The Use of Biofertilizer by Smallholder Farmers and its Impact on Productivity of Pulse-Cereal Cropping System in Arsi Zone, Oromia Regional State, Southeastern Ethiopia

Nigussie Alemayehu

Ethiopian Institute of Agricultural Research (EIAR), P.O. Box 2003, Addis Ababa, Ethiopia

Abstract: Commercial production and distribution of biofertilizer for increasing yields of pulse crops in Ethiopia started as recently as two decades ago after the agricultural research system began working on biofertilizer. Consequently, farmers have been inoculating seeds of pulse crops with rhizobium bacteria to get higher yields using rhizobium strains disseminated by the research system. Similarly, smallholder farmers in Lemu Bilbilo and Digelu Tijo districts (woredas) of Arsi Zone of the Oromia Regional State in southeastern Ethiopia have been inoculating faba bean and field pea seeds with rhizobium bacteria for increasing yields of the crops since 2010. However, there is no empirical evidence for agronomic and agroecological benefits that the farmers obtain from using the technology. Therefore, a methodical assessment was done to investigate the effects of biofertilizer (seed inoculation with rhizobium) on the productivity of faba bean and subsequently grown wheat and barley crops and the benefits that farmers obtain in terms of yield and sustainability of the farming system. Both qualitative and quantitative data were collected from four kebeles in the two woredas through focus group discussions (FGD) and key informant interviews (KII) involving 150 farmers, agricultural experts, development agents, researchers, and community leaders. The results revealed that smallholder farmers who planted rhizobium-inoculated faba bean seed gained additional yield benefits of 79%, 66%, and 42% for faba bean, wheat, and barley, respectively, over farmers who planted uninoculated seeds. In addition, farmers reported that they derived a range of other benefits which included improved soil fertility, need for lower amounts of nitrogen fertilizers to produce cereals, low faba bean disease incidence, more biomass production for returning to land as a crop residue, and larger-sized faba bean seeds that take shorter time to cook. The farmers also reported an opportunity to grow faba bean profitably on less fertile land. It is concluded that planting rhizobium-inoculated faba bean seed significantly increased the yields of all three crops grown in the rotation system, with significant implications for enhanced agroecological benefits and sustainable pulse-cereal production system.

Keywords: Cereal crops; crop rotation; faba bean; pulse crops; seed inoculation with rhizobium; wheat and barley

1. Introduction

Nitrogen and phosphorus are mineral nutrients that limit plant growth most (Sanchez, 2002). They are the most deficient nutrients in most of Ethiopian soils (Mamo *et al.*, 1988; Tsegaye, 1992). More than 85% of Ethiopian soils contain insufficient amounts of nitrogen for sustainable and profitable crop production (ATA, 2012). Therefore, the two nutrients in particular have to be replenished through mineral or organic fertilizers to sustain crop production. The most common source of nitrogen used in Ethiopia is the mineral fertilizer urea. Although farmers realize that crop yields are higher with application of urea, they very often use lower rates of the fertilizer than the rates recommended by the research system. This is attributed to inadequate supply and escalating prices of mineral fertilizers.

Soil management strategies that are solely dependent on mineral fertilizers, in addition to being unaffordable to resource-poor farmers, cause a serious threat to human health and the environment (Pearson *et al.*, 1995; Löschenberger *et al.*, 2008).

The use of biological N-fixation through cultivating pulse crops as a source of dietary protein as well as a supplementary way of improving soil fertility and environmental protection has been a subject of considerable research since the early 1980s (Beyene, 1988). In Ethiopia, the tradition of crop rotation where the cycle of continuous production of cereals is broken by producing pulse crops as a means of maintaining soil fertility and diversifying agricultural products is a common practice (Gorfu, 1998; Taa *et al.*, 1997). Likewise, the ability of pulse crops to restore soil fertility had been realized and exploited by farmers also in other parts of the world long before the symbiotic association between bacteria and the host plant was scientifically established (Lim and Burton, 1982; Hirsch, 2009).

*Corresponding author. E-mail: nalemayehua@yahoo.com

ISSN 1993-8195 (Online), ISSN 1992-0407(Print)

Rhizobia infect the legume root and form root nodules in which they convert atmospheric nitrogen into ammonia, which then can be utilized by the plant to produce valuable proteins, vitamins and other nitrogen-containing compounds that are required for normal growth and development of plants and thus better yields (Keyser and Li, 1992).

Exploitation of beneficial microbes as biofertilizer is of paramount importance in agriculture not only for their economic benefits and cost effectiveness but also for their potential role in food safety and sustainable crop production (Pearson *et al.*, 1995; Aryal *et al.*, 2003; Burger *et al.*, 2008; Löschenberger *et al.*, 2008). The term biofertilizer refers to the use of various live microorganisms that enhance soil fertility by fixing atmospheric nitrogen, solubilizing or mineralizing phosphorus and potassium or decomposing organic wastes or by producing plant growth-promoting substances at the root zone (Mohammadi and Sohrabi, 2012).

Biofertilizers, as one of the important components of sustainable agriculture, are products containing living microorganisms which have the ability to mobilize nutritionally important elements from non-usable to usable form through biological processes and they have the potential to increase the production of crop by improving yield and quantity (Glazer and Nikado, 2007). Biofertilizers are valuable to the environment as they enable reduced use of chemical fertilizers since they contain naturally occurring micro-organisms that are biologically multiplied to improve soil fertility and crop productivity in many parts of the world (IFPRI, 2010). They are also relatively low-cost source of nitrogen for smallholder farmers in Ethiopia (Gorfu *et al.*, 2000). Rhizobium inoculants coated on seeds of pulse crops before planting not only enhance growth and yield of the pulse crops but also provide nitrogen and organic carbon for subsequent or associated crops; and incorporating residues of pulse crops back into the soil will make this effect even more significant (de Boef *et al.*, 1996; Gan *et al.*, 2015; Masso *et al.*, 2015).

In Ethiopia, commercial production and distribution of rhizobium inoculants were started some twenty years after the research took the initiative to work on biofertilizer. Presently, some specific rhizobium strains are being produced and supplied for faba bean, chickpeas, lentils, field pea, common bean, soybean and mung bean production (Hailemariam and Asfaw, 2015; Assefa, *et al.*, 2018). It is also worth-noting that pulse crops not only avail soil nutrients through nitrogen fixation and nutrient solubilization but also serve to 'break' cycles of different cereal pests as non-host crops (Malhotra *et al.*, 2004; Kirkegaard *et al.*, 2008; Keneni *et al.*, 2016). Pulse crops offer these manifold merits to the farmer with only minimum external inputs as compared to cereals (Keneni *et al.*, 2006). The research system in Ethiopia has pursued the approach to make use of biofertilizer to increase the nitrogen availability for the pulse crops through biological nitrogen fixation as well as for cereal crops that are cultivated following them (Gorfu, 1998; Taa *et al.*, 1997; Tolera *et al.*, 2015; Assefa *et al.*, 2018; Negash *et al.*, 2018).

Despite availability of empirical evidence on the advantages of growing pulse crops in rotation with cereals, no conclusive results have been presented to show farm-level benefits derived from the legume crops as well as from subsequently grown cereal crops. Therefore, a study was conducted in early 2016 to investigate the benefits that smallholder farmers Arsi Zone gained from using biofertilizer, which was promoted as in as part of the production package for faba bean to improve that yield of the crop and those of subsequently grown wheat and barley crops. The study was aimed also at elucidating other benefits that smallholder farmers may derive from using biofertilizer through enhancements of household incomes, livelihoods, and farming system sustainability.

2. Materials and Methods

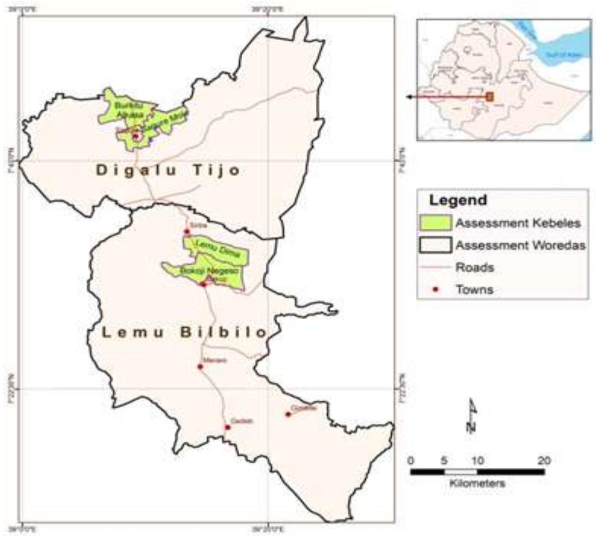
Informed by a body of literature and reports from research and business organizations engaged in activities related to biofertilizers in Ethiopia and extensive discussions held with relevant personnel of the institutions, the assessment was made in early 2016. These included discussions held with technical experts and Director of MBI, the Project Coordinator of N2 Africa-Ethiopia which is housed by the International Livestock Research Institute (ILRI), Ethiopia, and leaders of Soil Microbiology Research at Kulumsa and Holetta Agricultural Research Centers. After having general information about the status of research and the use of biofertilizer in the country, the assessment was conducted in four kebeles of Arsi Zone using participatory rural appraisal (PRA) tools to gather data and information used to disclose facts embedded in this relatively new technology of restoring soil fertility. The methodology is specifically described as follows:

2.1. Assessment Area

The assessment was conducted in two districts (woredas) of Arsi Zone (Lemu Bilbilo and Digelu Tijo), Oromia Regional State. Each woreda was represented by two kebeles. A 'kebele' is the smallest local administrative unit in a district (woreda) in Ethiopia. Thus, Lemu Bilbilo woreda was represented by Bekoji-Negeso and Lemu-Dima kebeles. Digelu Tijo woreda was represented by Sagure-Mole and Burkitu-Alkasa kebeles. '

The Arsi Zone was selected for this study as it is an area where the risks associated with cereal-cereal monoculture are high both at technical and policy levels and there is a need for aggressive introduction of inoculating seeds of pulse crops with rhizobium bacteria before planting particularly faba bean and field pea, which are the best and most preferred rotation crops with cereals in the area (Keneni *et al.*, 2016). The study sites are located some 200 to 35 km south-east of Addis Ababa, the capital city of Ethiopia (Figure 1).

The four kebeles where the assessment was undertaken are situated within the very center of major production areas of faba bean, field pea, wheat, barley and highland oilseed crops such as linseed and Ethiopian mustard.



The kebeles are situated in the central plateau of Arsi Zone with a typical highland agro-ecological setting of altitude greater than 2500 m above sea level (Table 1). The long-term average annual rainfall of the area is more than 1000 mm whereas the mean annual temperature ranges from 12-13 °C, with impressively minimum fluctuation (Table 1).

This combination of altitude, rainfall, and temperature is ideal for growing faba bean (Keneni *et al.*, 2006; 2007). Thus, no other area more than the present kebeles could better depict the potential economic and environmental benefits accruing from application of biofertilizer. Several strains of nitrogen-fixing bacteria have been identified and recommended by the research system for production of faba bean including strains 1018, 1035 and EAL 110 (EIAR, 2018). However, according to the woreda administration, development agents and researchers involved in the distribution of the biofertilizer, the Strain EAL 110 was the one most widely used by the farmers in the kebeles selected for this study.

Figure 1. Map of the study area.

Table 1. Geoclimatic descriptions of the four kebeles where biofertilizer was applied on faba bean.

Kebele	Altitude (m) (a.s.l.) *	Annual rainfall (mm)			Mean annual temperature (° C)		
		Min	Max	Mean	Min	Max	Mean
Burkitu Alkasa	2558	1175	1211	1196	13	14	13.12
Sagure Mole	2586	1158	1205	1188	13	13	13.00
Lemu Dima	2812	1077	1144	1112	11	13	12.33
Bokoji Negeso	2793	1061	1124	1096	11	13	12.52

Note: **a.s.l. = above sea level. Altitude, and rainfall and temperature data were sourced from Jarvis et al. (2008) and www.worldclim.org, respectively.*

2.2. Data Collection and Analysis

Both qualitative and quantitative data were collected in the assessment process. For collecting information and data, semi-structured questionnaires were developed, followed by Focus Group Discussions (FGD) and Key Informant Interviews (KII). Field visits were made where the crops were still growing during the period of the assessment to corroborate facts asserted by participants of the FGD and KII.

The FGD component was structured around a set of standardized participatory assessment tools to collect qualitative contextual data on the use of biofertilizer, the purposes and methods of the use and its impact on yield, profits, and household income. The preceding assessment tools were used in addition to the general situational description and information on the farming systems. The KII, which included farmers who used as well as who did not use rhizobium inoculants, was designed to capture the history and use of inoculants, sources of inoculants and details on any inoculant-related impact on yield, livelihoods, and sustainability.

The data collected and consolidated from the FGD and KII were designed to establish facts on (1) types of crops grown and rankings of their importance in terms of area of production and market values; (2) major constraints of crop production and their order of importance; (3) proportional distribution of crops produced by households (HH) for consumption, sale, seed or forage; (4) size of landholding and family size per HH; (5) proportional land allotment to crops and typical crop rotation patterns followed in the area; (6) practices of soil fertility maintenance through the use of chemical fertilizers and biofertilizer and the history and extent of use of rhizobial inoculants; and (7) general benefits of rhizobial inoculants in terms of the yields of the target legume as well as subsequent cereal crops, environmental sustainability in terms of reduction in the use of the chemical fertilizer urea for follow-on cereals.

Altogether, 158 (38 female) individuals representing farmers, development agents, woreda experts, community leaders, researchers and the private sector engaged in supplying biofertilizers took part in the interview and discussions. In order to quantitatively determine the benefits of biofertilizer on yields of faba bean and that of subsequent cereals rotated with the faba bean and incomes of the households (HHs), data were collected from face-to-face interviews of 145 farmers in the four kebeles. Seventy-nine of the interviewees used rhizobia-inoculated seeds once or multiple times while the remaining sixty-six did not use any rhizobia-inoculated seeds.

Therefore, it was possible to generate data points enough to statistically determine the effect of biofertilizer on the yields of faba bean as well as wheat and barley following the inoculated-faba bean. The SAS statistical package was used to process the quantitative data collected from individual interviews and perform t-tests and calculate CV values, while excel was used to construct frequency tables and pie and bar charts.

3. Results and Discussion

3.1. Crop Production System and Use

Crop types, importance and use: The average landholding of a household (HH), which has an average family size of 6 persons, is 2.5 hectares (Figure 2). However, this does not necessarily mean that every household owns land. For example, in one of the kebeles, out of 1078 HHs, only 500 HHs or about 46% of them possess land of their own while the remaining 54% of the HHs in that particular kebele are landless.

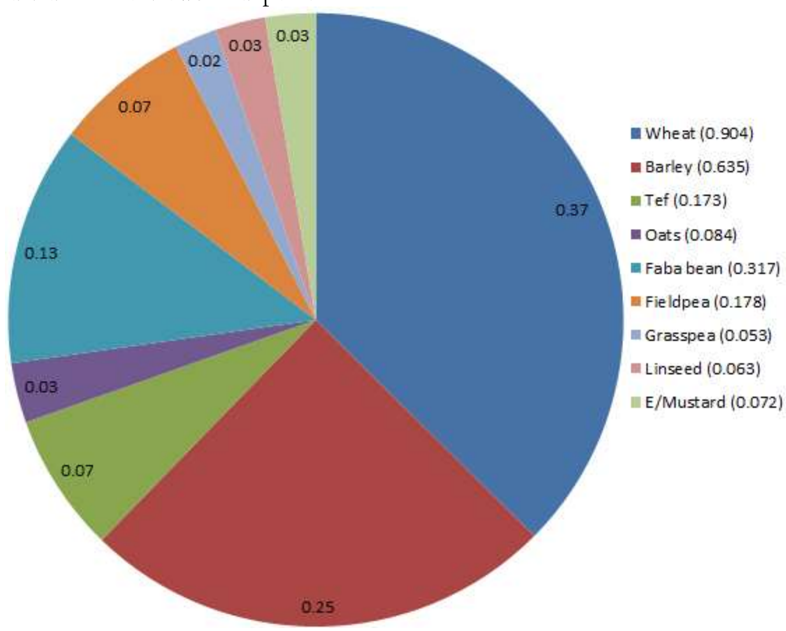


Figure 2. Crop composition, average area allotment (in hectare indicated in parentheses) and relative distribution (%) of each crop per household in Lemu Bilbilo and Digelu Tijo districts (woredas) of Arsi Zone

Figure 2 depicts that almost a whole range of crops are grown in the area, wheat and barley being the major ones. These cereals take the lion's share of the agricultural land allotment in both woredas, followed by faba bean and field pea and some tef only in *Burkitu Alkasa kebele*. Oat is grown sometimes as a forage crop on marginal land. It is interesting to point out that during the FGD, at *Sagure-Mole*, production and consumption of grass pea (*Lathyrus sativus* L.) was indicated to have been started only recently. Especially female farmers asserted that the consumption of grass pea in every household doubled compared to the amount of faba bean or field pea consumed. Production of the two oilseed crops, namely, linseed and Ethiopian mustard, is also common in the two woredas but only small parcels of land are allotted to cultivate both crops.

The data obtained from the FGD and KII indicated that the larger proportions of most of the crops produced by the households are marketed (Figure 3). However, the proportion of crops meant for sale was the highest for oilseeds followed by pulses and cereals in the same order. The opposite holds true for consumption where 60% of the barley, 50% of the tef and close to 40% of the wheat produced are destined for home-consumption and about 10%, except for Ethiopian mustard, is retained as seed for the next season. Since the seed rate required for Ethiopian mustard is small (Belayneh and Alemayehu, 1986), only four percent of the produce is retained by the HH. Earlier reports also indicated that production of particularly cereal crops in Ethiopia is mostly for consumption (60–80%), followed by sale (8-21%) and farmers mostly tended to sell more of high value pulse and oil crops (CSA, 2017).

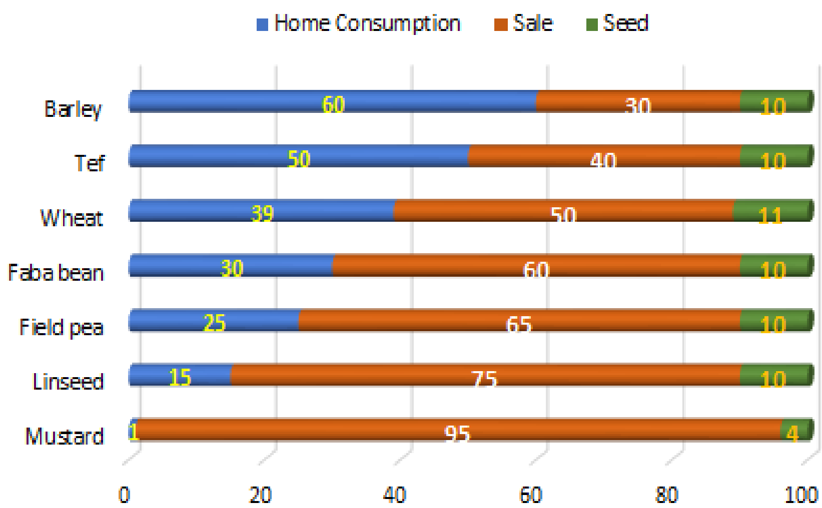


Figure 3. Farmers estimates of the proportions of their crops used for consumption, sale and seed in Lemu Bilbilo and Digelu Tijo districts (woredas) of Arsi Zone during the 2016 main cropping season.

Crop rotation patterns: Farmers in the study area generally know the importance of growing different crops on the same plot of land in rotation. They even ascribe improved soil fertility and reduced incidences of crop diseases to cereal-legume crop rotation. A similar study in North Shoa, Ethiopia, also revealed that farmers are aware of the impact of legumes and fallowing on improving soil fertility but they do not have the scientific knowledge about the role microbes associated with legume root nodules play in improving soil fertility (Teshome *et al*., 2018). These intuitive perceptions of farmers about the advantage of rotating crops of different species are corroborated by empirical research findings that crop rotation improves soil fertility restoration and soil health (Gorfu, 1998; Assefa *et al*., 2018) and soil physical and biological properties via increasing organic matter (Negash *et al*., 2018). Based on experiences accumulated over the years and generations and, most importantly, the rationale the farmers strive to match their needs and resources like land, seed and other inputs at their disposal, they follow some distinct crop rotation patterns in the area. Nevertheless, three crop rotation patterns indicated in Figure 4 stand as the most dominant and widely followed cropping sequences.

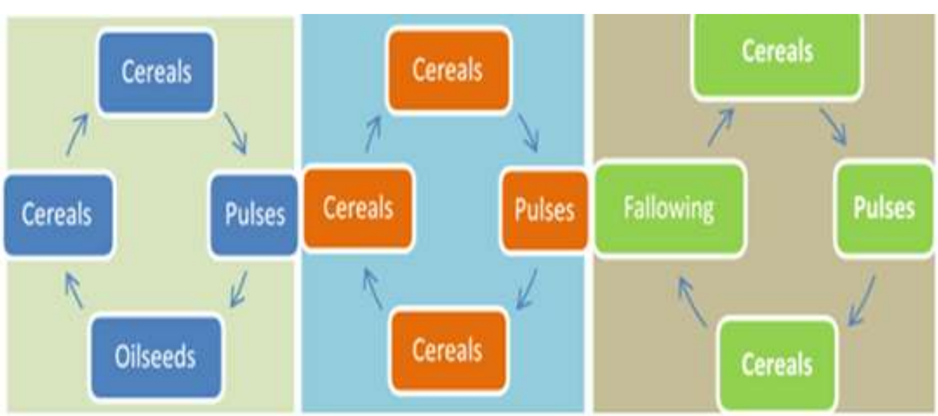


Figure 4. Crop rotation pattern traditionally followed by farmers in Lemu Bilbilo and Digelu Tijo districts (woredas) of Arsi Zone during the 2016 main cropping season

The arrangement of the first sequence, though including cereals, pulses and oilseeds, cannot be immune to foreseeable problems and thus technical disapproval as cereal-cereal mono-cropping cannot be disputed. Even worse is the second pattern as the cereal-cereal sequence is interrupted by a pulse break-crop only once in four years, which may make the system vulnerable to a range of biochemical as well as physical threats of sustainability as a large body of research findings reveal. For example, some authors recommended shorter rotations of pulse crops with cereals at least once every three years (Parr *et al*., 1983; Cox *et al*., 2010; Gan *et al*., 2015). Furthermore, including legumes in the rotation was found to be effective against pests and weeds through different mechanisms such as through being non-host crops and breaking the life cycles of crop-specific pathogens that would otherwise attack cereals (Malhotra *et al*., 2004; Kirkegaard *et al*., 2008; Keneni *et al*., 2011; Negash *et al*., 2018; Niu *et al*., 2018); reducing the amounts of inocula of pathogens that could afflict subsequent cereal crops (Krupinsky *et al*., 2002; Niu *et al*., 2018); and improving the soil with essential microbes providing ecological services in nutrient cycling (Bridge and Spooner, 2001; Lupwayi and Kennedy, 2007; Penton *et al*., 2014; Niu *et al*., 2018). In some countries like Canada, producers also follow a crop rotation scheme as a remedial measure against pests (The GoV of Saskatchewan, 2017). The risks associated with wheat-wheat monoculture being practiced in the four kebeles of the assessment is especially ominous as a result of excessive buildup of inoculums of the major diseases that are responsible for the failure of wheat varieties almost immediately after their release (Keneni *et al*., 2016).

An important point to note in the third pattern of rotation is that, fallowing agricultural land for one or two seasons is practised. Scientific evidence supports the perception of farmers such that fallowing can serve as a means of additional way of restoring soil fertility, particularly to promote the release of nitrogen via decomposition of soil organic matter and mineralization of nitrogenous compounds contained therein. Fallowing has such functions despite the fact that in the long-term, it relies on 'mining' the available soil N with depleting soil organic matter (Gan *et al*., 2015). In the present context, however, fallowing seems utterly untenable as it poses a lost production opportunity in terms of land for one or more production seasons. This may exacerbate the problem of land scarcity in the face of increasing number of young farming households. It is also imaginable that fallowing a bare land, which is often the case with cultivated land, has rather a negative consequence on soil stability especially where there is overgrazing by an increasing number of livestock, which is typical for the assessment kebeles. Furthermore, such heavy rainfall conditions as those prevailing in the areas where more than 1000 mm of rain is annually received (Table 1), the rate of erosion would be exacerbated. In addition, unless the ground is sufficiently covered with protective vegetation, the loss of surface soil caused by the torrential rains will undoubtedly be dire. Therefore, fallowing can no longer be a sustainable system in the face of ever-increasing pressure from increasing population in the rural setting on one hand and scarcity of cultivable land on the other.

Major problems of crop production in the target areas: Although there may be an array of technical, technological, economic, biological and social (including policy-related issues) factors constraining agricultural production, farmers have identified some problems of highest priority in their respective kebeles (Figure 5). The order of importance of the problems identified by the participants varied from kebele to kebele depending on the magnitude of incidence and households affected, but they essentially remained more or less similar.

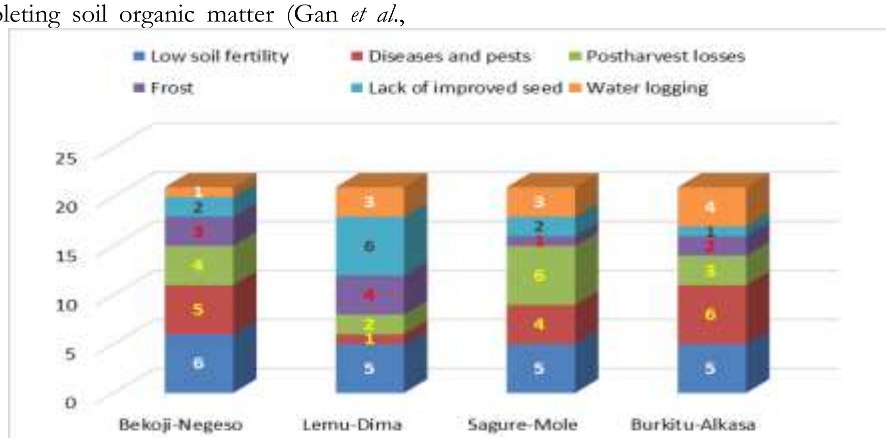


Figure 5. Major problems of crop production identified and ranked by the participants of the FGD and KII in the assessment kebeles in Lemu Bilbilo and Digelu Tijo districts (woredas) of Arsi Zone during the 2016 main cropping season. Note that highest score signifies highest priority and lowest score least priority.

3.2. The Use and Effect of Biofertilizer on the Yield of Faba Bean

The results of the study revealed that the use of biofertilizer for faba bean production in the two woredas of Arsi Zone began in 2010. According to the records from the respective Offices of Agriculture for the two woredas, a total of 5,767 households (1,362 female-headed and 4,405 male-headed households) in

Lemu Bilbilo Woreda and 4,175 households (1,075 female-headed and 3,100 male-headed households) in Digelu Tijo Woreda, were given a series of training on application of bio-fertilizer. The series of training were given not only to farmers but also to development agents (DA), subject matter specialists (SMS), supervisors and community leaders. Furthermore, on-farm demonstrations were made by Kulumsa Agricultural Research Center (KARC) for three consecutive years. Consequently, it was possible to distribute 4,550 bags of biofertilizer to farmers growing faba bean and 1,703 bags for those growing field peas since the time of its introduction of the technology into the area. Since each bag is prepared for a quarter of a hectare, implicitly 2,638 hectares of faba bean and 1,010 hectares of field pea were established with rhizobium-inoculated seeds during this period.

All farmers who used biofertilizer invariably stressed that yields of crops, including that of faba bean, have generally improved significantly. However, they also underlined that in order to reap the full benefit of yield advantage accruing from biofertilizer, optimal combination of such factors as good quality seed, appropriate agronomic practices, including proper pest control management should be implemented. The farmers also noted that Lemu Bilbilo and Digelu Tijo woredas are among the pioneer woredas in Ethiopia to have access to modern extension services through the Swedish International Development Agency (SIDA)-supported Chilalo Agricultural Development Unit (CADU) from the 1960's to the 1970's. Thus, the key informants emphatically asserted that farmers in the two woredas are accustomed to trying out new agricultural technologies, modify them to suit their specific production and economic circumstances, or discard it altogether if they find it not suitable for addressing their needs.

Unlike in most other parts of Ethiopia, even faba bean and field pea are grown in these woredas with application of chemical fertilizer, diammonium phosphate (DAP) at the rate of 67 to 100 kg ha^{-1}. Accordingly, in both woredas, the use of biofertilizer in faba bean started in 2010 and, as stated above, farmers have been using biofertilizer ever since. In fact, some of the farmers have used inoculated seeds on the same plot of land more than once although research recommends that one-time application is sufficient for more than four to five years. This is because once the bacteria are inoculated, they perpetuate themselves even from the surrounding fields (Lindemann and Glover, 1996; Abendroth *et al*., 2006). According to the same authors, frequent inoculation is not of any help because of competition between the established and new rhizobium introduction; but inoculation is critically needed if the native strain is not efficient, if the legume species was never grown before on the land or if the land was never cultivated to pulse crops.

Farmers in all the four kebeles unequivocally affirmed that the use of rhizobium inoculated seeds of faba bean enhanced the yield of the crop as well as restored and maintained soil fertility. The farmers reported that the increase in yield at times reached twice as much as the yield they used to obtain before the introduction of biofertilizer in the area. The farmers revealed that it was in fact the prospect of getting higher yields that enticed them to use rhizobium inoculated seeds mistakenly more than once on the same piece of land. Their unanimous claim of the increased yield of faba bean due to biofertilizer was extrapolated using data collected from the questionnaires and it was found that there was a highly significant ($p < 0.01$) increase in yield of faba bean from the use of rhizobium inoculated seeds in all the kebeles assessed (Table 2). The Table also shows that the average increase in faba bean yield from biofertilizer ranged from 40% (in Lemu-Dima) to more than 150% (in Burkitu-Alkasa) with 79% across the whole area. Corroborating the results of this study, Kwasi (2018) reported that farmers realized the significance of rhizobium seed inoculation and were willing to pay for production inputs for pulse crops including inoculant (Kwasi, 2018).

Farmers attributed the increase in yield to plant characteristics that they think would ultimately contribute to seed yield of faba bean. According to their observation and perception, plants grown from rhizobium-inoculated seeds exhibited such characters as seedling vigor and strong stems, a greater number of nodules, less abortive (sterile) flowers in which case flowering takes place from bottom to top, and ultimately well-filled and plump seeds. The results from the assessment are generally in agreement with the potential of biofertilizer that global experiences indicate (Gan *et al*., 2015; Kwasi, 2018) and even more so with the findings of research in Ethiopia conducted in the past two decades (Assefa *et al*., 2018). Consistent with the perception of the farmers that rhizobium-inoculated plants grow and yield better, Gan *et al*., (2015) reported that diversifying cropping systems with pulse crops enhanced soil water conservation, improved availability of soil nitrogen, and increased system productivity.

Table 2. The effect of biofertilizer on the yield of faba bean in the four assessment kebeles in Lemu Bilbilo and Digelu Tijo districts (woredas) of Arsi Zone during the 2016 main cropping season

Statistic	Bekoji-Negesso		Lemu-Dima		Sagure-Mole		Burkitu-Alkasa		Overall mean	
	Biofert (+)	Biofert (–)	Biofert (+)	Biofert (–)	Biofert (+)	Biofert (–)	Biofert (+)	Biofert (–)	Biofert (+)	Biofert (–)
Average (t ha^{-1})	2.94	1.76	3.03	2.16	2.72	1.64	3.30	1.29	3.00	1.67
Range (t ha^{-1})	2.0–4.8	1.5–2.0	2.8–3.2	1.6–2.6	2.0–3.2	1.4–2.0	2.4–4.6	1.0–1.5	2.0–4.8	1.6–2.6
Standard deviation	0.81	0.21	0.197	0.358	0.388	0.207	0.680	0.168	0.690	0.374
Sample size (n)	26	20	16	15	20	18	17	13	79	66
Test statistic (t)	3.503**		5.152**		7.096**		7.564**		9.083**	
CV (%)	23	12	06	17	14	13	21	13	23	22
Yield increase (%)	67		40		66		156		79	

Note: ** and ** respectively indicate that the differences are significant at 5% and 1% levels of significance; Biofert (+) = with biofertilizer and Biofert (–) = without biofertilizer.*

3.3. The Effect of Inoculant on the Yields of Subsequent Cereal Crops

As indicated above, wheat and barley are the two major cereals grown in the woredas assessed and faba bean or field pea are traditionally used as break crops in the crop rotation system. Farmers in all the discussion groups had the view that the use of chemical fertilizer over the last several decades adversely affected the fertility of their soil, i.e., made the soil less fertile and unhealthy. Thus, they said, "*we were taught in the training sessions by researchers, development agents, and woreda experts that the use of biofertilizer not only increases yields of pulses but also leaves behind a significant amount of nitrogen and organic matter (from the biomass [leaves and root material] from the faba bean plants) that will help to get a bumper harvest of the following cereal crop; therefore, we were so keen to accept and readily try the technology*". All the discussion groups pointed out that they were not disappointed by the results they got. They confirmed that both wheat and barley following cultivation of rhizobium-inoculated faba bean produced higher yields than they used to produce before the introduction of the biofertilizer int the area.

Analyses of the quantitative data from the KII (Tables 3 and 4) also confirmed what was perceived by the farmers that the yield of the wheat crop following inoculated-seeds of faba bean was significantly ($p < 0.01$) higher than the yield of the wheat crop following faba bean grown without rhizobium inoculation (Tables 3). The average increase in the yield of wheat was attributable to the effect of biofertilizer (i.e., 4.0 t ha^{-1} following faba bean with biofertilizer and 2.3 t ha^{-1} following faba bean without biofertilizer) scored a net increase of 73% or 1.7 t ha^{-1}. Since, on average, each household in the assessment kebeles allotted 0.904 ha of land to cultivation of wheat (Figure. 2), the household got an additional produce of more than 1.5 tons, which could be ascribed to inoculation of faba bean seed with rhizobium.

The benefits of biofertilizer reflected on the yield of barley were significant only in two of the four kebeles (Table 4). In the highlands of Arsi Zone, before wheat became a popular crop, barley was the predominant crop with versatile qualities treasured by the populace a staple food or for making beverage (local beer). However, soon after bread wheat varieties were introduced and promoted in the region in the late 1960s and with the advent of "modern" lifestyle where bread making became common and its cultivation began expanding, barley production was marginalized and relegated to a second place after wheat. Especially in areas that are suitable for the latter, the replacement was drastic (Demissie, 1991; Negassa, 1985; Asfaw, 2000; Keneni *et al.*, 2007). Nevertheless, the quantitative data obtained from the KII (Table 4) indicate that the effect of biofertilizer on the yield of barley following faba bean was so significant that more than 35% of average yield increase was realized by farmers who used rhizobia-inoculated faba bean seed. The results generally concur with global and local experiences where cereal crops following pulse crops inoculated with the appropriate strains of rhizobium give better yields (Gan *et al.*, 2015; Assefa *et al.*, 2018).

Table 3. Effect of faba bean-biofertilizer on the yield of subsequent wheat crop in Lemu Bilbilo and Digelu Tijo districts (woredas) of Arsi Zone during the 2016 main cropping season

Statistic	Bekoji-Negesso		Lemu-Dima		Sagure-Mole		Burkitu-Alkasa		Overall	
	Biofert (+)	Biofert (–)	Biofert (+)	Biofert (–)	Biofert (+)	Biofert (–)	Biofert (+)	Biofert (–)	Biofert (+)	Biofert (–)
Average (t ha^{-1})	4.00	2.33	4.47	2.57	4.69	3.35	5.27	2.000	4.61	2.78
Range (t ha^{-1})	3.2–4.8	2.0–2.5	4.2–4.8	2.0–2.9	3.6–5.6	2.2–5.0	4.8–5.6	1.6–2.4	3.6–5.6	1.6–5.0
Standard deviation	0.661	0.289	0.306	0.403	0.641	0.900	0.416	0.400	0.658	0.834
Sample size (n)	14	13	13	11	19	8	13	13	59	45
Test statistic (t)	4.14**		6.75**		3.57**		9.80**		7.42**	
CV (%)	16	12	7.0	16	14	27	8.0	20	14	30
Yield increase (%)	74		73		40		163		66	

Note: ** and ** respectively indicate that the differences are significant at 5% and 1% levels of significance; Biofert (+) = yield of wheat crop following faba bean with biofertilizer and Biofert (–) = without biofertilizer.*

Table 4. Effect of faba bean-biofertilizer on the yield of subsequent barley crop.

Statistic	Bekoji-Negesso		Lemu-Dima		Overall Mean	
	Biofert (+)	Biofert (–)	Biofert (+)	Biofert (–)	Biofert (+)	Biofert (–)
Average (t ha^{-1})	4.225	3.100	3.350	2.250	4.050	2.857
Range (t ha^{-1})	3.2–5.6	2.8–3.3	3.2–3.5	2.0–2.5	3.2–5.6	2.0–3.3
Standard deviation	0.752	0.235	0.212	0.353	0.762	0.479
Sample size (n)	18	15	20	12	38	27
Test statistic (t)	3.20**		3.77**		3.91**	
CV (%)	18	8.0	6.0	16	19	17
Yield increase (%)	36		49		42	

Note: ** and ** respectively indicate that the differences are significant at 5% and 1% levels of significance; Biofert (+) = yield of barley crop following faba bean with biofertilizer and Biofert (–) = without biofertilizer.*

Agricultural system sustainability is the paradigm of present-day planning or decision making with a very broad concept that cannot be defined by simple terms but should be guided by multiplicity of its use (Pennell and Schilizzi, 1999). Nevertheless, sustainable agriculture involves management of resources to satisfy increasing needs while maintaining or enhancing the quality of the environment as well as conserving natural resources. Sustainability is, therefore, the combination of all agricultural practices helping to increase crop productivity with low use of chemical inputs and labor while maintaining the environment, human and animal health (Mohammadi and Sohrabi, 2012). Such improvements include increasing production efficiency at given levels of inputs and consequently reduce input levels to achieve same yield. In the present context, therefore, sustainability is viewed from a standpoint that the potential microbial inoculants have to increase crop production and productivity through utilization of atmospheric nitrogen rather than using chemical nitrogen fertilizer.

Farmers at Lemu Bilbilo woreda revealed that because of significant increases in yields of faba bean due to application of biofertilizer, coupled with competitive market prices, they are now encouraged to increase the land they allot to growing the crop. This has reportedly enabled them to match crop fields of cereals and pulses to practise effective crop rotation. Furthermore, the farmers also evidently realized that repetitive cultivation of pulse crops with biofertilizer has improved the fertility and organic matter content of the soil and thus are convinced to stop fallowing as a means of soil fertility restoration. They also pointed that, earlier, they were able to grow faba bean only on relatively fertile soils rich in organic matter. However, they indicated that it is now possible for them to grow the crop even on less fertile fields using biofertilizer. The farmers also noted that the application of biofertilizer enhanced both plumpness and increased faba bean seed size in addition to increased yields of the crop as described above. They further hinted that plump seeds need less time to cook since they can absorb more moisture. This has a significant implication for saving cooking energy (use of less biomass as fuel especially cow dung) and the prospect of having spare organic matter for return to the land for soil and nutrient recycling.

In the group discussions, the farmers repeatedly indicated that DAP and Urea have been used in the area since the mid-1960s. The farmers perceived that the soil is virtually exhausted, compelling them to continuously increase the rate of fertilizer over the years. The farmers revealed that they are currently using twice as much DAP as recommended for wheat (up to 200 to 250 kg ha^{-1}. After the introduction of biofertilizer, however, they found the soil became more fertile and richer in organic matter content. As a result, they indicated that the wheat stands following faba bean looked relatively more vigorous, demanding less additional nitrogen fertilizer. According to the woreda experts, earlier, faba bean production was almost impossible without using fungicides against fungal diseases. But with the use of biofertilizer, the need for using the chemicals diminished as the incidence of the disease reduced. Less use of fungicides has obviously a positive contribution to environmental as well as economic sustainability. A body of literature supports this perception of farmers where biofertilizers can make plants tolerant to adverse environmental stresses including diseases (Bhattacharjee and Dey, 2014). The authors inferred that proper use of biofertilizers not only had impact on sustainable agriculture but also contributed to a sustainable ecosystem and wellbeing of farmers and consumers alike. Likewise, Monika *et al.* (2018) and Mohammadi and Sohrabi (2012) asserted that biofertilizers would generally play key roles in improving crop productivity and maintaining soil fertility, thereby enabling to achieve sustainable, economical, and environmentally friendly farming.

4. Conclusions

This study has demonstrated that the use of biofertilizer (seed inoculation with rhizobium bacteria) by smallholder farmers resulted in significantly higher yields of faba bean and subsequently grown wheat and barley in a rotation system in four kebeles of Lemu Bilbilo and Digelu Tijo districts (woredas) of Arsi Zone. Smallholder farmers who inoculated faba bean seed with rhizobium gained the benefit of relative seed yield increases amounting to 79%, 66%, and 42% for faba bean, wheat, and barley, respectively, in the rotation system, over smallholder farmers who used uninoculated faba bean seeds. In addition to the yield gains, a list of other benefits contributing to system sustainability were recognized by farmers that inoculated seed of faba bean with rhizobium before planting. These benefits included improved soil fertility, partly as a result of the prospect of return of more organic matter into the soil, less need to use miner fertilizers for growing cereals subsequent to growing faba bean. Rhizobium-inoculated faba bean was also reported to be more tolerant to fungal diseases and required less use of fungicide. The biofertilizer enhanced plumpness and increased seed size of faba bean which would absorb more water and cook faster, requiring less biomass energy. With the introduction of the biofertilizer, farmers indicated that they were able to grow faba bean on less fertile land, which was difficult before.

Rotation of cereals with pulse crops to restore soil fertility has been practiced by Ethiopian farmers and the advantages have long been realized. In view of making the best use of the biofertilizer and maximize economic and environmental benefits, there are areas that need further research. Research is needed to fully assess how exactly biofertilizer contributes to the yield of cereal crops that are planted following cultivation of faba bean inoculated with rhizobium and quantify the amount of nitrogen left behind after harvesting the faba bean. Research also is needed to generate quantitative data not only on the biological but also the ecological and economic benefits of biofertilizer. Future research should also provide explicit evidence to elucidate the limitations associated with long cycles of cereal monoculture and also refine or redefine the virtues and advantages of incorporating rhizobia-inoculated pulse crops in the rotation system to anchor sustainability of the farming system in general. The results of this study imply that there is a strong need to scale up the use of biofertilizer by strengthening technology multiplication and the public extension system. The increased involvement of private sectors and cooperative unions in production, distribution, and marketing of quality biofertilizer is also essential in such efforts.

5. Acknowledgements

The author wishes to thank the Agriculture Knowledge, Learning, Documentation and Policy (AKLDP) Project for logistical and financial support needed to conduct the assessment. Thanks are also due to Dr. Amare Tadesse (Kulumsa Agricultural Research Center) for guiding and facilitating the link with the agriculture offices and farmers of the woredas that took part in the study. The professional assistance received from Mr. Demeke Nigussie (EIAR) in compiling the geoclimatic data and mapping the assessment areas is duly acknowledged. An utmost gratitude is due to the farmers, Development Agents (DAs), woreda experts and local leaders in the study areas for sparing their time and energy to provide the important information and perspectives on the use of biofertilizer.

6. References

Abendroth, L.J., Elmore, R.W. and Ferguson, R.B. 2006. G06-1622 Soybean Inoculation: Applying the Facts to Your Fields (Part two of a two-part series), Historical Materials from University of Nebraska-Lincoln Extension. Paper 2077. http://digitalcommons.unl.edu/extensionhist/2077.

Aryal, U.K., Xu, H.L. and Fujita, M. 2003. Rhizobia and AM Fungal Inoculation Improve Growth and Nutrient Uptake of Bean Plants Under Organic Fertilization. *Journal of Sustainable Agriculture,* 21: 27–39.

Asfaw, Z. 2000. The barleys of Ethiopia. pp 77-107 *In*: S.B. Brush (ed.) Genes in the Field: On-farm conservation of crop diversity. Lewis Publishers, Washington, D.C., USA.

Assefa, F., Keneni, K. and Demissie, N. 2018. Overview of rhizobial inoculants research and biofertilizer production for increased yield of food Legumes in Ethiopia. *Ethiopian Journal of Crop Science* (Special Issue), 1: 255–271.

ATA (Ethiopian Agricultural Transformation Agency). 2012. Ethiopian Soil Information System (EthioSIS), *www.ata.gov.et/EthioSIS*.

Belayneh, H. and Alemayehu, N. 1986. Progress in rapeseed/mustard research in Ethiopia. pp. 12-17. *In*: Omran, A. (ed.) Proceedings of the Third Oil Crops Network Workshop, 6-10 Oct. 1986, Addis Ababa, Ethiopia, IDRC- Mr 153e, Ottawa, Canada.

Beyene, D. 1988. Biological Nitrogen Fixation Research on Grain Legumés in Ethiopia - An Overview. *In*: D.P. Beck and L.A. Materon (eds.) Nitrogen Fixation by Legumes in Mediterranean Agriculture. Developments in Plant and Soil Sciences, vol 32. Springer, Dordrecht.

Bhattacharjee, R. and Dey, U. 2014. Biofertilizer, a way towards organic agriculture: A review. *African Journal of Microbiology Research* 8(24): 2332–2342.

Bridge, P., and Spooner, B. 2001. Soil fungi: diversity and detection. *Plant Soil,* 232: 147-154.

Burger, H., Schloen, M., Schmidt, W. and Geiger, H.H. 2008. Quantitative genetic studies on breeding maize for adaptation to organic farming. *Euphytica,* 163: 501–510.

Cox, H.W., Kelly, R.M. and Strong, W.M. 2010. Pulse crops in rotation with cereals can be a profitable alternative to nitrogen fertilizer in central Queensland. *Crop and Pasture Science,* 61: 752–762.

CSA. 2017. LSMS-Integrated Surveys on Agriculture Ethiopia Socioeconomic Survey (ESS). A Report by the Central Statistical Agency of Ethiopia in Collaboration with the National Bank of Ethiopia and the World Bank, Central Statistical Agency, Addis Ababa.

De Boef, W.S., Berg, T. and Haverkort, B. 1996. Crop genetic resources. pp 103-128, *In*: J. Bunders, B. Haverkort, and W. Hiemstra (eds.) Biotechnology: Building on Farmers' Knowledge. Macmillan, London and Basingstoke.

Demissie, A. 1991. A decade of germplasm exploration and collecting activities by the Plant Genetic Resource Center/Ethiopia. pp. 202–217 *In*: J.M.M. Engels, J.G. Hawkes and M. Worede (eds.) Plant Genetic Resources of Ethiopia. Cambridge University Press, Cambridge.

EIAR. 2018. Faba bean production guideline using Rhizobial bio-fertilizer technology. Ethiopian Institute of Agricultural Research (http://www.eiar.gov.et, pp 35.

Gan, Y., Hamel, C., O'Donovan, J.T., Cutforth, H., Zentner, R.P., Campbell, C.A., Niu, Y. and Poppy, L. 2015. Diversifying crop rotations with pulses enhances system productivity. *Scientific Reports* (5): https://www.nature.com/articles/srep14625.

Glazer, A.N. and Nikaido, H. 2007. Microbial biotechnology. Fundamentals of applied microbiology, 2nd edition. Cambridge University press, Cambridge, New York.

Gorfu, A. 1998. The role of fertilizers and faba bean (Vicia faba) in sustaining production of cereals in different crop rotations in the South-eastern Ethiopian Highlands. Doctoral Dissertation, GeorgAugust-Universität Göttingen, Germany.

Gorfu, A., Kuhne, R.F., Tanner, D.G. and Vlek, P.L.G. 2000. Biological N fixation in faba bean (Vicia faba L.) in the Ethiopian highlands as affected by phosphorus fertilization and inoculation. *Journal of Biology and Fertilizer Soil,* 32: 353–359.

Hailemariam, A. and Asfaw, B. 2015. Benefits and prospects of biofertilizer In Ethiopian Agriculture. *In:* Proceedings of the Second Cereals and Legumes Group Meeting 26th February 2015, Addis Ababa, Ethiopia.

Hirsch, A.M. 2009. Brief history of the discovery of nitrogen-fixing organisms (http://www.mcdb.ucla.edu/Research/Hirsch/im agesb/ History DiscoveryN2fixingOrganisms.pdf).

IFPRI. 2010. Pulses value chain in Ethiopia: Constraints and opportunities for enhancing exports. Working Paper. International Food Policy Research Institute (http://www.ifpri.org/sites/default/files/ publications/ethiopian agsectorwp _pulses.pdf).

Jarvis, A., Reuter, H.I., Nelson, A. and Guevara, E. 2008. Hole-filled SRTM for the Globe Version 4, available from the CGIAR-CSI SRTM 90m Database (http://srtm.csi.cgiar.org accessed on May 2016).

Keneni, G., Bekele, E., Getu, E., Imtiaz, M., Damte, T., Mulatu, B. and Dagne, K. 2011. Breeding food legumes for resistance to storage insect pests: Potential and limitations. S*ustainability,* 3: 1399-1415.

Keneni, G., Fikre, A. and Eshete, M. 2016. Reflections on Highland Pulses Improvement Research in Ethiopia: Past Achievements and Future Direction. *Ethiopian Journal of Agricultural Sciences* (EIAR 50th Year Jubilee Anniversary Special Issue): 17–50.

Keneni, G., Jarso, M. and Wolabu, T. 2006. Faba Bean (Vicia faba L.) Genetics and Breeding Research in Ethiopia: A Review. pp. 42-52 *In*: Kemal Ali, Gemechu Keneni, Seid Ahmed, Rajendra Malhotra, Surendra Beniwal, Khaled Makkouk and M.H. Halila (eds.). Food and forage legumes of Ethiopia: Progress and prospects. Proceedings of a Workshop on Food and Forage Legumes. 22-26 Sept 2003, Addis Ababa, Ethiopia. ICARDA, Aleppo, Syria. ISBN 92-9127-185-4. p 351.

Keneni, G., Jarso, M. and Wolabu, T. 2007. Eco-geographic distribution and microcenters of genetic diversity in faba bean (*Vicia faba*) and field pea (Pisum sativum) germplasm collections from Ethiopia. *East African Journal of Sciences*, 1: 10-24.

Keyser, H.H. and Li, F. 1992. Potential for increasing biological nitrogen fixation in soybean. *Plant and Soil,* 141: 119–135.

Kirkegaard, J., Christen, O., Krupinsky, J. and Layzell, D. 2008. Break crop benefits in temperate wheat production. *Field Crops Research,* 107: 185–195.

Krupinsky, J.M., Bailey, K.L., McMullen, M.P., Gossen, B.D. and Turkington, T.K. 2002. Managing plant disease risk in diversified cropping systems. *Agronomic Journal,* 94: 198–209.

Kwasi, G. 2018. Farmers' willingness to pay for soya bean production inputs in northern Ghana. M.Sc. Thesis, Department of Agricultural Extension, Rural Development and Gender Studies, University for Development Studies (UDS), Ghana.

Lim, G. and Burton, J.C. 1982. Nodulation status of the Leguminosae. In: Nitrogen Fixation. Vol 2. Rhizobium, pp 1-34, (Broughton, W.J., ed). Oxford University Press, UK.

Lindemann, W.C. and Glover, C.R. 1996. Inoculation of Legumes, Guide A-130. https://www.csun.edu/~hcbio027/biotechnology/lec10/lindemann2.html.

Löschenberger, F., Fleck, A., Grausgruber, H., Hetzendorfer, H., Hof, G., Lafferty, J., Marn, M., Neumayer, A., Pfaffinger, G. and Birschitzky, J. 2008. Breeding for organic agriculture: the example of winter wheat in Austria. *Euphytica,* 163: 469–480.

Lupwayi, N.Z., and Kennedy, A.C. 2007. Pulse crops in Northern great plains: impacts on selected biological soil processes. Agron. J. 99, 1700–1709. doi:10.2134/agronj2006.0313s.

Malhotra, R.S. and Singh, K.B. 2004. Classification of chickpea growing environments to control genotype by environment interaction. *Euphytica,* 58: 5-12.

Mamo, T., Haque, I. and Kamara, C.S. 1988. Phosphorus status of some Ethiopian Vertisols. pp. 232-252 In: Jutzi, S.C., Haque, I., McIntire, J. and Stares, J.E.S. (eds.) Management of Vertisols in Sub-Saharan Africa. Proceedings of a Conference, 31 August-4 September 1987, ILCA, Addis Ababa, Ethiopia.

Masso, C., Juliet, R., Ochieng, A. and Vanlauwe, B. 2015. Worldwide Contrast in Application of Bio-Fertilizers for Sustainable Agriculture: Lessons for Sub-Saharan Africa. *Journal of Biology, Agriculture and Healthcare* 5(12): www.iiste.org ISSN 2224-3208 (Paper) ISSN 2225-093X (Online).

Mohammadi, K. and Sohrabi, Y. 2012. Bacterial biofertilizer for sustainable crop production: A review. *ARPN Journal of Agricultural and Biological Science,* 7: 307-316.

Monika, S. and Wati, L. 2018. Biofertilizers: Potential Candidate for Sustainable Agriculture. *International Journal of Current Microbiology and Applied Sciences,* 7. https://doi.org/10.20546/ijcmas.2018.703.327.

Negash F, Mulualem T, Fikirie K. 2018. Effect of Cropping Sequence on Agricultural Crops: Implications for Productivity and Utilization of Natural Resources. *Advanced Crop Science Technology,* 6: 326. doi:10.4172/2329-8863.1000326.

Negassa, M. 1985. Patterns of phenotypic diversity in an Ethiopian barley collection, and the Arsi-Bale Highlands as a centre of origin of barley. *Hereditas,* 102: 139–150.

Niu, Y., Bainard, L.D., May, W.E., Hossain, Z., Hamel, C. and Gan, Y. 2018. Intensified Pulse Rotations Buildup Pea Rhizosphere Pathogens in Cereal and Pulse Based Cropping Systems. *Frontiers in Microbiology*, 9: 1909. https://doi.org/10.3389/fmicb.2018.01909.

Pannell, D. and Schilizzi, S. 1999. Sustainable Agriculture: A Matter of Ecology, Equity, Economic Efficiency or Expedience? *Journal of Sustainable Agriculture,* 13(4): 57–66.

Parr, J.F., Paperndick, I. and Youngberg, I.G. 1983. Organic farming in the United Sates: Principles and perspectives. *Agroecosystem,* 8: 183-201.

Pearson, C.J., Norman, D.W. and Dixon, J. 1995. Sustainable dryland cropping in relation to soil productivity - FAO soils bulletin 72. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy.

Penton, C.R., Gupta, V., Tiedje, J.M., Neate, S.M., Ophel-Keller, K., Gillings, M. 2014. Fungal community structure in disease suppressive soils assessed by 28s lsu gene sequencing. *PLoS One,* 9:e93893. doi: 10.1371/journal.pone. 0093893.

Sanchez, P.A. 2002. Soil fertility and hunger in Africa. *Science,* 295: 2019–2020.

Taa, A., Tanner D.G., Kefyalew G., Gorfu, A. 1997. Grain yield of barley as affected by cropping sequence and fertilizer application in Southeastern Ethiopia. *Journal of African Crop Science,* 5: 135-146.

Teshome, B., Wassie, M. and Abatineh, E. 2018. The Traditional Practice of Farmers' Legume-Cereal Cropping System and the Role of Microbes for Soil Fertility Improvement in North Shoa, Ethiopia. *Agricultural Research & Technology* 13(4): 555891.DOI: 10.19080/ARTOAJ.2018.13.555891.

The GoV of Saskatchewan. 2017. Principles and Practices of Crop Rotation. https://pubsaskdev.blob.core.windows.net/pubsask-prod/85517/85517-principle_practices_crop_rotation_2017.pdf.

Tolera, A., Ernest, S., Tolera, D., Dagne, W. and Henok, K. 2015. Effect of faba bean break crop and N rates on subsequent grain yield and nitrogen use efficiency of highland maize varieties in Toke Kutaye, Western Ethiopia. *American Journal of Research Communication,* 3: 200–210.

Tsegaye, T. 1992. Vertisols of the Centeral Highlands, Ethiopia – characterization, classification and evaluation of the phosphorus status. M.Sc. Thesis, Alemaya University of Agriculture, Ethiopia.