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Assessment of sustainable intensification practices among maize-commercializing households of Eastern Uganda

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Abstract

Farmers' choices to invest in sustainable intensification practices are influenced by the likelihood that these practices fulfill a farmer's financial, agro-ecological, and/or social goals. This study aimed to assess the different sustainable intensification practices used by maize-commercializing households in eastern Uganda, based on ecological, economic, and social impacts, using a multi-criteria analysis. The study reveals that farmers employed a range of criteria to assess and adopt sustainable intensification innovations. The most important criterion in assessing ecological merit of a measure was the improvement of soil fertility. For economic goals, yield improvement was the primary focus, while social goals were assessed based on whether the measure was approved or adopted by peer farmers. Maize-legumes systems met the ecological, economic, and social goals, while improved maize varieties mainly fulfilled economic goals. Inorganic and organic fertilizers were accepted for their contributions to both economic and ecological goals. The study concludes that multi-criteria analysis is useful for assessing the sustainable intensification measures adopted by farmers for diverse purposes. It is therefore recommended that multiple sustainable intensification alternatives must be promoted based on their potential to support farmers in achieving their goals. Strong linkages between extension workers and policymakers with farmers are crucial for idetifying and developing appropriate sustainable intensification practices for smallholder farmers.

Introduction

Food crop commercialization can improve smallholder farmers' incomes in Uganda. However, the necessity for increased intensification associated with food crop commercialization can degrade the land resource used for production thereby hampering the potential of future generations to access food (Kim et al., 2019; Jones-Garcia & Krishna, 2021). Sustainable intensification (SI) has been recommended as the possible solution for addressing these challenges of degradation while at the same time, helping to increase productivity and reduce poverty (Foresight, 2011; Nabwire, 2015; Jones-Garcia & Krishna, 2021).

Central to SI is the goal of ensuring that more food is produced from the same area of land while reducing the environmental impacts (Epule et al., 2018; Okboi et al., 2012;

World Bank, 2011). Land degradation, low agricultural productivity, and poverty are particularly related due to the increasing shortage of cultivatable land. SI is not rigidly defined by a single innovation or set of practices, rather it offers a conceptual framing for achieving balanced outcomes (Smith et al., 2017). SI is nested in the complex concept of sustainability, including the social, ecological, and economic dimensions (Loos et al., 2014; Musumba et al., 2017).

Several studies (Asante et al., 2020; Haile et al., 2017; Kim et al., 2019; Wilkus et al., 2021) posit that SI aims to upgrade the less productive conservation agricultural practices such as minimum soil disturbance, organic fertilizer, rotation and leguminous intercropped system with complementary intensification practices such as use of improved crop cultivars and agrochemicals. Conventional practices are equated to sustainable practices while complementary practices are equated to intensification practices. It is argued that through the prudent adoption of conventional and complementary practices, crop production can be increased to make the farming households food- and income-secure (Kim et al., 2019; Jabbar et al., 2020). A recent study by Wanyama et al. (2023) emphasizes the importance of fertilizers in sustainable intensification practices. The research found that multi-nutrient fertilizers significantly increased maize yields by 400% compared to control groups and by 108% over conventional fertilizers in high-potential zones. This underscores the vital role of complementary inputs like fertilizers in boosting agricultural outputs. Nevertheless, excessive use of fertilizers can lead to the pollution of ground and surface water. Furthermore, the application of inorganic fertilizer without the use of conservational measures that build the soil may decrease soil pH, soil organic carbon, soil aggregation, and microbial life (Aidoo et al., 2017).

Chaudhary et al. (2023) and Silva et al. (2023) argued that if both developed and developing countries are to improve their food systems under the present environmental challenges, they need to adopt SI practices on their farms. This argument is based on the fact that SI ensures increased agricultural yields without causing adverse effects on natural, social, and human well-being, as farmers use their fixed available cultivatable land (Chaudhary et al., 2023). To achieve the objective of sustainability and intensification, the responsible entity for making the appropriate decisions is the farming household (Silva et al., 2023). However, most of the time, these farmers find themselves in a great dilemma about how they can achieve both objectives simultaneously (Buckwell et al., 2014; Pretty & Bharucha, 2014). As previously mentioned, SI uptake offers challenges and the decision to use the SI approach on the farm depends on individual farmer preferences and goals (Xie et al., 2019). Cognizant of the benefits mentioned above, the government of Uganda is promoting SI as a framework to improve agricultural productivity, household food security, and rural livelihoods. In the Eastern part of Uganda where poverty is widespread, diverse SI practices have been delivered among maize-commercializing farmers to increase maize (*Zea mays*) output while conserving soil potential (Uganda Bureau of Statistics [UBOS], 2020). The merit of using SI practices has mostly been determined by scientists or researchers (Teshome et al., 2014). However, the adoption rates of these SI practices vary considerably (Haile et al., 2017; Kansiime et al., 2022; Kassie et al., 2009; Kim et al., 2019; Wilkus et al., 2021), mostly because the adoption of these practices by the farmers could be influenced by their perceived ability to fulfill ecological, economic and social goals of the farmers.

Smallholder farmers aim to reduce poverty through the uptake of SI practices (Maertens & Barrett, 2013; Mubiru et al., 2017) and SI offers another advantage of reducing production costs per unit output (Kassie et al., 2013). This strategy enhances rural farmers' incomes and food security, and deepens the country's market share of the agricultural output (Maertens & Barrett, 2013). This is particularly the case under the present circumstances where almost every sub-Saharan African country is transitioning from low-productivity subsistence farming to commercial food crop production (Sheahan & Barrett, 2014). Commercialization entails increasing farmers' market engagement through trade in inputs and outputs, and investing in technologies that enhance productivity and income (Kyakuwa 2022; Mayambala et al., 2024a). Commercializing smallholder farmers perform a vital role in agriculture by creating rural markets for agro-inputs, acting as rural supply bases for urban industries and consumers, and increasing economic investment in agriculture and other sectors through trade (Kirsten et al., 2013). Carletto et al. (2017), Pingali and Rosegrant (1995), and von Braun (1995) contended that the commercialization process substitutes non-traded inputs with traded inputs for increased production, diversification, and marketing.

Worth noting is that, in Uganda, this transition from subsistence to increased market-oriented production has affected many food crops including maize as one of the priority commodities (Mayambala et al., 2024b). Maize, the crop used in the study context, is the world's second-largest food crop in terms of production preceded by rice (FAOSTAT, 2019). The crop is believed to have been introduced in Africa by the Portuguese in the 1550s to supply their trading forts and in Uganda by 1860s (Balirwa, 1992). Maize is the second crop with the highest production in the country, next to plantains in terms of crop area (UBOS, 2020).

Maize is an important food and income security crop that supports the livelihood of millions of small-scale farmers in Uganda. Maize importance is associated with increasing demand and a favorable climate that enables two cropping seasons in a year. Maize is a versatile food crop grown under a wide range of environments (lowlands, midlands, and highlands) (Otunge et al., 2010; Smale et al., 2013), and also a staple food for most people in Uganda and neighboring countries. Maize has high production elasticity and, for this reason, it is used as a major source of carbohydrates for humans and livestock (Smale et al., 2013). Green maize, in particular, has conventionally been used in the countryside as a rapid 'hunger reliever' (Akomo et al., 2019; Mubiru et al., 2017; UBOS, 2020). Accordingly, in Uganda, maize is one of the major food security commodities and cash crops (Otunge et al., 2010; RATES, 2003).

Food crop commercialization has introduced changes in production patterns, input use, and the separation of household production and consumption decisions (Kirsten et al., 2013). This is because it would make little sense for smallholder maize farmers to begin using new intensification practices that would increase production beyond their own consumption needs unless they are able and willing to commit to selling the surplus in the market. Conversely, farmers' decision to sell more commodities in the market would have little consequence unless they use new practices to increase their production above subsistence requirements (Kirsten et al., 2013). Thus, commercialization enhances the links between the intensive use of inputs and output sides of agricultural markets, implying that commercialization and farmers' readiness to apply new production innovations are mutually interdependent (Ito et al., 2007; Melesse, 2015).

The extant literature tends to measure the impact of SI mostly through monetary terms using the cost-benefit analysis (CBA) (Bizoza & de Graaff, 2012; Teshome et al., 2014). CBA is entirely based on financial rational views, and it argues that farmers accept to use SI practices only when the cost associated with the use of the practices is mathematically below the net gains. However, the concern for the environment also shows that SI practices can be measured in terms of their ability to attain unquantified parameters such as ecological and social impact (Tenge, 2005). This is particularly likely to be the case given the fact that while several SI alternatives are available, their selection for use by a farmer could be guided by conflicting objectives that are evaluated on a range of criteria (Amsalu, 2006). Additionally, farmers' decisions often differ significantly from those of experts such as the researchers and the extension personnel, as well as among households farming in differing ecological conditions. Farmers' objectives are quite often diverse. As such, they tend to go beyond improving soil fertility and maximization of financial gains (Tenge, 2005). Therefore, it can be argued that what merits as a SI practice cannot be fixed outside the farm and no single SI practice can offer the best outcomes.

In addition, the most widely used criterion in the expert evaluation of SI practices is cost-benefit analysis, which has been criticized for its failure to account for the cross-impact interactions. So, it is important to expand the rigor of evaluating SI practices to enhance the consideration of farmers' decision-making processes regarding the practices in policy and the development arena. Particularly, there is a need to assess the objectives and criteria of farmers regarding the use of SI practices based on ecological, economic, and social impacts. Therefore, this study aimed to assess the SI practices used by maize-commercializing farmers, using qualitative criteria from both farmers and experts based on perceived ecological, economic, and social impacts.

Efforts to promote food crop commercialization through SI alternatives are encouraging, but benefits will not accrue unless attention is given to the correct selection of measures and criteria based on farmers' preferences and goals. Therefore, participatory approaches involving researchers, extension workers, and farmers are central to all SI narratives.

Analytic Framework

A decision regarding choosing a SI practice and/or technologies is based on diverse, often conflicting objectives that can appropriately be understood using a multi-criteria analysis (MCA) (Mardani et al., 2017). MCA is a decision-making tool usually applied when choosing solutions involving several alternatives and conflicting criteria (Mardani et al., 2017; Teshome et al., 2014). For example, the economic and agroecological criteria may incline to objective reasoning which could make farmers' decisions based on social reasoning seem irrational. The main characteristics of MCA are multiplicity of objectives, heterogeneity of objectives, and plurality of decision makers (Seo and Sakawa, 1988). The analysis of the study was based on sustainable development economic theory, which ranks or scores the performance of decision options against multiple qualitative and or quantitative decision criteria (Mardani et al., 2017; Teshome et al., 2014). MCA was deemed appropriate for this study because it allows evaluations that involve economic and non-economic concerns, such as environmental criteria (Mendoza and Martins, 2006).

While MCA is cited to have many cons, including difficulties in comparing the streams of costs and benefits over time, and reliance on subjective weighting processes attached to the criteria by the stakeholders, MCA offers a great potential for addressing the weaknesses of other evaluation methods. For example, the evaluation of SI often relies on cost-benefit analysis (CBA), which is based on comparison across the experiment and control cases, or "before" and "after" cases, reducing the understanding of SI practices' effects to monetary values based mostly on the efficiency criterion. A suitable strategy is to improve MCA by including the efficiency criterion as one of its criteria (de Graaff, 2019). Thus, retaining MCA as one of the most suitable tools for assessing SI practices (Teshome et al., 2014).

MCA arrives at the best alternative on the relevant criteria by using sequential procedures (Ananda & Herath, 2009; Munda et al., 1994; Voogd, 1982) that involve: 1) determining the decision objectives; 2) identifying the alternatives/options contributing to the attainment of the objectives; 3) deciding on the evaluation criteria that shall be used to assess the performance of the alternatives; 4) determining of the effects of the scores on alternatives based on set criteria; 5) relevant stakeholders assign weights to criteria to represent their relative importance for the respective group and; 6) combining weighted scores for each alternative to rank the alternatives. Therefore, by using MCA, it was intended to support the farmers and experts in evaluating the most appropriate SI practices used in their maize commercialization. The objective was pursued with the assumption that the variety of the necessary inputs (objectives, selection criteria and alternatives) for farmers in different farm conditions to adopt SI practices points to the prevalence of disagreement among farmers and experts regarding which innovations qualify as SI practices.

Materials and Methods

Study area

The study was conducted in three rural districts of Eastern Uganda: Bulambuli, Namutumba and Mayuge, which were selected based on highest production of maize in the selected region. Bulambuli represented the lowlands, whereas Namutumba and Mayuge were highland areas Figure 1. Two sub-counties were purposively selected from each district based on district maize production records obtained from district production officers. These sub-counties were: Bukhalu and Bwikhonge under Bulambuli district, Bulange and Namutumba under Namutumba and Malongo and Bukabooli under Mayuge district.

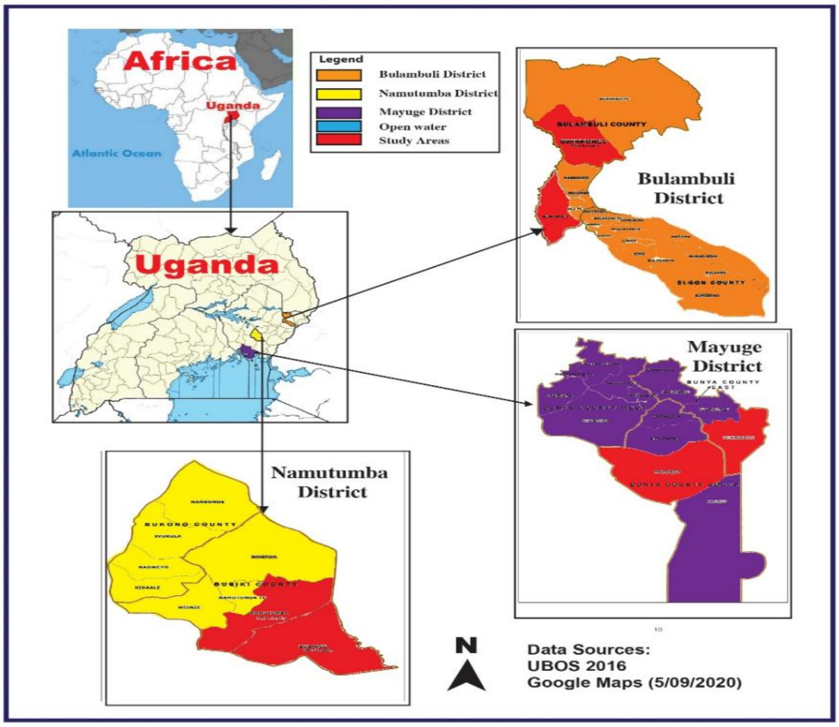

Figure 1. Map of Uganda showing the study districts.

Research approach

A mixed method design was used in this study. Farmers within rural households and extension workers were deemed the main stakeholders in the adoption of SI practices. A household was particularly targeted because it is the locus of sets of relationships where some resources are managed and claimed collectively, if not equitably (Evans, 1991). Also, it is the unit that links individuals and the larger society (Davidson, 1991). All the households selected grew maize primarily for income though not exclusively. Extension workers were deemed to be the social experts who extended the SI practices. Participants in this study were generated by a random sub-sample from 600 smallholder maize farmers who participated in a larger survey of 300 households in the study area conducted between July and August 2019. Data collection for this study was conducted using focus group discussion (FGD) and a survey. Two FGDs (with one for male farmers and the other for females) were conducted in each sub-county, each involving 10 farmers. This was done to gain an understanding of the SI innovations commonly implemented in the study area. The survey sub-sample included 120 maize farmers from 60 eligible households in which 20 from each sub-county were selected through the parish extension officers. Obtaining a sub-sample was appropriate for the identification of the SI practices in use before subjecting the practices to evaluation. In addition, 12 extension workers, each with a minimum of a bachelor's degree in Agriculture; 6 working under nongovernmental organizations and the other six under local government were interviewed to triangulate farmers' assessments.

SI alternatives

In this study, FGD data were subjected to thematic content analysis, where based on existing literature, the SI practices were classified into two categories: conservational practices and complementary practices (Haile et al., 2017; Kim et al., 2019). Conservation practices are improved soil management activities intended to produce more food while maintaining or improving soil quality by compensating for productivity losses due to land degradation (Goodlet et al., 2018; Thierfelder et al., 2018; Wanyama et al., 2023). Evidence has shown that conservation practices increase crop yield and income, improve soil resilience, and reduce soil erosion and land degradation (Darkwah et al., 2019). However, conservation practices cannot be easily assimilated into production systems unless complementary practices are in place. Practices are complementary when their joint adoption produces synergistic benefits, such as additional cost savings or enhanced environmental and productivity gains. This is because complementary practices are regarded as enablers required to make production systems more functional for smallholder farmers in the short and long term (Goodlet et al., 2018; Thierfelder et al., 2018; Wanyama et al., 2023).

The survey included 12 practices under conservation intensification practices and 9 complementary practices (Table 1). Extension workers introduced these under local government and non-government organizations. Practices that were used by less than 10% of participants (n=584) were considered less commonly applied and therefore excluded from the list of alternative SI practices. Thus, under conservation intensification practices, biological pest and disease control, organic pesticide use, constructed water channels, mulching and zero tillage were excluded. Commonly used practices across the cultivation of other crops grown in the area were eliminated if adoption of such practices does not greatly contribute to maize commercialization. Manual threshing, hand hoeing, home-saved seeds, manual planting, and weeding were eliminated because their adoption was beyond maize commercialization.

For complementary intensification practices, it was the use of mechanized planters, herbicides, foliar fertilizers, oxen, tractors, pesticides, and the use of machine threshers that did not merit inclusion on the two-factor selection criteria. Organic fertilizers and maize-legume intercropping are the conservational intensification measures that were included in the evaluation alternation. For complementary practices, these included inorganic fertilizers and improved maize seed varieties. Several studies also cited these practices as the main SI practices in maize farming systems (Haile et al., 2017; Kansiime et al., 2022; Wilkus et al., 2021; Wilkus et al., 2022). Thus, these four practices jointly with the "No measure" option constituted the five evaluation measures. The No measure is a plausible option when the measure is perceived to offer minimal gains on the criterion used in decision-making. Its inclusion accommodated situations where the farmers could have opted not to use a measure to attain a specific evaluation criterion under ecological, economic, and or social goals.

Table 1. Sustainable intensification practices (SIP) in eastern Uganda.

Practice	Uptake frequency	Sample size (n)	Percentage adoption (%)
Conservational intensifaction practices			
1. Biological pest and disease control	1	584	0.2
2. Organic pesticide use	1	584	0.2
3. Constructed water channels	4	584	0.7
4. Mulching	17	584	2.9
5. Zero tillage	23	584	3.9
6. Organic fertilizers	72	584	12.3
7. Manual threshing using sticks	210	584	36.0
8. Hand hoe	235	584	40.2
9. Home saved seeds	304	584	52.1
10. Maize-legume intercropping	420	584	71.9
11. Manual planting	570	584	97.6
12. Manual weeding	581	584	99.5
Complementary intensification pratices			
1. Mechanized planter	9	584	1.5
2. Herbicide use	32	584	5.5
3. Foliar fertilizer	48	584	8.2
4. Inorganic fertilizer use	128	584	21.9
5. Tractor use	154	584	26.4
6. Pesticides	351	584	60.1
7. Oxen use	355	584	60.8
8. Improved maize varieties	373	584	63.9
9. Machine thresher	408	584	69.9

SI criteria

The evaluation criteria on SI items were identified from the literature (Teshome et al., 2014) and then presented, discussed, and fine-tuned by farmers in discussion groups. The criteria included the ecological, economic and social goals for assessing SI measures. The ecological and economic goals each had four criteria while social goals had three. A total of 11 criteria were adapted to assess the reason for farmers' use of SI measures (Table 2).

Data collection

Evaluation and selection were subjected to farmer and expert ratings through trained interviewers using a three-part interview guide. Part I aimed to obtain information about the level of importance assigned to each evaluation criterion when making decisions regarding the use of SI practices. A fixed-point scoring technique was used (Hajkowicz et al., 2000). This required the farmers to distribute a fixed number of points depending on the perceived importance of criteria items. Fixed-point scoring is the most straightforward method for obtaining weighted outputs from a decision-maker (Teshome et al., 2014). To support the farmer weighting process, 20 balls (fixed-score) were offered. Each farmer was expected to distribute the balls to demonstrate how each measure helped fulfill the criteria set for assessing the goals. Part II aimed at having the participants rank on a five-point semantic differential scale (1=Worst, 2=Poor, 3=Fair, 4=Good and 5=Best) as the perceived capacity of the alternative SI measures to fulfill the set criteria. Respondents' data and the social economic conditions in which the farmers produced maize were captured in part III. The sample of respondents comprised equal numbers of females and males (n=120). The majority were married (85.7%) and between the ages of 30-49 years (56%). Ninety-seven percent of the farmers depended on farming for their livelihood and the majority (86%) had attained primary and level one secondary school education.

Table 2. Farmers' and expert's evaluation criteria of SI pratices (SIP) measures.

Objective	Criteria	Measurement
Ecological impact		
Erosion control	Minimize soil loss	Rank
Improve soil fertility	Minimize nutrient loss	Rank
Water retention	Maximize water retention	Rank
Enhance soil volume	Maximize soil volume increase	Rank
Economic impact		
Enhances crop yield	Maximize crop yields	Rank
Locally available	Minimize transaction costs	Rank
Minimize labour	Minimize use labour	Rank
Minimize recurring cost	Minimize incurring repeated costs	Rank
Social impacts		
Minimize pest and diseases risk	Minimize pest and disease risk	Rank
Used or approved by peers	Frequently used/endorsed by peer	Rank
Avoid disputes with neighbors	Minimize dispute with farmers	Rank

Data analysis

Data analysis aimed at ranking the most important SI criteria and alternatives. First, the weighted criteria using balls were transformed into percentages to render the different options among farmers and experts comparable. Second, the mean rankings (R) for the farmers across the study sub-counties and those of the experts were generated. The final matrix consisted of computed ranking means of each measure against the criteria for farmers in each sub-county. It also constituted the means for each criteria goal and the overall aggregated mean for the three goals. This step helped to comparatively understand individual farmers' assessment of the SI measures on the evaluation criteria. Third, rankings for each measure were normalized by multiplying them with corresponding weightings for each criterion. Normalization renders responses from different individuals comparable (Ndaula et al., 2021; Teshome et al., 2014).

Results and Discussion

Weighted criteria used to assess SI measures

Weighted criteria by the farmers and experts show the greatest focus being assigned to economic goals (≥ 40% but <50%, Table 3). This means that the ecological and social issues are secondary and tertiary goals, respectively. For SI practices to increase yield, they demand more investment in inputs (Dahlin & Rusinamhodzi, 2019). This means that the use of SI practices, primarily, though not solely, is an economic game. This may be true since most of the farmers investigated in the study were commercializing smallholder farmers whose main objective for farming was maximizing profits. They thus, opted for SI practices that could guarantee a robust productivity increase in crop yields to meet the rising market demand for maize. This is in line with Teshome et al. (2014) who found conservational measures for non-extreme slopes in the highlands of Ethiopia were preferred mainly for their economic benefits.

Table 3. Experts' and farmers' weighting (Wt in %) of sustainable intensification practices (SIP) evaluation criteria.

Criteria	Expert weighting			Farmers' weighting by sub-county						
	Lowland	Highland	Mean Wt[¥]	Bukhalu	Bwikhonge	Bulange	Namutumba	Malongo	Bukabooli	Mean Wt
Ecological impact										
Erosion control	4.1	9.3	6.7	4.5	3.2	9.1	9.3	4.3	8.3	6.5
Improve soil fertility	15.3	8.5	11.9	25.3	12.7	22.3	13.5	16.5	15.1	17.6
Water retention	4.2	7.5	5.9	4.8	3.8	7.5	7.0	4.5	3.6	5.2
Enhance soil volume	6.1	6.6	6.4	4.1	1.9	6.6	6.4	2.6	2.2	4.0
Subtotal	29.7	31.9	30.8	38.7	21.6	45.5	36.2	27.9	29.2	33.2
Economic impact										
Enhances crop yield	20.3	25.3	22.8	20.3	24.5	25.4	25.3	30.3	27.6	25.6
Locally available	15.0	9.4	12.2	15	12.3	4.7	5.4	6.4	5.4	8.2
Minimize labour	5.0	8.2	6.6	5.0	6.6	6.2	8.2	8.2	8.2	7.1
Minimize recurring cost	6.1	4.3	5.2	5.1	6.1	4.3	4.3	4.3	6.3	5.1
Subtotal	46.4	47.2	46.8	45.4	49.5	40.6	43.2	49.2	47.5	45.9
Social impacts										
Minimize pest and disease risk	5.6	4.3	5.0	5.6	5.4	2.3	4.0	6.3	6.7	5.05
Used or approved by peers	10.2	12.2	11.2	7.2	16.3	9.2	12.2	12.2	12.2	11.6
Avoid disputes with neighbors	8.1	4.4	6.3	3.10	7.2	2.4	4.4	4.4	4.4	4.3
Subtotal	23.9	20.9	22.4	15.9	28.9	13.9	20.6	22.9	23.3	20.9
Grand total	100	100		100	100	100	100	100	100	

[¥]Weighted (Wt) criteria range from 1 to 100%. They are obtained by transforming rankings done using balls into percentages. The mean values of weighted criteria also range between 1 – 100% for both the experts and the farmers.

Farmers in the six sub-counties, as well as the experts, revealed that the economic goal is evaluated through the ability of the measure to improve yields. Experts' ratings and that of farmers in Bukhalu and Bwikhonge sub-counties assigned importance to the local availability of the measure. Bukhalu and Bwikhonge are remote areas situated in the lowlands and face challenges about accessing measures that can contain soil nutrients without being leached. Similarly, consideration for ecological and social goal attainment was inclined to soil fertility improvement and whether peers use or approve others to use the SI measure, respectively. Surprisingly, both farmers and experts assigned a weight of less than 10% to criteria that typically contribute to soil fertility and yield. This suggests that farmers, either consciously or unconsciously, base their decisions on demonstrated results obtained from using SI measures. This could result in underestimation of criteria such as water retention, availability of inputs, and impact of pests and diseases on soil fertility and yield. Experts' messages on SI measures, which present the practices as measures to simultaneously improve crop yield and soil fertility, may explain for the high weightings farmers place on yield and soil fertility improvement. This aligns with the findings of Amsalu (2006) and Tenge (2005).

In addition, under uncertainty, peer approval and the use of a measure are used as a way to maintain social harmony and to make the right decisions (Mackie et al., 2015; Ndaula et al., 2021), without a farmer being obligated to experiment with the innovations. Young (2015) identified four main reasons for complying with one's peer approvals or actions: 1) social individuals desire to achieve a goal that is well coordinated with the actions of peers; 2) anticipating social rewards or social penalty for their compliance and non-compliance makes individuals try to achieve the former and avoid the latter, even when they may have preferred otherwise; 3) individuals' actions are symbol that signal belongingness to a group and; 4) benchmarking actions of others is a means to effective decisions.

Farmers and experts ranking of SI alternatives

Ecological goals

The farmers and experts ranked maize-legume intercrop and organic fertilizer as the best measures for achieving the ecological goals (Tables 4). The maize-legume intercrop and organic fertilizers were the best for controlling soil erosion and for improving soil water retention and volume. Soil fertility was best improved through maize-legume intercrop and the use of fertilizers. This shows that farmers aim to upgrade conservational practices with complementary practices to attain ecological goals in sustainable intensification. The results are in line with previous studies (Asante et al., 2020; Haile et al., 2017; Kansiime et al., 2022; Wilkus et al., 2022) which suggest that conservational practices provide the basis for soil fertility and are improved through complementary practices. Kim et al. (2019) also showed that farmers improve conservational measures through the judicious use of inorganic fertilizers.

Economic goals

Economic goals were primarily best attained through maize-legume intercrop, the use of inorganic fertilizers, and improved seeds (Table 5). The ranking was closely similar to that of experts. Intercropping maize with a legume minimizes the costs of relying on inorganic nitrogen, which has adverse consequences to the environment. Grain legumes fix atmospheric nitrogen gas in soils contributing to fields' nitrogen economics, including providing nutritional benefits to subsequent crops through retaining high nitrogen concentration in the soil and low carbon to nitrogen ratio (Srivastava et al., 2019). Cereal-legume intercrop is rewarding because the cereals benefit from the nitrogen fixed by the root nodules of the legumes, both in the current growing season and in the subsequent ones (Adu-Gyamfi et al., 2007; Giller, 2001).

Intercropped cereals with legumes are also shown to be the most feasible entry point to SI that enhances yield, income, and nutrition security (Mucheru et al., 2010; Rusinamhodzi et al., 2013). Where grain legumes attract high prices or are used as source of proteins for farming households, the cereal-legume intercrop is reported as the most economically beneficial SI measure (Ketema et al., 2021). In addition, the results show that the alternatives SI practices could have been selected because they boost yield, save labour, and are accessed locally. Yield is of economic importance because it is the main source of income and food. Moreover, labour-saving technologies and practices reduce operational costs whereas the availability of inputs in the farming community is important economically because it reduces transaction costs (Reich et al., 2021; Sseremba et al., 2021).

Table 4. Farmers' ranking (R) and ranking standardization (R*Wt) of merit sustainable intensification practices for ecological goal in study area.

Criteria	Area	Sustainable intensification practices										
			Organic fertilizers		Maize-legume intercrop		Inorganic fertilizers		Improved seeds		No measure	
		Wt	R	R*Wt	R	R*Wt	R	R*Wt	R	R*Wt	R	R*Wt
Erosion control	Bukhalu	4.5	4.0	18.0	5.0	22.5	2.0	9.0	3.0	13.5	1.0	4.5
	Bwikhonge	3.2	4.0	12.8	5.0	16.0	2.0	6.4	3.0	9.6	1.0	3.2
	Bulange	9.1	5.0	45.5	4.0	36.4	2.0	18.2	3.0	27.3	1.0	9.1
	Namutumba	9.3	5.0	46.5	4.0	37.2	2.0	18.6	3.0	27.9	1.0	9.3
	Malongo	4.3	4.0	17.2	5.0	21.5	2.0	8.6	3.0	12.9	1.0	4.3
	Bukabooli	8.3	4.0	33.2	5.0	41.5	2.0	16.6	3.0	24.9	1.0	8.3
	Mean value			28.9		29.2		12.9		19.4		6.5
Improve soil fertility	Bukhalu	25.3	3.0	75.9	4.0	101.2	5.0	126.5	2.0	50.6	1.0	25.3
	Bwikhonge	12.7	3.0	38.1	5.0	63.5	4.0	50.8	2.0	25.4	1.0	12.7
	Bulange	22.3	3.0	66.9	4.0	89.2	5.0	111.5	2.0	44.6	1.0	22.3
	Namutumba	13.5	3.0	40.5	5.0	67.5	4.0	54.0	2.0	27.0	1.0	13.5
	Malongo	16.5	4.0	66.0	5.0	82.5	3.0	49.5	2.0	33.0	1.0	16.5
	Bukabooli	15.1	4.0	60.4	5.0	75.5	3.0	45.3	2.0	30.2	1.0	15.1
	Mean value			58.0		79.9		72.9		35.1		17.6
Water retention	Bukhalu	4.8	5.0	24.0	4.0	19.2	2.0	9.6	3.0	14.4	1.0	4.8
	Bwikhonge	3.8	5.0	19.0	4.0	15.2	2.0	7.6	3.0	11.4	1.0	3.8
	Bulange	7.5	5.0	37.5	4.0	30.0	2.0	15.0	3.0	22.5	1.0	7.5
	Namutumba	7.0	5.0	35.0	4.0	28.0	2.0	14.0	3.0	21.0	1.0	7.0
	Malongo	4.5	5.0	22.5	4.0	18.0	2.0	9.0	3.0	13.5	1.0	4.5
	Bukabooli	3.6	5.0	18.0	4.0	14.4	2.0	7.2	3.0	10.8	1.0	3.6
	Mean value			26.0		20.8		10.4		15.6		5.2
Enhance soil volume	Bukhalu	4.1	5.0	20.5	4.0	16.4	1.0	4.1	3.0	12.3	2.0	8.2
	Bwikhonge	1.9	5.0	9.5	4.0	7.6	1.0	1.9	3.0	5.7	2.0	3.8
	Bulange	6.6	5.0	33.0	4.0	26.4	2.0	13.2	3.0	19.8	1.0	6.6
	Namutumba	6.4	5.0	32.0	4.0	25.6	2.0	12.8	3.0	19.2	1.0	6.4
	Malongo	2.6	5.0	13.0	4.0	10.4	1.0	2.6	3.0	7.8	2.0	5.2
	Bukabooli	2.2	5.0	11.0	4.0	8.8	1.0	2.2	3.0	6.6	2.0	4.4
	Mean value			19.8		15.9		6.1		11.9		5.8
Total mean value				132.7		145.8		102.4		82.0		35.0

Rs = R*Wt, where Rs = standardized ranking of the SI practice, R = expert or farmers ranking of SI practices (5, best; 1, worst), Wt = weights expert or farmer awards to SI practice

Table 5. Farmers' ranking (R) and ranking standardization (R*Wt) of merit SI practices for economic goal in study area.

Criteria	Area	Sustainable intensification practices										
			Organic fertilizers		Maize-legume intercrop		Inorganic fertilizers		Improved seeds		No measure	
		Wt	R	R*Wt	R	R*Wt	R	R*Wt	R	R*Wt	R	R*Wt
Enhances crop yield	Bukhalu	20.3	3	60.9	4	81.2	2	40.6	5	101.5	1	20.3
	Bwikhonge	24.5	2	49.0	4	98.0	5	122.5	4	98.0	1	24.5
	Bulange	25.4	3	76.2	3	76.2	3	76.2	4	101.6	1	25.4
	Namutumba	25.3	3	75.9	3	75.9	3	75.9	4	101.2	1	25.3
	Malongo	30.3	2	60.6	5	151.5	4	121.2	3	90.9	1	30.3
	Bukabooli	27.6	2	55.2	4	110.4	5	138.0	3	82.8	1	27.6
	Mean value			63.0		98.9		95.7		96.0		25.6
Locally available	Bukhalu	15	4	60.0	5	75.0	2	30.0	3	45.0	1	15
	Bwikhonge	12.3	4	49.2	5	61.5	2	24.6	3	36.9	1	12.3
	Bulange	4.7	4	18.8	5	23.5	2	9.4	3	14.1	1	4.7
	Namutumba	5.4	4	21.6	5	27.0	2	10.8	3	16.2	1	5.4
	Malongo	6.4	4	25.6	5	32.0	2	12.8	3	19.2	1	6.4
	Bukabooli	5.4	4	21.6	5	27.0	2	10.8	3	16.2	1	5.4
	Mean value			32.8		41.0		16.4		24.6		8.2
Minimize labour	Bukhalu	5	1	5.0	5	25.0	4	20.0	3	15.0	2	10
	Bwikhonge	6.6	1	6.6	5	33.0	4	26.4	3	19.8	2	13.2
	Bulange	6.2	1	6.2	5	31.0	4	24.8	3	18.6	2	12.4
	Namutumba	8.2	1	8.2	5	41.0	4	32.8	3	24.6	2	16.4
	Malongo	8.2	1	8.2	5	41.0	4	32.8	3	24.6	2	16.4
	Bukabooli	8.2	1	8.2	5	41.0	4	32.8	3	24.6	2	16.4
	Mean value			7.1		35.3		28.3		21.2		14.1
Minimize recurring cost	Bukhalu	5.1	3	15.3	4	20.4	2	10.2	1	5.1	5	25.5
	Bwikhonge	6.1	3	18.3	4	24.4	2	12.2	1	6.1	5	30.5
	Bulange	4.3	3	12.9	4	17.2	2	8.6	1	4.3	5	21.5
	Namutumba	4.3	3	12.9	4	17.2	2	8.6	1	4.3	5	21.5
	Malongo	4.3	3	12.9	4	17.2	2	8.6	1	4.3	5	21.5
	Bukabooli	6.3	3	18.9	4	25.2	2	12.6	1	6.3	5	31.5
	Mean value			15.2		20.3		10.1		5.1		25.3
Total mean value				118.0		195.5		150.5		146.9		73.2

Rs = R*Wt, where Rs = standardized ranking of the SI practice, R = expert or farmers ranking of SI practices (5, best; 1, worst), Wt = weights expert or farmer awards to SI pratice

Social goals

Broadly, social goals were accorded less importance by both the farmers and experts (Table 6). However, based on selection criteria, farmers ranked the maize-legume intercrop and the use of improved maize seed as best-suited SI measures for the attainment of social goals. This finding suggests that maize-legume intercrop and improved maize varieties intersect with farmers' aim to attain social goals. Typically, in an intercropping system, maize provides shade for the shorter crops. When grown under shady environments, most short crops can display stem elongation, lodging, and reduced leaf size, all of which result into low yields (Liu et al., 2016). Improved varieties of legume cultivars for intercropping models in various regions worldwide have been bred for their shade tolerance and high nitrogen fixation (Blessing et al., 2021). Semi-dwarf high-yielding and drought-tolerant maize can also help reduce the shade effect on intercropped legumes (Gong et al., 2014; Lee, 2020). Semi-dwarf cultivars allow closer planting strategies (Yang et al., 2014) maximizing benefits attainable from maize and legume intercrop (Liu et al., 2015).

Table 6. Farmers' ranking (R) and ranking standardization (R*Wt) of merit SI practices for social goal in study area.

Criteria	Area	Sustainable intensification practices										
			Organic fertilizers		Maize-legume intercrop		Inorganic fertilizers		Improved seeds		No measure	
		Wt	R	R*Wt	R	R*Wt	R	R*Wt	R	R*Wt	R	R*Wt
Minimize pest and disease risk	Bukhalu	5.6	3	16.8	5	28.0	2	11.2	4	22.4	1	5.6
	Bwikhonge	5.4	3	16.2	5	27.0	2	10.8	4	21.6	1	5.4
	Bulange	2.3	3	6.9	5	11.5	2	4.6	4	9.2	1	2.3
	Namutumba	4.0	3	12.0	5	20.0	2	8.0	4	16.0	1	4.0
	Malongo	6.3	4	25.2	5	31.5	2	12.6	3	18.9	1	6.3
	Bukabooli	6.7	4	26.8	5	33.5	2	13.4	3	20.1	1	6.7
	Mean value			17.3		25.3		10.1		18.0		5.1
Used or approved by peers	Bukhalu	7.2	2	14.4	5	36.0	3	21.6	4	28.8	1	7.2
	Bwikhonge	16.3	2	32.6	5	81.5	3	48.9	4	65.2	1	16.3
	Bulange	9.2	2	18.4	5	46.0	3	27.6	4	36.8	1	9.2
	Namutumba	12.2	2	24.4	5	61.0	3	36.6	4	48.8	1	12.2
	Malongo	12.2	2	24.4	5	61.0	3	36.6	4	48.8	1	12.2
	Bukabooli	12.2	2	24.4	5	61.0	3	36.6	4	48.8	1	12.2
	Mean value			23.1		57.8		34.7		46.2		11.6
Avoid disputes with neighbors	Bukhalu	3.1	3	9.3	5	15.5	2	6.2	4	12.4	1	3.1
	Bwikhonge	7.2	3	21.6	5	36.0	2	14.4	4	28.8	1	7.2
	Bulange	2.4	4	9.6	5	12.0	2	4.8	3	7.2	1	2.4
	Namutumba	4.4	4	17.6	5	22.0	2	8.8	3	13.2	1	4.4
	Malongo	4.4	3	13.2	5	22.0	2	8.8	4	17.6	1	4.4
	Bukabooli	4.4	3	13.2	5	22.0	2	8.8	4	17.6	1	4.4
	Mean value			14.1		21.6		8.6		16.1		4.32
Total mean value				54.5		104.6		53.4		80.4		20.9

Rs = R*Wt, where Rs = standardized ranking of the SI practice, R = expert or farmers ranking of SI practices (5, best; 1, worst), Wt = weights expert or farmer awards to SI practice

Farmers' selection of maize-legume intercrop and improved varieties was mainly centered on whether the measures were being used or are approved to be used by peers. As noted earlier, actions and approvals of peers serves as basis for efficient and socially accepted decisions when outcomes are uncertain and the cost of being wrong is high (Mackie et al., 2015; Ndaula et al., 2021; Young, 2015). This implies that by observing the actions and approval of peers regarding the maize-legume intercrop and the use of improved varieties farmers aim to determine the best crop varieties to grow and the proper methods to achieve better results. Additionally, farmers also can comply with signals from peers out of fear of rejection or being scolded as failing to adopt may lead others to perceive as neglecting to provide for their families (Ndaula et al., 2021). Based on MCA farmers and experts reveal maize-legume intercrop and improved varieties as the most appropriate SI measure (Tables 7-9).

Table 7. Expert ranking (R) and ranking standardization (Rs=R*Wt) of merit sustainable intensification practices for all goals in study area.

Criteria	Area	Sustainable intensification practices										
			Organic fertilizers		Maize-legume intercrop		Inorganic fertilizers		Improved seeds		No Measure	
		Wt	R	R*Wt	R	R*Wt	R	R*Wt	R	R*Wt	R	R*Wt
Erosion control	Lowland	4.1	4	16.4	5	20.5	2	8.2	3	12.3	1	4.1
	Highland	9.3	4	37.2	5	46.5	2	18.6	3	27.9	1	9.3
	Mean value			26.8		33.5		13.4		20.1		6.7
Improve soil fertility	Lowland	15.3	3	45.9	4	61.2	5	76.5	2	30.6	1	15.3
	Highland	8.5	3	25.5	5	42.5	4	34.0	2	17	1	8.5
	Mean value			35.7		51.9		55.3		23.8		11.9
Water retention	Lowland	4.2	5	21.0	4	16.8	2	8.4	3	12.6	1	4.2
	Highland	7.5	5	37.5	4	30.0	2	15.0	3	22.5	1	7.5
	Mean value			29.3		23.4		11.7		17.6		5.9
Enhance soil volume	Lowland	6.1	5	30.5	4	24.4	1	6.1	3	18.3	2	12.2
	Highland	6.6	5	33.0	4	26.4	2	13.2	3	19.8	1	6.6
	Mean value			31.8		25.4		9.7		19.1		9.4
Total mean value				123.5		134.2		90.0		80.5		33.9
Enhances crop yield	Lowland	20.3	3	60.9	4	81.2	2	40.6	5	101.5	1	20.3
	Highland	25.3	2	50.6	5	126.5	4	101.2	3	75.9	1	25.3
	Mean value			55.8		103.9		70.9		88.7		22.8
Locally available	Lowland	15	4	60.0	5	75.0	2	30.0	3	45	1	15.0
	Highland	9.4	4	37.6	5	47.0	2	18.8	3	28.2	1	9.4
	Mean value			48.8		61.0		24.4		36.6		12.2
Minimize labour	Lowland	5	1	5.0	5	25.0	4	20.0	3	15	2	10.0
	Highland	8.2	1	8.2	5	41.0	4	32.8	3	24.6	2	16.4
	Mean value			6.6		33.0		26.4		19.8		13.2
Minimize recurring cost	Lowland	6.1	3	18.3	4	24.4	2	12.2	1	6.1	5	30.5
	Highland	4.3	3	12.9	4	17.2	2	8.6	1	4.3	5	21.5
	Mean value			15.6		20.8		10.4		5.2		26.0
Total mean value				126.8		218.7		132.1		150.3		74.2

Table 7. *Continued…*

Criteria	Area	Sustainable intensification practices										
			Organic fertilizers		Maize-legume intercrop		Inorganic fertilizers		Improved seeds		No Measure	
		Wt	R	R*Wt	R	R*Wt	R	R*Wt	R	R*Wt	R	R*Wt
Minimize pest and disease risk	Lowland	5.6	3	16.8	5	28.0	2	11.2	4	22.4	1	5.6
	Highland	4.3	3	12.9	5	21.5	2	8.6	4	17.2	1	4.3
	Mean value			14.9		24.8		9.9		19.8		5.0
Used/ approved by peers	Lowland	10.2	2	20.4	5	51.0	3	30.6	4	40.8	1	10.2
	Highland	12.2	2	24.4	5	61.0	3	36.6	4	48.8	1	12.2
	Mean value			22.4		56.0		33.6		44.8		11.2
Avoid disputes with neighbors	Lowland	8.1	3	24.3	5	40.5	2	16.2	4	32.4	1	8.1
	Highland	4.4	4	17.6	5	22.0	2	8.8	3	13.2	1	4.4
	Mean value			21.0		31.3		12.5		22.8		6.3
Total mean value				58.2		112.0		56.0		87.4		22.4
Overall ranking				308.5		464.9		278.1		318.2		130.5

Rs = R*Wt, where Rs = standardized ranking of the SI practice, R = expert or farmers ranking of SI practices (5, best; 1, worst), Wt = weights expert or farmer awards to SI pratice

Table 8. Farmers' ranking of sustainable intensification practices based on ecological, economic, and social goals.

Criteria	Sustainable intensification practices				
	Maize-legume intercrop	Improved seeds	Inorganic fertilizers	Organic fertilizers	No measure
Ecological	145.8	82.0	102.4	132.7	35.0
Economic	195.5	146.9	150.5	118.0	73.2
Social	104.6	80.4	53.3	54.5	20.9
Overall ranking	445.9	309.3	306.2	305.2	129.1

Table 9. Experts' ranking of sustainable intensification practices based on ecological, economic, and social goals.

Criteria	Sustainable intensification practices				
	Maize-legume intercrop	Improved seeds	Inorganic fertilizers	Organic fertilizers	No measure
Ecological	134.2	80.5	123.5	90.0	33.9
Economic	218.7	150.3	126.8	132.1	74.2
Social	112.0	87.4	58.2	56.0	22.4
Overall ranking	464.9	318.2	308.5	278.1	130.5

Maize-legume intercropping was the best effective measure for achieving ecological, economic and social goals. Improved varieties primarily fulfilled the economic goals. While inorganic fertilizers were ranked higher than organic fertilizers, the closely similar aggregated scores for the two fertilizers indicated that farmers prioritize both measures for their ability to meet ecological and economic goals. Organic fertilizers are recognized as conservational practices with multiple ecological and economic benefits, while the judicious use of inorganic fertilizers can improve yields without causing negative outcomes to the environment. However, due to the misuse of fertilizers, experts disagreed with the farmers and considered inorganic fertilizers as the least appropriate measure for SI as it fulfills economic goals at the expense of ecological goals.

Conclusions and Recommendations

The findings of this study lead to the conclusion that for the farmers, the use of organic and inorganic fertilizers aims to achieve ecological and economic goals, while for experts these criteria were more relevant for the selection of organic fertilizer. According to the experts, inorganic fertilizers were beneficial for attaining economic goals. Surprisingly, despite being considered as a criterion for selecting maize-legume intercrop, social goals were not a priority in the selection of improved varieties, inorganic fertilizers, and organic fertilizers. This suggests that different measures are evaluated and adopted by farmers to fulfill various goals. The study further showed that farmers and experts place greatest emphasis on economic goals when choosing SI measures, while ecological and social measures ranking second and third positions, respectively. Since most of the farmers investigated in the study were commercializing maize, and their main objective was to maximize profits, it is recommended that SI practices that increase yields should be prioritized in policy interventions. Thus, multi-criteria analysis is an effective measure for assessing SI measures. It is recommended that SI alternatives be promoted based on farmers' preferences and goals. The extension programs should deliver SI measures to smallholder farmers, taking into account the ecological, economic, and social needs. Therefore, research-extension-farmers' linkage and participatory approaches should be strengthened to identify and package appropriate SI practices for farmers.

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No potential conflict of interest was declared by the authors.

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