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SOIL & CROP SCIENCES | RESEARCH ARTICLE

Determination of optimum plant density for faba bean (*Vicia faba* L.) on vertisols at Haramaya, Eastern Ethiopia

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Abstract: A field experiment was carried out to identify the optimum plant density, inter and intra-row spacing for the maximum agronomic performance of *Gachena* (a recently released faba bean variety). A three by three factorial combinations of inter-row (30, 40, and 50 cm) and intra-row (8, 10, and 12 cm) spacing were used as treatments and laid out in a randomized complete block design (RCBD) with three replications. The results of this experiment showed that there was a significant difference in all parameters measured except in 100 seed weight and harvest index. The widest inter and intra-row spacing (12 × 50 cm) gave a significantly higher number of branches per plant, number of pods per plant, seeds per pod and seed yield per plant. Besides, it helped the crop to mature earlier than under the narrowest spacing. On the other hand, the widest spacing produced a lower leaf area index (LAI), plant height, seed yield (kg ha⁻¹) and total dry biomass (kg ha⁻¹). 30 × 8 cm spacing combination was found to be optimum spacing that can give the optimum economic yield on vertisols.

Subjects: Bioscience; Earth Sciences; Environment & Agriculture; Food Science & Technology

Keywords: inter-row; intra-row; seed yield; spacing; vertisols

1. Introduction

Faba bean (*Vicia faba* L.) is the most important cool-season food legume in Ethiopia in terms of coverage, production, foreign exchange earnings, protein source, soil amelioration and cropping system

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PUBLIC INTEREST STATEMENT

Faba bean is very important cash and food crop. It is high in protein (23–26%) and composes plentiful of health-benefiting antioxidants, vitamins, and minerals. However, the productivity of faba bean is low when it grows under vertisol due to excessive soil moisture during heavy rain and cracking nature when it dries as the crop is sensitive to waterlogged conditions and cracking nature that hinder root growth. Many of these soils are underutilized because they are difficult to manage hard and cloddy when dry, and very sticky when wet. Faba bean productivity in vertisols can increase with proper management of the soil as well as the crop such as optimum plant density. Optimum plant density not only maximizes yield by exploit resource optimally but also increase the profitability of the farmers by reducing seed cost.

(Tafere, Tadesse, & Yigzaw, 2012). Ethiopia is the second largest faba bean producer in the world next to China and accounts for about 12% of the world area and production (Mussa & Gemechu, 2006) with an average seed yield of 1.14 t ha⁻¹ (Central Statistical Authority, 2012). Although the crop plays a significant role for Ethiopian farmers as a source of food, feed and cash crop, the yield generally is below the world average due to several factors: poor crop management practices, lack of high yielding cultivars, stress inflicted by harsh environmental conditions and poor soil fertility can be listed as some of the causes of low yield (Getachew, Asnake, & Ayalew, 2006; Tafere et al., 2012).

Plant density has been recognized as a major factor determining crop yield and is of a particular importance for larger seeded varieties (Matthews, Carpenter, Smith, & Fettell, 2001). Optimum plant density (i.e. the minimum population that produces maximum yield) and suitable plant arrangement per unit area allow crops to exploit resource optimally and produce high yields (Squire, 1993). However, optimum plant density varies depending on crop species or due to varietal difference in vigor, height and branching, time of sowing, and the nature of the season (Anderson, Sharma, Shackley, & D'Antuono, 2004). The response of crops to plant density tended to be less in the low as compared to the high yielding environments (Matthews et al., 2001). This can also depend on soil type, management practices like seedbed conditions and soil moisture, sowing depth, sowing time, fungicide dressings of seeds, presence of weeds and seasonal rainfall (Matthews et al., 2001).

Since plant density has a direct effect on the cost of seed and final yield, information on this line is highly vital when a new variety is released and growing environments are changed. Optimum plant density of a crop variety at one location may not apply at other locations because of variation in soil type and other environmental conditions, there is a need to develop site-specific recommendations. Recently, Haramaya University has released a faba bean variety *Gachena* (Ministry of Agriculture & Rural Development, 2008) for the highland areas of East and West Hararghe with a plant density of 250,000 plants per ha (40 cm inter × 10 cm intra-row spacing) which was simply based on the experiences from Holleta, central Ethiopia where soil and climatic conditions are different. Accordingly, there is no clear information as to whether the currently used spacing works out or not for achieving the highest yield in Eastern Ethiopia Vertisol. Therefore, this research was carried out with the objectives of determining the optimum plant density and inter and intra-row plant spacing to attain the maximum and economic yield of *Gachena* on vertisols at Haramaya.

2. Materials and Methods

2.1. Site description

The experiment was carried out during the 2009 cropping season at the research farm of Haramaya University. It is located at 9° 26' N and 42° 03' E and with an altitude of 1980 m a.s.l.; average annual rainfall of 780 mm and mean annual minimum and maximum temperatures are 9.6 and 24.1°C, respectively. The experimental soil is classified as chromic vertisols (Srivastava, Abebe, Astatke, Haile, & Regassa, 1993). The physical and chemical properties of the soil are presented in Table 1.

Table 1. Treatment combinations and corresponding plant population

Treatment No.	Treatments	Plants (m ⁻²)	Plants (ha ⁻¹)	Seed rate (kg ha ⁻¹)
1	30 cm × 8 cm	42	416,667	221
2	30 cm × 10 cm	33	333,333	177
3	30 cm × 12 cm	28	277,778	147
4	40 cm × 8 cm	31	312,500	166
5	40 cm × 10 cm	25	250,000	132
6	40 cm × 12 cm	21	208,333	110
7	50 cm × 8 cm	25	250,000	132
8	50 cm × 10 cm	20	200,000	106
9	50 cm × 12 cm	17	166,667	88

Table 2. Soil characteristics of the experimental site

Soil properties	Value
pH	6.70
Total N (%)	0.01
Available P (ppm)	14.5
K (meq/100 g soil)	2.40
CEC (meq/100 g soil)	40.8
OM (%)	1.34
Texture	Clay loam
Clay (%)	66.60
Sand (%)	12.00
Silt (%)	21.40

2.2. Experimental design and treatment

The experiment was conducted using three by three factorial combinations of inter (30, 40 and 50 cm) and intra-row (8, 10, and 12 cm) spacing and the treatments laid out in Randomized Complete Block Design (RCBD) with three replications. A gross plot size of 6.0 × 3.6 m (21.6 m²) and a net harvest plot size of 4.8 × 2.0 m (9.6 m²) was used for all treatments. The number of rows per plot for the 30, 40, and 50 cm inter-row spacing were 12, 9, and 7, respectively, and the number of plants per row for the 8, 10, and 12 cm intra-row spacing were 75, 60, and 50, respectively. The plant population in each treatment combination is presented in Table 1. The experimental material that was used in this study was a recently released faba bean variety called *Gachena*. The variety was released by the Highland Pulses Research Program of Haramaya University in 2007. The variety has an indeterminate growth habit and grows well in the Hararghe highlands with an annual rainfall of 700–1,000 mm (Ministry of Agriculture & Rural Development, 2008).

2.3. Agronomic practices and data collection

The experimental field was plowed and harrowed to a fine tilt using a tractor. The seeds were planted manually by placing two seed per hill on 19 July 2009. The plants were thinned to one plant per hill 10 days after emergence to maintain the prescribed intra-row population. Based on the initial soil chemical properties (Table 2) and crop requirement of N and P, a blanket application of 18 kg ha⁻¹ N and 46 kg ha⁻¹ P₂O₅ was applied at planting in the form of Diammonium Phosphate (DAP). Plots were regularly monitored and kept free from weeds and pests by manual weeding and pesticide application, respectively. Harvesting was done manually on 29 November 2009.

Agronomic data such as physiological maturity, stand count at emergency and at harvest, leaf area index at pod initiation (60 days after sowing), plant height, number of branches per plant, number of pods per plant and seeds per pod were collected before harvesting from 10 randomly selected plants. Seed yield per plant and hundred seed weight was collected from 10 randomly selected plants after harvest. Seed yield (kg ha⁻¹) and total dry biomass were determined by harvesting all plants from net harvested area. Harvest index (HI %) values were calculated by the following formula: $HI (\%) = \text{Seed yield} / \text{Total dry biomass}$.

2.4. Soil sampling and chemical analysis

Composite initial soil samples of 0–30 cm soil depth were taken from five random spots of the experimental site before planting from both soil types. The composite samples were analyzed for selected physicochemical properties mainly textural analysis (percent sand, silt, and clay), soil pH, total nitrogen, organic matter content, available phosphorus, exchangeable potassium and cation exchange capacity (CEC). The soil organic matter content was determined by Walkely and Black procedure (Walkley & Black, 1934) and total nitrogen by Kjeldahl method (Jackson, 1958). The pH of the soils was measured in water at soil to water ratio of 1:2.5 (Van Reewijk, 1992), and cation

exchange capacity was measured by ammonium acetate method after saturating the soil with 1 N NH_4OAc and displacing it with 1 N NaOAc (Chapman, 1965). Exchangeable K was extracted with 1 N NH_4OAc at pH 7 and the extract was read using a flame photometer. Available phosphorous was determined by the Olsen method (Olsen, Cole, & Dean, 1954) and soil texture analysis was performed by Bouyoucos hydrometer method (Bouyoucos, 1951).

2.5. Statistical analysis

All the measured parameters were subjected to analysis of variance appropriate to factorial experiment in a RCBD (Gomez & Gomez, 1984). Analysis of variance was computed using the SAS (SAS Institute Inc, 2002) computer software program. Mean separation was made using the Least Significant Difference (LSD).

2.6. Economic analysis

To investigate the economic feasibility of the treatments partial budget analysis was conducted. The average yield was adjusted downwards by 30% to reflect the difference between the experimental yield and the expected yield of farmers from the same treatment. This is done because experimental yields, even from on-farm experiments under representative conditions, are often higher than the yields that farmers could expect using the same treatments (The International Maize and Wheat Improvement Center [CIMMYT], 1988). The market price of 5.50 Ethiopian birr (ETB) kg^{-1} was taken. The amount of seed required was varied with inter and intra-row spacing. However, other input costs like fertilizer, labor and pesticides were considered to be constant for all treatments. A dominance analysis was carried out by first listing the treatments in order of increasing costs that vary (seed cost). Any treatment that has net benefits that are less than or equal to those of treatment with lower costs that vary is dominated. The process of calculating the marginal rates of return of alternative treatments, proceeding in steps from the least costly, and deciding if they are acceptable to farmers, is called marginal analysis. Marginal rate of return (MRR) is the marginal net benefit divided by the marginal costs, expressed as a percentage. According to CIMMYT (1988), the tentative recommendations were computed based on the comparisons of the rates of return between treatments and the minimum rate of return acceptable to farmers i.e. 100%. Consequently, any treatment that MRR is greater than 100% is considered as a profitable technology by farmers.

3. Result and discussion

3.1. Properties of experimental soils

The initial soil analysis showed that the texture of the soil was dominated by the clay fraction. On the basis of particle size distribution, the soil contains sand 26.00%, silt 30.40%, and clay 43.60% (Table 2). The soil reaction (pH) of the experimental site was 6.70, which was near neutral. According to FAO, the suitable pH range for most crops is between 6.5 and 7.5 in which total N availability is optimum (Table 2).

Crop productivity is closely linked to organic matter (Bauer & Black, 1994), plants growing in well-aerated soils are less stressed by drought or excess water. Since the experimental soil was vertisol, it had low organic matter content (1.37%). If the soil is highly compacted, plant root cannot easily penetrate the soil. The soil also low (0.01%) level of total N, indicating that the nutrient was not optimum for crop growth and moderate (14.54 ppm) available phosphorus. The K content (2.4 meq/100 g soil) and cation exchange capacity (40.80 meq/100 g soil) were high.

3.2. Physiological maturity

Inter and intra-row spacing had a significant effect on days to physiological maturity (Table 3). Plants grown in wider spacing (50 cm inter-row and 12 cm intra-row spacing) matured earlier than the rest of the spacing. Higher plant densities were found to delay the time required for maturity. This could be due to lower canopy temperatures in the narrow rows which potentially reduced heat accumulation by plants and thereby prolonged maturity period. These results are in line with the

Table 3. Inter and intra-row spacing effect on physiological maturity, LAI, plant height, number of branch per plant and stand count of faba bean

Treatment	Physiological maturity (days)	LAI	Plant height (cm)	Number of branch per plant	Stand count at emergency	Stand count at harvest
Inter-row spacing (cm)						
30	117.1a	8.0a	84.8a	3.9b	97	89
40	113.8b	8.6a	80.7b	4.0b	97	90
50	113.3b	6.8b	76.2c	4.3a	98	92
LSD ($p \leq 0.05$)	1.97	1.00	2.40	0.18	NS	1.45
Intra-row spacing (cm)						
8	116.4a	8.6a	84.5a	3.9b	97	89
10	114.7b	7.8a,b	80.0b	4.1b	97	90
12	113.6c	7.1b	77.1c	4.2a	97	91
LSD ($p \leq 0.05$)	1.97	1.00	2.4	0.17	NS	1.45
CV (%)	1.50	19.04	4.30	4.18	1.11	1.61

Note: Means with different letter are significantly different at 5% probability level.

findings of Emmanuel (1995) and López-Bellido, López-Bellido, and López-Bellido (2005) who reported a longer maturity period in closer spacing in soybean and faba bean, respectively.

3.3. Growth Parameters

Leaf area index (LAI) is a measure of leafiness per unit ground area and denotes the extent of photosynthesis. LAI was significantly affected by inter and intra-row spacing and inversely related to an increase in inter and intra-row spacing. The highest LAI was obtained in the narrowest inter and intra-row spacing while the lowest was for the widest spacing (Table 3). This was probably due to decrease in the ground area when intra-row spacing decreased. This is in line with López-Bellido et al. (2005) who indicated that it was positively associated with plant population.

Similarly, the narrowest inter and intra-row spacing gave significantly taller plants than the rest of the spacing (Table 3). Under narrow inter- and intra-row spacing, there is comparatively low solar radiation interception through crop canopy compared to wider inter- and intra-row spacing where there is a better solar interception. Therefore, high and low interplant competition for light in the narrow and wide spacing respectively could have resulted in such variation in plant height. These results are in agreement with Taj, Akber, Basir, and Ullah (2002) who found taller plants in a narrow spacing because of competition for light compared to the case in wider spacing where light distribution was normal.

There was a significant difference in the number of branches per plant as affected by inter- and intra-row (Table 3). The highest number of branches per plant was found from the widest inter and intra-row spacing. The production of more branches at the wider spacing might be attributed to the more efficient use of available growth nutrients, water, and light energy which could favor more photosynthesis and allocation of carbohydrate for all growth points compared to the closest spacing. In contrast, plants spaced closer gave less number of branches per plant; the decrease in branch number was parallel with the increase in both row to row and plant to plant spacing. The result is in agreement with Al-Suhaibani, El-Hendawy, and Schmidhalter (2013) who found a maximum number of branches per plant of faba bean under low plant population.

3.4. Yield and yield components

Initially, plant density was precisely maintained after thinning to attain the required densities under different treatments. As against initial plant stand (100%), final plant stands decreased and that might be due to interplant competition as well as due to environmental conditions prevailing during the season. The wider (50 cm) inter-row spacing had the maximum (93.3%) final stand count percentage to the initial stand as compared to 40 cm (91.0%) and 30 cm (90.1%) inter-row spacing (Table 3). At wider inter-row spacing (with lower population density) comparatively availability of more space might have resulted in less competition for resources (nutrients, moisture, and light) whereas at narrow spacing due to more intra-specific competition the weaker plants disappeared by the time the crop approached maturity. Similar results were reported by Abdel (2008) who found lower stand count at harvest at lower plant population due to the reduced plant competition and plant mortality.

Increasing inter- and intra-row spacing was found to significantly increase the number of pods per plant. A decrease in inter and intra-row spacing increases competition which eventually lead to a reduction in the number of pods on the individual plant (Table 4). An increase in the competition for light and nutrients in high population lead to a decrease in photosynthesis and so more abscission and lower pods per plant. The result is in line with Abdel (2008) and Shad et al. (2010) who reported a decrease in the number of pods per plant in faba bean due to a reduction in the number of stems per plant at the higher plant densities.

Likewise, the number of seeds per pod follows a similar trend (Table 4). The increase in the number of seeds per pod with wider plant spacing could be due to less competition for nutrient and water. This is in agreement with previous reports in faba bean (Abdel, 2008; Hodgson & Blackman, 2005) and soybean (Boroomandan, Khoramivafa, Haghi, & Ebrahimi, 2009).

Increasing pods per plant and seed per pod at high inter and intra spacing produces a higher seed yield per plant (Table 4). The reduction in yield per plant in high plant density (9 and 30 cm inter and intra spacing) could be explained by the canopy development at the early stages of this treatment

Table 4. Inter and intra-row spacing influence on number of pods per plant, number of seeds per pod, seed yield per plant (g/plant), 100 seed weight, seed yield (kg ha⁻¹), total dry biomass (kg ha⁻¹) and harvest index (HI %) of faba bean

Treatment	Number of pods per plant	Number of seeds per pod	Seed yield per plant (g/plant),	100 seed weight	Seed yield (kg ha ⁻¹)	Total dry biomass (kg ha ⁻¹)	HI (%)
Inter-row spacing (cm)							
30	22.0b	2.42b	23.6c	60.7	3,157a	6,909a	46
40	26.5a	2.67a	31.6b	63.2	2,263b	5,478b	41
50	28.3a	2.74a	36.5a	63.5	2,019b	4,505c	45
LSD (p ≤ 0.05)	1.66	0.12	4.04	NS	394	595	NS
Intra-row spacing (cm)							
8	24.4c	2.44b	26.5b	60.9	2,843a	6,373a	45
10	26.6b	2.61a	31.4a	62.1	2,392b	5,415b	44
12	28.6a	2.72a	33.7a	64.2	2,218b	5,705b	39
LSD (p ≤ 0.05)	1.66	0.12	4.04	NS	394	595	NS
CV (%)	9.28	7.01	19.48	7.01	15.91	10.58	14.68

Note: Means with different letter are significantly different at the 5% probability level.

which was insufficient to maximize light interception. Consequently, plants may compete against each other, and the performance of individual plants becomes poor. While, at low planting density, each individual plant performance was good due to low competition. This result is in collaborated with Al-Suhaibani et al. (2013) who reported higher seed yield per plant at low plant density. Singh and Singh (2002) also indicated that the yield potential of an individual plant is fully exploited when sown at wider spacing.

Unlike those agronomic parameters discussed above, 100 seed weight was not significantly affected by inter and intra-row spacing (Table 4). The individual seed weight is rarely affected by spacing as well as by other growth factors except in the case of severe water stress and hot desiccating winds causing forced maturity (Turk, Hall, & Asbell, 1980). This agrees with Thangwana and Ogola (2012) who reported the non-significant effect of plant density on 100 seed weight of chickpea.

Seed yield (kg ha^{-1}) was significantly affected by inter and intra-row spacing (Table 4). Higher seed yield (kg ha^{-1}) was observed in the narrowest as compared to the wide spacing which gave the lowest mean seed yield. However, lower number of pods per plant, seed per pod and seed yield in the narrow spacing, the seed yield (kg ha^{-1}) was significantly higher in narrow inter and intra-row spacing. This indicated that the main determinant of seed yield was plant population. Shad et al. (2010) also observed grain yield increased linearly with increase in plant density and reached the highest grain yield at a density of 450,000 plants ha^{-1} . The hardness and crackly nature of vertisol soils when dry that lead to restricted root development resulting reduce effective branch to compensate yield under low plant density. Under sub-optimal conditions, higher plant density may be preferred because tillering may not allow adequate compensation under low plant population. Similar finding in different faba bean varieties was reported by Tekle, Raghavaiah, Arvind, and Hamza (2015) who found high seed yield in 30 cm inter-row spacing and 7.5 cm intra-row spacing or 44 plants m^{-2} compared to 40 cm \times 5.0 cm (50 plants m^{-2}) and 60 cm \times 5.0 cm (33 plants m^{-2}) under vertisol. López-Bellido et al. (2005) indicated that with a longer growing season and under optimum environmental conditions, there is normally no additional response to densities over 20 plants m^{-2} , while in sub-optimal conditions, optimum plant density may increase normally to over 60 plants m^{-2} . Similarly, Al-Suhaibani et al. (2013) stated that when the planting density is too low each individual plant may perform at its maximum capacity but there may be insufficient total plants to reach the optimum yield. However, Dahmardeh, Ramroodi, and Valizadeh (2010) reported high seed yield on faba bean in sandy loam soil at low plant density (20 plants m^{-2}).

Total dry biomass was significantly affected by inter-row and intra-row spacing (Table 4). Seed yield of faba bean is commonly proportional to total biomass production. The higher biomass was obtained in narrower inter (30 cm) and intra (8 cm) row spacing than the wider spacing. This could be related to the higher LAI which provided a larger surface area for light interception resulting in higher net photosynthesis and might have led to greater biomass per unit area (Getachew et al., 2006). Similar results were reported by Al-Rifaae, Turk, and Tawaha (2004) who observed that at the final harvest of faba bean, the dry matter yield of aboveground parts increased with increasing plant population due to the increase in the number of plants per unit area and the associated increase in plant height. Worku and Demisie (2012) also reported that a high LAI at high plant density may attribute to improved light interception thus, ensuring high biomass and yield than at low plant density. Similarly, Dahmardeh et al. (2010) reported higher biological yield in sandy loam soil in higher plant density due to an increase in the number of plants in the unit's area.

The productive capacity of the faba bean depends on an effective translocation of assimilates to the seeds besides photosynthetic efficiency. The narrow inter and intra-row spacing (30 and 8 cm, respectively) gave higher harvest index but not statically significant difference from other treatments (Table 4). The result is in line with Khamooshi, Mohammadian, Saamdaliri, and Foroughi (2012) who reported the non-significant effect of plant density on HI of faba bean. In contrast, Edwards and Purcell (2005) who worked on vertisol and they reported that harvest index of soybean increased with increased plant density.

Table 5. Partial budget analysis of the effect of spacing for faba bean

Inter-row	Intra-row	Average yield (kg ha ⁻¹)	Adjusted yield (kg ha ⁻¹)	Cost of seed (ETB ha ⁻¹)	Gross benefits (ETB ha ⁻¹)	Net benefit (ETB ha ⁻¹)	B:C ratio
30 cm	8 cm	3,656a	2,559a	1,216a	14,076a	12,860a	11.6a,b,c
	10 cm	3,303a	2,312a	974b	12,714a	11,740a	13.1a,b,c
	12 cm	2,513b	1,759b	809b,c	9,675b	8,866b	12.0a,b,c
40 cm	8 cm	2,326b,c	1,628b,c	913b	8,955b,c	8,042b,c	9.80c
	10 cm	2,188b,c	1,532b,c	726b,c	8,425b,c	7,699b,c	11.6a,b,c
	12 cm	2,276b,c	1,593b,c	605c	8,761b,c	8,156b,c	14.5a,b
50 cm	8 cm	2,508b	1,755b	726b,c	9,655b	8,929b	13.3a,b,c
	10 cm	1,684c	1,179c	583c,d	6,485c	5,902c	11.1b,c
	12 cm	1,864b,c	1,305b,c	484d	7,177b,c	6,693b,c	14.8a
LSD ($p \leq 0.05$)		681	4,78	240	2,630	2,630	3.6

Note: Means with different letter are significantly different at 5% probability level.

3.5. Economic analysis

Since the cost of faba bean seeds increases each year, there is a greater need to define optimum plant density to maximize yields and economic return. According to the partial budget analysis, the highest seed cost (ETB 1,216 ha⁻¹) and net benefits (ETB 12,860 ha⁻¹) were obtained from 30 cm inter-row and 8 cm intra-row spacing (42 plants m⁻²) (Table 5). In contrast, the lowest net benefit was recorded in 50 cm inter-row and 10 cm intra-row spacing. The highest benefit: cost (B:C) ratio was obtained from wider inter and intra row spacing, but was not significantly different from narrow inter and intra row spacing (30 cm inter and 8 cm intra row spacing). This is due to the fact that the yield obtained from 30 cm inter-row and 8 cm intra-row spacing had compensated for the cost of the seed.

Dominance analysis showed that spacing combination of 50 cm inter and 10 cm intra, 40 cm inter and 10 intra, 40 cm inter and 8 cm intra and 30 cm inter and 12 cm intra spacing were dominated (Table 6) due to their net benefits were less than those of treatments with lower variable costs. These treatments were eliminated from further consideration (marginal analysis). All undominated treatments gave MRR which was greater than the minimum acceptable rate of return (100%). The highest MRR was obtained from 40 cm inter and 12 cm intra-row spacing followed by 30 cm inter and 10 cm intra-row spacing and then 30 cm inter and 8 cm intra-row spacing. The partial budget, B:C ratio,

Table 6. Dominant and Marginal analysis of the effect of spacing for faba bean

Inter-row	Intra-row	Cost of seed (ETB ha ⁻¹)	Marginal cost	Net benefit (ETB ha ⁻¹)	Marginal benefits	MRR (%)
50 cm	12 cm	484d		6,693b,c		
50 cm	10 cm	583c,d		5,902c	-791	D
40 cm	12 cm	605c	22	8,156b,c	2,254	10,245
40 cm	10 cm	726b,c		7,699b,c	-457	D
50 cm	8 cm	726b,c	0	8,929b	1,230	0
30 cm	12 cm	809b,c		8,866b	-63	D
40 cm	8 cm	913b		8,042b,c	-824	D
30 cm	10 cm	974b	61	11,740a	3,698	6,062
30 cm	8 cm	1,216a	242	12,860a	1,120	462
LSD ($p \leq 0.05$)		240		2,630		

Notes: MRR = marginal rate of return, D = dominant treatment.

Means with different letter are significantly different at the 5% probability level.

marginal analysis and minimum rate of return together give the information necessary to arrive at a tentative or candidate recommendation. Therefore, 30 cm inter-row and 8 cm intra-row spacing (42 plants/m²) gave highest net benefit with high B:C ratio and a MRR which was higher than the minimum rate of return (100%). The result is supported by Tekle et al. (2015) who reported the highest net benefits of faba bean at high plant density (44 plants m⁻²) under vertisol. In contrast, Al-Suhaibani et al. (2013) found a higher profit of faba bean from lower seed rate under different soil (sandy soil).

4. Conclusion

Generally, the overall performance of the faba bean variety *Gachena* was good and the results confirmed the existence of variations in the yield with plant density as a result of changing inter and intra-row spacing. Based on the results of this study, faba bean responded well at 30 cm inter and 8 cm intra-row spacing for obtaining maximum and economic yield under Vertisol.

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Competing Interests

The authors declare no competing interest.

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This work was carried out in collaboration between all authors.

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