Ethiop. J. Agric. Sci. 31(1) 31-52 (2021)

Exploring Optimum Crop Management Practices for Closing Yield Gaps using Crop Modeling

Wondafrash Mulugeta[1], Kindie Tesfaye[2], Mezegebu Getnet[3], Seid Ahmed[4], Amsalu Nebiyu[5], and Fasil Mekuanint[6]

[1]*Ethiopian Institute of Agricultural Research, Holeta Agricultural Research Center, Ethiopia*
[2]*International Maize and Wheat Improvement Center (CIMMYT), Addis Ababa, Ethiopia*
[3]*International Crop Research Institute for Semi-Arid Tropics (ICRISAT), Addis Ababa, Ethiopia*
[4]*International Centre for Agricultural Research in Dry Areas (ICARDA), Rabat, Morocco*
[5]*Jimma University College of Agriculture and Veterinary Medicine (JUCAVM) Jimma, Ethiopia* [6]*Ethiopian Institute of Agricultural Research, Melkasa Agricultural Research Center, Ethiopia*

አህፅሮት

የአየር ንብረት፣ የአፈር መረጃንና የሰብል ዕድገት ሞዴልን በመጠቀም የሰብል አያያዝን መወሰን በኢትዮጵያ አነስተኛ ነው። የጥናቱ ዓላማ CROPGRO የተባለውን የሰብል ዕድገት ሞዴል በመጠቀም በተለያዩ ቦታዎች የሰብል አያያዝን መወሰንና የምርት ልዩነትን በአርሶ አደሩና በምርምር መካከል ማቀራረብ ነው። በአጠቃላይ 432 ተጠኚዎችን አራት የባቄላ ዝርያ፣ ስድስት የዘር ወቅት፣ ሦስት የዘር መጠንና ስድስት የናይትሮጅን ማዳበሪያ መጠን ባካተተ በRCBD ዲዛይን በፋክቶሪያል አደራደር ዓመትን እንደ ድግግሞሽ በመውሰድ ሙከራው ተተንብዮል። የባቄላ ዝርያ ከዘር ወቅት ጋር ሲቆራኝ የተሻለ ምርት ይገኛል። ሰኔ አጋማሽ እስከ ሐምሌ መጀመሪያ ሳምንት ጎራ የተባለውን የባቄላ ዝርያ መዝራት በሆሳዕና፣ በቁሉምሳ፣ በመራሮና በሲናና ቦታዎች ከፍተኛ የእህል ምርት ያስገኛል። 450000 ተክል በሔክታር አንደ ቦታው የዘር ወቅት የተሻለ ምርት ይሰጣል። በአብዛኛው ቦታዎች 45 ኪሎ ግራም ናይትሮጅን የማዳበሪያ መጠን መጠቀም ከፍተኛ የእህል ምርት ይሰጣል። የጥናቱ ውጤት የሚያመላክተው የሰብል ዕድገት ሞዴል፣ የሰብል አያያዝና የሰብል ማሻሻያ ምርምርን በማጣመር ለግብርና ልማት ኢክስቴንሽን አስፈላጊውን መረጃ በመሥጠት ምርትን ባለው የሰብል ማሳ ላይ መጨመር ይቻላል።

Abstract

The use of crop models as decision support tools for exploring the consequences of various management decision options that interact with weather and soil factors are limited in Ethiopia. This study aimed to apply crop simulation CROPGRO-faba bean model in determining site-specific crop management practices to close the yield gaps. A total of 432 treatments consisted of four faba bean varieties with six sowing dates, three plant populations and six nitrogen fertilizer rates were considered in the study. Randomized Complete Block Design (RCBD) with factorial arrangement was used considering years as replications. *There was significant variety by sowing date interactions* $p \leq 0.05$ *in all locations. Grain yield was significantly affected by variety and sowing date. Sowing on late June to early July gave a highest grain yield with variety Gora at Hosana, Kulumsa, Meraro, and Sinana nitisols sites A plant population of 45 plants* m^{-2} *was found to be optimal depending on the sowing date and sites. The highest seed yield was obtained by applying 45kg* ha^{-1} *nitrogen* *fertilizer in most of the locations. The result showed the application of crop models in agronomic research, crop improvement and incorporation of the findings provides important information to prepare extension material and increase production on the existing crop land.*

Keywords: DSSAT, CROPGRO-Faba bean model, simulation, evaluation, yield gaps

Introduction

In Ethiopia 4.0 million smallholder farmers engage in faba bean production covering 492,271 ha of land with an average national grain yield of 2.1 t ha^{-1} (CSA, 2019). Faba bean is a valuable source of protein; incomes, animal feed and plays significant role in soil fertility restoration in cereal-based cropping system. Poor soil fertility, soil acidity and associated low phosphorus availability are among the major constraints affecting the productivity of cool-season food legumes in the highland Nitisols areas of the country (Getachew *et al.,* 2019).
Recently, the crop is threatened by new disease (faba bean gall disease) and parasitic weeds like *Orobache crenata* (Abebe *et al.,* 2018). Results showed that the yield gaps of 3.2 and 2.7 t ha^{-1} were obtained for both yield potential and water-limited yield respectively and Farmers are currently getting less than 40% of the water limited yield penitential of faba bean across the major faba bean growing zones in Ethiopia (Wondafrash *et al.,* 2019)

In recent years, cropping system models (CSM) like Decision Support System for Agro-Technology Transfer (DSSAT) are widely used as a useful computational tool in the evaluation of crop management options (Jones *et al.,* 2003; Basso *et al.,* 2011). Decisions regarding choice of varieties, sowing dates, plant population, fertilizer rates, and pest controls methods are considered fundamental to modern crop production to narrow yield gaps and reduce cost of production (Siddique *et al.,* 2012). Crop models can compensate for limitations associated with field experiments by allowing extrapolation of results to other environments beyond the experimental circumstances that are confined to specific locations or seasons (Chenu *et al.,* 2011). Closing the yield gap (Yg) via a fine-tuning of crop management practices provides an opportunity to increase crop production and productivity on existing crop land (Cassman *et al.,* 2003; van Ittersum *et al.,* 2013). The objective of this study was to apply crop simulation CROPGRO-faba bean model in determining site-specific crop management practices to close the faba bean yield gaps.

Materials and Methods

Description of study sites

The crop management practices were simulated for 24 major faba bean growing sites in Ethiopia representing Nitisols and Vertisols soil types. The sites were selected based on the availability of long-term weather, and soil profile data and suitability of the agro-ecology for faba bean production. The altitude, rainfall, and air temperature ranging from 1850 (Sirinka; Sekota) to 3000 m a.s.l (Nefas Mewcha), 728 to 1478 mm and 7 to 29 ^{0}C and their geographical coordinate presented Table 1.

Monthly weather data of maximum and minimum temperatures and rainfall for the period 1980 to 2009 were obtained from National Meteorological Agency of Ethiopia for the selected sites. Daily solar radiation was taken from the National Aeronautics and Space Administration for Climatology Resource for Agro-climatology (Stackhouse, 2010). Soil surface and soil profile characteristics were obtained from Africa Soil Information Service (AfSIS) project (Leenaars and Ruiperez, 2014.

Experimental details

CROPGRO is one of a model embed in DSSAT use to simulate particularly leguminous crops. In our experiment particularly the CROPGRO-Faba bean model was calibrated and evaluated using data collected from the field experiments on two soil types (Nitisols and Vertisols) during 2015 and 2016 crop season in Ethiopia. First season experimental data were used for model calibration while the second season data were used for model evaluation. The genetic coefficients of four faba varieties estimated by Wondafrash *et al.* (2019) were used in simulating the management practices. The CROPGRO-faba bean model simulation was run for 24 sites using 30 years (1980-2009) historical weather data.

Experimental materials

Four faba bean varieties Gora (EH91026-8-2 X BPL44-1) and Gebelcho (ILB4726 X 75TA26026-1-2) released for nitisols whereas Dagem (Grar -Jarso 89-8) and Walki (ILB4726 X 75TA26026-1-2) released for vertisols were used as a planting materials. These varieties were adapted to nitosols and vertisols of faba bean growing areas in the country and representing contrasting maturity and seed weight group.

Table 1. Simulated sites and associated weather and geographical information

Region	Zone	Site	Latitude (N)	Longitude (E)	Altitude (m)	Annual rainfall (mm)	T min (^{0}C)	T max (^{0}C)	Soil type	Agro-ecology
Amhara	North Gondar	Debark	13.156	37.883	2706	728	16	29	Vertisols	M4 (cool moist mid highland)
	North Wollo	Sirinka	11.750	39.050	1850	963	10	23	Vertisols	SM4 (cool sub-moist mid highland)
	South Gondar	Debre Tabor	11.850	38.017	2706	1118	16	28	Nitisols	M3 (Tepid moist mid highland)
		Nefas Mewcha	11.733	38.467	3000	1187	8	20	Nitisols	M4 (cool moist mid highland)
	West Gojam	Adet	11.276	37.492	2240	1251	11	24	Nitisols	M3 (Tepid moist mid highland)
		Gergera	11.167	37.667	2650	1027	12	24	Nitisols	M3 (Tepid moist mid highland)
	Waghimra	Sekota	12.631	39.035	1850	747	8	20	Nitisols	SM3 (Tepid sub-moist mid highlands)
Oromiya	Arsi	Bekoji	7.544	39.256	2780	1020	9	22	Nitisols	H4 (cool humid mid highlands)
		Meraro	7.408	39.249	2940	993	8	22	Nitisols	H4 (cool humid mid highlands)
		Kulumsa	8.019	39.153	2200	799	12	26	Nitisols	SM3 (Tepid sub-moist mid highlands)
		Arsi-Robe	7.884	39.628	2420	1059	11	24	Vertisols	H3 (Tepid humid mid highlands)
	Bale	Agarfa	7.283	39.817	2550	1046	7	22	Vertisols	SH4 (cool sub-humid mid highlands)
		Gasera	7.367	40.300	2320	1062	11	25	Vertisols	H3 (Tepid humid mid highlands)
		Sinana	7.143	40.350	2400	1009	14	27	Nitisols	M3 (Tepid moist mid highlands)
	Southwest Shewa	Adadi	8.633	38.013	2383	1105	10	23	Nitisols	M3 (Tepid moist mid highlands)
	West Arsi	Kofele	7.074	38.795	2660	1330	9	23	Vertisols	H4 (cool humid mid highlands)
	West Shewa	Ambo	8.966	37.859	2130	1170	10	25	Vertisols	M3 (Tepid moist mid highlands)
		Ginchi	9.033	38.150	2200	1221	9	21	Vertisols	M3 (Tepid moist mid highlands)
		Kuyu	9.800	38.400	2400	1468	9	21	Vertisols	M3 (Tepid moist mid highlands)
		Holeta	9.070	38.496	2400	1045	8	21	Nitisols	M3 (Tepid moist mid highlands)
SNNP	Gedio	Bule	6.300	38.417	2860	1478	10	24	Nitisols	H4 (cool humid mid highlands)
	Hadiya	Hosena	7.568	37.856	2306	1028	11	25	Nitisols	SH3 (Tepid sub-humid mid highlands)
	KembataTembaro	Angacha	7.333	37.850	2381	1077	11	26	Nitisols	SH3 (Tepid sub-humid mid highlands)
	Wolayta	Kokate	6.822	37.749	2161	1552	9	23	Nitisols	SH3 (Tepid sub-humid mid highlands)

Treatments and experimental design

The treatments consisted of factorial combination of the four faba bean varieties with six sowing dates (S) (20 June, 30 June, 10 July, 20 July, 30 July, 10 August), three plant population (P) (250000, 350000 and 450000 plants ha^{-1}) and six nitrogen fertilizer rates (0, 9, 18, 27, 36 and 45 kg N ha^{-1}). These crop management practices were chosen to represent local farming practices and consider the high and low values.

The computer model experiment was run in Randomized Complete Block Design RCBD in factorial arrangement which opened solution – analysis then analyst built in SAS and replicated thirty times per treatment in factorial combination with a total of four hundred thirty two treatments using 30 years (1980-2009) as replications. Simulation years were considered as replications (blocks), since years had unpredictable weather characteristics that was not needed formal randomization of simulation years (Mohammed *et al.*, 2016).

Statistical analysis

The analyses of variance (ANOVA), was done for individual sites separately employing SAS software version 9.0 (SAS Institute Inc., 2002). In the second stage combined analysis was done based on Hartley's F-maximum test by dividing higher mean square divided by smaller mean square (Rangaswamy, 1995). The analyses of variance were done separately for individual sites to recommend management practices for each target production environment. Besides simulate maximum and minimum grain yields were used for evaluating the important of management practices on faba bean grain yield in individual sites. Variance components analysis was done to estimate the contribution of each random effect to the variance of the dependent variable (grain yield) for 24 sites in 30 years. Fisher's restricted least significance difference (LSD) at $p \leq 0.05$ and $p \leq 0.01$ probability levels were used to establish the differences between means.

Results and Discussions

Analysis of variance components was done to determined the contribution of each management practices to total variation and estimates the contribution of each random effect to the variance of the dependent variable(grain yield). Environment (E) and variety were accounted to 32.7% and 21.3% of the total variation, respectively that far outweighed the variation of grain yield attributed by other management practices (Table 2).

Table 2. Contribution of each factor (management practices) to total variation

Source	DF	MS	SD	Total Variation (%)	VC	CV (%)
Variety (V)	3	15383269887	444.8	21.3	197826.3	11.2
Environment (E)	23	3965885483	550.3	32.7	302809.9	13.8
Sowing date (SD)	5	1082819086	144.5	2.3	20882.0	3.6
Plant population (P)	2	358852971.8	58.8	0.4	3458.3	1.5
Year (Y)	29	141105893.6	98.0	1.0	9610.0	2.5
Nitrogen fertilizer rate (N)	5	2302864.764	6.2	0.0	38.7	0.2
E x Y	667	41469784.95	308.7	10.3	95306.6	7.7
Error	310305	297352.8205	545.3	32.1	297352.8	13.7

MS; mean square, SD; standard deviation, VC; variance component, CV; coefficient of variation, V; variety, E; environment/site: Y; year: N; nitrogen fertilizer rate: P; plant population: SD; sowing date

The two-factor interaction effects were significant. However, there was no significant interaction that affect grain yield of faba bean for the third and fourth order interactions. Table 3 and Table 4).The result imply the application of both factors with interaction significantly increased grain yield of faba bean instead of application of sole factor.

Effects of management practices on grain yield

In every site, the analysis of variance revealed significant for grain yield at ($P \le 0.01$) main effects for varieties, sowing date, plant population except nitrogen fertilizer rates (Table 3 and 4). But there was no significance difference ($p \le 0.05$) among nitrogen fertilizer rates except at Debre Tabor (Table 3). Despite, there was significant difference among fertilizer rates 45 kg ha^{-1} gave the highest grain yield of (2.7 t ha^{-1}) at Nefas Mewcha and Debark (3.8 t ha^{-1}) (Data not seen). Nitrogen fertilizer rates from 27 to 45 kg ha^{-1} gave the same average grain yield of (3.1 t ha^{-1}) at Debre Tabor at ($P \le 0.05$). According to Amare et al., 2000 absence of fertilizer response across sites related with the residual fertility level of nutrients while negative response could be related to activities of soil micro organisms, which need further investigation. In an experiment conducted to determine N_2 fixation in three sites in Arsi highlands, the amount of N fixed by faba bean ranged from 139-210kg ha^{-1} (Amanuel *et al.,* 2000).

Nitosols

Variety × sowing date

The interaction effect of variety and sowing date was significant ($p \le 0.05$) for grain yield in all sites except Gergera. The highest average grain yield was obtained from Gora variety sown from late June to early July at Hosana, Kulumsa, Meraro and Sinana sites (Fig. 1). Moreover, variety Gora resulted in better grain yield for Nefas Mewcha and Sekota sown at mid-June, and for Bule and Holeta sown at 20 July Variety Gora sown 30 July to 10 August was identified an optimum for Adet and Kokate in the current study. Each site has got different onset of rain that determine sowing date and difficult to put a specific crop calendar base sowing date. In this regard considering 30 years weather data mid June to late June, 10 to 20 July and 20 to 30 July was recommended for Adadi, Angacha and Bekoji sites using Gora variety, respectively. Variety Geblecho with sowing date 30 June to early July gave better grain yield at Adadi, Bekoji and Meraro. Gora variety gave the highest mean grain yield comparing with Gebelcho where both recommended for nitosols soil type (Fig. 1).

In this study, grain yield was significantly affected by variety by sowing dates and variety by plant population interactions. Particularly in nitosol sites highest grain yield was obtained using Gora variety with late July to early August sowing. However, it is advisable to plant early as much as possible before the soil moisture reduces to mitigate and adopt the climate change. Similarly, Gora and Gebelcho varieties gave the highest grain yield in planting mid-June in both Nefas Mewecha and Sekota (Fig. 1).

Table 3. Analyses of variance on main and interaction effects of crop management practices on grain yield of faba bean in Ethiopia

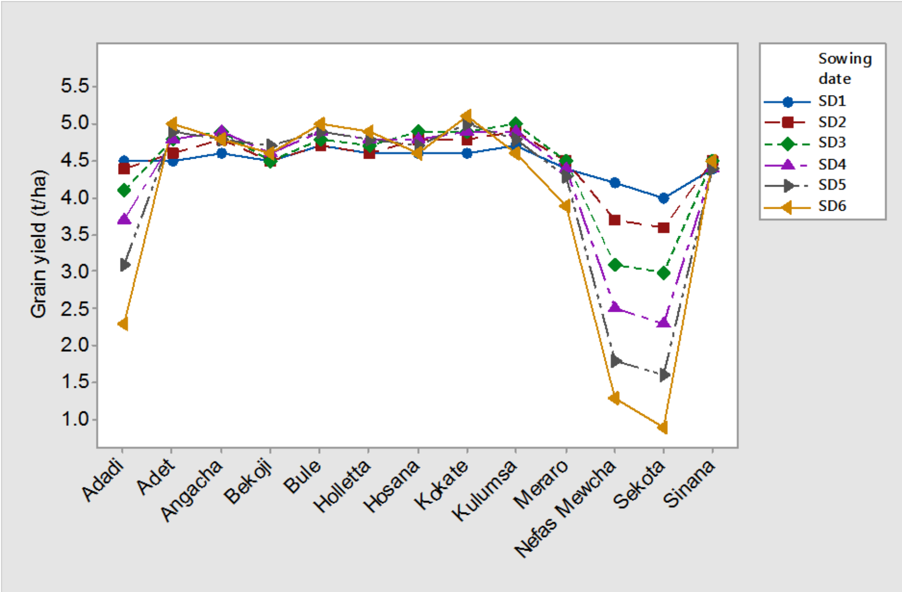
Sources of variation		Adadi	Adet	Angacha	Bekoji	Bule	Debre Tabor	Gergera	Holeta
Variety (V)	3	***	***	***	***	***	***	***	***
Sowing date (S)	5	***	***	***	***	***	***	***	***
Plant population (P)	2	***	***	***	***	***	***	***	***
Nitrogen (N) rate	5	ns	ns	ns	ns	ns	***	ns	ns
V*S	15	***	***	***	***	***	***	ns	***
V* P	6	ns	ns	ns	ns	ns	ns	ns	ns
V*N	15	ns	ns	ns	ns	ns	ns	ns	ns
S*P	10	ns	ns	ns	ns	ns	ns	ns	ns
S*N	25	ns	ns	ns	ns	ns	ns	ns	ns
P*N	10	ns	ns	ns	ns	ns	ns	ns	ns
V*S* P	30	ns	ns	ns	ns	ns	ns	ns	ns
V *S*N	75	ns	ns	ns	ns	ns	ns	ns	ns
V* P*N	30	ns	ns	ns	ns	ns	ns	ns	ns
V*S*P*N	200	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)		14.6	6.6	7.5	6.3	6.5	14	11	6
Error		527	284	322	275	278	427	440	273

LSD=Least significant Difference, ***=significant difference (P≤0.01), **=significant (P≤0.05), ns=Non significant; CV= Coefficient of variation

Table 3. Continued …

Source	DF	Hosana	Kokate	Kulumsa	Meraro	Nefas Mewcha	Sekota	Sinana
Variety (V)	3	***	***	***	***	***	***	***
Sowing date (S)	5	***	***	***	***	***	***	***
Plant Population (P)	2	***	***	***	***	***	***	***
Nitrogen (N) rate	5	ns	ns	ns	ns	ns	ns	ns
V*S	15	***	***	***	***	***	***	***
V * P	6	***	***	***	ns	ns	ns	***
V*N	15	ns	ns	ns	ns	ns	ns	ns
S*P	10	ns	ns	ns	ns	ns	ns	ns
S*N	25	ns	ns	ns	ns	ns	ns	ns
P*N	10	ns	ns	ns	ns	ns	ns	ns
V*S*P	30	ns	ns	ns	ns	ns	ns	ns
V*S*N	75	ns	ns	ns	ns	ns	ns	ns
V*P*N	30	ns	ns	ns	ns	ns	ns	ns
V*S*P*N	200	ns	ns	ns	ns	ns	ns	ns
CV (%)		8	7	8	9	10	16	7
Error		335	314	330	384	264	409	275

LSD; Least significance difference***=significant difference at (P≤0.01), **significant at (P≤0.05), ns=Non significant; CV= Coefficient of variation



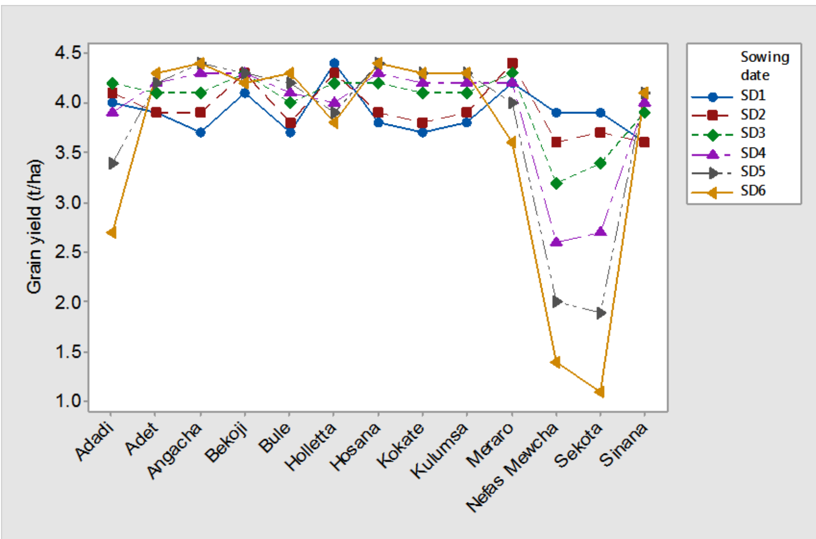
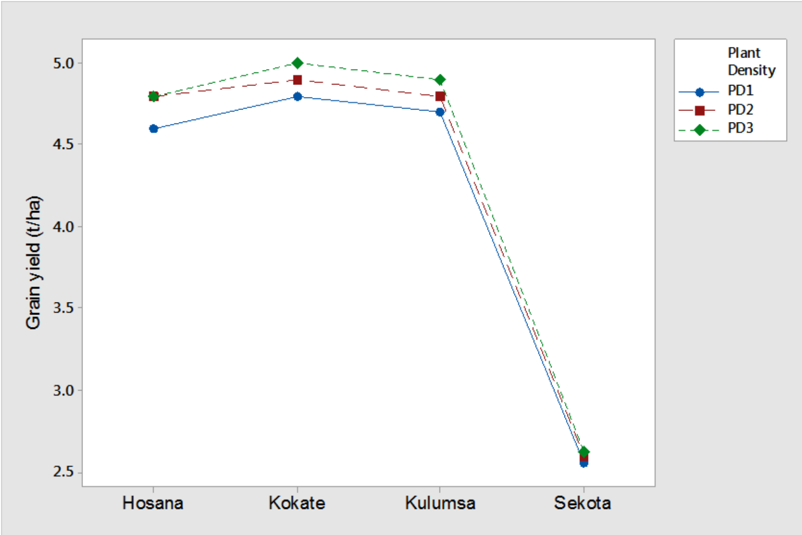


Figure 1. Effect of variety by sowing date interaction on grain yield (t ha^{-1}) in nitisols sites. Variety: Gora (left), Gebelcho (right) Sowing dates: SD_1; 20 June, SD_2; 30 June SD_3; 10 July, SD_4; 20 July, SD_5; 30 July, and SD_6; 10 August

Variety × Plant Population

The highest average grain yield was obtained using Gora variety and a plant population of 450000 plants ha^{-1} at Kokate (5.0 t ha^{-1}) and Kulumsa (4.9 t ha^{-1}) respectively. Similarly, plant population 250000 and 350000 plants ha^{-1} gave a grain yield of 2.6 and 4.8 t ha^{-1} at Sekota and Hosana respectively (Fig.2). Likewise, Gebelcho variety with plant population of 250000 plants ha^{-1} gave a grain yield of 2.8 and 4.1 tha^{-1}at Sekota and Kulumsa respectively. However, Gebelcho variety with plant population of 350000 plants ha^{-1} gave the highest grain yield of 4.2 and 4.1 t ha^{-1} at Hosana and Kokate sites (Fig.2). Amare and Adamu (1994) showed that higher yields were obtained in most cases from higher seed rates. Also Getachew and Missa (2011) reported variety by planting population interaction for grain yield of faba bean. The present study showed that the larger the seed weight requires the higher plant population that agreed with Getachew and Missa (2011) reported increasing planting density has significant effects on yield and yield components of faba bean.



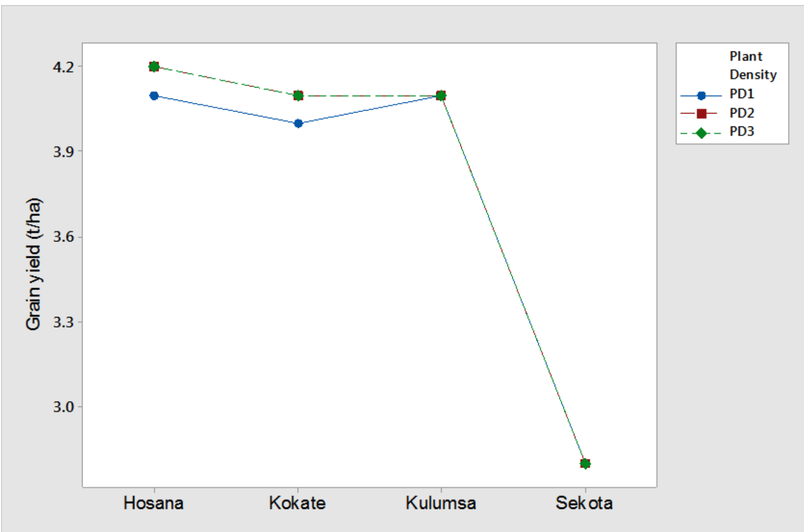


Figure.2 Effect of variety by plant population interaction on grain yield (t ha^{-1}) in nitsols sites. Variety; Gora, (left), Gebelcho (right); Plant population (PP_1; 250000 plants ha^{-1}, PP_2; 50000 plants ha^{-1} and PP_3; 450000 plants ha^{-1}).

Vertisols

Variety × sowing date

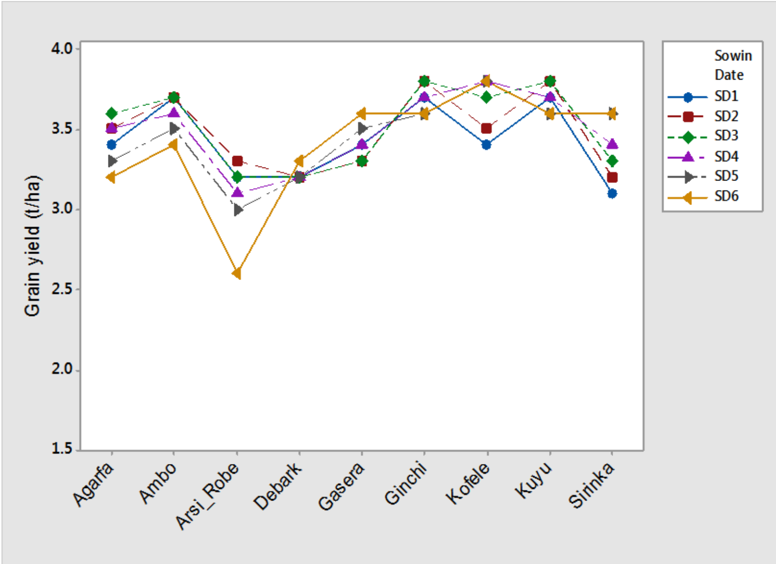
Variety and sowing date revealed significant ($p \leq 0.01$) interaction on grain yield (Table 4). The highest yield was attained through sowing Walki variety starting from mid June gave better grain yield at Arsi–Robe (Table 6). The same variety sown on mid July gave better grain yield at Ambo and Ginchi while early to mid-July was optimum for Agarfa and Kofele. Likewise, Walki variety with a sowing date at 20 July for Kuyu and Sirinka, 10 July for Debark and early August for Gasera result better grain yield (Fig. 3). In the case of Dagem variety, late June to early July resulted better grain yield at Arsi-Robie, Debark, Ambo, Ginch, and Kuyu. The same variety (Dagem) gave a high grain yield sown on 10 July at Agarfa, between 30 July and 10 August at Gasera, and on 20 July at Kofele (Fig. 4). Similarly, Walki variety gave a better yield sown on 10 July to 20 July, 20 July, early June, 20 July, 10 August, 30 July, 30 June, 20 July and 20 July at Agarfa, Ambo, Arsi-Robie, Debark, Gasera, Ginchi, Kofele, Kuyu and Sirinka sites, respectively (Fig. 3).

Sowing Walki variety between 20 to 30 June showed that early sowing in vertisols is an option to increase productivity at Arsi-Robie. This suggest that the plant uses the available water before it lost from the soil and can complete its growth early in the season. However, at Gasera and Kuyu, late July to early August sowing dates were recommended. However, earlier planting is advisable if the condition is favorable for land preparation and support the crop to escape terminal moisture stress and frost. Dagem variety sown from end of June to early August showed its better elasticity and give chance the variety to plant in different sowing dates in vertisol areas.

Table 4. Analyses of variance on main and interaction effects of crop management practices on grain yield of faba bean in Ethiopia

Source of variations	DF	Agarfa	Ambo	Arsi-Robe	Debark	Gesera	Ginchi	Kofele	Kuyu	Sirinka
Variety (V)	3	***	***	***	***	***	***	***	***	***
Sowing date (S)	5	***	***	***	***	***	***	***	***	***
Planting population (P)	2	***	***	***	***	***	***	***	***	***
Nitrogen (N) rate	5	ns	ns	ns	***	ns	ns	ns	ns	ns
V*S	15	ns	***	***	***	***	***	***	***	***
V* P	6	ns	ns	***	***	ns	***	***	ns	***
V*N	15	ns	ns	ns	ns	ns	ns	ns	ns	ns
S*P	10	ns	ns	ns	ns	ns	ns	ns	ns	ns
S*N	25	ns	ns	ns	ns	ns	ns	ns	ns	ns
P*N	10	ns	ns	ns	ns	ns	ns	ns	ns	ns
V*S*P	30	ns	ns	ns	ns	ns	ns	ns	ns	ns
V*S*N	75	ns	ns	ns	ns	ns	ns	ns	ns	ns
V*P*N	30	ns	ns	ns	ns	ns	ns	ns	ns	ns
V*S*P*N	200	ns	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)		7.1	6.0	17	6	7	2	8	6	7
Error		294.9	265	486	228	299	286	352	289	299

LSD; Least significance difference, ***=significant difference at ($P \leq 0.01$), **significant at ($P \leq 0.05$), ns=Non significant; CV= Coefficient of variation



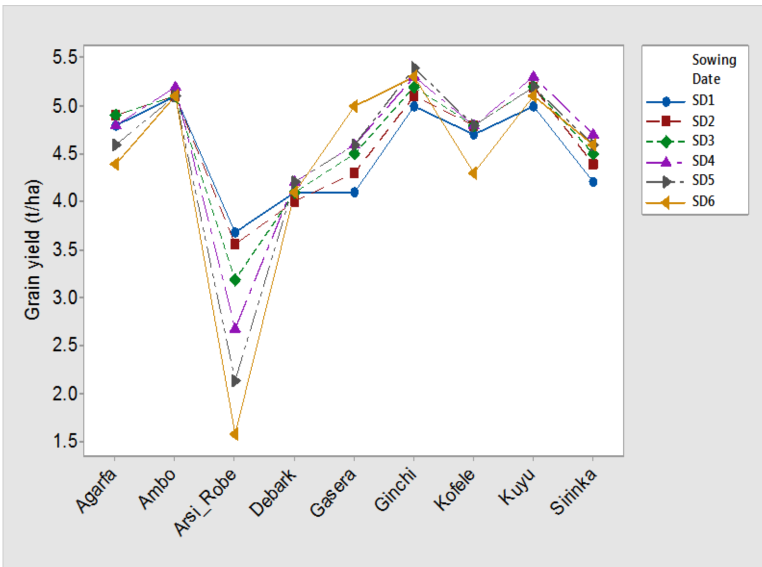


Figure 3. Effect of variety by sowing date interaction on grain yield (t ha^{-1}) in vertisols sites. Varieties: Dagem (left) and Walki (right), Sowing dates: SD_1; 20 June, SD_2; 30 June SD_3; 10 July, SD_4; 20 July, SD_5; 30 July, and SD_6; 10 August

Variety × plant Population

The analysis of variance revealed significant variety by plant population interactions ($p \le 0.05$) Accordingly, Dagem variety with plant population 250000 plants ha^{-1}, gave a grain yield 3.1 t ha^{-1} at Arsi-Robe· While 350000 plants ha^{-1} gave a grain yield 3.6 and 3.4 t ha^{-1} at Ginchi and Sirinka sites respectively. Moreover, plant population 450000 plants ha^{-1}gave grain yield of 3.3 and 3.6 t ha^{-1}at Debark and Kofele respectively (Fig. 4).

In other hand, Walki variety with plant population of 350000 plants ha^{-1} gave a the highest and lowest grain yield of 5.2 and 3.2 t ha^{-1} at Ginchi and Arsi-Robe sites respectively. Walki variety and plant population 450000resulted a grain yield of 3.3, 4.2, 5.3 and 4.8 t ha^{-1} at Arsi-Robe, Debark, Ginchi and Kofele sites respectively (Fig. 4).

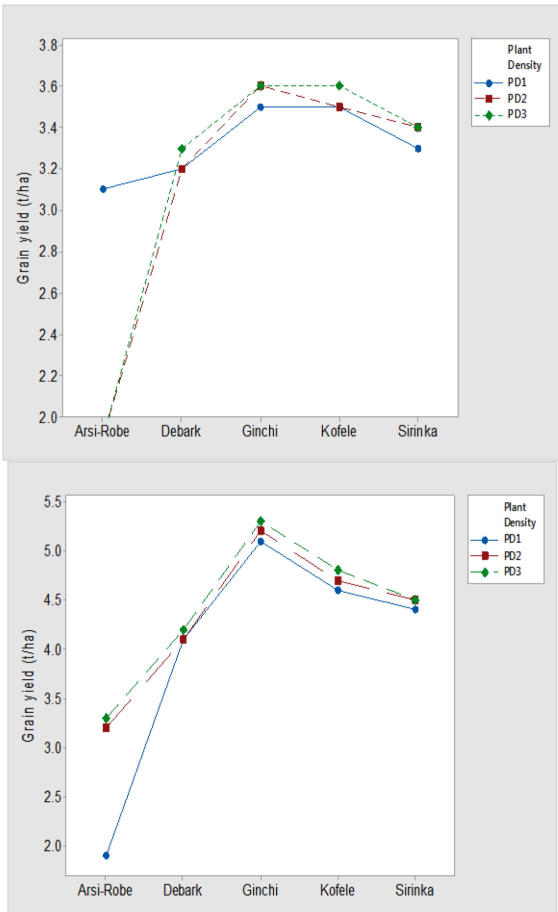


Figure 4 Effect of variety by plant population interaction on grain yield (t ha^{-1}) in vertisol sites. Variety; Dagem (left), Walki (right), Plant density, PP$_1$; 250000 plants ha^{-1}, PP$_2$; 350000 plants ha^{-1} and PP$_3$; 450000 plants ha^{-1}

Maximum and minimum grain yields across sites

Nitisols

The maximum and minimum seed yields of faba bean were identified based on the mean grain yield obtained by combining all possible management practices (variety, sowing date, and plant population and nitrogen fertilizer rates. Maximum and minimum grain yields were simulated for 30 years' mean weather data considered with the management factors included in the study. In nitiosols, the maximum average grain yield ranged from 3.7 to5.2 t ha^{-1} while the minimum grain yield ranged from 0.9 to 4.0 t ha^{-1} (Table 5). Combining Gora variety, August 10 sowing date, 450000 plants ha^{-1} and 45 kg ha^{-1} nitrogen fertilizer showed the highest yield of 5.2 t ha^{-1} at Adet and Kokate. Meanwhile, the minimum grain yield obtained when the above treatments were applied 0.9 and 1.3 t ha^{-1} at Nefas Mewcha and Sekota, respectively. However, 4.2 and 4.1 t ha^{-1} maximum yields were obtained by shifting the sowing date to 30 and 20 June, respectively (Table 5). In general the mean grain yield of 3.3 and 3.6 t ha^{-1} was recorded for variety Gora and Geblecho on field experiments conducted at Holetta and Kulumsa representing Nitosols soil types during 2014 and 2015.

Table 5. Simulated grain yield (t ha^{-1}) of different management practices (varieties, sowing date, plant population and N levels) on grain yield in nitosols sites.

Location	Management practices		Simulated grain yield ±SD (t ha^{-1})	
	Minimum	Maximum	Minimum	Maximum
Adadi	Gora, 10 August, 250000 and 0	Gora, 20 June, 450000 and 45	2.3±0.9	4.6±0.3
Adet	Gebelcho, 20 June, 250000 and 0	Gora, 10 August, 450000 and 45	3.8±0.3	5.2±0.3
Angacha	Gebelcho, 20 June, 250000 and 18	Gora, 10 July, 450000 and 45	3.6±0.3	5.1±0.2
Bekoji	Gebelcho, 10 August, 250000 and 0	Gora,30 July, 450000 and 45	4.1±0.5	4.8±0.3
Bule	Gebelcho, 20 June, 250000 and 0	Gora, 10 August, 450000 and 45	3.7±0.3	5.1±0.3
Debre Tabor	Gora, 10 August, 250000 and 0	Gora, 20 June, 450000 and 45	2.2±0.8	3.7±0.2
Geregera	Gora, 10 August, 250000 and 0	Gora, 30 July, 450000 and 45	3.1±0.8	4.9±0.4
Holeta	Gebelcho, 10 August, 250000 and 0	Gora, 30 July, 450000 and 45	3.7±0.5	5.0±0.4
Hosana	Gebelcho, 20 June, 250000, and 45	Gora, 10 July, 450000, and 45	3.7±0.4	5.0±0.4
Kokate	Gebelcho, 20 June, 250000 and 45	Gora, 10 August, 450000 and 45	3.7±0.3	5.2±0.3
Kulumsa	Gebelcho, 20 June, 250000 and 0	Gora, 10 July, 450000 and 45	3.7±0.3	5.1±0.4
Meraro	Gebelcho, 10 August, 250000 and 0	Gora, 30 June, 450000 and 45	3.6±0.7	4.5±0.2
Nefas Mewcha	Gora, 10 August, 450000 and 45	Gora, 30 June, 450000 and 45	1.3±0.5	4.2±0.6
Sekota	Gora, 10 August, 450000 and 45	Gora, 20 June, 450000 and 45	0.9±0.6	4.1±0.7
Sinana	Gebelcho, 30 June, 250000 and 9	Gora, 30 June, 450000 and 45	3.5±0.2	4.6±0.2

Vertisols

In vertisols, combining Walki variety, July 20 sowing date, 450000 plants ha^{-1}, and 45 kg ha^{-1} nitrogen fertilizer showed the highest yield of 5.3, 5.5 and 5.4 t ha^{-1} at Ambo, Ginchi and Kuyu, respectively (Table 6). While, the minimum yield obtained when Walki variety was sown on 10 August, 250000 plants ha^{-1}, and 0 kg ha^{-1} nitrogen fertilizer showed 0.5 t ha^{-1} yield at Arsi-Robie. However, using Dagem instead of Walki and shifting the sowing date to early June and plant population to 350000 plants ha^{-1} and applying 45 kg ha^{-1} increased the yield to 4.1 t ha^{-1} (Table 6). While the mean grain yield of 2.4 and 2.7 t ha^{-1} was obtained for variety Dagem and Walki, respectively on field experiments conducted at Ambo and Kuyu representing Vertisol soil types during 2014 and 2015.

Consistently, applying higher plant population of 450000 plant ha^{-1} combined with 45 kg ha^{-1} nitrogen fertilizer rate resulted in higher faba bean grain yield in all locations. The result showed that there is an opportunity to harvest a high grain yield using the available land and water resources and integrating different management practices.

Table 6. Simulated grain yield (t ha^{-1}) of different management practices (varieties, sowing date, plant population and N levels) on grain yield in vertisols sites

Location	Management practices		Simulated grain yields ± SD (t ha^{-1})	
	Minimum	Maximum	Minimum	Maximum
Agarfa	Gebelcho, 10 August, 250000 and 0	Gora, 30 July, 450000 and 45	3.5±0.6	4.8±0.3
Ambo	Dagem, 20 June, 250000 and 45	Walki, 20July, 450000 and 45	4.4±0.3	5.3±0.6
Arsi-Robe	Walki, 10 August, 250000 and 0	Dagem, 20 June, 350000 and 45	0.5±0.3	4.1±0.7
Debark	Gebelcho, 20 July, 250000 and 9	Gora, 10 July, 450000 and 45	3.6±0.2	4.2±0.2
Gasera	Walki, 20 June, 250000 and 0	Walki, 10 August, 450000 and 45	4.0±0.3	5.0±0.6
Ginchi	Dagem, 20 June, 250000 and 45	Walki, 30 July, 450000 and 45	4.5±0.3	5.5±0.5
Kofele	Dagem, 10 August, 250000 and 0	Walki, 10 July, 450000 and 45	4.2±0.6	4.9±0.4
Kuyu	Dagem, 20 June, 250000 and 45	Walki, 20 July, 450000 and 45	4.5±0.3	5.4±0.5
Sirinka	Dagem, 20 June, 250000 and 9	Walki, 20 July, 450000 and 45	3.1±0.1	4.8±0.5

Conclusion and Recommendation

The effect of sowing date on grain yield was mainly due to the low in moisture availability and the increase in temperature in the cropping season location like Sekota. In the case of short rainy season, using supplemental irrigation can solve the moisture stress condition and fully support faba bean production. In general, the variety choice has got an influence in decision of sowing date in a location in relation to moisture availability. At location such as Nefas Mewcha, 20 to 30 June gave the highest grain yield which were consistent across varieties (Fig.1).

Sowing Gora variety from 20 to July 30 show no significant difference in grain yield at Holeta and hence sowing at the end of June is advisable to fully utilize the growing season rainfall and escape frost. In contrast using Gebelcho, planting 20 to 30 June gave a higher grain yield of 4.4 and 4.3 t ha^{-1}, respectively. The result agreed with research recommendation for the area (EIAR, 2017). Thus, the longer the maturity period of the variety, the early sowing date is recommended to reduce the prevailing high temperature and termination of rainfall before the plant reach physiological maturity. The presence of management practices interaction showed faba bean grain yield was affected by different factors. Thus the recommendation should give emphasis for treatment combination of each factor in target sites before applying the individual factors is valuable.

In conclusion, more integrated efforts are needed to develop modeling tools taking into account both, environmental and socio-economic effects on farmer's behavior and future yields. Most measures to narrow current yield gaps also have a high potential to maintain or increase crop yield levels under future climatic conditions. There is a large potential for sustainable intensification of crop production by closing yield gaps e.g. with enhanced water and nutrient management (Mueller *et al.*, 2012).

Acknowledgments

This research is based on a PhD study conducted by the financial support from the Ethiopian Institute of Agricultural Research (EIAR), Austria Development Agency (ADA) through the International Center for Agricultural Research in the Dry Areas (ICARDA), Jimma University College of Agriculture and Veterinary Medicine (JUCAVM), International Maize and Wheat Improvement Center (CIMMYT), and Agricultural Growth Program II (AGP- II) of Ethiopia.

References

Abebe T, Belay GW, Gemechu KW, and Tadesse TM. 2018. Fungicidal management of the newly emerging faba bean disease "gall" (*Olpidium viciae* Kusano) in Tigray, Ethiopia. Crop protection 107:19-25.

Adem Mohammed, Tamado Tana, Piara Singh, Adamu Molla. 2016. Modeling climate change impact on chickpea production and adaptation options in the semi-arid North-Eastern Ethiopia. Journal of Agriculture and Environment for International Development.110: 377-395.

Amanuel GA, Kühne R, Tanner D, Vlek P. 2000. Biological nitrogen fixation in faba bean (*Vicia faba L.*) in the Ethiopian highlands as affected by p fertilization and inoculation. Biology and Fertility of Soils.32: 353-359

Amare Ghizaw,Beniwal SPS, Dejene Mekonen Mekonnen Wolde Mariam, and M.C.Saxena. 2000. Relative importance of some crop management factors on the productivity of Faba bean. Ethiopian Journal Agricultural Science.17:17-31.

Cassman KG, Dobermann A, Walters DT, Yang HS. 2003. Meeting cereal demand while protecting natural resources and improving environmental quality. Annual Review Environment Resource 28: 315-358.

Basso B, Ritchie JT, Cammarano D, Sartori L. 2011. A strategic and tactical management approach to select optimal N fertilizer rates for wheat in a spatially variable field.European Journal of Agronomy. 35: 215–222

Chenu K, Cooper M, Hammer GL, Mathews KL, Dreccer MF, Chapman SC. 2011. Environment characterization as an aid to wheat improvement: interpreting genotype- environment interactions by modeling water deficit patterns in North-Eastern Australia. Journal of Experimental Botany 62: 1743-1755

CSA (Central Statistical Agency). 2019. Agricultural Sample Survey 2018/2019. Report on Area and Production of major Crops (Private Peasant Holdings, Meher Season). Central Statistical Agency Ethiopia, Addis Ababa, Ethiopia. Statistical bulletin: 589. pp.58

Ethiopian Institute of Agricultural Research (EIAR) 2017.Pulses Research Strategy (2016-2030).

Ethiopian Institute of Agricultural Research. Addis Ababa, Ethiopia. pp. 33-64

Getachew Agegnehu and Missa Demissie. 2011. Effect of Seed Size, Planting Density and Phosphate Fertilizer on Yield and Yield components of Faba Bean in the central Highlands of Ethiopia. Ethiopian Journal of Agricultural Science.21:95-107.

Getachew A, ChilotY, and Teklu E. 2019.Soil Acidity Management.Ethiopian Institute of Agricultural Research (EIAR). Addis Ababa, Ethiopia. pp.56

Jones JW, Hoogenboom G, Porter CH, Boote KJ, Batchelor WD, Hunt LA, Wilkens PW, Singh U, Gijsman AJ, and Ritchie JT. 2003. DSSAT Cropping System Model. European Journal of Agronomy.18:235-265.

Leenaars, JGB. 2012. Africa Soil Profiles Database, Version 1.0. A compilation of geo-referenced and standardized legacy soil profile data for Sub Saharan Africa (with dataset). ISRIC - World Soil Information, Droevendaalsesteeg 3, Wageningen.

MoA (Ministry of Agriculture). 2000. Agro-ecological Zonations of Ethiopia. Ministry of Agriculture Addis Ababa, Ethiopia.

Muller C, Cramer W, Hare WL, Lotze-Campen H. 2011. Climate change risks for African agriculture. Proceedings of the National Academy of Sciences of the United States of America 108:4313–4315.

National Aeronautics and Space Administration (NASA) Prediction of Worldwide Energy Resource (POWER) Climatology Resource for Agroclimatology *Website URL:http://power.larc.nasa.gov*. Access 2015

NMA (National Meteorological Agency of the Federal Democratic Republic of Ethiopia). 2009. Daily precipitation and temperature data. Ethiopian Government, Ethiopia

Peterson Roger. 1994. Agricultural field experiments Design and analysis. Marcel Dekke, Inc. New York, pp. 409.

Rangaswamy R. 1995. A Text Book of Agricultural Statistics. Wiley Eastern Limited. New Delhi. pp 496.

SAS/STAT guide for personal computers, Version 9.0 Edition, SAS Institute Inc., Cary, NC, 2002.

Siddique KHM, Johansen C, Turner NC, Jeuffroy M, Hashem A, Sakar D, Gan Y, Alghamdi S. 2012.Innovations in agronomy for food legumes. A review. Agronomy for Sustainable Development.32:45-64.Doi: 10.1007/s13593-011-0021-5.

Stackhouse Jr P. 2010.Prediction of worldwide energy resources. NASA, Washington, DC, USA. Available at http://power.larc.nasa.gov. (Accessed 25 May, 2015).

Van Ittersum MK, et al., 2013. Yield gap analysis with local to global relevance- A review. Field Crops Res. 143, 4–17.

Wondafrash Mulugeta, Kindie Tesfaye, Mezegebu Getnet, Seid Ahmed, Amsalu Nebiyu, and Fasil Mekuanint. 2019. Quantifying Yield Potential and Yield Gaps of Faba Bean in Ethiopia. Ethiopian Journal Agricultural Science 29 (3):105-120.