Soil fertility management practices for faba bean (*Vicia faba* L.) production in Wolaita zone, Southern Ethiopia

Prácticas de manejo de la fertilidad del suelo para la producción de habas (*Vicia faba* L.) en la zona de Wolaita, sur de Etiopía

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ABSTRACT

Faba bean is an important food security crop in Southern Ethiopia. Understanding the soil fertility management practices of faba bean farmers could aid in finding a method to replenish soil fertility. However, information on the type and extent of soil fertility management practiced by smallholder faba bean farmers is scarce. Therefore, a study was conducted in the districts of Damot Gale and Sodo Zuria in Wolaita zone in Southern Ethiopia to assess soil fertility management practiced by farmers for faba bean production. In the 2019 main crop season, 310 farmers were purposively selected by using Yamane's simplified formula to calculate the sample size and a short structured questionnaire was used to elicit information. The results revealed that faba bean production in the districts studied was constrained by scarcity of arable land that resulted in extensive exploitation of soil nutrients, poor inherent soil fertility, and soil acidity. Poor soil fertility limited grain yield productivity about 57.4%. Additionally, 36.5% of the farm yield was constrained by soil acidity. However, only 27.7% of farms managed the soil by using mineral fertilizers, 32.3% applied farmyard manure, 3.5% used liming, and 2.9% used fallowing. Consequently, the average grain productions of both fertilized and unfertilized faba bean farms were far less than the national average yield of 2.1 t ha^{-1}. The study concluded that soils of the study districts are managed inadequately to enhance their fertility and improve crop yield.

Key words: fertilizer, liming, production constraints, national average yield.

RESUMEN

Las habas son un cultivo importante para la seguridad alimentaria en el sur de Etiopía. Comprender las prácticas de manejo de la fertilidad del suelo de los agricultores de habas podría ser de ayuda para encontrar un método para reponer la fertilidad del suelo. Sin embargo, la información sobre el tipo y el alcance del manejo de la fertilidad del suelo practicado por los pequeños agricultores de habas es escasa. Por lo tanto, se realizó un estudio en los distritos de Damot Gale y Sodo Zuria en la zona de Wolaita en el sur de Etiopía para evaluar el manejo de la fertilidad del suelo practicado por los agricultores para la producción de habas. En la temporada agrícola principal de 2019, se seleccionaron intencionalmente 310 agricultores mediante el uso de la fórmula simplificada de Yamane para calcular el tamaño de la muestra y se utilizó un breve cuestionario estructurado para obtener información. Los resultados revelaron que la producción de habas en los distritos estudiados estaba restringida por la escasez de tierra cultivable que resultó en una explotación extensiva de los nutrientes del suelo, la pobre fertilidad inherente del suelo y la acidez del mismo. La mala fertilidad del suelo limitó la productividad del rendimiento de grano alrededor del 57.4%. Además, el 36.5% del rendimiento de las granjas se vio limitado por la acidez del suelo. Sin embargo, sólo el 27.7% de las granjas manejó el suelo utilizando fertilizantes minerales; el 32.3% aplicó estiércol de corral, el 3.5% utilizó encalado y el 2.9% utilizó barbecho. En consecuencia, la producción promedio de granos de las granjas de habas fertilizadas y no fertilizadas fue mucho menor que el rendimiento promedio nacional de 2.1 t ha^{-1}. El estudio concluyó que los suelos de los distritos del estudio se manejan de manera inadecuada para mejorar su fertilidad y el rendimiento de los cultivos.

Palabras clave: fertilizante, encalado, restricciones de producción, rendimiento promedio nacional.

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Introduction

Faba bean (*Vicia faba* L.) is one of the major pulse crops grown in the highlands of Ethiopia (Fedaku *et al.*, 2019). Currently, it occupies 31% of the area cultivated to pulses (1,863,445 ha) in the country (CSA, 2019). The crop plays significant roles in human and livestock feed and the improvement of soil fertility (Mulugeta *et al.*, 2019). However, the productivity of the crop in the country is low (2.12 t ha^{-1}) compared to the average yield (3.7 t ha^{-1}) obtained in major faba bean producing countries in the world (FAOSTAT, 2017; CSA, 2019). In Wolaita zone, faba bean occupies 96.4% of the area of land cultivated to pulses (1,074.91 ha) (CSA, 2019), while the farmers harvest a lower average yield (1.2 t ha^{-1}) than the national average yield obtained in the country (CSA, 2018). The major factors usually mentioned for the low yield of faba bean in Wolaita zone include climatic conditions, edaphic factors (soil fertility and acidity), biotic factors (diseases, pests, and weeds), scarcity of improved varieties, and poor agronomic practices (Buraka *et al.,* 2016).

Extensive exploitation and depletion of nutrients occur in Ethiopia due to continuous cropping, limited fallowing and crop rotation, complete removal of crop residues, and minimum or no use of mineral fertilizers and lime on acidic soil (Haileslassie *et al.*, 2006; Abera & Belachew, 2011). The loss of nitrates, phosphates, and potassium in the soils results in macronutrient imbalance (Ayalew & Dejene, 2011; Shanka *et al.*, 2018). Kassa Colbe *et al.* (2020) indicate that the soil management intervention of Wolaita zone farmers is also inadequate to improve soil fertility and produce high yield. The cumulative effect of nutrient deficiency in the soils has resulted in less productivity of faba bean in Wolaita zone (Buraka *et al.,* 2016; Belete *et al.*, 2019).

Several researchers studied soil fertility management practices for faba bean production in different parts of Ethiopia (Agegnehu & Yirga, 2009; Fedaku *et al.*, 2019; Mesfin *et al.*, 2020). Those reports revealed that significant improvements in the yield of faba bean can be brought about by proper soil fertility management like crop rotation, crop residue management, fallowing, application of balanced fertilizer, and use of lime on acidic soils. However, in Wolaita zone, limited research is done on the soil fertility management practices of faba bean producing farmers, and little information is available. Concrete information is required about farmer soil fertility management for faba bean production to rate the potential and limitations of the soils for faba bean productivity in the farming area of Wolaita zone. In the meantime, the findings enable the formulation of strategies for soil fertility management and forward directions to enhance the crop production of smallholder farmers. Therefore, this study aimed to investigate the effects of farmer soil fertility management on faba bean productivity.

Materials and methods

Study area

The study was conducted in Damot Gale and Sodo Zuria woredas (districts), Wolaita zone, in Southern Ethiopia (Fig. 1) during the 2019 growing season. The districts were selected based on their high faba bean production potential. Ethiopia is located from 3°00’00” to 14°08’00” N, and 33°00’00” to 48°00’00” E in Eastern Africa. Damot Gale district is located from 6°55’22” to 7°05’00” N and 37°45’31” to 37°59’58” E. The elevation of Damot Gale district ranges from 1501 to 2950 m a.s.l. (Mota *et al.*, 2019). Sodo Zuria district is located from 6°46’60” to 6°56’45” N and 37°38’10” to 37°50’60” E at an elevation from 1500 to 3500 m a.s.l. (Bashe *et al.*, 2018). According to MOA (1998) classification, faba bean producing areas of both Damot Gale and Sodo Zuria districts are predominantly characterized by cool sub-humid climates (Woinadega). The total annual rainfall of Damot Gale district in the last ten years (2011-2020) was 1,181 mm and that of Sodo Zuria district was 1,426 mm. Both districts have a bimodal rainfall pattern, which consists of *Belg* (short rainy season) and *Meher* (long main rainy season) (FAO, 2020). The *Belg* rainfall in the Zone occurs mainly during March, April, and May and the *Meher* rain occurs during June, July, and August. In Damot Gale district, about 32.9% and 38.2% of the precipitation occurred during the *Belg* and *Meher*, respectively. The last ten-year mean monthly temperature of Damot Gale district ranged from 13.8 to 24.9°C with an average of 19.4°C. In Sodo Zuria district, about 31% and 40% of precipitation occurred during the *Belg* and *Meher*, respectively. The mean monthly temperature of Damot Gale district in the last ten years ranged from 15.4 to 25.8°C with an average of 20.6°C. The agricultural practices are predominantly small-scale mixed subsistence farming. The cropping system is mainly based on continuous cultivation without any fallow periods (Laekemariam *et al.*, 2016). The colors on the map indicate six sub-districts of the study.

Sampling method and sample size

The sample size for each district was fixed according to Yamane’s (1967) simplified formula to calculate the sample size:

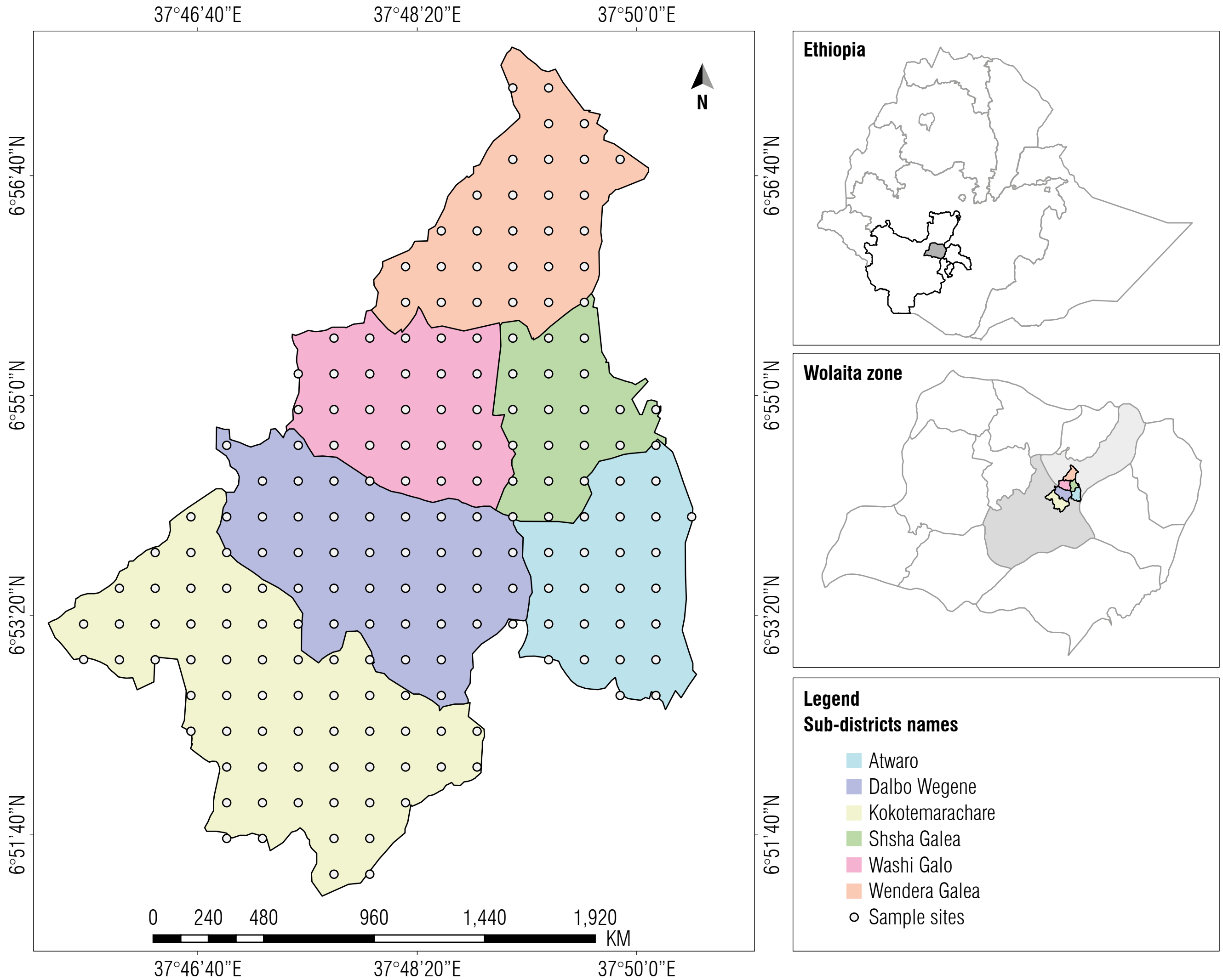

FIGURE 1. Map of the study area.

$$n = \frac{N}{1+N(e^2)} \tag{1}$$

where n is the sample size, N is the population size, and e is the level of precision at 95% confidence level. The number of samples varied in the sub-districts depending on the number of the human population residing in the areas. Hence, 310 household heads (163 from Damot Gale and 147 from Sodo Zuria) were interviewed about the soil management practices for faba bean production.

Data collection

The short-structured questionnaire (Supplementary material 1) used to record the soil fertility management practices included cropping history, crop rotation practices, fallowing, cropping intensity, production constraints, soil fertility management practices, crop residue management, seed use (local seed purchased from the local market and improved seed obtained freely from a research center), and fertilizer use (types and rates). The altitude and latitude of each farm was recorded by using the global positioning system (GPS).

Statistical analysis

To analyze the data, descriptive statistics were employed. Mean and percentage were computed for different variables. Pearson chi-square, t, and F tests also were calculated. Data analysis was carried out using the statistical package for social sciences (SPSS) software version 20 (SPSS, 2011).

Results and discussion

Faba bean farmer soil classification

In the study area, the faba bean producing farmers classified and assigned the local names to the soils to manage these accordingly. Farmers in both Damot Gale and Sodo Zuria districts used similar parameters to classify and name the soils. These farmers characterized and named seven faba bean growing soil types by using *bita as* a suffix, which connotes the term "soil" in the Wolaitia language. According to this, the soils were *Arradabita* (Eutric Nitosols), *Lada bita* (Haplic Alfisols), *Kareta bita* (Humic Nitisols), *Zo'o bita* (Vertisols), *Gobo bita* (Vertisols), *Chare bita* (Orthic Luvisols), and *Talla bita* (Haplic Alisols) (Fig. 2). The first six soils are common in both districts, except for *Talla bita,* which is found in Damot Gale district only. Among the soil types, *Arrada bita* is predominant in both districts, followed by *Lada bita*. *Zo'o bita* is less represented in both districts (Fig. 2).

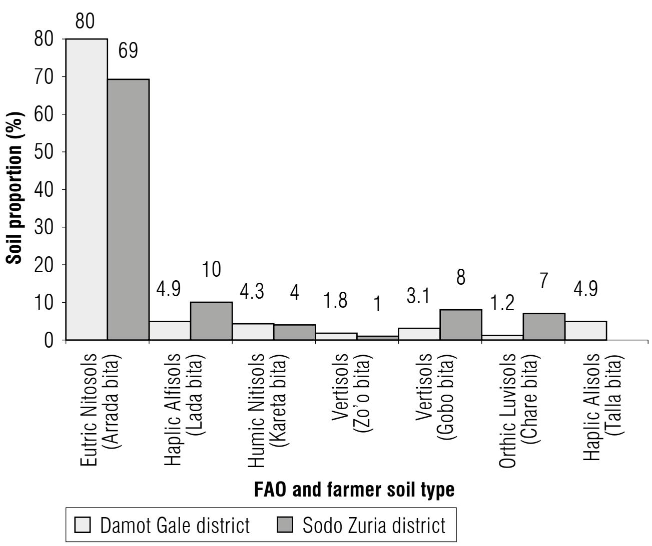

FIGURE 2. FAO and farmer soil types for samples collected from Damot Gale and Sodo Zuria districts in Wolaita zone, Southern Ethiopia.

Most farmers used soil color, soil fertility, workability, and water permeability as the criteria for classification (Tab. 1). Accordingly, farmers considered black/dark soil as fertile and suitable for faba bean productivity, while the brown/red soil is considered of low fertility and less productive. The perception of farmers was also reported by Bobo *et al.* (2017) and Corbeels *et al.* (2000) who stated that the dark soil is more fertile than brown. In general, farmers ranked *Arrada bita* in the highest to medium fertility status. Similarly, most faba bean farmers preferred *Arrada bita* for enhanced productivity.

On the contrary, *Lada*, *Gobo*, *Zo'o* and *Chere bita* were ranked as of low fertility and were the less preferred soils for faba bean production. The farmers ranked *Talla* and *Kareta bita* under medium to low soil fertility class (Tab. 1). Overall, as noticed from the interview, the majority of the farmers planted faba bean in fertile soil (*Arrada bita*).

Cropping history of faba bean farms

Crop intensity

The number of crops grown each year on a faba bean production field varies from one to three, depending on the soil fertility and amount of rainfall in the cropping season. The cropping intensity varied significantly among districts ($\chi^2 = 22.93$, $P \leq 0.001$) (Tab. 2). Also, the intensity was in the order of two crops>one crop>three crops per land per year (Tab. 1). About 54% and 63.3% of the interviewed farmers have grown two successive crops a year in the same field at Damot Gale and Sodo Zuria districts, respectively. On the other hand, 42.3% and 22.5% of the sampled farmers have grown only one crop per year on a plot of land at Damot Gale and Sodo Zuria districts, respectively. However, very few Damot Gale (3.7%) and Sodo Zuria district (14.2%) farmers had grown three successive crops a year in the same field (Tab. 2). The majority (58.4%) of the interviewed farmers had grown more than one crop each year (Tab. 2).

TABLE 1. Classification and commonly perceived soil characteristics by faba bean farmers at Damot Gale and Sodo Zuria districts in Wolaita zone, Southern Ethiopia.

Common soil name (FAO, 1984)	Soil classification	Textural class (Laekermariam *et al.*, 2016)	Farmer's parameter for classification			
			Color	Fertility	Workability	Permeability
Eutric nitosols	*Arrada bita*	Silty clay	Black/dark	High to medium	Easy	High
Haplic alfisols	*Lada bita*	Clay	Red	Low	Moderate	Moderate
Haplic alisols	*Talla bita*	Clay	Reddish brown	Medium to low	Difficult (sticky)	Low
Humic nitisols	*Kareta bita*	Silty clay loam	Black/dark	Medium	Difficult	Moderate
Vertisols	*Zo'o bita*	Clay	Brown	Low	Moderate	Moderate to low
Vertisols	*Gobo bita*	Clay	Red	Low	Moderate	Moderate to low
Orthic luvisols	*Chere bita*	Silty clay	Brown	Low	Difficult	Very low

"*Bita*" means soil in Wolaita language.

TABLE 2. Faba bean farmer cropping practices in the sampled agricultural fields at Damot Gale and Sodo Zuria districts of Wolaita zone, Southern Ethiopia.

Source of variations	DF	Sampled farmers	Districts		
			Damot Gale (%)	Sodo Zuria (%)	Total (%)
Crop intensity per year	1	χ^2 value	N = 163	N = 147	N = 310
One			42.3	22.5	32.9
Two		22.93***	54	63.3	58.4
Three			3.7	14.2	8.7
Varieties planted	1		N = 163	N = 147	N = 310
Local		0.98 NS	65.6	64	64.8
Improved variety			34.4	36	35.2

χ^2 - Chi-square value; N - number of sampled farmers involved in faba bean cropping practices; ***Significant at $P<0.001$; NS - not significant; DF - degree of freedom.

The sampled smallholder farmers indicated poor soil fertility, inorganic fertilizer prices and a limited labor force as challenges to grow more than one crop each year on a field. Hence, most of the study area farmers were economically poor, leading a hand to mouth lifestyle. Similarly, soil fertility constraints, limited rainfall, and financial problems were reported in different parts of Ethiopia (Headey *et al.*, 2014; Kemaw & Fentahun, 2018). In general, cultivating only faba bean per plot each year would reduce over-exploitation of soil nutrients and would increase grain production. Nevertheless, multiple cropping had a relative yield and economic advantage to single cropping. Increased cropping intensity requires better soil fertility management (Kemaw & Fentahun, 2018). In this regard, the sampled faba bean fields were not managed adequately. Therefore, increased cropping intensity results in large nutrient exploitation, unless proper soil management practices are applied to balance required nutrients.

Faba bean varieties used in studied districts

The number of farmers who grow improved varieties did not show statistical differences between both districts (Tab. 2). The local faba bean variety was dominant over-improved varieties and covered about 65.6% and 64% at DamotGale and Sodo Zuria districts, respectively (Tab. 2). Different research studies conducted on acidic soils in Ethiopia showed that the improved varieties had a significantly higher grain yield over the local variety (Agegnehu & Yirga, 2009; Belachew & Stoddard, 2017). However, the results in this study indicated that very few farmers grow improved varieties (Tab. 2). As noticed from the discussion, farmers used only 'Dosha' as the improved faba bean variety. Thus, the predominant growth of the local variety might be among the reasons for far lower productivity in the studied districts.

Faba bean production constraints

Land shortage

The number of faba bean farmers challenged by land shortage did not significantly vary between Damot Gale and Sodo Zuria districts (Tab. 3). The survey recognized that most of the farmers have less than a "Timad" or 0.25 ha of land per household. In line with the findings of this study, the Wolaita Zone Administration (2019) indicated that 60% of households in Wolaita zone possessed less than 0.25 ha of farmland, which is smaller than the national average of 1.01 ha (Milas & Aynaoui, 2004). Overall, 85.3% and 78.9% of farmers interviewed in Damot Gale and Sodo Zuria districts, respectively, indicated farm size as a constraint for faba bean production (Tab. 3). Consequently, the abandonment of fallowing in the studied districts was recorded, which resulted in low soil fertility and faba bean productivity. Different studies conducted in Ethiopia also indicated small farmland size as a reason for continuous cultivation and less crop productivity (Headey *et al.*, 2014; Kemaw & Fentahun, 2018). In general, continuous cultivation without fallowing due to small farm size affected the soil fertility and faba bean productivity in the studied districts. Hence, maintenance of the soil fertility status through fertilizer application and the use of different soil management interventions are required to restore the soil and faba bean productivity.

Poor soil fertility

Farmers used the soil color, workability, water permeability, and water holding capacity as criteria to judge the soil fertility status. Bobo *et al.* (2017) and Corbeels *et al.* (2000) also reported similar perceptions of farmers to classify the soil fertility status. Thus, the dark soil, which has high water retention and is easy to plow, is classified

TABLE 3. Major faba bean production constraints in the sampled agricultural fields at Damot Gale and Sodo Zuria districts of Wolaita zone, Southern Ethiopia.

Source of variations	DF	Sampled farmers	Districts		
			Damot Gale (%)	Sodo Zuria (%)	Total (%)
Land shortage	1	χ^2	N = 163	N = 147	N = 310
Yes		2.15 NS	85.3	78.9	82.3
No			14.7	21.1	17.7
Low soil fertility	1	χ^2	N = 163	N = 147	N = 310
Yes		1.12 NS	54.6	60.5	57.42
No			45.4	39.5	42.58
Soil acidity	1	χ^2	N = 163	N = 147	N = 310
Yes		0.11 NS	35.6	37.4	36.5
No			64.4	62.6	63.5
Soil erosion	1	χ^2	N = 163	N = 147	N = 310
Yes		4.93**	39.9	27.9	33.9
No			60.1	72.1	66.1

N represents the number of farmers involved in cropping practices; ** Significant at $P<0.01$; NS - not significant; DF - degree of freedom.

as fertile by faba bean growers in both districts. Accordingly, the farmer perception about the soil fertility status did not significantly vary between Damot Gale and Sodo Zuria districts (Tab. 3).

About 54.6% and 60.5% of the interviewed farmers at Damot Gale and Sodo Zuria districts complained about the poor soil fertility as one of the faba bean production constraints (Tab. 3). In line with the findings of this study, Buraka *et al.* (2016) indicated poor soil fertility as one of the faba bean production constraints in Wolaita zone. Though poor soil fertility constrains faba bean growers, farmers have limited capacity to improve the soil fertility by applying adequate mineral fertilizer, liming and managing residues. Thus, soil fertility interventions require special attention.

Soil acidity

The short-structured questionnaire was used to verify whether soil acidity is a constraint for faba bean production in the studied districts. Most of the interviewed farmers did not know what soil acidity means. However, those few who indicated soil acidity as a constraint used the wilting of leaves, stunted growth, and inadequate fertilizer application conditions as the criteria to judge. The chi-square statistic revealed a non-significant difference between Damot Gale and Sodo Zuria districts in the number of farmers who perceive soil acidity as a constraint (Tab. 3). About 35.6% of Damot Gale and 37.4% of Sodo Zuria district farmers complained about soil acidity as a constraint for faba bean production (Tab. 3). Buraka *et al.* (2016) also reported soil acidity as a serious constraint for faba bean production in Wolaita zone. Hence, soil acidity is a problem for optimal faba bean productivity, even with fertilized soil. Therefore, identifying the proper lime rate and timely application is required to reduce the soil fertility problems and to improve faba bean productivity.

Soil erosion

The number of farmers who complained about soil erosion as a constraint for faba bean production showed significant variation ($\chi^2 = 4.93$, $P \leq 0.01$) between both districts (Tab. 3). Out of the interviewed farmers, 39.9% and 27.9% indicated soil erosion as a production constraint at Damot Gale and Sodo Zuria districts, respectively (Tab. 3). This implied that soil erosion is among the major constraints for faba bean production.

The erosion problem is more serious at Damot Gale than at Sodo Zuria. The higher erosion in Damot Gale district may be due to steeper slopes than in Sodo Zuria district (Laekemariam, 2015). In general, intensive crop cultivation, complete crop residue removal, and high nutrient depletion may intensify erosion in the soils under faba bean cultivation (Buraka *et al.*, 2016).

Soil fertility management practices for faba bean production

Mineral fertilizer application

The mineral fertilizer application practice significantly varied between districts ($\chi^2 = 0.50$, $P \leq 0.05$) (Tab. 4). Only

TABLE 4. Faba bean farmer soil management practices in the sampled agricultural fields at Damot Gale and Sodo Zuria districts of Wolaita zone, Southern Ethiopia.

Management practices	DF	Sampled farmers	Districts		
			Damot Gale (%)	Sodo Zuria (%)	Total (%)
Number of plow	2	χ^2	N = 163	N = 147	N = 310
Plough once		0.18 NS	35.6	35.4	35.4
Plough twice			33.1	31.3	32.3
Plough three times			31.3	33.3	32.3
Mineral fertilizer application		χ^2	N = 163	N = 147	N = 310
Yes		0.50*	29.5	25.9	27.7
No			70.5	74.1	72.3
Type of fertilizer applied	2	χ^2	N = 48	N = 38	N = 86
DAP		0.46 NS	48	52.3	51.1
Urea			0	0	0
DAP + Urea			52	47.7	48.9
Amount of fertilizer applied	1	F-test	N = 48	N = 38	N = 86
DAP (kg ha^{-1})		0.66 NS	81.5±3.5	84.5±1.0	82.7±2.3
Urea (different kg ha^{-1}) + DAP (100 kg ha^{-1})		4.22*	147.1±2.9	144.0±2.9	146±3.0
Farmyard manure (FYM)	1	χ^2	N = 163	N = 147	N = 310
Yes		0.48 NS	31.3	33.3	32.3
No			68.7	66.7	67.7
Amount of FYM applied	1	F-test	N = 51	N = 49	N = 100
FYM applied (t ha^{-1})		23.65***	1.4±0.2	1.2±0.1	1.3±0.3
Lime applied	1	χ^2	N = 163	N = 147	N = 310
Yes		0.23 NS	3.1	4.1	3.5
No			96.9	95.9	96.5
Amount of lime applied	1	F-test	N = 5	N = 6	N = 11
Lime application (t ha^{-1})		0.21 NS	1.6±0.1	1.5±0.1	1.6±0.6
Faba bean residue management	2	χ^2	N = 163	N = 147	N = 310
Remain on field		0.02 NS	1.8	2	1.9
Incorporated into the soil			0	0	0
Clearing			98.2	98	98.1
Faba bean rotation	1	χ^2	N = 163	N = 147	N = 310
Yes		3.49 *	31.3	41.5	36.1
No			68.7	58.5	63.9
Fallowing	1	χ^2	N = 163	N = 147	N = 310
Yes		0.25 NS	2.5	3.4	2.9
No			97.5	96.6	97.1

N represents the number of farmers involved in cropping practices; *, *** significant at $P\leq0.05$, 0.001, respectively; NS - non-significant difference; DAP- diammonium phosphate; FYM - farmyard manure; DF - degree of freedom.

29.5% and 25.9% of the sampled farmers applied mineral fertilizer in Damot Gale and Sodo Zuria districts, respectively (Tab. 4).

The farmers mentioned limited financial capacity and increasing price of mineral fertilizer as the reasons for limited fertilizer application. Other researchers also mentioned these factors as a challenge for applying adequate amounts of fertilizers (Abebe & Abebe, 2016; Guteta & Abegaz, 2016). A significant number of farmers are skeptical of the application of mineral fertilizers. Those farmers believed that a crop does not require inorganic fertilizer. However, the previous study in the neighboring district of Boloso Sore, Wolaita zone by Buraka *et al.* (2016) indicated a significant yield improvement in faba beans when fertilizers were applied. Farmer perception of fertilizer use should be corrected to improve faba bean yield. Identifying the type of fertilizer and defining the best rate is required for optimum economic return of the faba bean.

Type of fertilizer applied

The type of inorganic fertilizers used among farmers did not show statistical differences between both districts. The mineral fertilizer applied by farmers was either diammonium phosphate (DAP) alone and/or DAP and urea together at a different time (Tab. 4). Farmers in both districts did not apply urea fertilizers alone for faba bean production.

Overall, about 48% and 52.3% of the sampled faba bean fields were managed with DAP fertilizer alone at Damot Gale and Sodo Zuria districts, respectively. The remaining 52% (Damot Gale) and 47.7% (Sodo Zuria) sampled fields were managed with DAP and urea fertilizers together (Tab. 4). Those farmers who used urea and DAP in combination applied DAP at the time of sowing and urea at the active vegetative stage.

Amount of fertilizer applied

The amount of combined application of urea and DAP fertilizer significantly varied (4.22, $P<0.05$) between districts (Tab. 4). The sampled farmers applied 100 kg ha^{-1} DAP and 50 kg ha^{-1} urea at planting and active vegetative stage, respectively. This rate is in line with EIAR (2018) blanket recommendations of 100 kg ha^{-1} DAP and 50 kg ha^{-1} for all legume crops. However, due to the differences in inherent soil properties and spatial variation, the blanket management approach could not address yield-limiting nutrients in the soils to enhance faba bean productivity. Thus, adequate site-specific fertilizer recommendation is required for improved crop productivity (Mulugeta *et al.*, 2019).

The rate of combined application of urea and DAP was significantly higher in the Damot Gale (147.1±2.9) than in Sodo Zuria district (144.0±2.9) (Tab. 4). Laekemariam *et al.* (2016) also reported that more urea and DAP were applied for crop production in Damot Gale than in Sodo Zuria district. Generally, the use of low amounts and non-balanced nutrients leads to nutrient depletion and reduced faba bean productivity.

Farmyard manure application

The use of cow farmyard manure (FYM) for faba bean did not show significant variation between both districts (Tab. 4). Only 31.3% of Damot Gale and 33.3% of Sodo Zuria district farmers applied farmyard manure for faba bean production (Tab. 4).

Most farmers who applied FYM did so near to their residence rather than to distant faba bean plots. Additionally, growers indicated the farm distance from their residence and a shortage of manure as the major reasons for lower manure application. Corbeels *et al.* (2000) also reported for the Tigray regional state in Northern Ethiopia higher FYM rate near residence than on distant plots due to the difficulty in transportation. However, the application of an adequate amount of FYM for faba bean is of substantial importance to improve the productivity of small-scale farmers (Fedaku *et al.*, 2019).

Farmyard manure application rate

The FYM applied rate for faba bean indicated significant (23.65***) variations among the studied districts (Tab. 4). The FYM application rate was significantly greater in Damot Gale than in Sodo Zuria district (Tab. 4).

The amount of FYM applied both in Damot Gale and Sodo Zuria ranges from 1 to 2 t ha^{-1}. Among FYM applying farmers, 59.2% and 81.6% applied 1 t ha^{-1} in Damot Gale and Sodo Zuria districts, respectively, and the remaining farmers applied 2 t ha^{-1}. The average application rate for faba bean varies between 1.4±0.2 t ha^{-1} and 1.2±0.1 t ha^{-1} in Damot Gale and Sodo Zuria districts, respectively (Tab. 4). Buraka *et al.* (2016), in a study in the neighboring district of Boloso Sore in Wolaita zone, revealed that faba bean required 4 t ha^{-1} for optimum growth. Yield improvement of faba bean was reported in different parts of Ethiopia due to FYM application, in which pH, available P, and cation exchange capacity of the soil increased (Agegnehu & Yirga, 2009; Fedaku *et al.*, 2019). Thus, the FYM rate used in the studied districts is very low and negatively affects the soil fertility status, requiring replenishment of nutrients.

Lime application

Faba bean farmers who applied lime in the study used $CaCO_3$ as the liming material. Lime application had no significant statistical differences between both districts (Tab. 4). About 3.1% and 4.1% of the farmers applied lime in Damot Gale and Sodo Zuria districts, respectively (Tab. 4). Similarly, Ayalew and Dejene (2011) and Buraka *et al.* (2016) showed the limited knowledge of farmers to apply lime in Woliata zone. However, different researchers have reported soil acidity as a serious problem for crop productivity in Wolaita zone (Ayalew & Dejene, 2011; Buraka *et al.*, 2016; Shanka *et al.*, 2018; Kassa Colbe *et al.*, 2020). For instance, Shanka *et al.* (2018) reported pH values of 4.4 and 4.6 at Kokate and Areka in Wolaita zone, which are very low (Landon, 1991). Though soil acidity is a serious constraint, most farmers do not solve the problem adequately. Therefore, soil acidity might lead to further grain yield reduction; additional research must be conducted to identify the optimum lime rate and soil acid-tolerant faba bean variety.

The rate of lime application

The rate of lime application in faba bean farms did not show significant variation between both districts (Tab. 4). The lime applied in faba bean farms varied from 1 to 2 t ha^{-1} with an average rate of 1.6±0.1 t ha^{-1} and 1.5±0.1 in Damot Gale and Sodo Zuria districts, respectively (Tab. 4). Kassa *et al.* (2014) indicated the soil of Wolaita zone requires 4 t ha^{-1} for improved common bean production. Overall, the average lime applied rate (1.6±0.6 t ha^{-1}) on the faba bean fields in the studied districts is not sufficient to mitigate soil acidity. Therefore, to secure a higher faba bean production in the studied districts, further research is required to reclaim the soil by using optimum lime and fertilizer balance.

Faba bean residue management

Faba bean residue management did not show significant differences among the districts (Tab. 4). Farmers were not aware of the advantage of retaining and incorporating faba bean residues into the soil. Faba bean residues were removed in 98.2% of Damot Gale and 98% in Sodo Zuria districts farms (Tab. 4). Laekemariam *et al.* (2016) also reported that crop residues were removed for varied purposes in Wolaita zone. Furthermore, southeastern Ethiopia farmers clear the crop residues for construction material, fuel, and animal feed (Abera & Belachew, 2011). Hence, faba bean residue retention and/or incorporation into the soil require special attention to restore soil fertility and improve crop productivity in the studied area.

Faba bean rotation

Faba bean rotation with different crops significantly varied (χ^2 = 3.49, P<0.05) between districts (Tab. 4). Sodo Zuria (41.5%) showed significantly higher faba bean rotation than Damot Gale district (31.3%) (Tab. 4). Thus, in Sodo Zuria, the soil fertility is significantly better than in Damot Gale district.

Faba bean is often rotated with cereals and infrequently rotated with roots and tubers (potato, sweet potato, and yam). Most farmers implement the rotations as maize - faba bean - cereals and/or root and tubers - faba bean - cereals. Pound and Jonfa (2005) also reported similar faba bean rotation practices in Wolaita zone. On the other hand, crop rotation in Tigria regional state in Northern Ethiopia is dominated by cereals (Corbeels *et al.*, 2000). However, including legumes at least once in the rotation cycle influences the soil microbial activities (Abera & Belachew, 2011). These practices enable the soil to increase soil organic matter (OM), creating an ideal condition for crop productivity (Aschi *et al.*, 2017). Thus, including grain legumes in crop rotation provides multiple environmental, agricultural, and economic benefits, such as fixing the atmospheric nitrogen, releasing high-quality OM in the soil, and facilitating soil nutrient circulation and water retention. Moreover, the type of legume species used for rotation purposes affects the mineralization process and the amount of fixation. Faba bean is the preferred legume for rotation purposes, due to its powerful nitrogen-fixing (177-250 kg ha^{-1} per crop) capacity (Mulugeta *et al.*, 2019). In line with this, Aschi *et al.* (2017) reported faba bean-rape-wheat rotation

TABLE 5. Grain yield production of faba bean in the sampled agricultural fields at Damot Gale and Sodo Zuria districts of Wolaita zone, Southern Ethiopia.

Year of production	Mean yield (t ha^{-1})			
	Fertilizer application	Damot Gale (N = 163)	Sodo Zuria (N = 147)	F-test
Production in 2016	No	0.52±0.2	0.50±0.1	4.05*
	Yes	1.80±0.6	1.72±0.7	1.73*
	t-test	***	***	
Production in 2017	No	0.77±0.3	0.71±0.3	5.9**
	Yes	1.88±0.7	1.74±0.6	0.01**
	t-test	***	***	
Production in 2018	No	0.63±0.3	0.61±0.4	6.73*
	Yes	1.84±0.12	1.84±0.11	0.84 NS
	t-test	***	***	

N represents the number of farmers involved in cropping practices; *,**,*** significant at $P\leq$0.05, 0.01, and 0.001, respectively; NS - not significant.

as a suitable crop rotation to improve soil fertility status. In general, farmers are aware of the benefits of faba bean rotation with other crops to improve soil fertility. Most farmers indicated their preference for faba bean rotation than fallowing, due to the limited farmland size.

Fallowing

The interviewed farmers revealed that the practice of fallowing did not significantly vary within the studied districts (Tab. 4). In this regard, only about 2.5% of Damot Gale and 3.4% of Sodo Zuria farmers practiced fallowing. Overall, the fallowing practice is very limited (2.9%) (Tab. 4). The farmers are aware of the significant role of fallowing in reclaiming soil fertility. However, the small farmland size in the studied districts forces farmers to limit fallowing. Thus, the problem of fallowing abandonment is common in Wolaita zone (Pound & Jonfa, 2005; Laekemariam *et al.*, 2016). Similarly, the limited practice of fallowing due to small farmland size was reported in different parts of Ethiopia (Corbeels *et al.*, 2000; Abera & Belachew, 2011; Mamuye *et al.*, 2020). Thus, the abandonment of fallowing negatively affects soil fertility and grain yield productivity (Mamuye *et al.*, 2020). The soil fertility constraints due to continuous cropping requires immediate attention for sustaining faba bean production in the studied districts.

Faba bean grain yield production

From 2016 to 2018, faba bean grain yield production showed statistically significant differences (P<0.001) between fertilizer application and non-aplication. In all three years, fertilized and unfertilized faba bean farms had an average grain yield of 1.8±0.8 t ha^{-1} and 0.62±0.3 t ha^{-1}, respectively (Tab. 5). In line with this, CSA (2018) reported average grain production of 1 t ha^{-1} in Wolaita zone, which is far less than the national average (2.1 t ha^{-1}).

In 2016, the yield (t ha^{-1}) of fertilized faba bean was 1.80±0.6 and 1.72±0.7 in Damot Gale and Sodo Zuria districts, respectively. However, in the same year, the yield of an unfertilized farm was very low in both Damot Gale (0.52±0.2 t ha^{-1}) and Sodo Zuria (0.50±0.1 t ha^{-1}) districts (Tab. 5). A fertilized faba bean farm in 2017 yielded 1.88±0.7 t ha^{-1} and 1.74±0.6 t ha^{-1} in Damot Gale and Sodo Zuria districts, respectively.

The yields in an unfertilized farm in 2017 were lower in Damot Gale (0.77±0.3 t ha^{-1}) and Sodo Zuria (0.71±0.3 t ha^{-1}) districts (Tab. 5). The fertilized field in 2018 yielded about 1.84±0.12 t ha^{-1} and 1.84± 0.11 t ha^{-1} in Damot Gale and Sodo Zuria districts, respectively. In 2018, the yield of an unfertilized farm was lower at Damot Gale (0.63±0.3) and Sodo Zuria (0.61±0.4) districts (Tab. 5). Scarcities of arable lands, poor soil fertility, erosion, soil acidity, limited fallowing and poor residue management are the reasons for reduced faba bean yield.

Conclusions

The results of this study demonstrate that the productions of faba bean in the studied districts are constrained mainly by poor soil fertility, soil acidity, erosion, and lack of soil acidity tolerant varieties as well as small landholdings. In general, the soil management practices by farmers were inadequate to improve the soil fertility status and to enhance faba bean productivity. Consequently, the grain yield productivity of unfertilized farms was below 1 t ha^{-1}. Thus, adequate soil fertility management practices are necessary. Intensive soil fertility management interventions including faba bean residue management, crop rotation, application of sufficient and balanced organic and mineral fertilizers, adequate lime application, and use of soil acidity tolerant varieties are required to improve faba bean productivity in the study area.

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Conflict of Interest statement

The authors declare that they have no conflict of interest regarding the publication of this article.

Author's contributions

BA, ND, TT, and Fl designed the experiments, BA and TT contributed to the data analysis, and BA wrote the article. All authors reviewed the manuscript.

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SUPPLEMENTARY MATERIAL

1. Survey questionnaire

Project title: Soil fertility management practices for faba bean (*Vicia faba* L.) production in Wolaita zone, Southern Ethiopia.

Part A: structured interview guide

Part I: informed oral consent

Hello, my name is Bekalu Abebe and I am a student at Haramaya University. This is my colleague [name]. We are conducting a study of Faba bean (*Vicia faba* L.) as part of my education at the university.

Do you grow faba bean? ☐ Yes ☐ No

▸ If yes, the brief objective of this study is indicated as follows.

The purpose of this study is to understand faba bean management by farmers and evaluate soil and plant nutrient status.

I would like to ask you questions about faba bean. Of course, your participation is entirely voluntary. These interviews require less than one hour. I do not anticipate that the interview will pose any risks to you. Because I am a student, I cannot pay you.

We hope that our research will benefit farmers in Wolaita by promoting the diversity of faba bean and giving direction for agronomic management. If you agree to an interview, you do not have to answer all my questions, and you can tell me at any time if you would like to stop. I will record your answers to my questions using my cell phone and my notebook. I will include this information in my dissertation, and it will be shared with other researchers who are interested in faba bean. Do you have any questions? If you have any questions in the future, here is my contact information. Do you agree to participate in this study of faba bean?

▸ If yes, let us proceed to the following interview.

Part II: structured Interview

SECTION 1: basic Information (complete prior to interview)

Date of interview:	Start time of interview:
Name of interviewer:	
Wereda/district:	Kebele:
Latitude (in decimal degrees N):	Longitude (in decimal degrees):
Altitude (in meters):	
Agro-ecological	
Relative wealth on farmers' association list: ☐ Low income ☐ Middle income ☐ High income	

SECTION 2: general Information about the informant

Name of informant:
Language spoken by informant during interview: ☐ Wolaitigna ☐ Amharic ☐ Other (specify): _ _ _ _ _ _ _ _ _ _ _
Age (observed): ☐ 18 to 30 ☐ 30 to 45 ☐ 45 to 60 ☐ 60+
Gender (observed): ☐ Male ☐ Female
Is the informant the household head? ☐ Yes ☐ No
☐ If no, household-head gender: ☐ Female-headed ☐ Male-headed

SECTION 3: inter-specific diversity of legume crops

Are you growing any legume this year? ☐ Yes ☐ No
For each of the legumes you listed, how many hectares of land did you plant in 2018 (June to September including any areas under intercropping).

SECTION 4: cropping and crop management practices

1. What is your perception about the soil fertility status of farmland you used for faba bean? A. Highly fertile B. Moderately fertility C. Poor in fertility
2. Local soil name (type) of farm used for faba bean: Reasoning evidence (major classification criteria) 1. Color: dark/red/brown 2. Fertility: fertile/infertile 3. Workability: hard/easy to plough in dry and wet 4. Water retention: high/low 5. Other: _
3. Number of crops per year growing land used for faba bean farm: _
4. What are the major production constraints for faba bean in your community? (check all that apply) ☐ Land shortage ☐ Drought ☐ Poor soil fertility ☐ Soil acidity ☐ Diseases ☐ Insect pests ☐ Weeds ☐ Lack of seeds ☐ Flooding ☐ Erratic rain ☐ Low market value ☐ High price of inputs ☐ Other (specify): _ _ _ _ _ _ _ _ _ _ _ _ _
5. Do you observe change in the fertility status of the agricultural soils in your village? ☐ Yes ☐ No
6. If yes, what are the indicators compared to the past A. Reduced crop growth (e.g., non-healthy color, plant height) B. Reduced yield C. Farm does not respond without fertilizer D. Other: _
7. What are the driving forces that resulted in those changes in soil fertility? A. Soil erosion B. Inadequate fertilizer application (organic and chemical) C. Absence of soil conservation structure D. Lack of response after applying fertilizer E. Continuous cropping/no fallowing F. Complete residue removal G. Other _
8. Do you maintain soil fertility status for better productivity of faba bean? ☐ Yes ☐ No
▶ If yes, what are the major practices you implement to improve soil fertility?
9. Do you use chemical fertilizers for faba bean production? ☐ Yes ☐ No
10. Fertilizer rate for the crop grown on sampling plot 1. Type: N = NPS, U = Urea, C = Compost, FYM = Biomass 2. Rate (kg): N------------ U------------ C------------ FYM ------------
▶ If no, why? _
11. Do you apply both organic and chemical fertilizer together at a time: ☐ Yes ☐ No
▶ If no, your reason: A. I don't know the advantage of using both together B. Tried but not found the benefit C. I know the advantage, but to share fertilizer sources to individual fields D. Other:

12. Do you know about soil acidity? ☐ Yes ☐ No
▶ If yes, what do you do to alleviate soil acidity problem for faba bean? ☐ Lime ☐ Ash ☐ Other (specify): _ _ _ _ _ _ _ _ _ _ _ _ _ _ _
13. Do you rotate faba bean with other crops? ☐ Yes ☐ No
▶ If yes, with which crops do you rotate with faba bean? _
▶ If yes, how often do you plant faba bean within the crop sequence? _
▶ If no, why? _
14. Do you intercrop faba bean with other crops? ☐ Yes ☐ No
▶ If yes, with which crops do you plant faba bean in the same field? _
▶ If no, why? _
15. What varieties of faba bean have you grown in the past three years? _
16. What is the estimated yield in the plot of land you planted (Qt ha-1)
17. Do you fallow the land? ☐ Yes ☐ No
▶ If Yes, Duration/at what time interval: i.e. Every year _ _ _ _ _ _ _ _ _ _ _ _ ▶ If No, Reason: _
18. Crop residue management on bean growing farm? a. Burned b. Cleared c. Remain in the field d. Other _ _ _ _ _ _ _ _
19. Do you control insect pests on faba bean? ☐ Yes ☐ No ▶ If yes, which type of control? ☐ Chemical ☐ Other (specify) _ _ _ _
20. Do you control weeds? ☐ Yes ☐ No ▶ If yes, which type of control on faba bean? ☐ Chemical ☐ Other (specify) _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _
21. Do you control diseases on faba bean? ☐ Yes ☐ No ▶ If yes, which type of control? ☐ Chemical ☐ Other (specify) _ _ _ _ _ _ _ _ _ _ _ _ _ _ _
22. What is the yield you gained on plot of land for last three years and your estimate for this year? _