

# Soil Fertility and Crop Management Research on Cool-season Food Legumes in the Central Highlands of Ethiopia

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## አህፅሮት

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## Abstract

Land degradation and depletion of soil fertility is the critical challenge for sustainable crop production in the highlands of Ethiopia. This paper reviews advances in the major activities and achievements of soil fertility, crop and land management research on the highland pulses, which have been done for the last two decades in the central highlands of Ethiopia. Inappropriate agronomic practices, poor internal drainage, soil acidity and associated low phosphorus (P) availability are major constraints affecting productivity of highland food legumes. Production practices differ across the major highland pulse growing areas of the country. Research findings showed that twice tillage before planting and one properly timed hand weeding resulted in optimum yields of faba bean and field pea. Substantial increments in seed and biomass outputs of faba bean and chickpea were recorded on Vertisols due to the integrated application of improved surface drainage, sowing date and genotypes. At Holetta, the application of lime as calcium carbonate at the rate of 1, 3 and 5 t ha<sup>-1</sup> on Nitisols increased mean seed yield of faba bean by 45, 77 and 81%, respectively over non-treated plots. Similarly, application of 23/20-32/30 kg N/P ha<sup>-1</sup> on Nitisols resulted in the highest net benefit for faba bean and field pea production. Phosphorus by farmyard manure interaction significantly increased faba bean seed yield. Field pea seed yield also increased at the low and medium soil fertility levels with increasing rates of P application. In conclusion, a concerted effort is necessary to extend the available technologies in order to improve the productivity of highland food legumes.

## Introduction

Faba bean (*Vicia faba* L.), field pea (*Pisum sativum* L.), chickpea (*Cicer arietinum* L.) and lentil (*Lens culinaris* Medik.) are important cool-season food legumes (CSFL) of low-input 'break' crops in the highlands of Ethiopia. These crops are very useful in a crop rotation system that is dominated by cereals. Faba bean, chickpea, field pea and lentil cover 27, 13, 16 and 6% of the total pulse area and provide 31, 12, 17 and 5% of total production, respectively (CSA, 2016). They are cultivated predominantly by smallholder farmers and their yields are very low (Asfaw *et al.*, 1994; CSA, 2016).

Although Ethiopia is the major producer of these crops with production being distributed throughout the country their productivity is affected by several biotic and abiotic factors. Soil and seedbed requirements, erosion, acidity and low phosphate availability, lack of drainage, inadequate soil moisture, and poor agronomic practices are major factors affecting the productivity of CSFL (Hebblethwaite *et al.*, 1983; Asfaw *et al.*, 1994; Getachew, 2009; Getachew and Woldeyesus, 2012). Pulses produced on Vertisols, which receives high rainfall during the main rainy season, are constrained by impeded drainage (Jutzi, 1988; Jutzi and Mesfin, 1989; Getachew and Woldeyesus, 2012). Research findings showed that improved drainage practice markedly increased productivity of faba bean and chickpea grown on Vertisols (Mesfin and Jutzi, 1989; Getachew *et al.*, 2004; Getachew and Woldeyesus, 2012).

Inadequate seedbed preparation and soil fertility management practices are the most important causes of low yields of faba bean and field pea (Amare *et al.*, 1999; Getachew and Chilot, 2009; Getachew and Hailu, 2009). In most cases, seeds of CSFL are broadcast and covered by local plow. Amare and Adamu (1994) reported that two to three plowings with the local plow or one disc-plowing followed by two disc-harrowing significantly increased faba bean and field pea seed yields.

Farmers indicated that the blanket fertiliser recommendation for faba bean and field pea (100 kg DAP ha<sup>-1</sup>) is not appropriate for the different types of soils, which have different levels of fertility. Faba bean and field pea are mainly produced on Nitisols in the highlands of Ethiopia, where their productivity is constrained by low soil pH and associated low P availability. These soils have pH values of less than 5.5, which result in low yields. The low yields in such soils could mainly be either due to the deficiency of nutrients, such as P, Ca and Mg (Somani, 1996; Getachew and Sommer, 2000; Getachew *et al.*, 2005), or toxicity of Al, Fe and Mn (Sharma

*et al.*, 1990; Fageria and Baligar, 2008). As a result P deficiency is one of the most widespread soil constraints in these soils.

## Tillage and Soil Management

### Tillage and crop management

Research results on tillage frequency and weed control showed that twice, thrice and four times tillage including the last pass for seed covering increased mean seed yields of faba bean by 26, 52 and 54% compared to the control i.e., planting with the first plowing (Table 1). Tillage by weed control interaction significantly increased faba bean seed yield. The highest mean seed yield (2198 kg ha<sup>-1</sup>) of three years for the tillage and weed control interaction was obtained from two plowings before planting accompanied with one properly timed hand weeding. The results of economic analysis indicated that the treatment with three times tillage and weeding once by hand is the best option with a marginal rate of return of 227%, which is economically the most feasible alternative for faba bean producers.

Table 1. Tillage frequency and weed control effects on seed and total biomass yields of faba bean in Welmera area, 1999-2001

Factor	Seed yield (kg ha <sup>-1</sup> )	Total biomass (kg ha <sup>-1</sup> )
<b>Tillage (T)</b>		
Control (once)	1379c	2796c
Twice	1740b	3607b
Thrice	2092a	4714a
Four times	2121a	4812a
LSD (5%)	202.95	457.16
<b>Weeding (W)</b>		
No weeding	1675b	3773b
Weeding once	1991a	4191a
LSD (0.05)	143.51	323.26
T×WC	*	**
CV (%)	16.50	17.11

\* Significant at  $P \leq 0.05$  and  $P \leq 0.01$  probability levels, respectively; ns = Not significant  
Source: Getachew *et al.* (2005)

The effects of tillage frequency, phosphate fertilizer, and weed control on field pea were studied on Nitisols of Welmera and Chelia, West Shoa. The results of the study revealed that the frequency of tillage, P fertilization, and weed control treatments had significant effects on yield and yield components of field pea. Plowing twice, three and four times, including the last pass for seed covering increased mean seed yield of field pea by 38, 55

and 43%, respectively, compared to the control. Yield of field pea positively responded to P fertilizer. The application of P fertilizer at the rates of 10, 20 and 30 kg P ha<sup>-1</sup> resulted in seed yield advantages of 30, 53 and 50%, respectively, compared to the control, i.e., without P fertilizer treatment. The combined analysis of variance over two cropping seasons showed that there was significant ( $P < 0.01$ ) tillage by P fertilization (T×P) interaction effect for mean field pea seed yield. The increase in field pea seed yield due to tillage frequency (twice and three times) and P fertilization (10, 20 and 30 kg P ha<sup>-1</sup>) was significantly higher than once tillage and unfertilized plots. Twice and three times tillage frequency resulted in seed yield increments of 1181 and 1229 kg ha<sup>-1</sup> at 20 kg P ha<sup>-1</sup> compared to field pea seed yield obtained from once tillage and without P application, with the corresponding yield advantages of 149 and 155% (Table 2). The results of economic analysis indicated that the treatment with three times tillage, application of 20 kg P ha<sup>-1</sup> and weeding once by hand is the best option with a marginal rate of return of 423%, which is economically the most feasible alternative for field pea producers.

Table 2. Interaction effects of tillage frequency and P fertilization on field pea seed yield (kg ha<sup>-1</sup>) at Welmera and Chelia, 2003 and 2004

Source	Phosphorus fertilization (kg ha <sup>-1</sup> )			
	0	10	20	30
Tillage frequency	794	1190	1376	1389
Once	1153	1533	1975	1908
Twice	1449	1840	2023	2052
Three times	1383	1641	1947	1836
LSD <sub>0.05</sub>	126.60			

Source: Getachew and Hailu (2009)

## Management of Vertisols

### Drainage method and variety effects on yield of legumes

High moisture level limits faba bean production on Vertisols, as the crop is highly sensitive to waterlogged conditions. The response of three faba bean cultivars (CS 20DK, KUSE-2-27-33 and local land-race) were evaluated to different drainage methods, namely the broad beds and furrows (BBF), flat, ridges and furrows (RF) and camber beds (CB). Results indicated that faba bean seed yield significantly differed among drainage methods. The highest seed yield increment (98%) using the BBF over the flat seedbed conditions was obtained in 1998 crop season (Table 3). The maximum seed yield was recorded from BBF drainage system. The lowest rainfall was recorded during 1999 at which the highest grain yield was obtained, indicating that higher rainfall even under improved drainage method

limits growth and yield of legumes on heavy clay soils. However, as there was no need to drain excess moisture due to low rainfall, yield obtained from the flat seedbed method was almost equivalent to yield obtained from BBF, but higher than the yield obtained from camber bed drainage method.

Table 3. Effect of drainage methods on total biomass and seed yields of faba bean at Ginchi, 1997-2000

Factor	Mean seed yield (kg ha <sup>-1</sup> )				
	1997	1998	1999	2000	Mean
<b>Drainage (D)</b>					
BBF	1418b	1049a	2469ab	1231	1542a
Flat	1249b	529c	2491ab	996	1316b
Ridge and furrow	977c	846ab	2911a	1130	1466ab
Camber bed	1759a	753bc	1781b	1236	1382ab
LSD(0.05)	196.0	248.5	673.3.	NS	165.9
<b>Variety (V)</b>					
CS 20 DK	1575a	827	2517	1325a	1561a
KUSE-2-27-33	1528a	817	2441	1116ab	1476a
Local	947b	755	2280	995b	1244b
LSD (0.05)	151.9	NS	NS	218.8	165.8
D × V	**	NS	NS	*	NS
CV (%)	13.0	25.2	29.2	22.1	28.6

Note: Means in a column with different letters are significantly different ( $P < 0.05$ )

Source: Getachew and Amare (2004)

Likewise, the effects of three drainage methods namely the broad beds and furrows (BBF), ridges and furrows (RF) and flat beds (FB), four sowing dates (18 and 31 August, and 14 and 28 September) and three chickpea genotypes (Akaki, Worku and Local) were studied at Ginchi for three years (2003-2005). Results revealed that year, drainage method, sowing date, genotype and their interaction effects were significant on chickpea seed yield. Improved drainage method (BBF) increased chickpea seed yield by an average of 45% over the flat seedbed. There was a quadratic relationship between seed yield and sowing date with a peak yield in mid-September. The interaction effects of drainage method by sowing date (D×S), drainage method by genotype (D×G), sowing date by genotype (S×G), year by drainage and sowing date (Y×D×S), and year by drainage and genotype (Y×D×G) were significant ( $p < 0.01$ ) for seed yield. Improved genotypes were significantly more yielding than the local landrace under improved drainage system, but not under the flat bed system. Graphic display of the pattern of Y×S, D×S and S×G interactions are given in Figure 1a, b and c, respectively. Differences among sowing dates were highly significant ( $p < 0.0001$ ) under each of the three drainage systems, but the response was large for flat and BBF systems and very small for the RF drainage system.

Overall, planting improved chickpea varieties about mid-September using BBF could markedly increase yield of chickpea on Vertisols in Ethiopia.

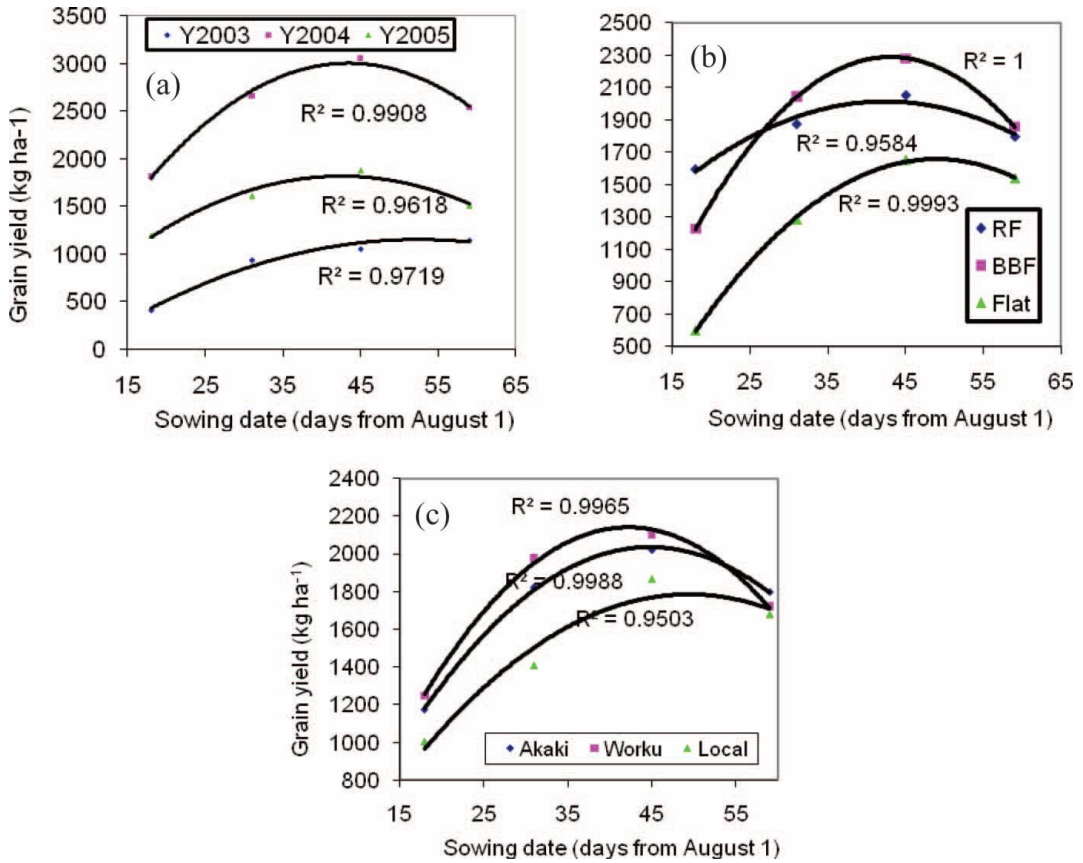


Figure 1. The relationship between sowing date and seed yield as affected by (a) year, (b) drainage system and (c) variety in chickpea tested under three drainage methods and three sowing dates in three years using three varieties at Ginchi, Ethiopia. Source: Getachew and Woldeyesus (2012)

## Soil Fertility and Plant Nutrient Management

### Application of lime

The effects of four rates of lime in the form of calcium carbonate (0, 1, 3 and 5 t ha<sup>-1</sup>) were studied on Nitisols of Holetta. The combined analysis of variance over three years indicated that mean seed yield of faba bean was highly significantly ( $P < 0.001$ ) affected by lime application. The application of lime at the rates of 1, 3 and 5 t ha<sup>-1</sup> resulted significantly in linear response with mean seed yield advantages of about 45, 77 and 81% over the control (Figure 2). Mahler *et al.* (1988) reported that seed yields of legumes were optimal between soil pH values of 5.7 and 7.2 and yields of pea could be

increased by 30% due to the application of lime to soils with pH values less than 5.4.

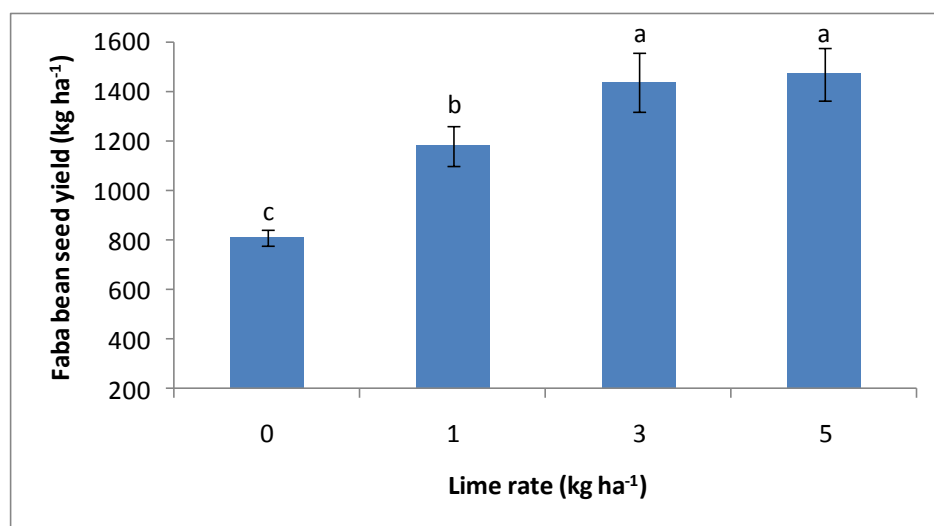


Figure 2. Faba bean mean seed yield as influenced by the application of lime in the form of calcium carbonate at Holetta (LSD at 5% = 192), 1998-2000. Source: Getachew et al. (2006)

### Phosphate fertilizer

Based on the results of the PRA study and farmers' need optimum NP fertilizer rates were determined for faba bean and field pea on locally known soil types as *dila* and *dimile*, respectively. These are drained Nitisols in which *dila* is medium in its fertility status, while *dimile* soil representing the largest share of the cultivated area is characterised by low soil fertility. Results indicated that the application of phosphate fertilizer in the form of diammonium phosphate (DAP) significantly ( $P < 0.01$ ) increased seed yields of faba bean and field pea over the control and the magnitude of responses varied with the fertilizer rates. The application of phosphate fertilizer at the rates of 9/10, 18/20 and 27/30 kg N/P ha<sup>-1</sup> resulted significantly in linear response with mean faba bean seed yield advantages of 24, 66 and 80% over the control (Table 4). Likewise, the application of phosphate fertilizer at similar rates resulted significantly in linear response with mean field pea seed yield advantages of 55, 103 and 152% over the control (Table 4). In conclusion, the application of 18/20 kg N/P ha<sup>-1</sup> for faba bean and 27/30 kg N/P ha<sup>-1</sup> for field pea as DAP could be recommended on *dila* and *dimile* soils, respectively.

The effect of nitrogen and phosphorus fertilizers on seed yield of faba bean was studied at different locations. The results of the study showed that application of N fertilizer did not result in significant yield difference at

seven out of eight locations. Nitrogen fertilization resulted significantly in linear response only at Adet with seed yield advantages of 15, 25 and 33% over the control. In contrast, P fertilization increased faba bean seed yield significantly ( $P < 0.01$ ) in linear response at all locations (Table 5). It was found that response of faba bean to phosphorus fertilizer application was dependent on the residual P fertility level of the soil (Hebblethwaite *et al.*, 1983). The authors recommended that further study is required involving the determination of critical levels of soil available P for optimum faba bean yield.

Table 4. Effect of NP fertilizer on seed yield of faba bean on *dila* and field pea on *dimile* soils in Wolmera, 1999-2001

Factor	Mean seed yield (kg ha <sup>-1</sup> )	
	Faba bean	Field pea
N/P rate (kg ha <sup>-1</sup> )		
0/0	949c	820d
9/10	1181b	1270c
18/20	1578a	1661b
27/30	1711a	2064a
LSD (0.05)	186.9	201.1
CV (%)	16.0	14.8

Note: Means in a column followed by the same letter are not significantly different at  $P \leq 0.05$ .

Source: Getachew *et al.* (2003)

Table 5. Effect of NP fertilizer on faba bean seed yield (kg ha<sup>-1</sup>) at eight locations, 1992-1993

Factor	Holetta	Burkitu	Chefa	Sinana	Sheno	Adet	D/Zeit	Alemaya
N rate (kg ha <sup>-1</sup> )								
0	1375	3228	3128	2306	1287	2885	2241	1624
18	1462	2876	2734	2207	1537	3318	2269	1537
27	1474	3557	2865	2184	1506	3602	2410	1389
36	1578	2971	2998	2217	1546	3836	2156	1486
F-test								
Rate	NS	NS	NS	NS	NS	*	NS	NS
Linear	NS	NS	NS	NS	NS	**	NS	NS
P rate (kg ha <sup>-1</sup> )								
0	914	1809	1935	1339	1174	2835	2044	1328
10	1267	2867	2559	1868	1433	3168	2187	1485
20	1584	3510	3369	2596	1541	3669	2453	1519
40	2124	4444	3862	3110	1729	3970	2392	1704
F-test								
Rate	**	**	**	**	**	**	**	**
Linear	**	**	**	**	**	**	**	**
SE	76.8	193.5	117.9	85.8	72.7	208.2	71.9	74.7
CV (%)	29.5	34.7	22.8	21.8	28.0	29.9	17.9	28.0

\*\*Significant at  $P < 0.05$  and  $P < 0.01$ , respectively; NS = Not significant

Source: Amare *et al.* (1999)



The effects of four levels of P fertilizer (0, 10, 20 and 30 kg P ha<sup>-1</sup>) as triple-super phosphate (TSP) and two levels of weeding (W<sub>0</sub> = No weeding and W<sub>1</sub> = Hand weeding once) were studied at Welmera and Robgebeya, west Shewa. Experimental results showed that highly significant positive responses of seed yields of faba bean to P fertilizer and weeding were noted. Application of phosphorus at the rates of 10, 20 and 30 kg P ha<sup>-1</sup> increased mean seed yields by 20, 41 and 53%, respectively compared to the control over locations. Phosphorus level by weed control interaction over three years significantly ( $P \leq 0.01$ ) influenced faba bean seed yield over locations. Application of 30 and 20 kg P ha<sup>-1</sup> and weeding once resulted in the highest mean seed yield of 2181 kg ha<sup>-1</sup> followed by 2015 kg ha<sup>-1</sup>, respectively, with respective yield advantages of 87 and 72% (Figure 3). The results of economic analysis indicated that the highest marginal rate of return (200.3%) was obtained from weeding once six weeks after crop emergence and application of 20 kg P ha<sup>-1</sup>, which is economically the most feasible alternative for faba bean production on Nitisols of central Ethiopian highlands.

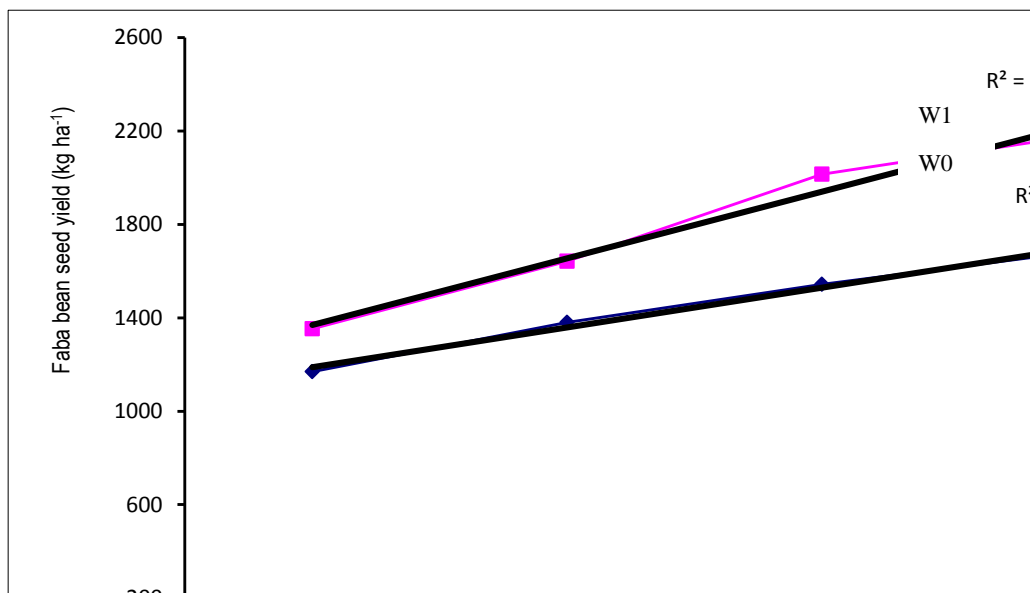


Figure 3. Faba bean seed yield as influenced by the interaction of phosphorus and weed control across locations, 2001-2003

Note: ■ W1 = Weeded and ◆ W0 = Unweeded. Source: Getachew and Rezene (2006)

Similarly, the effects of four levels of P fertilizer (0, 10, 20 and 30 kg P ha<sup>-1</sup>) as TSP and two levels of weeding (W<sub>0</sub> = no weeding and W<sub>1</sub> = hand weeding once) were studied on yield of field pea at Welmera. The application of P fertilizer and weed control resulted in a linear response function (Figure 4). The regression line showed that mean seed yield of field pea was strongly

positively correlated with phosphorus rate under weeded and unweeded condition (Figure 4). This shows that the yield of field pea has increased as the level of P increased. The optimum dose of P for attaining an economic yield of field pea was found to be 20 kg ha<sup>-1</sup> under weeded condition.

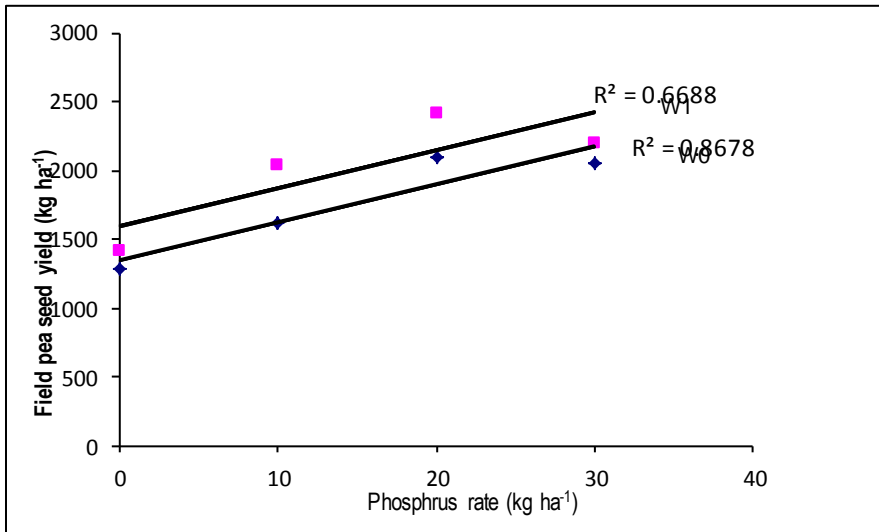


Figure 4. Field pea seed yield as influenced by the interaction of phosphorus and weed control, 2003-2004

Note: ◆ WO = Unweeded; ■ W1 = Weeded once by hand

Source: Getachew (2009)

### Integrated soil fertility and plant nutrient management

Integrated soil fertility management approach has proven to be a viable option for improving soil productivity and enhancing yield (Vanlauwe *et al.*, 2010; Mponela *et al.*, 2016; Getachew and Tilahun, 2017). Accordingly, the main and interaction effects of farmyard manure (FYM) at three rates (0, 4 and 8 t FYM ha<sup>-1</sup>) and five levels of phosphorus fertilizer (0, 13, 26, 39 and 52 kg P ha<sup>-1</sup>) were investigated on yield and yield components of faba bean on Nitisols of Holetta.

Results indicated that seed yield was positively influenced by FYM and P applications. The application of FYM at 4 and 8 t ha<sup>-1</sup> increased faba bean seed yield by 34 and 53% respectively compared to the control. The application of P fertilizer significantly increased seed yield with yield advantages of ranging between 16 and 32% over the control. Phosphorus by FYM interaction significantly improved faba bean seed yield. The highest mean faba bean seed yield was recorded from the application of 8 t FYM ha<sup>-1</sup> and 39 kg P ha<sup>-1</sup> (Figure 5). Based on the economic analysis, application of 8 t FYM ha<sup>-1</sup> was found to have the highest marginal rate of return (2027%), suggesting for each Birr invested in faba bean production, the

producer would reap Birr 20.27 after recovering his investment. Application of 4 t FYM ha<sup>-1</sup> and 13 kg P ha<sup>-1</sup> is also above the minimum acceptable rate of return (134%). Therefore, although the highest MARR was achieved from application of 8 t FYM ha<sup>-1</sup> the option could be left for a producer.

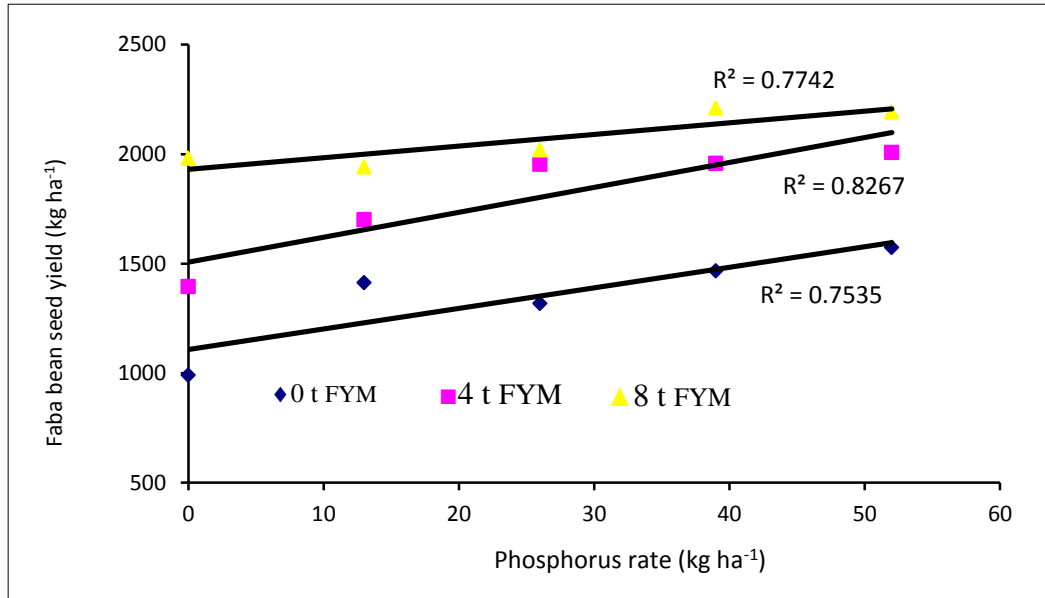


Figure 5. Interaction effects of FYM and phosphorus on faba bean seed yield, 2002-2003.

Source: Getachew and Chilot (2009)

The response of field pea to phosphorus fertilizer (0, 10, 20, 30, 40 and 60 kg P ha<sup>-1</sup>) was evaluated at Holetta and Bekoji. Research results from both locations indicated that seed yield of field pea was significantly improved by the application of P fertilizer at Holetta and Bekoji (Table 7). At Bekoji the most economical P rate was 20 kg P ha<sup>-1</sup> for cv. Tegegnech, 10 kg P ha<sup>-1</sup> for G22763-2C and 5 kg P ha<sup>-1</sup> for cv. Cheffa local. Getachew (2009) also reported that application of phosphate fertilizer at the rates of 10, 20 and 30 kg P ha<sup>-1</sup> increased mean grain yield of field pea by 36, 67 and 57%, respectively compared to the control at Welmera, west Shewa. Similarly, research carried out at Welmera and Chelia of west Shewa showed that application of phosphorus fertilizer at the rates of 10, 20 and 30 kg P ha<sup>-1</sup> increased mean seed yields of field pea by 30, 53 and 50%, respectively, compared to the control (Getachew and Hailu, 2009).

Table 7. Summary of analysis of variance for grain yield and pods per plant at confidence levels of  $P < 0.05$  or  $P < 0.01$ \*\*

Factor	Holetta		Bekoji	
	Grain yield	Pods per plant	Grain yield	Pods per plant
Year (Y)	**	**	**	**
Phosphorus (P)	**	**	**	**
Variety (V)			**	**
YP				**
YV	**		**	**
PV			*	
YPV				
Mean	1272.5	6.7	2403.8	10.7
CV (%)	32.3	24.9	18.3	27.4

\*,\*\*Significant at  $P < 0.05$  and  $P < 0.01$ , respectively  
 Source: Amare et al. (2005)

Similarly, the response of field pea cultivars to phosphorus fertilizer (0, 10, 20, 40 and 80 kg P ha<sup>-1</sup>) was studied under three fertility levels (low, medium and high) at Ilala and Cheffa. Results revealed that field pea seed yield increased at the low and medium soil fertility levels with increasing rates of P application. However, at the high P fertility level the seed yield decreased with increasing rate of P application (Figure 6). Phosphorus fertility level by P application rate interaction was significant for field pea seed yield.

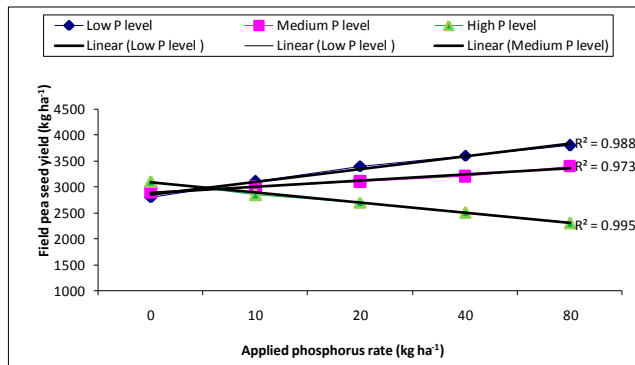


Figure 6. Phosphorus fertility level by P application rate interaction effect on seed yield of field pea at Cheffa site.

Source: Amare et al. (2007)

## Conclusions and Recommendations

Poor soil fertility, soil acidity and the associated low phosphorus availability are among the major constraints affecting the productivity of cool-season food legumes in the highland Nitisol areas of the country

where faba bean and field pea are mainly grown. As soil pH declines important macro- and micronutrients, such as phosphorus, boron and molybdenum become deficient. Hence, such soils need to be ameliorated using physical, chemical and biological methods. Moreover, further study is required involving the determination of critical levels of soil available P and other soil fertility ameliorating sources for optimum faba bean and field pea yield.

The role of cool-season food legumes in cropping systems should be emphasized. Both short and long term cropping sequence experiments in different environments with different food legumes involving N-budget component need to be carried out. Then for each area a reasonable calculation will be made of the proportion of cereal production that could have a food legume rotation based on actual markets and socio-economic considerations.

The inefficient traditional practice of crop culture should be replaced with improved crop management techniques for sustainable crop production. During high rainfall seasons, waterlogging problem is severe and crop damages are commonplace on Vertisols. Thus, emphasis should be given to drainage methods, time of planting, varieties, and crop management techniques to improve the productivity of legumes in the highland areas of the country. In summary, the available soil fertility management technologies and improved agronomic practices developed in the country pertaining to the production of highland food legumes need to be demonstrated and scaled up to users to increase their adoption.

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