Boosting land use efficiency, profitability and productivity of finger millet by intercropping with grain legumes

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Abstract: Sustainable intensification of agriculture is a means of reducing the demand for increased land resources. A field experiment was conducted at two major finger millet producing areas of northwestern Ethiopia from 2017 to 2018 cropping seasons with the objective of assessing land use efficiency, profitability, and productivity of finger millet in finger millet-legume additive design intercropping. Factorial combinations of two legume crops (haricot bean and lupine) intercropped with finger millet, two planting methods (row and mixed) and three finger millet-legume planting ratios (100%:75%, 100%:50% and 100%:25% of the recommended seed rate of sole crops) were laid out in a randomized complete block design with three replications. Two sole crop finger millets (planted in rows and broadcast) and two sole crop legumes (haricot bean and lupine) were included for comparison purposes. Results revealed that the primary objective of maintaining the “full” grain yield of finger millet in an intercropping was achieved in finger millet-haricot bean row intercropping at 100:25 (2.68 tone ha⁻¹) and 100:50 (2.72 tone ha⁻¹) planting ratios. Average over the three scenarios, the latter cropping system (65%) and finger millet haricot bean intercropping at 100:75 planting ratio (56%) gave...
significantly higher yield advantage over sole cropping of finger millet and haricot bean separately. Maximum marginal rate of return was observed in finger millet-lupine mixed intercropping (1281%) and finger millet-haricot bean row intercropping (1175%). Thus, it could be concluded that the latter cropping system could be used for improving household food security to smallholder farmers by increasing the productivity of finger millet, land use efficiency, and profitability.

**Subjects:** Crop Science; Agriculture and Food; Biodiversity; Agriculture

**Keywords:** mixed intercropping; row intercropping; land equivalent ratio; profitability

1. Introduction

In Ethiopia, burgeoning human population on one hand and progressively shrinking agricultural land availability per capita on the other (Gashaw, Zewdu, & Assefa, 2017; Wuletaw, 2018) warrants temporal and spatial intensification of cropping system (Kiwia, Kimani, Harawa, Jama, & Sileshi, 2019; Niguse & Reddy, 1996). Achieving greater plant diversity such as intercropping within agricultural systems is increasingly recognized as an important pillar of sustainable development (Jensen et al., 2015; Laurent, Hauggaard-Nielsen, Naudin, & Corre-Hellou, 2015). The extent and importance of intercropping increases as farm size decreases (Niguse & Reddy, 1996). Intercropping is defined as the simultaneous growth of two or more crop species grown in the same area where they share the use of resources during all or part of their growing season (Panda, 2010). It has among the most efficient land use systems adopted in tropical regions, where farmers have only limited access to the agricultural inputs (Laurent et al., 2015). On the other hand, the continuous diffusion of modern varieties has changed the landscape from on-farm crop genetic diversity to increasingly planting genetically uniform varieties (Chandra, Pardha, Maikhuri, Saxena, & Rao, 2010). This result in increasing disease, insect pest and weed attack facilitates and increased the harmful impacts of continuous and intensive cereal cultivation on soil fertility. Growing non-leguminous crops with legumes in an intercropping system provides climbing solution for this problem (Getachew, Amare, & Woldeyesus, 2008). Indeed, several authors described intercropping as an eco-functional intensification practice which has been widely used to boost crop productivity, increase the land utilization ratio (Laurent et al., 2015), provide a balanced diet, reduce labor peaks, minimize crop failure due to adverse effects of biotic and abiotic factors, protect soil against erosion, improve the use of limited resources, increase stability of yield and provide higher returns (Getachew et al., 2008; Tsubo, Walker, & Ogindo, 2005). Productivity advantages of intercropping may arise from the complementary use of growth resources such as N and water in either space or time (Chu, Shen, & Cao, 2004; Zhang & Li, 2003). Moreover, the productivity of mixtures could exceed those of sole crops, as the mixing of the two crops may favor more significant yield components in either crop (Getachew et al., 2008).

Depending on the production objectives, additive, replacement and intermediate designs may be used to combine species in intercropping systems (Connolly, Goma, & Rahim, 2001; Laurent et al., 2015). Thus, where different plant species grow together, inter-specific competition and facilitation between plants may occur (Vandermeer, 1989). Inter-specific competition is mainly high in additive designs compared with other intercropping designs (Connolly et al., 2001). On the other hand, facilitative interactions are common for both intercrop designs (Malezieux, Crozat, & Dupraz, 2009). Experimental evidences indicated that as far as the agronomic factors affecting intercropping competition and complementary are kept optimum, the extra yield of legume crop could be obtained by using any type of intercropping design without affecting the main crop yield (Niguse & Reddy, 1996). Besides, depending on the character of the crops, mixed and row intercropping systems are the most common cropping systems practiced by Ethiopian farmers (Areaga, Manyong, & Gockowski, 2006). Both mixtures have their own merits and demerits (Senbayram et al., 2016). For the success of these intercropping systems, however, several aspects need to be taken into consideration. For instance, the potential of cereal-legume intercropping system to provide...
additional nitrogen depends on crop species, density of the component crops and planting pattern 
(Brintha & Seran, 2009). Due to bypassing these considerations, component crops in an intercrop 
have given low productivity compared with their respective sole crops. For instance, Akuja, 
Akundabweni, and Chweya (2003) showed that Crotalaria brevidens-finger millet (E.coracana) 
and Trifolium quartinianum-finger millet intercropping depressed and increased the yield of finger 
millet, respectively.

Cereal-legume intercropping is a common practice in Sub-Saharan Africa aimed at minimizing 
risks associated with monoculture (Getachew et al., 2008; Zhang et al., 2008). That means, it 
ensures diversification of diets and risk reduction in the case of failure of one of the crops (Kiwia 
et al., 2019). Generally, cereals are nutrient-exhaustive crops and absorb nutrients from the upper 
soil layers (Layek et al., 2018). Legume, (i) being able to fix atmospheric N in soil, improves the soil 
fertility and reduces the completion of limited soil nutrients within the soil (Layek et al., 2018) (ii) 
help in absorbing nutrients from deeper soil layers due to their robust tap root system (Laurent 
et al., 2015; Layek et al., 2018). Among the cereal-legume intercropping systems, combination of 
finger millet with pigeon pea (C.caian), soybean (G.max), haricot bean (P.vulgaris) and groundnut 
(A. hypogaea) are the common farming practices in Sub-Saharan Africa (Thilakarathna & Raizada, 
2015). Finger millet is the fivth of the top 10 lists of most frequently used intercrop crops (Jasem 
& Ahmad, 2014). In Ethiopia, rising input costs, decline in farm size and soil quality, and buildup of 
insect pests, diseases and weeds have threatened the ecological and economic sustainability of 
major crop production (Getachew et al., 2008). Consequently, due to the ability to tolerate drought 
and disease and other factors, finger millet has been widely grown by low input farmers (Awol, 
Masresha, & Kassahun, 2013; Fetene, Okori, Gudu, Mnenev, & Tesfaye, 2011). It is traditionally 
grown as a main crop in combination with pulse crops for the purpose of spreading environmental 
or marketing risks and providing a range of different foods for their own consumption (Minale, 
Tilahun, & Alemayehu, 2001; Niguse & Reddy, 1996).

On the other hand, haricot bean (Vidigal, Romeiras, & Filipa Monteiro, 2019; Yayeh, Getachew, 
Enyew, & Alemayehu, 2019) and lupine (Lekawunt, Kijora, von Santen, & Peters, 2012) are 
multipurpose crops (food grain, animal feed and improving soil fertility) that have been grown in 
mid-altitude of northwestern Ethiopia. Intercropping of these legume crops (mainly lupine) as 
a supplementary crop with finger millet has been practiced by subsistence farmers under infertile 
soil (Bantie, Fetien, & Tadesse, 2014; Lekawunt et al., 2012). However, its application follows simple 
and natural principles that have been practiced only by the experience of farmers. The land use 
efficiency and profitability of this cropping system and its effect on productivity of finger millet 
have not been investigated yet under research. Rather, much experimental work has shown that 
most intercropping researches in Sub-Saharan Africa is mainly focused on the combination of 
staple cereal crops with beans (Matusso, Mugwe, & Mucheru-Muna, 2014; Vidigal et al., 2019). 
Moreover, in most intercropping experiments, the land use efficiency has been determined based 
on the land equivalent ratio (LER) values from block-wise grain yield of the component sole crop 
while the profitability of intercropping was determined at most based on 1-year cost of production. 
However, this kind of evaluation could not provide a complete picture of the production efficiency 
of intercropping systems. Selection of compatible legume crops in finger millet-legume additive 
design intercropping with proper planting methods and ratios using various scenarios of sole crop 
production and labor cost is hence crucial for adopting the right intercropping system. Thus, the 
objective of this study was to assess the effect of legume crops, planting methods and ratios on 
land use efficiency, profitability and productivity of finger millet in finger millet based legume 
intercropping.

2. Materials and methods

2.1. Descriptions of the study sites

A field experiment was conducted in two major finger millet producing areas of northwestern 
Ethiopia (South Achefere and Mecha districts) during 2017 and 2018 cropping seasons. The
experimental site in the former district is located at 11°20'26.05"N latitude and 36°56'3.45"E longitude with an altitude of 2028 meters above sea level (masl), while the other site in the latter district is located at 11°23'29.24"N latitude and 37°6'29.69"E longitude with an altitude of 1981 masl. Weather data (rainfall and temperature) of the experimental year for experimental sites were collected in the northwestern Ethiopia meteorology station office in Bahir Dar, Ethiopia. The total rainfall at South Achefere during 2017 and 2018 cropping seasons were 1089 mm and 1521 mm, respectively (Figure 1), while at Mecha it was 1144 mm and 1769 mm, respectively (Figure 2). At South Achefere the minimum and maximum temperatures were 14°C and 29°C during 2017 and 11°C and 29°C during 2018. Whereas at Mecha the minimum and maximum temperatures in 2017 and 2018 cropping seasons were 11°C and 28°C and 11°C and 29°C, respectively. Both study areas exhibited mono-modal rainfall pattern and generally are found in agro-ecological zone of moist Wayena Dega (mid-highland) (Alemayehu et al., 2016).
To identify the general soil characteristics of both study sites before the start of the experiment, soil samples were taken at five points diagonally at 0–20 cm soil depth and composited during the respective years. The composite soil samples were submitted to the Soil Chemistry and Water Quality Laboratory Section of Amhara Design and Supervision Works Enterprise in the respective years. The soil samples were air-dried, crushed and sieved through a 2 mm sieve and analysed to determine soil texture, total nitrogen, pH, available phosphorus, organic carbon and electrical conductivity and cation exchange capacity. The methods and results of the soil analysis are presented in Table 1. The results of the soil analysis before the start of the experiment indicated that both study sites have clay texture and relatively comparable soil properties.

2.2. Experimental treatments and design

Two legume crops (haricot bean and lupine (L. angustifolius)) were intercropped with finger millet at the same time using two intercrop planting methods (row and mixture) and three finger millet-legume planting ratios (100%:75%, 100%:50% and 100%:25% of the respective recommended seed rate of sole crops) (additive design intercropping). Two sole crop finger millet (planted in a row and broadcast) and two sole crop legumes planted in a row (haricot bean and lupine) were used as a check. A total of 16 treatments (Table 2) was laid out in a randomized complete block

| Soil properties          | South Achefere | Mecha | Method of soil analysis                     | Rating                                      |
|--------------------------|----------------|-------|--------------------------------------------|---------------------------------------------|
| pH (H₂O)1:2.5            | 5.29           | 6.53  | pH meter (H₂O 1:2.5)                       | Moderately acidic at South Achefere and slightly acidic at Mecha (Panda, 2010) |
| CEC (cmol(+) kg⁻¹)       | 20.77          | 24.03 | Ammonium acetate method (Chapman, 1965)    | Medium (Landon, 1991)                       |
| EC (ds m⁻¹)              | 0.13           | 0.09  | Unfiltered 1:5 soil: distilled water suspension (EC 1:5) at 25°C (FAO, 2008) | Low (FAO, 2008)                            |
| OC (%)                   | 1.26           | 1.21  | Walkley and Black method (Heanes, 1984)    | Very low (Landon, 1991)                     |
| TN (%)                   | 0.12           | 0.14  | Micro-Kjeldahl method (Bremer & Mulvaney, 1982) | Low (Landon, 1991)                         |
| Ava.P (ppm)              | 8.77           | 10.23 | Bray method (Bray & Kurz, 1945)            | Low (Landon, 1991)                         |
| BD (g cm⁻³)              | 1.05           | 1.04  | Soil core method (Blake & Hartge, 1986)    | Low (Landon, 1991)                         |
| Soil texture             |                |       | Hydrometer method (Gee & Bauder, 1986)     |                                             |
| Sand (%)                 | 10.12          | 12.33 | -                                          |                                             |
| Silt (%)                 | 23.34          | 22.12 | -                                          |                                             |
| Clay (%)                 | 68.27          | 66.5  | Clay                                       | Clay (Landon, 1991)                        |
| Soil textural class      | Clay           | Clay  | Cay (Landon, 1991)                         |                                             |
| Soil moisture level (%)  | 19             | 23    | Gravimetric FAO (2008)                     | Good (FAO, 2008)                           |

Mean of the 2 years (2017 and 2018)

OC: organic carbon; TN: total nitrogen; Ava.P: available phosphorus; EC: electrical conductivity; CEC: cation exchange capacity; BD: bulk density.
design (RCBD) with three replications (Figure 3). The recommended seeding rate of sole finger millet, sole haricot bean, and sole lupine were 15 kg ha$^{-1}$, 100 kg ha$^{-1}$ and 40 kg ha$^{-1}$, respectively. Gross and net areas of the experimental plot were 4.8 m x 3 m (14.4 m$^2$) and 3.2 m x 2 m (6.4 m$^2$) with a distance of 0.5 m and 1 m between adjacent plots and replications, respectively (Figure 3).

2.3. Experimental materials and procedures

*Mecha*, *Batu* and *Sanabor* varieties of finger millet, haricot bean and lupine with average maturity period of 151, 84 and 122 days, respectively, were used for the present study. In row intercropping treatments, seeds of finger millet were drilled in rows at its recommended, inter-row spacing of 40 cm, while seeds of legume crops (haricot bean or lupine) were planted in rows between every after one (1:1 row ratio), two (2:1 row ratio) and three (1:1 row ratio) rows of finger millet, respectively, in an intra-row spacing of 10 cm (Figure 4(b)). In mixed intercropping treatments, seeds of 25%, 50%, and 75% of the recommended seeding rate of sole legume crops, were mixed before planting and sown by randomly broadcasting with the recommended seed rate of finger millet (Figure 4(a)). Sole crop legumes were planted in a row at the spacing of 40 cm x 10 cm between rows and plants, respectively. Sole crop finger millet planted in a row

| NO. | Treatments combination | Abbreviations |
|-----|------------------------|---------------|
| 1   | Finger millet-haricot bean (FM+HB) | Row intercropping (RI) | F+HB RI at 100:75 |
| 2   | Finger millet-haricot bean | Row intercropping | F+HB RI at 100:50 |
| 3   | Finger millet-haricot bean | Row intercropping | F+HB RI at 100:25 |
| 4   | Finger millet-haricot bean | Mixed intercropping (MI) | F+HB MI at 100:75 |
| 5   | Finger millet-haricot bean | Mixed intercropping | F+HB MI at 100:50 |
| 6   | Finger millet-haricot bean | Mixed intercropping | F+HB MI at 100:25 |
| 7   | Finger millet-lupine (FM+L) | Row intercropping | F+L RI at 100:75 |
| 8   | Finger millet-lupine | Row intercropping | F+L RI at 100:50 |
| 9   | Finger millet-lupine | Row intercropping | F+L RI at 100:25 |
| 10  | Finger millet-lupine | Mixed intercropping | F+L MI at 100:75 |
| 11  | Finger millet-lupine | Mixed intercropping | F+L MI at 100:50 |
| 12  | Finger millet-lupine | Mixed intercropping | F+L MI at 100:25 |
| 13  | Sole finger millet planted in rows (recommended planting method) | SFMR |
| 14  | Sole finger millet planted in broadcast (traditional/existing planting method) | SFMB |
| 15  | Sole haricot bean planted in rows (recommended planting method) | SHB |
| 16  | Sole lupine planted in rows (recommended planting method) | SL |
(SFMR) was planted similar to row intercropping, while the second sole crop finger millet was planted in the broadcast planting method (SFMB) (Figure 4(a)). During the first weeding, excess finger millet plants were uprooted to leave millet spaced at 3 cm between plants (for row planted), while for broadcast mixed cropping treatments, excess finger millet plants were uprooted to leave 1200 plants plot\(^{-1}\). Finger millet planted in both planting methods and cropping systems received N and P\(_2\)O\(_5\) fertilizers at the rates of 46 kg ha\(^{-1}\). All recommended amounts of P\(_2\)O\(_5\) and half of N fertilizers were applied at planting time of finger millet, while the remaining half N was applied at tillering stage. Legume crops planted in intercropping and sole cropping received 18 kg ha\(^{-1}\)N and 46 kg ha\(^{-1}\) P\(_2\)O\(_5\) at planting time. The fertilizer application method for row planted crops were in band with a depth of 2 cm, while for sole finger millet and mixed intercrops planted in broadcasting, fertilizer was in broadcast method.

### 2.4. Data collection and measurements

#### 2.4.1. Agronomic attributes of finger millet

In all planting methods, plant height, total tillers plant\(^{-1}\) and length of fingers were determined at physiological maturity from 10 randomly sampled finger millet plants in the net plot area. The total above-ground biomass of the component crops were measured after the plants from the net plot area were harvested and sun-dried for 2 weeks with average air temperature of 25–27°C till constant dry weight attained. Similarly, grain yield of both component crops was determined after the grain yield was separated from the total biomass yield. The grain yield of finger millet and legumes were then dried, threshed, cleaned and adjusted to 12% and 10% moisture level, respectively. To estimate the leaf area index (LAI) of the cropping system, field photograph pictures were taken at 1 m\(^2\) quadrat using a digital camera (Coolpix 4500, Nikon, Tokyo, Japan) from 1 m above ground at a common period of full vegetative stage of legumes and at full tillering stage of finger millet. Measurements were usually carried out shortly before sunset. All the
photographs were imported to the computer and saved as uncompressed, high-resolution files. All these files are directly imported to the LAI calculator software to analyze the LAI (Thimonier, Sedivy, & Schleppi, 2010).

2.5. Data analysis
Data analysis for intercrop experiments was conducted using the GLM (general linear model) procedure of SAS version 9.2 (Statistical Analysis System [SAS] Institute, 2008) for each site and year. Finally, the data were combined over sites since values for the error mean square of the two sites were homogeneous (Gomez & Gomez, 1984). In the combined analysis, year was considered as a random variable and site as fixed variable. Crop characteristics that showed significant differences (P < 0.05) were further tested using single degree of freedom orthogonal contrasts to determine the significance of each factor. Linear regression analysis was also carried out to examine the relationship between finger millet grain yield with planting ratio and grain yield of legumes.

2.6. Evaluation of land use efficiency
Land equivalent ratio (LER) is a measure of the efficiency of land use in an intercropping experiment. It indicates the efficiency of intercropping for using the resources of the environment compared with mono-cropping (Zhang, Zaibin, & Shuting, 2014). The LER was calculated using the formula outlined by Mead and Willey (1980):

$$\text{LER} = \frac{\sum_{i=1}^{n} \left( \frac{Y_i}{Y_m} \right)}{n}$$

where Yi and Ym are yields of component crops in intercrop and sole cropping, respectively, and n is the number of the crops involved. The value of unity is the critical value. When partial land equivalent ratio (PLER) of crop a is greater than 0.5 and PLER of crop b is less than 0.5 in an intercropping, indicating that crop a is highly competitive in terms of growth resource use (Chen,
Westcott, Neill, Wichman, & Knox, 2004). When PLER of crop \( a \) is higher than that of \( b \), showing that the crop \( a \) contributed more to the total LER of the intercropping system than \( b \) (Feng et al., 2016). When LER = one, there is complementarity between component crops. When the LER is greater than one, the intercropping favors the growth and yield of the species. In contrast, when LER is lower than one the intercropping negatively affects the growth and yield of the plants grown in mixtures (Mead & Willey, 1980). To get more complete picture of LER, sole crop of the component crops were obtained in the following four production situation scenarios (Federer, 1999):

1. LER \((\text{LER}_1)\) from block-wise grain yield of sole crop finger millet and legumes.
2. LER \((\text{LER}_2)\) from mean yields from “r” replicates for the sole crops (where \( r \) is the number of replications).
3. LER \((\text{LER}_3)\) from farmer’s yields averaged over 3 years (1.7, 1.2 and 1.5 tone ha\(^{-1}\) for finger millet, haricot bean and sweet lupine, respectively) (average yield from 2016–2018, the Central Statistical Agency of Ethiopia).
4. LER \((\text{LER}_4)\) from a theoretical “optimum value” of grain yield for the sole crop (4.3 tone ha\(^{-1}\) (Ethiopian Agricultural Research Organization [EARO], 2004) and 2.5 ton ha\(^{-1}\) (Lekawunt et al., 2012) for finger millet, haricot bean and sweet lupine, respectively).

2.7. Partial budget analysis
Economics of the intercropping system was analyzed following the procedure of the International Maize and Wheat Improvement Center (International Maize and Wheat Improvement Center [CIMMYT], 1988) at three scenarios (cost price ratios) based on the existing trend in the increasing cost of production. Cost price ratios were calculated by dividing the labor cost man day\(^{-1}\) with grain prices of legumes kg\(^{-1}\), keeping legume grain price constant while labor cost man day\(^{-1}\) increased from 50 to 75 and to 100 Ethiopian Birr (ETB). Labor cost included costs for planting, harvesting, threshing, and cleaning of the component crops in each treatment. The average grain prices, used for the determination of cost price ratios were ETB 9.0, 25.0 and 15.0 kg\(^{-1}\) for finger millet, haricot bean, and lupine, respectively, based on the average local market prices in the months from October to February. Thus, the three cost/price ratios as labor cost man-day\(^{-1}\)/haricot bean grain price kg\(^{-1}\) of 2, 3 and 4, and labor cost man-day\(^{-1}\)/lupine grain price kg\(^{-1}\) of 3, 5 and 8 were assumed. The net return was calculated by deducting the total variable cost from the gross return. Acceptability of intercropping by farmers is best judged by the marginal rates of return (MRR), an approach to maximize profit (Kiwia et al., 2019). Therefore, MRR for each treatment was calculated by deducting the net return of the treatment from the sole crop finger millet and then divided by the cost incurred for the treatment. As a rule of thumb MRR less than 50% is considered low and unacceptable to farmers; a higher cut-off value (MRR > 100%) has been recommended if the technology involves significant change from current farmer practices (Kiwia et al., 2019).

3. Results

3.1. Response of finger millet agronomic attributes to intercropping
Results showed plant height, total tiller plant\(^{-1}\), finger length, biomass yield of finger millet (Table 3), LAI and grain yields of the component crops (Table 4) were significantly \((P < 0.05)\) affected by treatments in both years. During the two experimental years, maximum plant height was observed in a row (FM+L RI) (110–110.57 cm) and mixed (FM+L MI) (106–107.91 cm) intercropping of finger millet and lupine at 100:75 planting ratio. The minimum plant height was recorded in SFMR (76.78–80.83 cm). In both years, significantly higher finger length was recorded in finger millet-haricot bean row intercropping (FM+HB RI) at 100:50 (8.00–9.00 cm) planting ratio, while the lowest finger length was recorded in FM+L MI at 100:75 (6.70–7.06 cm) planting ratio. Similarly, maximum total finger millet tiller plant\(^{-1}\) was recorded in FM+HB RI at 100:50 planting ratio (5.78–6.84) while the lowest was recorded in FM+L MI (2.39) and FM+L RI (3.47) at 100:75 planting ratio in 2017 and 2018, respectively. Generally, LAI in finger millet-haricot bean intercropping was significantly higher than in finger millet-lupine intercropping (Table 4). Specifically, maximum LAI was recorded in FM+HB MI at
| Intercropping treatments | Plant height (cm) | Total tiller per plant | Finger length(cm) | Biomass yield (tone ha⁻¹) |
|--------------------------|------------------|------------------------|-------------------|-------------------------|
|                          | 2017  | 2018  | 2017  | 2018  | 2017  | 2018  | 2017  | 2018  |
| **Legume**               |       |       |       |       |       |       |       |       |
| Haricot bean             |       |       |       |       |       |       |       |       |
| Row 100:75               | 80.50a | 83.76a | 4.00c | 4.75dc | 7.72a | 8.10cd | 11.37b | 12.03b |
| 100:50                   | 84.33cde | 82.62d | 5.78a | 6.84a | 9.00a | 8.97a | 11.90a | 12.36a |
| 100:25                   | 80.00ef    | 80.59d  | 5.28b | 5.49b | 7.94cd | 8.60e | 11.39e | 12.18e |
| Mixed 100:75             | 83.22efg   | 82.88d  | 3.61cde | 4.50cde | 7.39f | 7.40ef | 18.50c | 27.92a |
| 100:50                   | 93.50bc    | 86.12c  | 3.56cde | 4.10def | 7.33g | 7.26ef | 20.00b | 28.04a |
| 100:25                   | 88.22cde   | 82.07d  | 3.78cdef | 4.53cdef | 8.33b | 7.77de | 20.17b | 28.33b |
| Lupine                   |       |       |       |       |       |       |       |       |
| Row 100:75               | 110.50a   | 110.57a | 2.83df | 3.47f | 7.56g | 6.83f | 11.30f | 7.64f |
| 100:50                   | 93.00bc   | 94.77c  | 3.22cde | 3.80cde | 7.28g | 7.77de | 8.36f | 9.47f |
| 100:25                   | 97.72a    | 97.51c  | 3.61cde | 4.30cde | 8.17abc | 8.13bc | 9.24f | 9.53f |
| Mixed 100:75             | 106.11a   | 107.91a | 2.39ef | 3.63be | 7.06a | 6.70e | 22.00a | 18.75d |
| 100:50                   | 98.78b    | 103.40a | 2.94f | 3.87dfe | 7.89cde | 7.13def | 20.17b | 20.68c |
| 100:25                   | 94.33bc   | 94.93c  | 3.17ef | 4.63dce | 6.83f | 7.27efg | 15.33d | 21.61c |
| Sole finger millet planted in row | 76.78a | 80.83a | 5.89c | 6.47bc | 7.89cde | 8.56cde | 11.41c | 12.64c |
| Sole finger millet planted in broadcast | 90.39cd | 83.74d | 3.50d | 4.23d | 8.17bc | 7.60cd | 20.67b | 25.85b |
| LSD                      | 6.95**   | 5.83** | 0.45** | 1.01** | 0.34** | 0.52** | 1.02** | 1.68** |
| CV (%)                   | 4.54     | 3.82   | 6.96   | 13.10 | 2.63  | 4.04  | 4.02  | 5.67  |
| SE±                      | 4.95     | 1.95   | 0.16   | 0.43  | 0.11  | 0.20  | 0.50  | 0.56  |

*Data were combined over sites (South Achefere and Mecha districts)
PM: planting method; PR: planting ratio.
** is significant difference at 0.01 probability level. Means with the same letter are not significantly different.
Table 4. Effect of additive design intercropping treatments on LAI and grain yields of the component crops in northwestern Ethiopia*

| Intercropping treatments | Leaf area index | Finger millet grain yield (tone ha$^{-1}$) | Legume grain yield (tone ha$^{-1}$) |
|--------------------------|----------------|------------------------------------------|----------------------------------|
|                          |                | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 |
| **Legume**               | PM   | PR | 2017 | 2018 | 2017 | 2018 | 2017 | 2018 |
| **Haricot bean**         | Row   | 100:75 | 4.36b | 3.96ab | 2.11f | 2.60b | 0.93b | - | 1.08b | - |
|                          |       | 100:50 | 3.53c | 4.67a | 2.75a | 2.78a | 0.58a | - | 0.56a | - |
|                          |       | 100:25 | 3.43c | 4.20a | 2.62b | 2.74a | 0.39f | - | 0.40a | - |
|                          | Mixed | 100:75 | 5.61a | 3.68a | 2.10 | 2.45 | 0.65a | - | 0.50a | - |
|                          |       | 100:50 | 4.29c | 3.77bc | 2.29a | 2.41a | 0.54c | - | 0.50a | - |
|                          |       | 100:25 | 4.58d | 2.76de | 2.35a | 2.46a | 0.43c | - | 0.41a | - |
| **Lupine**               | Row   | 100:75 | 1.37a | 2.06a | 1.38h | 1.37b | 1.41b | - | 2.28a | - |
|                          |       | 100:50 | 3.99c | 2.54d | 2.18a | 2.02d | - | 0.90c | - | 1.38d |
|                          | Mixed | 100:75 | 3.71c | 2.66de | 2.33a | 1.83a | - | 0.72a | - | 1.23a |
|                          |       | 100:50 | 1.11c | 1.84b | 1.03c | 1.31d | - | 1.80b | - | 2.41a |
|                          |       | 100:25 | 1.25c | 2.12c | 1.13c | 1.35c | - | 1.27c | - | 2.02c |
| **Sole finger millet planted in row** |       |       | 2.50c | 4.31a | 2.43c | 2.74a | - | - | - | - |
| **Sole finger millet planted in broadcast** |       |       | 4.20a | 4.09a | 2.22a | 2.56b | - | - | - | - |
| **Sole haricot bean**    |       | 3.35c | 2.19a | - | - | 1.20a | - | 1.45a | - | - |
| **Sole lupine**          |       | 2.98d | 1.75a | - | - | - | 1.97a | - | 2.50a | - |
| **LSD**                  |       | 1.61** | 1.18** | 0.06*** | 0.06** | 0.21** | 0.18** | 0.08** | 0.22*** |
| **CV%**                  |       | 28.78 | 22.95 | 1.92 | 2.00 | 18.26 | 15.28 | 6.85 | 6.60 |
| **SE**                   |       | 0.01 | 0.56 | 0.02 | 0.02 | 0.07 | 0.06 | 0.03 | 0.07 |

*Data were combined over sites (South Achefera and Mecha districts)

PM: planting method; PR: planting ratio.

**, *** are significant difference at 0.01 and 0.001 probability level, respectively. Means with the same letter are not significantly different.
100:75 planting ratio (5.61) in 2017 and in FM+HB RI at 100:50 planting ratio (4.67) in 2018. However, these cropping systems are statistically similar effect on LAI in 2018. The lowest LAI of the system was observed in FM+L MI at all planting ratios (1.47–3.15).

Significantly higher biomass yield in 2017 was observed in FM+MI at 100:75 planting ratio (22.00 ton ha\(^{-1}\)), while in 2018, it was recorded in finger millet-haricot bean mixed intercropping (FM+HB MI) (27.92–28.33 tone ha\(^{-1}\)) followed by SFMB (25.85 tone ha\(^{-1}\)) (Table 3). In both years, the lowest finger millet biomass yield was recorded in FM+L RI (8.91–9.47 tone ha\(^{-1}\)) followed by FM+HB RI (11.70–12.13 tone ha\(^{-1}\)) at all planting ratios. In both years, the maximum grain yield of finger millet was recorded in FM+HB RI at 100:50 (2.7–2.78 tone ha\(^{-1}\)) followed by 100:25 (2.62–2.74 tone ha\(^{-1}\)) planting ratios (Table 4). Meanwhile, the lowest grain yield of finger millet was observed in FM+L MI at 100:75 planting ratio (1.03–1.31 tone ha\(^{-1}\)). Generally, the grain yield of finger millet was higher in finger millet-legume row intercropping treatments (1.37–2.76 tone ha\(^{-1}\)) than in finger millet-legume mixed intercropping (1.17–2.41 tone ha\(^{-1}\)). Moreover, finger millet grain yield obtained from finger millet-haricot bean intercropping treatments (2.28–2.76 tone ha\(^{-1}\)) was much higher than obtained from finger millet-lupine intercropping (1.17–2.59 tone ha\(^{-1}\)). Notably, FM+HB RI at 100:50 and 100:25 planting ratios gave 15.48% and 12.13% higher finger millet grain yield, respectively, over SFMB. Besides, the respective cropping systems gave 6.56% and 3.47% higher finger millet grain yield over SFMR.

Regression analysis showed that grain yield of finger millet significantly and negatively related to planting ratios (Figure 5). This means that, as the seed rate of legume crops increased from 25% to 75% of the recommended seeding rate of the sole crop legume, finger millet grain yield in a mixture was reduced by 9.76% and 38.46% when intercropped with haricot bean and lupine, respectively. This is further supported by the direct linear relationship between grain yield of legume crops with planting ratios (Figure 6) and the indirect linear relationship between grain yields of legume crops with finger millet (Figure 7).

### 3.2. Land use efficiency in finger millet based legume intercropping

Results revealed that partial land equivalent ratio (PLER) of finger millet and haricot bean in scenario 1 (LER\(_1\)) and 2 (LER\(_2\)) in all treatments were greater than 0.5, while PLER of lupine in a row and mixed finger millet-lupine intercropping at 100:75 planting ratio was less than 0.5 (Table 5). In scenario 3 (LER\(_3\)) PLER of finger millet in FM+HB MI and FM+L RI at all planting ratio was less than 0.5, while PLER of both legume crops was greater than 0.5 only in a row and mixed finger millet-legume intercropping at 100:75 planting ratio. On the other side, PLER of finger millet and legumes were greater and less than 0.5, respectively, in all intercropping systems in scenario 4 (LER\(_4\)). The LER in scenario 1 (LER\(_1\)), 2 (LER\(_2\)) and 3 (LER\(_3\)) were greater than one, while LER in scenario 4 (LER\(_4\)) was less than one in all intercropping treatments (Table 5). In scenarios 1 and 2 maximum LER was recorded in FM+HB RI at 100:50 followed by FM+HB MI at 100:75 planting ratios, while in scenarios 3 and 4 maximum LER was rescored in FM+HB RI at 100:50 followed by 100:75 planting ratios. Overall the LER of intercrops was higher in scenario 3 followed by scenarios 1 and 2. Moreover, the mean of LER over the three scenarios indicated that maximum LER was obtained in FM+HB RI at 100:50 planting ratio (1.65) followed by FM+L by both planting methods at 100:75 planting ratio (1.56). This result indicates that 56%-65% more land is required in case of sole crop or about 56%-65% yield advantage can be obtained from the intercrop over the sole cropping. Contrarily, FM+L RI at 100:75 and FM+L MI at 100:25 and 100:50 resulted in 3.5% and 9.5% yield reduction, respectively, compared to sole cropping.

### 3.3. Profitability of finger millet based-legume intercrops

In the present study, according to a partial budget analysis (Table 6), across the three labor cost to legume price ratios, the three highest NR and MRR were obtained from FM+HB RI at 100:50 planting ratio, and FM+L MBI at 100:50 and 100:75 planting ratios. On average the respective monetary advantages of these intercrops were 37.50% (12,973 ETB ha\(^{-1}\)), 46.03% (15,921 ETB ha\(^{-1}\)) and 64.62% (22,352 ETB ha\(^{-1}\)) relative to the sole crop finger millet. However, average over the three labor cost to legume price ratios, the MRR was greater than 100% in FM+HB and FM+L RI at all planting
Similar trends are observed in FM+L MI at all but at 100:25 planting ratios. On the other hand, the MRR was lower than 100% for FM+HB MI at 100:75 (−1.06) and 100:25 (−1.80) and FM+L at 100:25 (−2.86) planting ratios. The study had also revealed that as labor cost to legume grain price ratio increased, MRR from the intercrop was decreased. For instance, in FM+HB RI at 100:50 planting ratio, MRR was decreased by 34% as labor cost to legume price ratio increased from 2 to 4.
4. Discussion

Although the response of finger millet varies across years, the effect of each intercropping treatment on most agronomic attributes of finger millet were consistent over the years. Generally, the grain yield of the component crops during 2017 was considerably lower than during 2018, since at both experimental sites rainfall was much higher and uniformly distributed during 2018 compared with the 2017 cropping season (Figures 1 & 2). The highest plant height in FM+L RI and FM+L MI at 100:75 planting ratio might be due to strong competition for light resulted from long co-growing period in an intercropping (Yayeh, Getachew, Enyew, & Alemayehu, 2019b), while the lowest plant height in SFMR and FM+HB RI at 100:50 planting ratio might be due to absence and lower interspecific competition for light, respectively. The long co-growth of finger millet and lupine (122 days) (Yayeh et al., 2019b), and the high number of lateral branches plant$^{-1}$ and long plant height of lupine (Lekawunt et al., 2012) in mixture owing to intense light and nutrient competition. This in turn leads to increase finger millet plant height and reduction in finger length and total tiller plant$^{-1}$. Corroborated with this result, Bantie et al. (2014) claimed that in cereal-lupine additive design intercropping experiment finger millet plant height increased while total tiller plant$^{-1}$ decreased with increasing lupine seed proportion.

Recent studies show that total shoot dry weight (above-ground biomass) and grain yield of intercropped cereals and legumes was significantly higher in intercropping than in sole crop (Latati et al., 2016) which is consistent with the present study. This is may be because intercropping promotes the ability of legume and cereal to facilitate phosphorus and nitrogen acquisition through root-induced processes. Moreover, legumes, with their adaptability to different cropping patterns and their ability to fix N2, may offer opportunities to sustain increased plant biomass for intercropped species Latati et al. (2016). Maximum biomass yield in FM+HB MI than FM+L MI at all planting ratios might be due to high temporal niche differentiation (TND) between finger millet and haricot bean thereby the reduction of growth resource competition than between finger millet and sweet lupine (Yayeh et al., 2019b). Tosti and Guiducci (2010) showed that the competitive effect of the faba bean reduced the biomass accumulation of the intercropped wheat, since faba bean and wheat had long co-growing period. Moreover, regardless of planting methods and type of intercropped legumes, biomass yield of finger millet was increased in line with seed the proportion of
### Table 5. Effect of additive design intercropping treatments on land use efficiency in northwestern Ethiopia

| Legume    | PM       | PR | PLERFM1 | LER1 | PLERFM2 | LER2 | PLERFM3 | LER3 | PLERFM4 | LER4 | LER*  |
|-----------|----------|----|---------|------|---------|------|---------|------|---------|------|-------|
| **Finger millet intercropping** |          |    |         |      |         |      |         |      |         |      |       |
|           |          |    |         |      |         |      |         |      |         |      |       |
| Haricot bean | Row     | 100:75 | 0.91  | 0.88  | 1.79  | 0.91 | 0.86    | 1.77 | 1.38    | 0.51 | 190   | 0.59 | 0.20 | 0.79 | 1.56 |
|           | 100:50  | 1.07 | 0.77    | 1.84  | 1.07   | 0.75 | 1.82    | 1.62 | 0.45    | 2.07 | 0.69  | 0.18 | 0.87 | 1.65 |
|           | 100:25  | 1.04 | 0.52    | 1.56  | 1.04   | 0.51 | 1.54    | 1.58 | 0.30    | 1.88 | 0.67  | 0.12 | 0.79 | 1.44 |
|           | Mixed   | 100:75 | 0.95  | 0.86  | 1.82  | 0.95 | 0.85    | 1.80 | 1.34    | 0.51 | 185   | 0.57 | 0.20 | 0.77 | 1.56 |
|           | 100:50  | 0.98 | 0.66    | 1.64  | 0.98   | 0.65 | 1.63    | 1.38 | 0.39    | 1.77 | 0.59  | 0.16 | 0.74 | 1.45 |
|           | 100:25  | 1.01 | 0.76    | 1.76  | 1.01   | 0.75 | 1.76    | 1.42 | 0.45    | 1.86 | 0.60  | 0.18 | 0.78 | 1.54 |
| Lupine    | Row     | 100:75 | 0.53  | 0.54  | 1.07  | 0.53 | 0.54    | 1.07 | 0.81    | 0.35 | 1.16  | 0.34 | 0.21 | 0.56 | 0.97 |
|           | 100:50  | 0.81 | 0.55    | 1.37  | 0.81   | 0.55 | 1.36    | 1.23 | 0.36    | 1.59 | 0.52  | 0.22 | 0.74 | 1.27 |
|           | 100:25  | 0.80 | 0.35    | 1.16  | 0.80   | 0.35 | 1.16    | 1.22 | 0.23    | 1.46 | 0.52  | 0.14 | 0.66 | 1.11 |
|           | Mixed   | 100:75 | 0.49  | 0.86  | 1.35  | 0.49 | 0.86    | 1.34 | 0.69    | 0.56 | 1.25  | 0.29 | 0.34 | 0.63 | 1.14 |
|           | 100:50  | 0.52 | 0.51    | 1.03  | 0.52   | 0.50 | 1.02    | 0.73 | 0.33    | 1.06 | 0.31  | 0.20 | 0.51 | 0.91 |
|           | 100:25  | 0.62 | 0.46    | 1.07  | 0.62   | 0.45 | 1.07    | 0.87 | 0.30    | 1.17 | 0.37  | 0.18 | 0.55 | 0.97 |
| SFMR      | -       | -   | 1.00    | -     | -      | 1.00 | -       | 1.52 | 0.65    | -    | 0.65  | 1.04 |
| SFMB      | -       | -   | 1.00    | -     | -      | 1.00 | -       | 1.41 | 0.60    | -    | 0.60  | 1.00 |
| SHB       | 1.00    | 1.00 | 1.00    | 1.00  | 1.00   | 1.00 | -       | 0.60 | 0.60    | -    | 0.24  | 0.24 | 0.71 |
| SL        | 1.00    | 1.00 | 1.00    | 1.00  | 1.00   | 1.00 | -       | 0.66 | 0.66    | -    | 0.39  | 0.39 | 0.76 |
| SE±       | 0.01    | 0.05 | 0.05    | 0.01  | 0.05   | 0.05 | 0.01    | 0.03 | 0.03    | 0.00 | 0.01  | 0.02 | 0.03 |

*Data were combined over sites (South Achefere and Mecha districts)

*Mean of LER over all scenarios

PM: planting method; PR: planting ratio; PFM and PLG: partial land equivalent ratio of finger millet and legume, respectively, SFMB and SFMR: sole finger millet planted in broadcast and in a row, respectively, SHB and SL: sole haricot bean and lupine, respectively. The numbers 1, 2, 3 and 4 are block-wise grain yield, mean grain yields of the replicates, farmer's grain yields averaged over 3 years (2016–2018) and a theoretical “optimum value” of gain yield for sole cropping of the component crops, respectively.

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Table 6. Net return and marginal rate of return from finger millet-legume additive design intercropping in northwestern Ethiopia.

| Intercropping treatment | CPR1 (2 and 3) | CPR2 (3 and 5) | CPR3 (4 and 8) | MRR* |
|-------------------------|---------------|---------------|---------------|------|
|                         | PM            | PR            | NR (ETB ha⁻¹) | MRR (%) | NR (ETB ha⁻¹) | MRR (%) | NR (ETB ha⁻¹) | MRR (%) |
| Haricot bean Row        | 100:75        | 52,743        | 562           | 48,778 | 430           | 44,813 | 341           | 666.5   |
|                         | 100:50        | 51,045        | 958           | 47,566 | 763           | 44,087 | 629           | 1175    |
|                         | 100:25        | 38,100        | 429           | 34,637 | 311           | 31,174 | 236           | 488     |
| Mixed                   | 100:75        | 37,219        | -67           | 32,248 | -71           | 27,276 | -75           | -106.5  |
|                         | 100:50        | 40,606        | 109           | 35,966 | 91            | 31,332 | 76            | 138     |
|                         | 100:25        | 37,900        | -123          | 33,235 | -120          | 28,570 | -117          | -180    |
| Lupine Row              | 100:75        | 49,427        | 428           | 45,439 | 329           | 41,452 | 261           | 509     |
|                         | 100:50        | 39,504        | 336           | 39,972 | 259           | 32,439 | 205           | 400     |
|                         | 100:25        | 38,108        | 355           | 34,546 | 253           | 30,984 | 188           | 398     |
| Mixed                   | 100:75        | 61,947        | 701           | 56,945 | 596           | 51,943 | 515           | 906     |
|                         | 100:50        | 55,189        | 942           | 50,514 | 849           | 45,839 | 771           | 1281    |
|                         | 100:25        | 36,688        | -204          | 31,985 | -190          | 27,281 | -178          | -286    |
| SFMB                    | 31,419        |               | -             | 28,402 |               | 25,385 |               | -       |
| SFMR                    | 39,101        |               | 34,593        |       |               | 30,084 |               | -       |

*Data were combined over sites (South Achefere and Mecha) and years (2017 and 2018).
PM: planting method; PR: planting ratio; SFMB: sole finger millet planted in broadcast; SFMR: sole finger millet planted in a row; CPR: cost price ratio; ETB: Ethiopian Birr; NR: net return; MRR: marginal rate of return.

*-mean marginal rate of return over the three labor cost to legume price ratios.
legumes which might be due to increase in uptake of N from fixed N. This is consistent with the works by Yayeh, Fetien, and Tadesse (2014) for finger millet-white lupine mixture.

Likewise, significantly higher finger millet grain yield in FM+HB RI at 100:50 followed by 100:25 planting ratios compared with all other cropping systems might be due to (i) efficient resource utilization resulted from Long TND (ii) compared to mixed cropping, FM+HB RI might reduce the shading effect of the component crops thereby favoring more efficient photosynthesis and (iii) specific fertilizer application through designed row intercropping increased the efficiency of fertilizer utilization. Moreover, the increase in finger millet grain yield by 6.56% and 15.48% from FM+HB RI at 100:50 planting ratio compared with SFMR and SFMB, respectively, confirmed why most low input farmers in sub-Saharan Africa use intercropping of millet with legumes (Laurent et al., 2015). This might be happened due to the transfer of fixed nitrogen from legume to non-legume crop, the improvement of phosphorus uptake as its mobilization is enhanced by the acidification of the rhizosphere via legume root release of organic acids and protons (Alemayehu et al., 2016), high CO$_2$ fixation attributed by increased leaf area index (Table 4) in an intercrops and improvement of nutrient use efficiency by associated cereals in an intercropping (Kiwia et al., 2019). This result is consistent with the works by Maitra, Ghosh, Sounda, Jana, and Roy (2000) for finger millet-pigeon pea and finger millet-groundnut mixtures. The decline of grain yield of finger millet by 20.41% and 5.39% from lower to higher planting ratios of lupine in FM+L MI (in addition to narrow TND) and haricot bean in FM+HB MI, respectively might be due to high plant population that led to high competition for growth resources, the shading effect of the component crops on photosynthesis efficiency and the lower fertilizer utilization efficiency in mixed than row intercropping. This is further supported by the negative linear relationship between planting ratios and grain yield of finger millet. As planting ratio of legume crops in an intercropping increased from 25% to 75%, the grain yield of finger millet reduced by 9.83% and 39.49% when intercropped with haricot bean and lupine, respectively (Figure 5), while the grain yield of haricot bean and lupine increased by 94% and 79%, respectively (Figure 6), suggesting that there is a trade-off within the two crop yields. Similarly, Laurent et al. (2015) in their meta-analysis study showed that cereal and legume grain yield in an intercropping had indirect relationship.

The values of partial land equivalent ratios (PLER) garter than 0.5 for finger millet and haricot bean in scenarios 1 and 2 indicated that there was an advantage for both component crops in these finger millet based intercropping systems in terms of growth resource use during their co-growing period. In the same scenarios, PLER of lupine in FM+SL RI and MI at 100:75 planting ratio was less than 0.5 which indicated an advantage for finger millet and disadvantage for lupine in these intercropping systems. More specifically, PLER of finger millet in all finger millet-haricot bean intercropping and FM+L RI, respectively might be due to high plant population that led to high competition for growth resources, the shading effect of the component crops on photosynthesis efficiency and the lower fertilizer utilization efficiency in mixed than row intercropping. This is further supported by the negative linear relationship between planting ratios and grain yield of finger millet. As planting ratio of legume crops in an intercropping increased from 25% to 75%, the grain yield of finger millet reduced by 9.83% and 39.49% when intercropped with haricot bean and lupine, respectively (Figure 5), while the grain yield of haricot bean and lupine increased by 94% and 79%, respectively (Figure 6), suggesting that there is a trade-off within the two crop yields. Similarly, Laurent et al. (2015) in their meta-analysis study showed that cereal and legume grain yield in an intercropping had indirect relationship.

The LER greater than one almost in all intercrops at all scenarios, but scenario 4 could be due to maximum total land output yield caused by high system LAI (Table 4) in intercrops compared with the sole cropping’s. The higher LER obtained from all scenarios in FM+HB than FM+L might be attributed to the wider TND between the former intercropped crops resulted in lower inter-specific
competition. Of all cropping systems, the highest LER in scenario 1 and 2 from FM+HB RI and MI at 100:50 and 100:75 planting ratio might be due to improvement of finger millet grain yield in intercropping than in sole cropping and higher grain yield of haricot bean at a higher planting ratio (Table 4). The second reason could be intercropping increases availability of applied nutrients and improves nutrient use efficiency by associated cereals and thereby increased the total land output yield (Kiwi et al., 2019). Moreover, in the finger millet-haricot bean combination, the greater yield advantage from intercropping was also brought about by the greater efficiency of light conversion (spatial complementarity of resource use). This effect has been ascribed to a better dispersion of light over a larger area of leaf in the intercrop, and perhaps to some complementary interaction between the C₄ finger millet and the C₃ haricot bean canopies (Reddy & Willey, 1981). Generally, Vandermeer (1989) noted that both competition and facilitation take place in many intercropping systems, and that it is possible to obtain the net result of LER>1, where the complementary facilitation is contributing more to the interaction than the competitive interference. Specifically, under scenario1 (LER₁), 0.84 ha and 0.82 ha more areas would be required by a sole cropping system to equal the yield obtained from FM+HB RI at 100:50 and 100:75 planting ratios, respectively. Thus, yield and higher land use efficiency in intercrops imply that farmers could produce more without putting extra land under cultivation. The increase in yields is expected to diversify food and income sources for household. This result was in agreement with several research results, including finger millet-white lupine (Bantie et al., 2014), pearl millet-cluster bean (Yadav & Yadav, 2001) and pea-barley (Chen et al., 2004) intercropping systems. However, LER obtained from FM+HB RI at 100:50 under LER₃ and LER₄ was 13% and 52% higher and lower than LER₁, respectively. This is mainly due to lower yield of the component sole crop produced by farmers (LER₂) and the component sole crop obtained from the theoretical "optimum yield" (LER₄) was much higher than the yield of intercropped component crops. Thus, to sum up all LER obtained from scenario 1, 2 and 3 were above one, which gave an advantage of these mixtures over sole crops, while LER values obtained from scenario 4 was blow one, which gave a disadvantage of these mixtures over the respective sole crops. The latter explicitly indicated that component crops produced in this intercropping need improvement through appropriate nutrient application, variety selection, etc., at least to increase the yields near to the optimum theoretical sole crop yield. In agreement with the latter, LER below 1.00 were found in wheat-pea (Naudin, Corre-Helliou, Pineau, Crozat, & Jeuffray, 2010) and barley-lupine (Bantie et al., 2014) mixtures. Laurent et al. (2015) noted that the advantages of the intercrops are higher when the yield of one or both of the respective sole crops is quite low (Laurent et al., 2015).

Assessing the impacts of various intercropping combinations on smallholders' farm incomes in poor regions facing ecological degradation is critically significant (Dai, Pu, & Rao, 2017). In the present study, average over the three labor cost to legume price ratios, for every ETB invested, it was recovered with the additional profit of ETB 12.81 for FM+L MI and ETB 11.75 for FM+HB RI at 100:50 planting ratios and ETB 9.06 for FM+L at 100:75 planting ratio from shifting current farmers’ practice (SFMB) and SFMR to finger millet-legume intercropping. Generally, these intercrops allow interspecific facilitation to be fully expressed, thus improving the land utilization rate and increasing economic benefits. With farmgate prices often two times more than finger millet, market opportunities for both legume crops are greater than those for finger millet in the study areas. Consequently, the highest NR and MRR obtained from FM+HB RI at 100:50 planting ratio could be due to the higher productivity of finger millet coupled with better market prices of haricot bean. Whilst, maximum values of NR and MRR in FM+L MI at 100:75 and 100:50 planting ratios might be attributed to optimum lupine production (Table 4) coupled with better market price and reduction of labor cost in mixed intercropping. These intercropping performed better net incomes for the farmer compared to the sole crops; it is regarded as a better safeguard. Consistent with these results, profitability of groundnut-pearl millet (Rao & Singh, 1990), maize-common bean (Alemayehu et al., 2016; FAO, 2015), maize–pea (FAO, 2015; Yang, Fan, & Chai, 2018) intercropping were increased with an increase in total planting density compared with the respective sole cropping. On the other hand, following farmers’ practice and SFMR, the ETB invested was lost for FM+HB MI at 100:75 (MRR = -1.06) and 100:25 (MRR = -1.80) and FM+L at
100:25 (MRR = −2.86) planting ratios. A treatment is considered a worthy investment by the farmer if the MRR is higher than the minimal acceptable rate of return of 100% (CIMMYT, 1988). Therefore, application of these cropping systems and sole crop finger millet are not economical in the study areas.

5. Conclusion
Regardless of the planting method and ratio, finger millet was more compatible with haricot bean than lupine. Finger millet and legume crops had negative and a positive linear relationship with the planting ratio of legumes when grown in a mixture. Among the intercropping systems, the primary objective of maintaining the “full” grain yield of finger millet in finger millet based legume intercropping was achieved in FM+HB RI at 100:25 (2.68 tone ha⁻¹) and 100:50 (2.72 tone ha⁻¹) planting ratios. The latter cropping system achieved 6.16% and 13.41% higher finger millet grain yield over sole crop finger millet planted in a row and broadcast, respectively. All LER values obtained from scenario 1, 2 and 3 were above one indicating that an advantage of intercropping over sole cropping, while LER values obtained from scenario 4 was blow one. However, among all intercropping treatments, FM+HB RI at 100:50 planting ratio (65%) followed by the same intercropping using both planting methods at 100:75 planting ratio (56%) gave significantly higher mean yield advantage over sole cropping. Average over the three labor cost to legume price ratios, maximum MRR was recorded in FM+L MI (1281%) and FM+HB RI (1175%) at 100:50 planting ratio, indicating that for every ETB invested, it was recovered with the additional profit of ETB 12.81 and ETB 11.75, respectively. Specifically, it could be concluded that FM+HB RI at 100:50 planting ratio offers much opportunity to smallholder farmers for increasing productivity of finger millet, land use efficiency and profitability and hence it would be a viable option for increasing household food security. Further studies should be focused on (i) the evaluation of relay intercropping of lupine with finger millet, (ii) the impact of finger millet-legume (haricot bean and lupine) intercropping system on soil propriety.

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Data Availability Statement
The data that support the findings of this study are available from the corresponding author, Yayeh Bitew, upon reasonable request.

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