	7.6	1.38	7.6	3.8

Means with the same letter are not significantly different at P >0.05; CV = Coefficient of Variation NS = Not significant

Table 2. The main effects of nitrogen and sulphur application on leaf area index, number of effective nodules and number of pods per plant at Haramaya and Hirna during the 2012 main cropping season

	Leaf area index		**Number of effective nodules (plant-^{1})**		**Number of pods per plant**	
Nitrogen (kg N/ha)	**Haramaya**	**Hirna**	**Haramaya**	**Hirna**	**Haramaya**	**Hirna**
0	2.56b	3.0c	45.5	31.3	15b	27b
23	4.35a	4.8b	44.6	32.7	22a	33a
46	4.41a	5.9a	48.0	25.2	21a	37a
LSD5%	0.89	0.44	NS	NS	4.4	5.5
Sulphur (kg S/ha)						
0	3.7	4.8	28.5c	18.6b	20	31
20	4.0	4.2	47.3b	30.9a	20	32
40	3.5	4.3	45.2b	38.1a	19	35
60	3.8	4.9	63.6a	31.4a	18	33
LSD (5%)	NS	NS	15.7	11.2	NS	NS
CV%	26.7	10.8	33.1	36.5	26.1	19.1

Means with the same letter are not significantly different at P > 0.05; CV = Coefficient of variation NS = Not significant.

Table 3. Effect of nitrogen and sulphur on aboveground dry biomass yield, grain yield and harvest index of common bean at Haramaya and Hirna during 2012 cropping season

	Aboveground dry biomass yield (t ha^{-1})		Grain yield (t ha^{-1})		Harvest index	
Nitrogen (kg N/ha)	Haramaya	Hirna	Haramaya	Hirna	Haramaya	Hirna
0	9.4b	10.6c	5.0b	5.6b	0.53	0.53b
23	10.4a	11.4b	5.6a	6.7a	0.54	0.59a
46	10.6a	12.1a	5.2b	6.4a	0.49	0.53b
LSD5%	0.8	0.67	0.3	0.24	NS	0.04
Sulphur (kg S/ha)						
0	10.18	11.5	5.3	6.2	0.53	0.54
20	10.3	11.4	5.2	6.1	0.51	0.53
40	9.9	11.3	5.4	6.3	0.54	0.56
60	10.1	11.3	5.2	6.4	0.51	0.57
LSD (5%)	NS	NS	NS	NS	NS	NS
CV%	9.1	6.67	7.0	4.4	10.1	7.9

Means with the same letter are not significantly different at P > 0.05; CV = Coefficient of Variation NS=Not significant.

Table 4. The effect of nitrogen and sulphur on seed quality of common bean at Haramaya during 2012 cropping season

Treatment	Protein (%)	Total phosphorus (mg kg^{-1})	Zinc (mg kg^{-1})	Iron (mg kg^{-1})
Nitrogen(kg /ha)				
0	20.9	2792^{b}	19.07	86.7
23	21.0	3429^{a}	18.29	92.0
46	21.6	3192^{ab}	18.61	86.5
LSD (5%)	NS	*	NS	NS
Sulphur (kg/ha)				
0	21.6	3101	19.11	86.0
20	21.0	3100	19.72	88.8
40	21.1	3247	17.90	88.1
60	21.0	3104	17.89	89.4
LSD (5%)	NS	NS	NS	NS
CV%	6.0	17.0	15.1	16.7

Means with the same letter are not significantly different at P >0.05; CV = Coefficient of Variation NS= Not significant.

46 kg N ha^{-1}, plant height increased by about 5.4% and 9 %, respectively. Similarly, at Hirna the application of nitrogen from 0 to 23 and 46kg N ha^{-1}, plant height was increased by 4.2% and 7% respectively. However, at both location the height of plants grown at 23 and 46 kg N ha^{-1} were in statistical parity (Table 1). The significant increase in plant height in response to the increased rates of nitrogen application might be ascribed to the increased availability of nitrogen in the soil for uptake by plant roots, which may have sufficiently enhanced vegetative growth through increasing cell division and elongation (Marschner, 1995; Halvin *et al*., 2003). However, no significant variation was observed for this parameter due to the main effect of sulphur (Table 1).

Leaf area index

The analysis of variance showed that leaf area index was significantly influenced by the main effect of nitrogen at both locations. However, at both locations, neither the main effect of sulphur nor their interaction responded to leaf area index (Appendix Table 3 & Table 5).

At Hirna, with the increased rate of nitrogen application from 0, 23, and 46 kg N ha^{-1} leaf area index significantly increased by about 60% and 96.7%, respectively. At Haramaya, leaf area index increased only up to 23 kg N ha^{-1}, which were statistical parity with the leaf area index recorded for plants grown with the supply of 46 kg N ha^{-1} (Table 2). The lowest leaf area indices were recorded for plants grown without nitrogen application at both, locations.

The optimum leaf area index (5. 89) of common bean was obtained in response to the application of 46 kg N ha^{-1} at Hirna. The superiority of the leaf area index of plants grown at Hirna to the leaf area index of plants grown at Haramaya the highest rate of nitrogen supply was about 33.7 %. This result could be ascribed to the differences in growth condition between the two locations. Moreover, increase in leaf area index may be attributed to more availability of the nutrients which may have enhanced cell division and cell enlargement thereby increasing the leaf area. This is in line with the suggestion of Sale (1975), Aguilar *et al.* (1977), and Fanjul *et al.* (1982) who reported that the optimum leaf area index of common bean is 5.0 and ranges between 7 to 8 for dwarf and climbing types of bean, respectively. Thus, common bean plants were grown at Haramaya generally fell short of attaining optimum leaf area index, which could be attributed to the less conducive environment of Haramaya for bean growth, compared to the environmental condition at Hirna.

Nitrogen is required in large amounts in plant tissues, since it is an integral component of many compounds essential for plant growth processes, including chlorophyll and many enzymes including proteins, amino acids, nucleotides, nucleic acids and chlorophyll (Grant and Bailey, 1990). The increase in leaf area index may also be attributed to more availability of nutrients which may have enhanced cell division and cell enlargement thereby increasing the leaf area. Similarly, the investigation carried out by Kushwaha (1994) on a sandy loam soil at Indian Institute of Pulses Research on French bean revealed that leaf area index increased with increasing levels of nitrogen from zero to 120kg ha^{-1}. Consistent with the results of this study, Thakur *et al*. (1999) at Palampur (India) on a silty clay soil (pH 5.8), observed significantly increased leaf area index in French bean due to increasing nitrogen fertilization up to 75 kg ha^{-1}. Veeresh (2003) reported that leaf area index of French bean during *kharif* increased from 1.75 to 2.13 in response to increasing nitrogen levels from 40 to 120 kg ha^{-1}. From the field experiment carried out at Keonjhar (Bhubaneswar) on French bean, Behura *et al*. (2006) reported that leaf area index exhibited increasing trend with increasing nitrogen level up to 120 kg N ha^{-1}.

Similarly, there was also no significant main effect of sulphur and its interaction with nitrogen on leaf area index.

Effective nodules

The effect of nitrogen application at both locations had no significant influence on the number of effective nodules per plant (Table 2). That nitrogen application does not affect or suppresses formation of effective nodules was earlier confirmed by Saito *et al*. (1984) and Mangual-Crespo (1987), who found that fertilization with as little as 20 to 50 kg N ha^{-1} suppressed nodule formation and fixation activity in common bean. However, Dadson and Acquaah (1984) also reported that, in nitrogen deficient soils, small starter doses of applied nitrogen may stimulate nodule formation and enhance the grain yield of legumes. In contrast to the results of this study, some researchers reported that application of nitrogen in the range of 22 to 33 kg N ha^{-1} enhanced both nodulation and seed yield (Muller *et al*., 1993; Tsai *et al*., 1993).

Sulphur application significantly ($P < 0.05$) increased the number of effective nodules over no sulphur application at both locations (Appendix Table 3& 5). At Haramaya maximum effective nodules were recorded from the application of 60kg S ha^{-1}followed by 20 kg S ha^{-1} and 40kg S ha^{-1}. At Hirna significantly higher number effective nodules were recorded from the application of sulphur rates (20 to 60 kg S ha^{-1}) over the control. At Haramaya with the increase in sulphur application rates, there were increases in effective nodules. This result is in line with the finding of Ganeshamurthy and Reddy (2000) who found a significant increase in the number of active nodules with the application of sulphur up to 20 kg ha^{-1}, at which point nodule production reached a plateau and did not increase further. Consistent with the results of this study, Khandkar *et al.* (1985) reported that the formation of a nodule in black gram was increased in response to sulphur application which is involved in the formation of nitrogenous enzyme known to promote nitrogen fixation in legumes (Saraf, 1988; Scherer *et al.*, 2006).

Number of pods per plant

The analysis of variance showed highly significant ($P < 0.05$) differences in the number of pods per plant due to the main effects of nitrogen application at Haramaya and Hirna (Appendix Table 4 & Table 6).

At Haramaya, the plants had significantly lower number of pods than at Hirna. The average number of pods per plant at Hirna exceeded the average number of pods per plant at Haramaya additionally by about 76.2% (Table 2). This difference may be ascribed to the differences in environmental conditions that prevailed at the two locations. These differences may have resulted in more plant height and canopy cover at Hirna that might have resulted in the interception of more sunlight for enhanced photo assimilation.

At Haramaya increasing the rate of nitrogen application from 0 to 23 kg, N ha^{-1} resulted in about 46.7% additional increase in the number of pods per plant. However, the numbers of pod per plant obtained at 23 and 46kg N ha^{-1} were in statistical parity (Table 2). At Hirna maximum number of pods per plant (37) was obtained in the application of 46kg N ha^{-1} which was statistically at parity with a number of pods per plant (33) obtained in the application of 23kg N ha^{-1}. The higher rate of nitrogen (23 and 46kg N ha^{-1}) might have resulted in more vigorous vegetative growth. From studies on French bean at Dholi (Bihar), Sharma *et al*. (1996) observed that increasing the levels of nitrogen up to 120kg ha^{-1} increased the number of pods per plant. However, the difference between 80kg N ha^{-1} and 120kg N ha^{-1} was not significant whilst the highest number of pods per plant was recorded in plots that received 150kg N ha^{-1} at Varanasi, India as reported by Singh and Rajput (1995).

Similar results of the effect of increased nitrogen on pod production per plant have also been reported elsewhere in India (Rana and Singh, 1998; Singh and Singh, 2000; Tewari and Singh, 2000). However, Dhanjal *et al*. (2001), Veeresh (2003), and Prajapati *et al*. (2003), recorded significantly higher number of pods per plant for treatments that received 120 kg N ha^{-1} and up to 180 kg N ha^{-1} (Singh *et al*., 2006) in the field experiments conducted in different locations in India. This differential response to applied nitrogen in different locations may be due to different soil types and environmental interactions. Application of sulphur and its interaction did not have a significant effect on the number of pods per plant.

Aboveground dry biomass

Aboveground dry biomass was significantly ($P < 0.05$) influenced by the main effects of nitrogen application at both locations. However, the main effects of sulphur and its interactions were not affected aboveground dry biomass of common bean plants (Appendix Table 4 & Table 6).

The effect of nitrogen on aboveground dry biomass (grain + straw) at Haramaya was significantly lower than that at Hirna. This could be attributed to the significantly lower plant height, a number of pods per plant (Table 2) that contributed to lower aboveground dry biomass yield, despite the production of significantly heavier seeds at this location. At Haramaya the result showed that with the increased level of nitrogen application, the aboveground dry biomass yield increased significantly up to 23 kg N ha^{-1} beyond which no significant increase was noted. At Hirna aboveground dry biomass significantly increased consecutively with the successive application of nitrogen from 0 to 23 and 46kg ha^{-1}. This increase in aboveground dry biomass yield was 7.5 and 14.1 % with the successive increases in nitrogen application rates, respectively. This result is in accord with that of Veeresh (2003) who reported that total dry matter production per plant increased significantly from 12.0 to 16.03 g due to increased nitrogen application from 40 to 120 kg N ha^{-1}. Prajapati *et al*. (2003) also reported from a field trial conducted at Sardar Krushinagar (Gujarat) that application of 120 kg N ha^{-1} significantly increased the dry weight per plant in French bean during the winter season.

Similarly, Singh *et al*. (2006) in Varanasi revealed that dry weight per plant significantly increased in response to increasing nitrogen levels up to 180 kg N ha^{-1} in common bean. Like its effect on plant height and leaf area index (Table 2), and yield attributes (Table 3) of common bean, the sulphur application did not result in significant differences in aboveground dry biomass.

Grain yield

Grain yield at Haramaya was significantly ($P<0.05$) and at Hirna highly significantly ($P < 0.01$) affected by the main effect of nitrogen, however, the main effects of sulphur as well as its interaction did not affect grain yield of the crop at both locations (Appendix Table 4 & Table 5).

The significantly higher grain yields were recorded at Haramaya in response to the application 23 kg N ha^{-1}. At Hirna the highest grain yield was obtained in response to the application of 23 kg N ha^{-1} which was statistically at a party with grain yield obtained in the response of 46kg N ha^{-1}. The lowest grain yields were scored in response to the application of nil. The grain yield obtained at Hirna at 23 kg N ha^{-1} exceeded that obtained at Haramaya at 23kg N ha^{-1} with additional increments of 19.6%. In general, at both locations, 23 kg N ha^{-1} led to the production of optimum grain yields (Table 3). This signifies the importance of moderate amounts of nitrogen in enhancing common bean production in the study areas. The negative effect of higher rate of nitrogen (46 kg N ha^{-1}) on grain yield may be attributed to the tendency of higher rates of nitrogen to enhance vegetative growth that might have resulted in self-shading thereby reducing the overall yield, which was evident from the lower harvest index (Table 3).

Confirming the results of this study, Boroomanndan *et al.* (2009) reported that seed yield increased significantly at 40 kg N ha^{-1} compared to the control treatment. However, application of 80 kg N ha^{-1} decreased seed yield, indicating that there is a limit to the maximum level of nitrogen to be supplied to avoid its detrimental effect on the plant. Reductions in grain yield of beans in response to increased rates of nitrogen application were earlier reported by Rana and Singh (1998) and Dhanjal *et al*. (2001). Several researchers reported the differential response of common bean grain yield to applied nitrogen. Dwivedi *et al*. (1994) and Kushwaha (1994) found increased yield due to increasing levels of nitrogen up to 100 kg ha^{-1}. However, the difference between 80 and 100 kg N ha^{-1} was not significant. From a field investigation on French bean, Koli and Akashe (1994) had the highest grain yield (1.41 t ha^{-1}) with 60 kg N ha^{-1}, while still higher yield (2.88 t ha^{-1}) was obtained with 120 kg N ha^{-1} as reported by Verma and Saxena (1995). However, no significant difference in grain yield was observed between 80 and 120 kg N ha^{-1} (Sharma *et al*., 1996).

The grain yield of common bean without nitrogen application at Hirna was at statistical parity with the grain yield obtained in response to the application of 23 kg N ha^{-1} at Haramaya. While comparing the yield under different nitrogen application rates, the yield at Hirna was significantly higher than that at Haramaya. This variable response of common bean to nitrogen application might be due to variation in soil types and the environmental conditions (locations). Some researchers reported that bean grain yields greater than 1,500 kg ha^{-1} might be obtained by creating conditions favorable for biological nitrogen fixation and applying a limited amount (25 kg N ha^{-1}or less) of nitrogen fertilizer (Mangual-Crespo *et al*., 1987; Manrique *et al*., 1993). Biological fixation can be affected by edaphic factors such as pH or availability of nutrients, photosynthesis, climatic factors, and management of the legumes.

The environmental conditions prevailing during the crop season at Hirna might have favored the crop much more than the environmental conditions at Haramaya. The plants at Hirna attained significantly more plant height (Table 1) and leaf area index and pods per plant (Table 2) that might have contributed significantly to the higher grain yields. Blackshaw *et al*. (1999) reported that higher temperatures are more favorable for growth and yield of common bean. This showed that the yield is a complex function of individual yield components in response to the genetic potential of the cultivar, inputs used and the environment under which the crop is grown.

The sulphur application had no significant influence on grain yield, although the seed yield tended to increase with the increase in the applicable rates of the nutrient (Table 3). This may be attributed to the high native soil sulphur content, (106 ppm) (Appendix, Table 1) which is much higher than the sufficiency range for optimum growth of most crops (30-40 ppm) (Kelling *et al*., 1999)

Harvest index

Harvest index was significantly ($P < 0.05$) affected by the main effect of nitrogen at Hirna. However, at Haramaya none of the factors affected harvest index (Appendix Table 4 and Table 6). At Hirna the application of 23kg N ha^{-1} resulted in significantly higher harvest index than in the control and 46 kg N ha^{-1}. The reduction in harvest index with the application of 46 kg N ha^{-1} might be due to profuse vegetative growth with higher nitrogen rate that disrupted the balance between the total aboveground dry biomass and the grain yield. At both location application of sulphur had no significant variation in harvest index.

Seed quality

The protein, zinc and iron contents of seed remained unaffected while the phosphorus content was significantly influenced due to the application of nitrogen (Table 4).

Similar to the results of this study, Gaydou and Arrivets (1983) in soybean and Abdelgani *et al*. (1999) in fenugreek did not find significant changes in the protein content of the application of nitrogen. On the contrary, the significantly high protein was obtained with nitrogen application in faba bean (Bakiber., 1995) and fenugreek (Tunçtürk *et al*., 2011).

The application of 23kg N ha^{-1} resulted in highest phosphorus content (3429 mg kg $^{-1}$ dry weight). However, it did not vary significantly with the phosphorus content obtained at 46kg N ha^{-1} in the seed of common bean. This signifies that the availability of sufficient nitrogen in the soil is important for uptake of more of the other nutrients such as phosphorus and potassium for enhanced crop growth and yield (Mengel and Kirkby, 2001).

The application of sulphur had no significant effect on protein, total phosphorus, Zn and Fe content of grain, although the sulphur application is known to increase the solubility of micronutrients like Zn and Fe (Mengel and Kirkby, 2001).

CONCLUSION

It could, thus, be concluded that nitrogen application significantly increased growth and seed yield of common bean. Optimum grain yields were obtained in response to the application of 23 kg N ha^{-1} at both locations. Beyond this level of N supply, increasing N supply led to apparent detrimental effects on the crop plants. The results also revealed that significantly higher seed yields of the crop were produced at Hirna than at Haramaya, indicating a more conducive environment for bean production at the former than the latter. On the other hand, sulphur did not generally lead to increased growth and yield of the crop. In this connection, it should be realized that the common notion that common beans fix nitrogen and do not require external sources of the nutrient, as a result of which most smallholder farmers do not apply N-containing mineral fertilizers to the crop, is wrong. Thus, smallholder farmers in the region should apply 23 kg N ha^{-1} to optimize the grain yield of the crop for improved household food security and income. In addition, similar research should be conducted to validate the results further at different locations.

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APPENDICES

Appendix Table 1: Physico-chemical properties of soils of the experimental fields

Properties	Haramaya	Hirna
Total Nitrogen	0.13	0.18
Available Phosphorus (mg/kg)	19.14	32.14
Available potassium (cmol (+)/kg	0.49	0.68
Organic carbon (%)	1.00	1.75
Available sulphur SO_4^2 (mg/kg soil)	106.60	44.63
pH 1:2.5(soil water ratio)	8.10	7.09
Cation Exchange Capacity	26.95	41.67
Clay (%)	45.0	45.0
Silt (%)	22.0	28.0
Sand (%)	32.0	27.0
Soil Class	Clay	Clay

Source: Jije analytical Service Laboratory (JASL), Addis Ababa

Appendix Table 2: Weather parameters at Haramaya and Hirna for the 2011 main cropping season

Month	Haramaya				Hirna	
	Temperature (°C)		Rainfall (mm)	Relative humidity(%)	Rainfall (mm)	Temperature (°C)
	Maximum	Minimum				
July	25.4	14.8	126.0	61.1	113.0	*Annual mean*
August	23.4	13.9	225.0	73.1	160.5	*Maximum* **27.0**
September	23.3	12.9	156.0	67.0	98.5	*Minimum* **16.0**
October	25.6	5.3	0.0	31.3	0.0	
Mean/Total	**24.4**	**11.7**	**538 .3**	**58.1**	**371.5**	

Source: National Meteorological Agency, Haramaya/ Hirna branch

Appendix Table 3: Analysis of variance showing mean square values of days to flower initiation and days to physiological maturity, plant height, leaf area index and number of effective nodules per plant as influenced by nitrogen, sulphur and their interaction at Haramaya during the 2012 main cropping season

Source of variation	Df	Days to Flowering	Physiological maturity	Plant height (cm)	Leaf area index	No of effective nodule per plant
Replication	2	0.86	1.19	119.9	0.92	14.5
Nitrogen (N)	2	2.19NS	10.19*	187.9NS	24.8*	37.5NS
Sulphur (S)	3	1.29NS	1.65NS	39NS	1.03NS	1903.7*
NXS	6	0.26NS	1.15NS	37.3NS	0.77NS	3072.7NS
Error		2.1	0.79	60	0.24	233.3
CV(%)		3.9	1.00	7.57	10.8	33.18

Appendix Table 4: Analysis of variance showing mean square values of a number of pod per plant, Aboveground dry biomass yield, grain yield and harvest index as influenced by nitrogen, sulphur at Haramaya during the 2012 main cropping season.

Source of variation	D.f	Number of pod plant^{-1}	Aboveground biomass yield (t ha^{-1})	Grain yield(t ha^{-1})	Harvest index
Replication	2	6.86	3.53	0.30	0.002
Nitrogen (N)	2	131.4*	4.89*	1.20*	0.007NS
Sulphur (S)	3	11.62NS	0.24NS	0.13NS	0.002NS
NXS	6	6.8	0.79NS	0.21NS	0.005NS
Error		24.7	0.84	0.14	0.002
CV (%)		26.05	9.1	6.9	10.1

D.f= degree of freedom; CV= coefficient of variance;*= Significant at 0.05 at probability level; **= Significant at 0.01 at probability level; NS= Not significant at 5% level

Appendix Table 5: Analysis of variance showing mean square values of days to flower initiation and days to physiological maturity, plant height, leaf area index and number of effective nodules per plant as influenced by nitrogen, sulphur and their interaction at Hirna during the 2012 main cropping season

Source of variation	Df	Days to Flowering	Physiological maturity	Plant height(cm)	Leaf area index	No of effective nodule per plant
Replication	2	0.69	2.58	6.2	1.35	17.3ns
Nitrogen(N)	2	4.11*	10.3*	197.6*	13.2*	191.1ns
Sulphur (S)	3	4.9*	0.96ns	7.96ns	0.39ns	597.9*
NxS	6	1.8ns	1.4ns	9.24ns	1.71ns	99.5ns
Error		0.78	1.5	20.9	1.01	118.2
CV(%)		2.58	1.4	3.8	26.7	36.5

Appendix Table 6: Analysis of variance showing mean square values of number of pod per plant, Aboveground dry biomass yield, grain yield, and harvest index as influenced by nitrogen, sulphur at Hirna during the 2012 main cropping season

Source of variation	Df	Number of pod plant^{-1}	Aboveground biomass yield (t ha^{-1})	Grain yield(t ha^{-1})	Harvest index
Replication	2	59.33	0.35	0.007	0.007
Nitrogen (N)	2	283.7*	7.33*	3.49**	0.01*
Sulphur (S)	3	21.6NS	0.06NS	0.18NS	0.002NS
NXS	6	33.2NS	0.20NS	0.09NS	0.001NS
Error		38.8	0.57	0.07	0.001
CV (%)		19.1	6.67	4.36	7.9

D.f= degree of freedom; CV= coefficient of variance;*= Significant at 0.05 at probability level; **= Significant at 0.01 at probability level; NS= Not significant at 5% level