Assessment of maize-legume intercropping as a way for sustainable intensification in mixed farming systems for smallholder farmers in Jimma, Ethiopia

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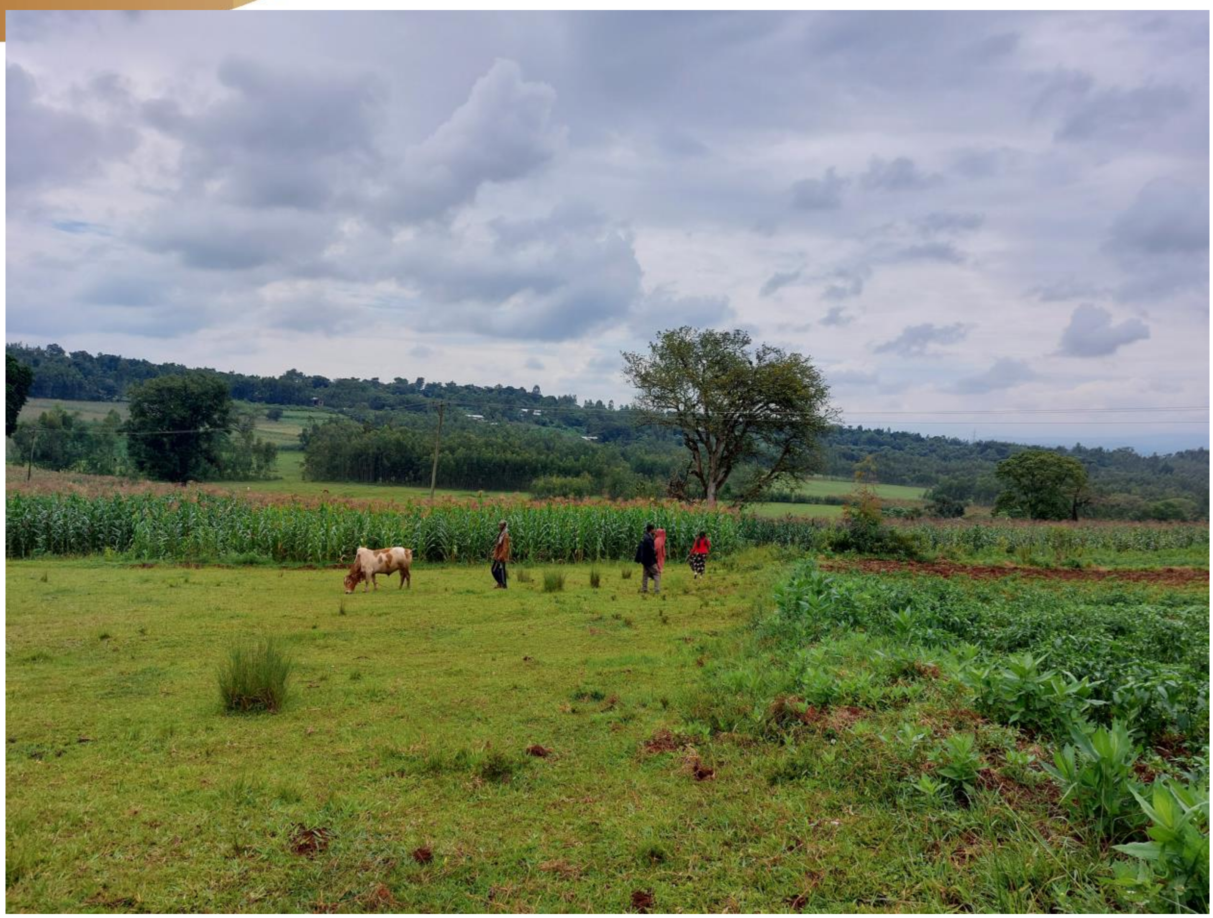

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The Sustainable Intensification of Mixed Farming Systems Initiative aims to provide equitable, transformative pathways for improved livelihoods of actors in mixed farming systems through sustainable intensification within target agroecologies and socio-economic settings.

Through action research and development partnerships, the Initiative will improve smallholder farmers' resilience to weather-induced shocks, provide a more stable income and significant benefits in welfare, and enhance social justice and inclusion for 13 million people by 2030.

Activities will be implemented in six focus countries globally representing diverse mixed farming systems as follows: Ghana (cereal–root crop mixed), Ethiopia (highland mixed), Malawi: (maize mixed), Bangladesh (rice mixed), Nepal (highland mixed), and Lao People's Democratic Republic (upland intensive mixed/ highland extensive mixed).

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Country background and research objective

Ethiopia is one of the targeted countries in the SI-MFS project to represent highland MFS in East and Southern Africa. The agriculture sector is a source of livelihood for more than 80% of the population and contributes 45% to the GDP in Ethiopia, showing the importance of agriculture in the country (Dendir & Simane, 2019). Similar to other developing countries, MFS, especially animal production, plays an important role in supporting the livelihood of the population as Ethiopia has the largest livestock population (Worqlul et al., 2022).

Crop production in Ethiopia is cereal-dominated (Belachew et al., 2022). Most crops are cultivated in the rainy season, from mid-June to mid-September, as almost all grain production by smallholders is rainfed (Belachew et al., 2022; World Bank Climate Change Knowledge Portal, 2021). The main calorie requirements are provided by maize (Zea Mays), teff (Eragrostis tef), sorghum (Sorghum bicolor L. Moench), wheat (Triticumaestivum L.), and barley (Hordeum vulgare) among cereals, and enset (Ensete ventricosum) provides the most among roots and tubers in the Ethiopian diet (Abate et al., 2015).

Legume integration, specifically intercropping of legumes with maize was proposed as a potential technical innovation of the SI-MFS project in Ethiopia. Integration of legumes into the farming systems brings multiple benefits with different system levels, i.e., food system level, production system level, and cropping system level (Stagnari et al., 2017). Firstly, at the food system level, legumes are rich in protein and slow-release carbohydrates as well as minerals and vitamins. This makes them especially important in the diet of people with low income in developing countries (Tharanathan & Mahadevamma, 2003). Secondly, at the production-system level, legumes increase soil fertility by fixing atmospheric nitrogen. They also release high-quality organic matter in the soil and facilitate the circulation of soil nutrients. These features make legumes especially useful in low-input farming systems. Additionally, legumes also help reduce greenhouse gas emissions by replacing synthetic fertilizers and contributing to carbon sequestration. Thirdly, at the cropping-system level, the integration of legume species diversifies farming systems which are based on a few major species. This gives benefits such as breaking the cycle of pests and diseases (Stagnari et al., 2017). Besides, early ground cover by legumes reduces raindrop impact and soil water evaporation, therefore contributing to soil moisture conservation (Namatsheve et al., 2020).

However, intercropping also has some potential challenges. Firstly, the design of an appropriate intercropping system, which is a prerequisite of successful intercropping, is quite complex. This is because the optimal intercropping design depends on the context such as the interactions between the component species, the available management practices, and the environmental conditions (Gaudio et al., 2021; Mahmoud et al., 2022; Qiao et al., 2022). Secondly, intercropping is generally more labour intensive as it requires extra work or more time-taking practices such as preparing and planting the seed mixture, weeding, and harvesting (Lithourgidis et al., 2011). For example, in the case of weeding, more careful operation was needed in the mixture of crops and with typically smaller companion crops (Rusinamhodzi et al., 2012). Therefore, careful assessment is needed to know the feasibility of intercropping in the targeted area as the viability of intercropping highly depends on each context.

Whereas intercropping can increase the productivity per unit of land, it is necessary to well understand the context, namely farming systems, to assess if the practice fits the local area due to the context dependency of the feasibility of intercropping. And this assessment was not yet done thoroughly with the perspective of legume integration in Jimma, where trials of SI-MFS project in Ethiopia locate. Therefore, the overall research objective of this study is: describing the mixed farming systems in Jimma, Ethiopia, and assessing the feasibility of integration of legumes in the area by intercropping with maize for sustainable intensification.

This is specified by five research questions (RQ) as follows.

1. RQ1. How are the current farming systems in Jimma characterized and how do they vary among farmers? What does it imply for the legume promotion?
2. RQ2. What is the trend of crop production in terms of area and the history of legume cultivation over the last 10 years?
3. RQ3. What are the opportunities and constraints that the farmers see in cultivation of legumes on their farms?
4. RQ4. What are possible advantages and disadvantages of intercropping legumes with maize for farmers in Jimma?
5. RQ5. What are the potential socio-technical innovation bundles to stimulate adoption of legume innovation?

Methodology

Study area

The study was carried out in Kersa and Omo Nada districts, in Jimma zone, Western Ethiopia (Figure 4). Jimma is in the mid-altitude area, and its elevation is approximately 1,700 m above sea level. The annual average temperature is 20 °C (Haile et al., 2010). The average annual rainfall ranges from 1,200 to 2,800 mm (Demissie Tola et al., 2022). The main rainy season is from mid-June to mid-September, following the short rainy season from February to April (Haile et al., 2010).

Figure 1. Location of Jimma zone in Ethiopia (Google, n.d. modified by Hinase Yatogo). The area marked in blue is shown in Figure 2.

Figure 2. Location of study site villages and Jimma city (Google, n.d. modified by Hinase Yatogo).

Demonstration trials of the SI-MFS initiative were established in the Kersa district and the Omo Nada district in the Jimma zone. Distance from Jimma city, the zonal capital, to Kersa and Omo Nada districts are about 23 km and 71 km, respectively. Kersa ranges from flat (0°) area to very steep (71°) area (Tsegaye, 2021). In Omo Nada, 28% of the area falls into the slope category of 5-10%, followed by 26% in the category of 15-30% (Regassa, 2015). The dominant agricultural soils in Omo Nada are Nitisols and Vertisols (Regassa, 2015), while soil texture in Kersa is sandy clay loam (53% sand 23% clay) (Mulat et al., 2021; Soil Texture Classes, n.d.).

For this study, four villages were chosen from these districts as study sites, which were Balto, Babo, Chala, and Sakote (Figure 5). Two of these villages, Balto and Babo, were in the Kersa district and the other two villages, Chala and Sakote, were in the Omo Nada district. Those villages, except for Babo, had ongoing maize-legume intercropping demonstration trials on the host farmers' land. Soybean (*Glycine max*), forage soybean, pigeonpea (*Cajanus cajan*), and lablab (*Lablab purpureus*) were chosen as companion legumes for the intercropping for their availability of seeds for the trials.

Research steps

Thirteen farmers were chosen as respondents in each village, resulting in 52 in total. The respondents were selected with the help of a local coordinator. In the villages with demonstration trials, we started with host farmers as respondents and spread to neighbor farmers. Some of the respondents were found by talking to a farmer in the village regardless of the host farmers and were checked if they meet the respondent criteria which is explained later. For Babo, all respondents were found in the latter way due to the absence of an ongoing demonstration trial. The respondent criteria were to be involved in the farming decisions and to know enough to answer specific questions regarding farming practices such as the amount of fertilizer used. This usually meant the household head. The local coordinator briefly checked if the respondent met the criteria while searching. At the same time, we tried to diversify the background of the respondents as much as possible in terms of gender, age, resource endowments of the farm, location of the house, etc. to cover a wide range of farming systems in the area.

The survey consisted of 5 sections: (A) General household information, (B) Livelihood sources, (C) Crop production, (D) Animal production, and (E) Access to market, services, and labour. Section A included general questions about household head's age, education level, and family size. The constitution of their income source was asked in section B to assess the impact of the farming activity on the household economy. In Section C, specific questions were asked for the main food crop, cash crop, and legume as well as general farming practices. Section D consisted of questions regarding the type of animals they had, their management, and the use of the animal products, etc. Finally, section E focused on if and how they access to various inputs and services regarding farming as well as access to markets.

The semi-structured interview was conducted immediately after the farm characterizing survey. The interview was meant to be a conversational style to dig into the background of their farming decisions. Hence, follow-up questions were asked to take advantage of open questions rather than only asking exactly the same fixed questions to all of the respondents.

Results

Farming in Jimma

Household size was on average 7 persons in Jimma area. In Kersa 58% of the households solely depend on farming for their income while in Oma Nada this was 81%. The average contribution of farming to household income was about 90%, showing the importance of farming in Jimma. The total farm size was 1.9 ha on average in Jimma area. In the Omo Nada district, the share of land owned (74%) was significantly lower than in Kersa (88%; $p<0.1$). Land which was not owned by the farmer was always shared-in from other farmers. No other forms of borrowing or renting land were practiced in Jimma. Average land sizes for main food crop (MFC), main cash crop (MCC), and main legume crop (MLC) were 0.8, 0.3, and 0.08 ha, respectively.

All farmers practiced maize cultivation as the MFC except for two farmers in Omo Nada, who had teff as MFC. Nitrogen fertilizer application was about 105 kg N/ha for MFC and phosphorus application was 33 kg P/ha. Herbicide was used on 35% of the farms, and although it was twice as high in Kersa (46%) than in Omo Nada (23%), the difference was not significant. The average maize yield was 2.3 t/ha and teff yielded 0.65 t/ha. All farmers in Omo Nada fed crop residues of the MFC to livestock and only 4% of the farmers left some residues in the field, while in Kersa, 77% fed it to livestock, and 35% of the farmers either entirely or partially left MFC residue in the field.

Crop rotation was common in both districts as farmers knew maize would be less productive without rotation. Indeed, 96% of the farmers practiced a rotation for main food crops. It should be noted that even though rotation was commonly found for maize, they often rotated only on the mainland and not for maize in the backyard, which is a small area of land around their homestead. In terms of the sequence of crops in rotation, it was slightly different from one farm to another. Chili pepper was most likely to be grown after maize. Farmers were aware of the residual effect of chili pepper, to which they applied a substantial amount of fertilizer. One farmer said the reason for this high application was that they believe the more fertilizer they apply, the more yield of chili pepper they get, so they try to apply as much as possible. Another farmer said that they 'store' fertilizer in the soil so that they will get a higher yield of maize on the land in the following season. In some other farms, cereals such as teff, wheat, and sorghum followed maize. Some of the rotations included grazing land.

Haricot beans and soybeans were the most common legume crops in Jimma and less than 0.1 ha of land was allocated to legume crops on average. None of the farmers applied any synthetic fertilizer to haricot beans, which was intercropped with maize. On the other hand, all farmers who had soybeans as legume crop applied either synthetic fertilizer or compost and cultivated it as a sole crop. legume crop residue was left in the field in 85% of the farms. A few farmers having soybeans as legume crop said that they used the soybean residue as fertilizer to improve the soil fertility. More than 90% of legume crop was consumed at home on average.

Feed scarcity was common during the off-season (January to March) and before harvest (June to August). Twelve farmers mentioned that they had irrigation during the off-season to grow wheat, maize, and sometimes vegetables. Those farmers tended to report feed scarcity during the off-season because they had to tie livestock to protect irrigated crops, which could be released otherwise. Similarly, during crop season before harvest, farmers tie their livestock to protect crops. During those times, they don't have crop residue yet, so farmers need to search for feed as a supplement to feed them well. It should be noted that the balance of severity of the feed scarcity of these periods differed from farmer to farmer even within the same village. This is because it depends on multiple factors such as the presence of irrigation, the presence/size of grazing land, storage of feed, and access to supplemental feed.

Legume cultivation in Jimma

Haricot bean is one of the most common crops that is grown for a long time in Jimma. Many farmers with haricot beans said they had haricot beans since the beginning of their farming. Only 3 farmers, including young farmers who started farming recently, had no experience of growing haricot beans in their farm. Maize-haricot bean intercropping was almost a "default" intercropping practice. However, mainly due to the advent of the use of herbicide, which kills dicots, intercropping with haricot beans was observed to be declining these days.

Soybean is a newly introduced crop under the extension by the government. Twenty farmers, 16 of whom were in Omo Nada, had never grown soybeans. Other 16 farmers tried growing soybeans in the past but stopped due to reasons such as market issues for selling the produce and access to inputs for growing it such as seeds, inoculant, and labor. The rest 16 farmers still had soybeans on their farms.

Opportunities and constraints for legume integration

Reasons for (not) having started/stopped growing the legumes revealed the opportunities and constraints of growing them. The opportunities and constraints for growing legumes are presented in Table 1. The food and market values were mentioned to be important incentives for both soybeans and haricot beans. For soybeans, improvement in soil fertility was mentioned as an opportunity even though none of the farmers mentioned it as their main reason for growing legumes in the survey. The optimism of the soybeans market issue being solved in the near future was another reason for farmers to find opportunities.

Table 1. Opportunities and constraints of integrating legumes into their farm. Numbers on the right shows the number of farmers who mentioned each item in the interview. Note that not all the farmers answered for all of the cells in the table as they were open questions. Items mentioned by more than one farmer were listed.

	Opportunities	N	Constraints	N
Soybean	> Food value	22	> Concern of market demand	14
	> Potential income source by selling on the market	20	> Absence/lack of seeds	12
	> Improve soil fertility	6	> Absence/lack of information	9
	> Output market issue is on the way to be solved	5	> Not common in the community	7
	> Becoming more common in the community	2	> Damage by pigeons/wild animals	5
	> Access to seeds from DA/market	2	> Absence/lack of supply of inoculant	5
	> Agricultural office/research center will buy the produce	2	> Difficulty of weed management (absence of herbicides)	4
	> Less demand of fertilizer	1	> Less preference/interest as food	3
Haricot bean	> Food value	9	> Damage by wild animals	5
	> Sell in the market	7		
	> Use as forage	2		
General			> Land shortage	9
			> Priority on other crops	6
			(attention, fertilizer)	5
			> Crop decision issue for land sharing	3
			> Lack of fertilizer	2

Constraints and opportunities were often two sides of the same coin. For example, the (concern of) market demand and (lack of) prevalence of the legume in the community were mentioned both as constraints and opportunities. As for soybeans, shortage or lack of inputs such as information, seeds, and inoculants was a big constraint since soybean was a newly introduced crop in the area. Damage to legumes by wild animals was problematic both for soybeans and haricot beans. Specifically for soybeans, severe pigeon attacks right after emergence were reported by multiple farmers.

Advantages and disadvantages of intercropping

Table 2 shows the advantages and disadvantages of intercropping legumes with maize for farmers in Jimma. No additional requirement of inputs such as land, fertilizer, and labor were seen as major advantages of intercropping. Hence, efficient use of these resources was the key advantage of intercropping in general for farmers in Jimma. This is in line with the fact that some farmers had land shortages or labor shortages in addition to fertilizer accessibility issues.

Table 2. Advantages and disadvantages of intercropping legumes with maize for farmers. Numbers on the right shows the number of farmers who mentioned each item in the interview. Note that not all the farmers answered for all of the cells in the table as they were open questions. Items mentioned by more than one farmer were listed. See Appendix G for a full list of items mentioned.

Advantages	N	Disadvantages	N
> No additional land required	9	> Soybeans/chickpea unproductive in shade	18
> No additional fertilizer required	4	> Herbicide for maize affect legumes	13
> Physical support for haricot beans	4	> Performance of maize declines	9
> Familiar with the practice	4	> Performance of haricot beans declines	6
> Less attack to legumes by wild animals	3	> Upper limit of density of haricot beans	4
> Efficient use of land (temporal/spatial)	3		
> Less additional labour required	2		
> Improve soil fertility	2		

The disadvantages of intercropping could be largely divided into two factors. One is the competition between maize and the companion legume. Most farmers were reluctant to grow soybeans as intercropping because the shading affects the growth of soybeans. The second factor is the virtual decrease of labor use efficiency of intercropping due to the advent of herbicide for maize. As mentioned above, farmers didn't need additional labor by intercropping haricot beans with maize, which was one of the major advantages of intercropping for them. However, with the advent of an option to use herbicide, which negatively affects the growth of haricot beans, farmers have to invest 'more' labor by weeding manually if they want to intercrop.

Discussion

The expansion of maize, chili pepper, and eucalyptus along with a reduction of livestock production and grazing land shows that the farming system in Jimma is shifting towards more crop-based and cash-oriented systems. Similar transition from food-oriented system to cash-oriented system in populated areas close to markets was reported in Southern Ethiopia (Mellisse et al., 2018). In a larger timescale, a transition from forest-based to crop-based systems in Southwest Ethiopia was also reported (Kassa et al., 2017). Maize expansion in Jimma particularly shows their growing demand for food.

Shortage of land and labor were often observed as the main constraints for legume cultivation in general and these influenced their decision whether or not they grow the legumes. These constraints are often found in smallholders in developing countries (Autio et al., 2021; Leonardo et al., 2015). At the same time, most farmers complained about issues regarding fertilizer, such as amount, prices, and timing of supply, as the main big problem in managing their farm at the moment.

The coordination of the output market for legumes is necessary to promote legume cultivation as it is a main driver for farmers to grow especially a new crop. The agricultural office already started working on it for soybeans. Particularly for soybeans, considering its large global market (Chen et al., 2022), it could be an idea to introduce an organization or company that buys soybeans from farmers for export in addition to the coordination of the local market.

When considering intercropping maize with legumes in Jimma, one has to be aware that the top priority is given to maize production as a staple food crop. In the context of maize-legume intercropping, soybean may not be the best candidate as a companion legume. Even though wider spacing of maize was proposed to avoid soybeans being shaded, which was the main disadvantage of intercropping soybeans, it is still questionable if this practice aligns with the farmers' preferences.

Decision making of crop selection on shared land was found to be one of the potential constraints for legume integration for farmers. It should be noted that sharecropping was the only form of borrowing/lending land from/to others in Jimma. Landowners typically have a larger influence on the decision because they contribute more by offering their land. But it goes the other way around in limited cases, for example when the landowner has a severe labor shortage, and the land borrower both manages everything and offers oxen for ploughing. As 37% of the farmers share-in some of their land, the crop decision issue on shared land is a factor to be considered.

Conclusions

In this study, farming systems in Jimma were described to assess the feasibility of the integration of legumes by intercropping with maize for sustainable intensification. Significant differences were found in the choice of main legume crop (MLC), soil bunds adoption, access to information from the research center and university, and credit use between the two districts, which could be attributed to their geographical difference in terms of distance to Jimma city. Over the last 10 years, maize and chili pepper have expanded in the area with their growing demand for food and cash. The farming system in Jimma seemed to be shifting towards more crop-based and cash-oriented systems. As was seen in the opportunities and constraints of growing legumes, the market demand is an important driver for farmers to integrate legumes into their farms, especially for soybean as a new crop in the area. Several facts indicated that the Jimma area may be approaching the phase in which they should shift the focus to intensification rather than expanding the farming area. Therefore, maize-legume intercropping can be a candidate to realize land intensification. However, the intercropping design in terms of companion legume species needs further assessment since many farmers didn't prefer intercropping of soybeans due to the negative effect of shading. For soybeans, it might be better to grow as a sole crop in rotation with maize. In any case, establishment of the output market for legumes is a prerequisite to promoting a new legume in the area. In addition, improvement in current credit service, matching the supply of inputs such as seeds, fertilizer, and inoculants, and ensuring equitable information provision in terms of gender and farmers' resource endowments are needed to enhance legume integration for sustainable intensification.

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