Gender, Sustainable Agricultural Intensification, and food security in the context of climate change: a Literature Review

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Table of Contents

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1. Introduction

Faced with climate change and environmental degradation, agriculture and food production must be transformed in such a way that a growing world population can ensure food security without compromising the planetary boundaries and while coping with unprecedented climatic risks. This means that food production must be continuously increased to be able to feed a growing population without more resources being available for smallholder farmers. At the same time, environmental damage already caused must be reversed as much as possible.

Smallholder farmers and their families produce most of our food worldwide. However, many of them still live in poverty and food insecurity. Agricultural research and public extension services in the past have focused mainly on male household heads and technocentric innovations and have therefore tended to reinforce already existing gender and social inequalities. Gender and social inclusion are still emerging themes in agricultural research worldwide, and this is also true for research about gender and sustainable agricultural intensification. However, the literature shows that if not only male household heads but also women and youths were more explicitly recognized as farmers, the livelihoods of all family members would be improved. If research into and development of agricultural systems focused not only on technical but also on social and environmental innovations and their potential for increasing gender equality at all levels, improving the livelihoods of all the members of smallholder farming households would become a much greater priority for sustainable agricultural intensification and development. This would in turn not only increase smallholder farmers' resilience to climate change but also make possible more rapid changes in food production. This is urgently needed to reduce environmental damage caused in the past, help restore soil degradation, deforestation, and replace other damaging agricultural practices.

Sustainable Agricultural Intensification (SAI) stands for a combination of technical innovations that are expected to be effective in transforming food systems and agricultural production in a way that reduces and restores environmental damage. However, the need for social sustainability is often ignored, and the environmental impact of SAI technologies is still in debate. Most agricultural research about SAI has focused on testing the effectiveness of individual technical innovations and their impact on improving the yields of selected crops; transforming food systems under climate change conditions instead requires a more systemic approach so that they become environmentally sustainable and socially just.

Recently, agricultural research has begun to consider the perceptions of smallholder farmers and their family members about how their livelihoods are impacted by SAI practices. Although women and youth in smallholder farm households are key actors in the transformation of food systems

to make them more resilient to climate change, considering their perceptions of how their livelihoods are affected by SAI practices is a relatively new focus in SAI research. This literature review aims to identify contested issues and missing and emerging themes in gender and SAI research and to make recommendations for future research and development on this topic.

Described variously in agricultural research as Sustainable Intensification (SI), Sustainable Agricultural Intensification (SAI) or Sustainable Intensification of Agriculture (SIA), most authors understand that SAI is based on conservation agriculture (CA) or climate-smart agriculture (CSA). Contemporary literature does not offer a uniform definition for SAI, and in this report, we use the term SAI for convenience and relevance. The term Integrated Soil Fertility Management (ISFM) is sometimes used for a specific combination of SAI technologies, as well as Sustainable Land Management (SLM) practices or Sustainable Land and Water Management (SLWM) practices. These abbreviations refer to different packages of technologies because they vary according to the context and specific objectives of the interventions. All these SAI practices include different combinations of improved seed, organic and inorganic fertilizers, minimized soil disturbance, sustainable water management, legume intercropping, agroforestry, integrated soil management, and climate-smart agriculture technologies (Fischer 2022). The principal objective is to get more output from less input (Guo et al. 2020), thus minimizing adverse environmental and social impacts and enhancing ecosystem services (Pretty et al. 2011**,** cited in Guo et al. 2020). Conservation agriculture, a version of SAI, is a production system based on three interrelated agronomic practices: 1] minimized soil disturbance; 2] maintenance of permanent soil cover; and 3] crop diversification (FAO, 2014).

Although SAI practices started in the USA and Latin America, there has recently been a strong emphasis on SAI research in Africa and Asia. In the context of climate change, although social and gender researchers and development specialists increasingly call for more inclusive SAI, including the increased engagement of women and youth (see Grabowski et al. 2021), there are still few research efforts in this area.

With this review, we have been looking especially for the perceptions of rural women and men in small farming households concerning SAI technologies in conditions of climate change, and how these farmers are impacted by these technologies in different ways in their local context. To get a clear view of the current state of inclusive SAI interventions in different parts of the world, we have looked at reviews about SAI research since 2015 in order to identify emerging trends as well as gaps in research.

2. Scope and methodology of the review

We used a strategic review methodology, searching for studies performed in low-and-middle-income countries (LMICs) that were released or published in the English language after 2015 and available online. We looked for evidence of how gender was treated in the literature concerning sustainable intensification, with a special focus on Asian and African countries.

We conducted our analysis in three steps: First, we conducted an electronic search using the Web of Science search engine, looking for recent reviews about SAI research and SAI articles published since 2015, using the search terms “women” AND “sustainable intensification”; this yielded 82 articles. We retained these articles and continued to search with other search terms, as the articles did not meet our requirements. We used search terms such as “gender” AND “sustainable intensification” that yielded 109 articles; “farmer participation” AND “sustainable intensification” that produced 262 articles; and “gender” AND “sustainable intensification” AND “benefit” that yielded another 24 articles. In this way we made a list of 477 articles and filtered out those that were not relevant for our review. Firstly, we looked for articles that were repeated when we searched using different keywords and filtered out 23 articles. Next, we did additional searches on “gender” AND “sustainable intensification” AND "tradeoffs”; on “sustainable intensification” AND “inequity”; and on “sustainable intensification” AND “social sustainability”; and found some additional articles, SAI guidelines and SAI indicators for gender and social inclusion. However, since SAI is referred to in many different ways as explained in the introduction, we kept finding additional articles by looking at different bibliographies of the key articles reviewed about gender and SAI with different titles. Among others, we added articles about “youth and sustainable intensification”.

In the second step, after discarding repeated articles and those not relevant for our study, we reviewed the title and abstract of the articles. Many articles that focused on sustainable intensification did not consider gender and social equity as outcomes of the interventions. Other articles were not focused on LMICs, while the search terms also picked up some articles that did not include any discussions on gender or sustainable intensification. Finally, in the third step, we conducted an in-depth review of 174 articles with these specific research questions in mind:

1. What are the trends and gaps in the most recent literature about research into sustainable agricultural intensification and gender and social inclusion?
2. What kind of differential impact does the adoption of SAI technologies have on the livelihoods of women and men in small farming households and on food security?
3. How do social and gender structures and norms restrict women from adopting SAI technologies?
4. What is the potential of inclusive SAI and how can this potential be leveraged to transform gender relations towards more gender equality and social sustainability in this time of climate change?

At each step, we briefly summarized our findings, trying to be specific about the study context, population studied, timing of study, methods used, and how concepts were measured. An additional consideration during our search was to keep only papers that used a transparent and robust methodology (whether quantitative, qualitative, or using mixed methods) and that had clearly undergone a rigorous peer review, and we did not consider the materials that were based on grey literature prepared for internal documentation purposes.

The geographical distribution of the articles included for review is presented in Figure 1.

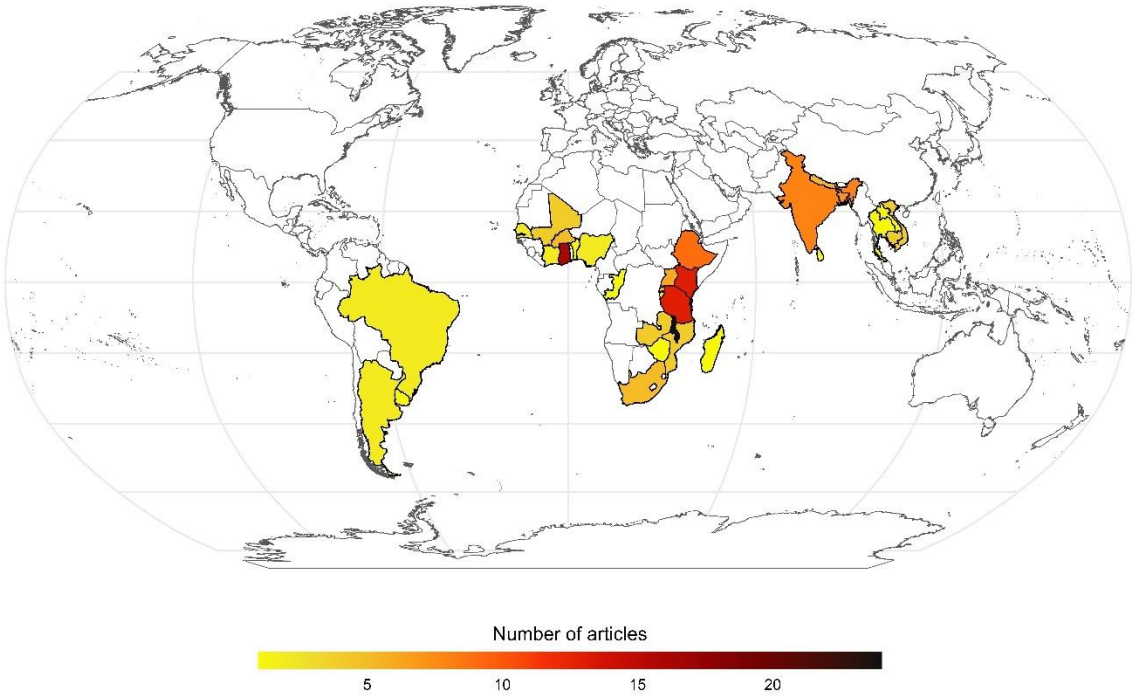

Figure 1: World map showing the geographical distribution of the articles reviewed.

3. Overview of recent literature reviews on SAI

Interestingly, ten articles about review studies conducted on research about sustainable agricultural intensification have been published since 2018 (Table1). However, not all of them included gender in their analysis.

Two of them did not include any reference to gender; one was based on a worldwide literature review and included some primary case studies (Weltin et al. 2018); and another one was entirely based on the review of 63 published articles on smallholder farmers' adoption of sustainable agricultural practices worldwide (Foguesatto et al. 2020). One review article based on the African

context mentioned gender as one driver for the adoption of SAI technologies by small farmers together with other eight drivers but did not include any gender-specific conclusions (Guo et al. 2020**).** In the same period, five literature reviews on SAI provided some gender-relevant conclusions (Salmon et al. 2018; Xie et al. 2019; Braidotti et al. 2021; Reich et al. 2021; Snyder and Sulle 2022**).** Finally, two reviews were specifically about gender and conservation agriculture (Wekeshah et al. 2019 and Flora 2021). The last one also included case studies without specifying how many articles and case studies were reviewed.

Table 1: gender-relevant findings found in 10 literature reviews about SAI since 2018

Authors	**Regional focus**	**Scope**	**Key gender-relevant findings of literature reviews about SAI**
1. Weltin et al. 2018	Worldwide	Review of 349 papers and some case studies about SAI implement-ation	No reference to gender.
2. Foguesatto et al. 2020	Worldwide	Review of 63 papers on SAI adoption among small farmers	No reference to gender.
3. Guo et al. 2020	Southern African Development Community (SADC)	Review of 21 papers on SAI adoption among small farmers	Gender is identified as one driver together with eight others for the adoption of SAI technologies by small farmers.

4. Salmon et al. 2018	Livestock sector in low- and middle-income countries	Review of an undefined no. of papers and of seven case studies	Interventions towards SAI in livestock systems may not benefit women and men equally. More intensified systems could negatively affect women by increasing their workload and resulting in limited benefits for them. The inclusion of environmental, economic, and social indicators and perspectives would improve the success of SAI efforts.
5. Xie et al. 2019	Worldwide	Undefined no. of articles reviewed	Gender differences among heads of small farmer households have been studied mainly in articles about SAI in Africa. Women's rights' constraints are mentioned as influencing their SAI farming practices and technology adoption. Preferences, needs, and women farmers' roles are often not taken sufficiently into account when designing SAI interventions.
6. Braidotti et al. 2021	Worldwide, on the use of soil quality indicators and participatory techniques	43 studies reviewed test	Women's involvement in participatory research about SAI is still an exception. 16 of the 17 studies reporting the involvement of women were carried out in African countries. This is related to the fact that women in this region account for about 50% of the agricultural labor force, and that the incidence of women's headship is higher than in other regions.
7. Reich et al. 2021	Worldwide	A systemic literature review of 241 articles about SAI in agriculture	Gender-sensitivity and adoption are included as "a social aspect" along with other economic, environmental, and human conditions and "social dimensions of sustainability" (2021: 8) for an inclusive approach. Gender was only found in 4–5 % of all reviewed studies. More participative research on SAI in agriculture is recommended to find out more about labor, gender, and adoption indicators. More research needs to be done on assessing tradeoffs for the environment and social domains.
8. Snyder and Sulle 2022	3 African and 3 Asian countries: Malawi, Ghana, Ethiopia,	160 papers reviewed about the impact and outcomes of SAI initiatives on	The authors findings coincide with those of Porciello et al. 2021 about consistent gaps in the evidence for outcomes focused on nutrition, social inclusion, and gender empowerment across nearly every domain. Most papers and projects reviewed focus on productivity, followed by the economic domain (often through modelling). Far less attention is given to the environment, human condition, and social domains, and even less to impacts in farmer-managed fields. Evidence about environmental impacts or the social, economic, and political

	Laos, Bangladesh, Nepal	women, men, and other social groups	contexts that can hinder or encourage adoption of these impacts is missing. The need for greater participatory action research is emphasized. More involvement of social scientists from the beginning of an SAI project design through to completion is recommended. Very few truly interdisciplinary papers were found: they were either social-science focused or natural-science focused. Some papers suggested that labor increased, while others suggested a decrease, but they did not differentiate by gender. There needs to be better research on how men and women farmers adapt SAI interventions and innovations and how they build on local/existing knowledge.
9. Wekeshah et al. 2019	Gender and conservation agriculture (CA) in sub-Saharan Africa	64 articles reviewed	Evidence on gender and CA showed mixed results. Women farmers adopted CA less and disadopted it more compared with men, due largely to gendered barriers, including lack of access to land, machinery, inputs, extension services and credit facilities. CA increased women's income, labor involvement, and household food security. CA also increased the risk for women of land and crop dispossession by men when CA made farming lucrative. It also increased workloads, employment opportunities and health risks for women. CA positively altered gender relations, increasing women's participation in agricultural decision-making at the household level. Research gaps: long-term impact of CA on gender relations and on incomes for men and women, the sustainability of strategies for supporting women's participation in CA, and the dynamics of women's access to local farmland markets in relation to their involvement in CA. Research about gender and CA still fails to provide a consolidated perspective on key issues and lessons, and remains irrelevant to the knowledge of funders, decision-makers, and agricultural groups. Studies found are described to be limited in number and robustness, short-term, conducted in few countries and with little basis for reliable conclusions. Gender as a dynamic social construct rather than a biological phenomenon hinders a robust appreciation of how it affects and is affected by CA in sub-Saharan Africa.

10. Flora 2021	Worldwide, including case studies from Latin America	Literature review combined with case studies. No specific numbers indicated	Gender-inclusive SAI has the potential to provide a way for rural households to stay on the land in a community with economic security and social inclusion in a healthy ecosystem. Men, women, and youth all have different perspectives on productivity and on economic, environmental, human and social aspects that need to be considered. SAI requires access to and control of natural resources, but unequal access is found to be an important obstacle. Women are found to be more likely to mix different varieties of the same crop in the same plot and to intercrop, which aids in preserving and improving the soil. Women access a wide variety of wild foods, generally observe changes in flora and fauna and adapt their livelihood strategies in response. As keepers of traditional cultural capital, women are more oriented to nature and fellow community members. These relationships are reinforced by rituals of respect for the land and each other. The local language, which women are more likely to speak and thus preserve, is important for SAI, because "when you can name something, you can act toward it", as there are many words related to natural capital that do not exist in the dominant language of education. Female-headed households are found to have fewer individuals inside or outside the community on whom they can depend for help (although that varies by country) and less adult-equivalent household labor. Collective knowledge creation, sharing, and implementation are critical. Men and women have different networks: female household heads may disproportionately be members of religious organizations compared to other organized groups, as they meet there with women from other communities. These religious organizations as well as women's organizations are found to be key in adapting and developing technologies for female as well as male household heads. With the introduction of technology, especially when it generates income, gender roles change and men generally take over, particularly when women do not have access to financial capital. Female-headed households have less access to capital, including farming tools and machinery.

4. Gender, SAI, and food security in the climate-change context

This section reviews the gendered adoption patterns identified, overcoming the simplified explanations that relate the lack of adoption of SAI practices by women only to less access to resources. It will start with referring to case studies that show how women are interested and eager to learn and adopt specific practices, and even in some cases how women household heads show higher rates of adoption and innovation in agricultural practices than their male counterparts, making them key agents of socioecological changes in their communities. Subsequently, it will explore other SAI gendered adoption patterns such as crop type, purpose of practice, and labor requirements. Finally, by reviewing cases in which women's participation in collective farming groups counterbalances labor and knowledge constraints, it will argue that collective action by women can facilitate the adoption of SAI technologies and can offer an opportunity for delivering agricultural extension services.

4.1. Gendered adoption patterns of SAI

Most of the research focuses on the adoption patterns of specific technologies or crops by male- or female-led smallholder farm households.

In general, adoption of SAI is more frequent when farmers are better off and have greater access to resources. Therefore, the immediate, non-gendered response is to simplify adoption patterns by arguing that farmers with more land and resources are generally more able to adopt SAI technologies than poorer farmers. Consequently, since women in small farming households generally have less access to resources than men, they are less likely to adopt SAI practices.

However, this does not always seem to be the case. Several articles argue that women adopt SAI practices more frequently and sometimes more intensively than men (Guo et al. 2020; Musafiri et al. 2022; Fischer et al. 2021a**;** Mucheru-Muna et al. 2021). It also emerges that gendered adoption patterns of SAI practices overall are very context specific. The cases reviewed demonstrate that adoption of specific technologies is extremely context-sensitive and depends on the local knowledge of farmers and stakeholders (Weltin et al. 2018). Local agroecological and sociocultural contexts are key factors affecting adoption patterns. These include gender normative framework, as well as the specific gendered livelihood strategies influenced by smallholder migration in some areas, and gendered land and agri-food systems (Zimmer, 2015).

4.2. Women as key agents of socioecological change

It is evident that women are interested in SAI technologies and eager to learn about them, while men may be more inclined to cling to their traditional farming practices (Fischer et al. 2021a). For instance, Guo et al. (2020**)** suggest that female smallholders are more likely than men to adopt

SAI. Beshir et al. (2021) found that both female and male farmers are very interested in sustainable intensification technologies. These studies highlight that development actions should consider preference heterogeneities (including by gender) among farmers when developing their programs.

Similarly, Musafiri et al. (2022) found that women in western Kenya adopted climate-smart agriculture (CSA) more frequently than men, and that women practiced agroforestry with crops of little or no commercial value. Sumner et al. (2015) studied how in Cambodia, both women and men embraced conservation agriculture (CA) and collectively negotiated the transition to CA-based production systems (Sumner et al. 2015).

Mucheru-Muna et al. (2021) observed that gender was a factor that significantly influenced the degree of farmers' knowledge about fertilizer use and integrated soil inputs; female-headed households in Kenya were more knowledgeable about these practices and more willing to adopt an Integrated Soil Fertility Management, (ISFM) package. Likewise, Baba et al. (2016) found that female household heads were more likely to use inorganic fertilizers than male heads, although gender differences did not influence the adoption of other innovations. This shows that women's appreciation of SAI's different attributes is mainly driven by their concern for the food security and nutrition of their households. Women also provide considerable labor in farming and are thus more inclined to learn and implement new technologies.

Several articles found that women are better positioned than men to be agents of socioecological change in their communities, and this is an important insight for understanding the gendered dynamics of SAI technology adoption. The reasons for this are rarely explored, though it might be due to women's greater concern for food security and nutrition. One possible sociological explanation is that in areas with high rates of male outmigration, women household heads are increasingly taking on leadership roles in farming both in the household and in the community. A further important finding might be that women household heads are more likely to be innovators because they have more decision-making power and control over their own resources (Farnworth et al. 2017; Mutenje et al. 2019). This is also found in Tran et al. (2020), who show how female-headed households in Vietnam are champions of climate-smart farming technologies.

In their assessment of the eco-efficiency of smallholder perennial cash crop production in Ghana and Kenya, Heidenreich et al. (2022) found that gender plays a major role. Eco-efficiency is an important underlying principle in sustainable intensification, as it considers simultaneously the increase in agricultural value added per unit of land and the reduction of related environmental damage. Female-headed households were found to be more open to and better able to manage innovation for increasing agricultural value as key agents of change and innovation in their communities.

This finding is also corroborated by other articles. For instance, in a study assessing the impact of an integrated co-learning extension approach to SAI in western Kenya, Marinus et al. (2021) describes how an elderly widowed woman whose fields were heavily infested with striga was

successful in intercropping maize with soybean and applying manure in combination with mineral fertilizer. Through this, she became an agent of change in her community and contributed to mindset changes among other farmers. A wealthy male farmer who was skeptical about the new approach changed his mind after visiting the woman's maize field. These findings contradict common assumptions and extension narratives that regard men as being more inclined to take risks and innovate.

Similarly, Upadhyay et al. (2020) found that Lao women cassava farmers made decisions about integrated pest management (IPM) and, even if they possessed comparatively little knowledge about the subject, favored agroecological approaches and took on key tasks in selecting propagation material. The study concluded that women were well-positioned to promote IPM practices such as the use of disease-free planting material, and that extension services should build women farmers' knowledge to empower them as agents of change and drivers of IPM adoption. Moreover, female farmers stressed the importance of letting cassava "grow naturally", which signals their greater connection to nature and inclination toward agroecological approaches (Griffin, 1978; Merchant, 1989). The authors argue that women understand intuitively how to use natural resources sustainably and embrace ecological values that protect nature.

Finally, Zimmer et al. (2015) show how male migration to urban areas and the continued "feminization of agriculture" in many smallholder farming systems influences intensification and deintensification in complex ways. While the greater income gained means that the household is no longer solely dependent on agriculture for survival, it often results in the gendering of land use, turning women farmers into the main decision-makers on how to invest remittances from male migration. This investment is crucial for the adoption of innovative techniques, for sustainable intensification, and for increasing socioecological resilience.

4.3. Gendered adoption patterns by crop type, management, and labor requirements

Gender normative frameworks and gendered livelihood strategies across landscapes affect the adoption of SAI practices. In this regard, a key topic identified in this review was how the type of crop targeted for sustainable intensification has profound gender implications, as crops are linked to traditional gender norms that designate certain crops as the concern of either women or men.

Gender preference for specific crops depends very much on the context. Cereals and highly commercialized grain legumes are often considered as "male" crops, whereas less commercialized grain and vegetable legumes are regarded as "female" crops (Nassary et al. 2020). For instance, in patrilineal Ghana, planting millet that is typically controlled by men does not give women an incentive to adopt the new practices. Conversely, the introduction of a "more gender-neutral" crop such as maize enhances women's control and benefits as well as household food security (Fischer et al. 2021a). The same effect is found in the analysis of SAI practices

targeting rice-production systems in Tien Geng province in Vietnam *(*Lovell et al. 2020). Since rice can also be an important cash crop it tends to be dominated by men. Therefore, SAI packages targeting rice as a cash crop will automatically attract more men than women. The most popular SAI practices among men are reduced tillage, water-saving practices, and integrated pest management.

Likewise, Fischer et al. (2021a) show that in matrilineal Malawi, while women were typically more interested in SAI than men, this changed when the SAI project introduced a high-yielding, drought-tolerant cowpea variety, which caught the interest of both women and men participants. This led to a renegotiation of intra-household land allocation, with women giving men a separate plot for cowpea farming.

Several articles point to the purpose of an agricultural practice as another crucial factor in understanding gendered SAI adoption practices. For instance, women in some contexts are willing to adopt practices if the subsistence consumption and nutrition of the family can be improved. Conversely, men are more interested in applying SAI if it is accompanied by positive marketing options for increasing monetary income. This difference is well illustrated by Kizito et al. (2021) in their analysis of landscape restoration interventions such as terraces and grass strips in Kenya. Women showed a preference for grass strips because they were interested in forage biomass for milk production for home consumption and nutrition. Men rated terraces more highly because they considered social prestige and looked further along the value chain at the quantity of fodder for sale. Sustainable land management (SLM) practices increase soil protection while improving cropland water infiltration. Men tend to prefer soil and water conservation for social prestige and economic gains related to labor demands and land ownership.

Tufa et al. (2022) present the adoption rates of technologies by sex of the plot manager. They found that crop rotation was the most frequently adopted technology, followed by the use of improved varieties, crop residue retention, intercropping, manure use and minimum tillage. Intercropping and minimum tillage were practiced more in female-managed plots, whereas improved varieties, crop rotation and crop residue retention were applied more in male-managed plots. There were statistically significant differences between female- and male-managed plots in the adoption of all technologies except for manure use. A plausible explanation of why women were more likely to adopt maize-legume intercropping and minimum tillage could be because of their preference for producing diverse crops to be used for home consumption (Croppenstedt et al. 2013 in Tufa et al. 2022) or because of their socially assigned role as food crop producers.

It emerges clearly that willingness by women to innovate depends largely on the type of practice. Nevertheless, the existence of marketing opportunities is a driver of SAI for both women and men. Dubbert et al. (2021) found that in cashew production in Ghana, the intensity of sustainable farm practices for female-headed households was 29% points lower than that of male-headed households. However, when they participated in contract farming, the intensity of their sustainable farm practices increased by 47% compared with that of male-headed households.

Finally, in some case studies, women were found to be less likely to adopt practices that were labor- and knowledge-intensive. In Sri Lankan rice systems, a variety of practices are promoted to help reduce the sensitivity of the production to water stress. Women were found to be less likely than men to diversify into other crops on uplands during *Maha (secondary seasons)*. Where diversification into other field crops occurred, it was driven primarily by younger and male-headed households. This was attributed to structural inequalities between men and women in terms of mobilizing labor and capital, but also to the fact that knowledge-intensive practices may be difficult to implement for less-educated women (Bandara, S. et al. 2021). Conversely, women's preference for intercropping in Malawi was also driven by the need to reduce their labor input into weed control (Tufa et al. 2022).

4.4. Women's collective action facilitates the adoption of SAI technologies.

Fostering collective action by women is seen as partly counterbalancing not only land-related obstacles to involvement in projects faced by women at the household level, but also the labor and knowledge constraints that women might face in their individual plots. For instance, as shown by Fischer et al. (2021a), in Ghana, smallholder farmers emphasized the unity and mutual support that women had established in their farming groups. This included labor support as well as knowledge-sharing about new technologies. Thus, the way that intensification interacts with exchange networks in the community emerged as an important investigation area.

These results highlight the importance of fostering collective action by women through participation by extension in women's groups that help women gain access to new technologies; women's groups can offer an opportunity for the successful delivery of extension services (Kristjanson et al. 2014; Flora 2021). For example, in Bangladesh, the SIAGI (promoting socially inclusive and sustainable agricultural intensification in West Bengal and Bangladesh) interventions were designed to empower individuals and groups to participate in agricultural intensification. These interventions included activities to foster the agency and collective action of women's self-help groups, water user groups and tribal minorities (Merritt et al. 2022). Also, participation in self-help groups in India helped women gain access to new technologies and own livestock. However, the women also reported an increased workload regarding farming and responsibility in terms of loan repayments (Kuchimanchi et al. 2021).

Similarly, in an assessment of the SAI of cereal production in Burkina Faso, it was demonstrated that addressing an extension service male bias by engaging with women's groups, along with improving women's access to resources (including credit and equipment) and income, contributed to greater gender equality of interventions (Theriault et al. 2017 in Salmon et al. 2018).

This is consistent with the findings of the review about gender and SAI by Flora (2021), who found that men and women have different networks, and that organized women's groups can be used to foster certain adoption patterns of SAI technologies.

5. Gendered impacts of SAI practices on food and nutrition security

This chapter provides an overview of the gendered impacts of SAI practices on female and male farmers and on food security. However, lack of systematic impact studies makes it difficult to reach robust conclusions regarding the gendered and social impacts of specific SAI packages across rural geographies and socioecological contexts. Overall, it emerges clearly that the impact of SAI on women and men's resilience to climate change; food security and nutrition; and broader social, gender and intergenerational equity; is often unintended, fragmented, and poorly researched. What is clear is that even the most benign technology can change intra-household labor relations and resource-allocation dynamics, sometimes with negative spill-over effects on women's time and well-being.

Gendered impact studies are limited, as the primary focus of most articles is on understanding adoption determinants, with gender featuring as an important intersecting factor. This is consistent with findings from a systematic literature review on gender and conservation agriculture (CA) in sub-Saharan Africa (Wekesah et al. 2019), which concluded that only a few studies captured the impact of CA on women's income, health, and food security among female-headed households and on gender relations at household levels. The authors conclude that the lack of a focus on gender as a dynamic social construct rather than as a biological phenomenon hinders a robust appreciation of how it affects and is affected by CA in sub-Saharan Africa.

In general, there seems to be little emphasis on the different perceptions of women and men in smallholder farming households about how they are directly impacted by SAI technologies. Perceptions are only considered in assessing the differential preferences of women and men for different varieties of specific products, for example by Ronner et al. (2019) in the case of climbing bean cultivation in Uganda. Most of the articles based on household surveys are trying to track some specific technical aspect from the farmers' point of view, for example, whether the productivity of a specific product and water consumption increased); whether nutrition of the family improved (Fiorella et al. 2016); whether plants were protected from specific pests (Upadhyay et al. 2020); or whether soil quality improved, (Tu et al. 2022), etc. Some articles include farmers' perspectives about impacts on their livelihoods, but few relate them directly to specific technical innovations and to how women and men are differently affected by these technologies. Zulu et al. (2021) argue that "*assessments of gender and intergenerational inequities in SAI costs and benefits sharing often remain overgeneralized, theoretical, or locally irrelevant"* (Zulu et al. 2021**:** 376, quoted in Snyder et al. 2022). Therefore, participatory impact studies are needed that focus on the perceptions of male and female farmers about SAI technologies, in order to develop locally relevant indicators for measuring the gendered impacts of SAI.

Wendy et al. (2022) address the lack of attention to gendered impacts by showing how integrated approaches (IA) to research-for-development (R4D) around agricultural intensification projects can be used to assess complex social and agroecological problems and different and integrated impact dimensions (e.g., economic, social, gender, food security etc.). The authors state the

importance of research activities that embrace co-creation and justice concepts as central to the process. Further approaches that have potential for assessing how SAI has different impacts on the women and men in small farming households include the ecosystem approach (Timberlake et al. 2022; Estrada-Carmona et al. 2020 and Flora 2021), and the so-called network approach that observes a combination of technical, ecological, and social impacts, (Timberlake et al. 2022).

5.1. SAI technologies and women's workloads

One of the most controversial aspects found in our review concerns the impact of SAI technologies on rural women's workloads in small farming households. One of the unintended impacts of SAI technologies is in many cases an increase of women's workloads; this is described in detail in several reviewed articles. But in other cases that we will also refer to in this section, some SAI technologies may alleviate women's workloads in specific contexts. For instance, Fischer et al. (2020) documented the labor-saving effect of a push-pull organic pest control system for women in Kenya. According to the authors, the push-pull technology (PPT) reduced the need for weeding, a laborious activity largely undertaken by women in the study areas (Diiro et al. 2021). PPT further serves as a quality source of fodder for livestock production, which can increase farm income and source of animal protein for the household. (Kassie et al. 2015. Dixon et al. (2020) also found evidence that in many South Asian countries, both female- and male-headed households practicing a rice-wheat farming system did not register any increase in labor because of adopting Conservation Agriculture for Sustainable Intensification (CASI). By eliminating tillage and reducing labor and water use, CASI practices saved energy in all cropping systems and increased energy-use efficiency by 13–15% for rice-wheat, rice-maize, and rice-lentil systems. Rola-Rubzen et al. (2016, and 2019 quoted in Dixon et al. 2020) emphasize the positive perceptions of CASI by women and men farmers, as well as a variety of direct and indirect benefits. Due to additional income and saving of time, the reported benefits include better nutrition for the family, reduced drudgery for women, more time for other productive tasks or leisure activities, and better education for the children (Rola-Rubzen et al. 2016; Brown et al. 2021*).*

Socially determined gendered patterns of labor distribution in farming greatly influence preferences and adoption. Consequently, some studies have focused on the potential reduction of women's workloads with SAI practices and show how the adoption of certain SAI technologies can generate changes in women's labor requirements, thus discouraging adoption. A notable example is found in Malawi, where enhanced women's empowerment in decision-making is associated "*with a higher probability of planting legumes but a much lower likelihood of manure intensification"* (Mponela et al. 2020)*.* This finding is consistent across research (e.g. Kihara et al. 2022; Mustafa-Msukwa et al. 2011), and may be because women find manure application (e.g. preparation and transportation) too labor-demanding. Where transport facilities are limited, and the usual way of transporting heavy product/s is on people's heads and shoulders, transporting manure is constrained by labor allocation requirements. Related to that is the evidence that livestock are usually owned by men (Kihara et al. 2022). A high number of household dependents

was also found to lower the likelihood of applying organic manure and limit the quantity of fertilizer applied (Mponela et al. 2020).

The gender impacts and labor requirements of SAI vary across type and number of practices adopted and are highly context-specific. However, evidence from research suggests that a parallel shift from previously male to female tasks often occurs. Additionally, there seems to be a new tendency in agricultural development to promote SAI technologies by arguing that they generally alleviate women's workloads. In response, several authors have shed doubt upon some of these arguments because of lack of convincing empirical evidence.

The most common trend is that the higher labor demand for the specific tasks and practices of SAI is often met by rural women, with far-reaching consequences on their time poverty and health. Westengen et al. 2018 refer to the already-mentioned shifts of labor from men to women in the context of SAI.

"*Reduced weeding presupposes the use of herbicides as reduced till is associated with a higher weed pressure than ploughing, and the reduced burden on women on land preparation is highly dependent on the type of reduced till practiced. Our focus group interviews (in Zambia) revealed that in cases where labor shifted where land preparation shifted from ploughing to permanent basins, the labor shifted from men to women, since ploughing is considered a male job and hand hoe tilling… a women's responsibility*" (2018: 6).

The presumed labor-saving potential of CA has also been challenged by Montt et al. (2020). They argue that the higher labor demand is driven by more work during the harvesting and threshing stages, which is usually provided by women and children. The study also remarks that the labor-saving potential of CA is usually in land preparation, weed control and threshing, as a result of the implementation of minimum tillage. However, minimum tillage is very difficult to adopt as it involves long-term investments to restore soil quality as well as investment in direct-seeding equipment that few people can afford. CA packages also involve a change in the use of various inputs. Too often, CA adoption is not accompanied by these complementary practices in an optimal way (notably chemical inputs, skills, and machinery), leading to lower yields and higher labor demand.

Kuya et al. (2021) also found that, while basin planting is effective in reducing the risk of crop loss and cultivating land previously not suitable for cultivation, it is labor-intensive and may induce a shift in labor input from men to women in regions where plowing is done by men. Overall, recent conservation agriculture projects in African smallholder farming that promote agroecology-friendly technologies sometimes impair their own goals through a burdensome, gendered shift of labor-time responsibilities to women. According to these authors, this is one of the main causes of slow adoption and contributes to ramping up negative perceptions among farmers.

In Sri Lanka, Bandara et al. (2021) found that the high investment required for SAI in terms of labor input may force both women and men farmers to abandon off-farm income opportunities, thus dissipating the benefits of SAI in terms of increased income. Alternative recommended

options are to replace labor with capital or mechanization for improving welfare, although mechanization is highly gendered and often found to benefit men more than women. Describing mechanized forage chopping in Tanzania, Fischer et al. (2019) showed how labor and income allocation can lead to gender struggles, because although men's appropriation of mechanized chopping may reduce women's labor input, it may also create dependency on male household or hired temporary labor, causing new labor demands that affect women's workloads.

A pattern of increased women's workloads is also found in sustainable livestock intensification. In India, for example, the transition to intensive systems that are more market-orientated has been inclusive of both lower caste groups and women in terms of increased ownership of large ruminants and access to technologies. At the same time, intensification has led to an increase in women's workloads in farming, driven by the shift from grazing-based livestock rearing to stallfed market-oriented systems and from rainfed food crops to irrigated cash and vegetable crops (Kuchimanchi et al. 2021). Women reported that rearing improved cattle in stallfed systems demanded more time, e.g., for feeding, cleaning sheds, and animal health care, than was needed for rearing cattle in grazing-based systems. The shift from rainfed food crops to irrigated cash and vegetable crops also increased workloads, particularly for tasks from multiple harvests to packing that is carried out exclusively by women.

The potential increase in women's workloads also depends on the number of practices adopted. According to Mottet et al. (2018), an increase in labor demand most affects those households that adopt the three components of CA, namely crop diversification, minimal soil disturbance (no-tillage) and permanent soil cover. Also, the high labor demand associated with the adoption of a combination of Integrated Soil Fertility Management (ISFM) technologies, which can be empowering if implemented in a gender-sensitive manner (Gartaula et al. 2022), is found to disfavor women in certain areas of sub-Saharan Africa (SSA) (Cyamweshi et al. 2022). Soil-management dynamics at the household level are gendered, and plots run by women managers (in both female-headed and couple households) are more likely to have crops with a single ISFM component than plots managed by men. This is because labor demands for both women and men rise with the number of ISFM components, although women's labor tends to be significantly higher. Yet women's interest in soil management practices is confirmed by several studies. According to Burke and Jayne (2021) soil management is a pressing issue, particularly for women as they generally have less access to quality land. According to them, "*interventions to improve the lowest quality soils would benefit the most disadvantaged farmers by default, and these are disproportionately women"* (2021: 8). The tradeoff between gendered labor requirements and the potential benefits of technology adoption emerges as a critical, though poorly-explored issue.

Gendered decisions over labor use tend to be male-dominated and are usually informed by traditional and highly rigid norms over women and men farmers' respective roles in decision-making. Discussions about the importance of renegotiating the gender division of labor in the context of sustainable intensification are virtually absent in the literature. Men's power to command and mobilize family labor within the household is often justified by the fact that they exert control over land and crops (Fischer et al. 2021a), particularly in highly patriarchal settings.

The unintended increase of women's labor is a direct consequence of poorly designed SAI packages, which means that gender and labor dynamics in farming systems are overlooked in technology testing and delivery. For instance, a sustainability impact assessment carried out in Tanzania found that the increased workload and time-intensive nature of agricultural practices under SAI were seen as more problematic for women than for men (Schindler et al. 2016). In Bangladesh, due to cultural dynamics, treadle pumps were designed for male operation but were actually used by women, exhausting them and reducing the time that they could spend on domestic activities.

When the additional labor inputs required by the adoption of certain SAI technologies are mostly provided by women rather than hired laborers, it is sometimes seen as a substitution strategy to compensate for the higher costs of the SAI technology packages. For instance, in Ghana, Michalscheck et al. (2018) found that high investment costs and labor constraints were the main obstacles to SAI adoption identified by both low- and medium-resource-endowed households, though these concerns were voiced more by male than by female household members. In Senegal, most of the agroecological systems observed displayed a significantly higher number of working hours by women per hectare and a lower number of wage workers per hectare, suggesting substitution between these two labor types (Laske & Michel, 2022). Montt et al. (2020) also remark how in sub-Saharan Africa the increase in labor demand for CA is largely met by household labor, and to a large extent by women and children with little input from hired labor.

Hiring additional laborers might be unaffordable, particularly for poorer households, including households headed by women who already struggle with chronic lack of resources. Yet the increased participation of family labor in intensified production might also lead to job losses for the poorest women wage workers. Such a reduction in the demand for women's as well as men's wage labor can have huge social costs. Gathorne-Hardy et al. (2016) analyze how rice intensification systems in India provide environmental and economic gains, but at the expense of social sustainability. Lower-caste women were found to be less involved in agricultural wage labor, which in turn reduced their ability to meet household food and health expenses. These findings suggest the importance of embedding broader considerations of labor impacts in the analysis of sustainable intensification, along with environmental and productivity concerns. Understanding this is crucial, as it might facilitate or limit the adoption of certain SAI practices. For example, Sinha (2022) analyzed how the change from cotton to paddy cultivation in India has led to a growing number of unemployed landless Dalit women, whose farm labor is no longer needed. This calls for the creation of a politics of labor that is equitable to both gender and caste.

Finally, Upadhyay et al. (2020) mention how norms concerning gender roles in farming are important for pest control in cassava crop protection in Laos and Vietnam. These gender roles are described in detail to show how they restrict women's participation in pest control:

"Women's inclination to plant naturally infers a traditional approach to agriculture characterized by low levels of formal knowledge, limited use of external inputs, and minimal involvement of

farmers outside the basic tasks of planting, weeding, and harvesting. This markedly passive approach to pest control appears to dominate local farming communities and possibly could be influenced by certain gender-specific attitudes or roles" (2018: 14)

This also relates to the degree of women's knowledge and education, showing how planting legumes is the preferred choice of women because they have greater knowledge of and control over these crops; this is accentuated by gender inequity in access to education in places such as the Tien Giang province of Vietnam. For instance, the average education span of the female household heads participating in training was 3.8 years versus 6.7 years for the males.

In some cases, SAI impact on gender division of labor is largely misunderstood and only superficially analyzed. Westengen et al. (2018) report that the framing that women benefit from SAI because it reduces their labor is not well documented (Whitfield et al. 2015b cited in Westengen et al.). Baudron et al. (2018) also argue that since women only make up an average of 30 % of labor in agriculture, their participation and workloads are exaggerated. However, women's participation in domestic and caring responsibilities is overlooked in the analysis. They also wrongly assume that if wage laborers are contracted, women's labor in agriculture can be reduced, without considering women's roles in managing and supervising labor contracts. Mechanization is also said to benefit women as much as men, without considering that women's labor taken over by machines is then generally considered to be men's labor.

5.2. Gender, SAI, and impacts on food security

Studies assessing the impact of SAI on food security and nutrition are also scant and rarely informed by gender considerations, despite the crucial and increasing role played by women as food producers and farm managers. This finding does not coincide with those of the review of Flora 2021, who concluded that in the past, nutrition was the main focus of gender and SAI research. Using the Household Food Insecurity Access Scale (HFIAS) indicator for the measurement of food access, Yahaya et al. (2018) found that households participating in SAI training in north-western Ghana were more likely to have better access to food than non-participating farmers. While the gender dimension of this finding is not explicitly assessed, it is stated that more female- than male-headed households participated in training and thus benefited from improved access to food. Nevertheless, the analysis of household food access fails to address the most challenging question of *access for whom?*

This is a critical gap, considering that enhancing food security and nutrition by increasing yield per hectare while reducing environmental damage from agricultural production is one of the main goals of SAI. Lovell et al. (2020) criticize the mainstream SAI paradigm for focusing on productivity increase, thus overlooking social, political, and distributive issues, which are often the root cause of food security problems.

Many studies capture SAI outcomes in terms of increased yield, sometimes assuming that this will have a positive spillover effect on smallholder farmers' household food security. For instance, Teklewold et al. (2019) in their analysis of how climate-smart agricultural practices can improve

household food security and nutrition, argue that this is driven by increasing agricultural income either through higher yields or by freeing up labor for alternative economic activities. (Teklewold, 2019).

In a systematic review of SAI practices, Reich et al. (2021) found that crop yield was one of the top indicators discussed in SAI research up to now. They identified several important research gaps, including more systematic assessments of food security, gender, labor, and wild biodiversity. Snyder et al. (2022) confirm this finding, arguing that increased productivity must be assessed for its other possible impacts beyond profitability — on labor, on equity, on the environment and on food security (2022: 10). While there is positive evidence that SAI interventions improve yields, how this translates into improved income or food security is still unclear. Multiple factors have impacts on food security and nutrition, including post-harvest losses, market access, fluctuations in market prices, etc. (Snyder et al. 2022).

From a gender perspective, while acknowledging the vital nexus between enhanced productivity and food security, overemphasis on increased yields fails to address the existing gendered power dynamics within households and food systems, and how these determine women and men's ability to sustainably access resources and a sufficient amount of nutritious food. For instance, Fischer et al. (2021a) show that enhanced productivity per se might actually reduce women's access and control over the harvest in contexts where land and crops are strictly controlled by men, which might undermine household food security and nutrition.

Conversely, they remark that when higher productivity is combined with a flexible crop allocation, men's control over agricultural produce tends to relax. This happened in patrilineal Ghana, where the intercropping of legumes with a more flexible crop — meaning neither women's nor men's — such as maize, secured women's access to harvest and benefits. They argue that this is a situation that can be particularly beneficial for women and children.

Gender participation in crop sales is also an important factor that influences food security outcomes. Me-Nsope et al. (2016), quoted in Nassary et al. 2020) found that when only men were involved in marketing farm products, the sales did not translate into improvements of the household's food security. Similar outcomes are also observed in intensified dairy systems. For instance, while women in Kenya play a greater role than men in milking, major decisions on trading and the use of income from milk sales are taken by men (Salmon et. al. 2018). Women and men can have different perceptions about the purpose of livestock rearing and intensification, (Heffernan et al. 2003 quoted in Salmon et al. 2018**)**: women see it as a means to enhance family food security, whereas for men it is a lucrative investment. These conflicting perceptions can lead to intra-household tensions and jeopardize food security.

Therefore, the key question for maximizing the food security impact of SAI is how to ensure that productivity enhancement is accompanied by measures that can enable more gender-equitable resource distribution and control patterns.

Wairegi et al. (2018**)** also provide evidence that poorer female coffee producers continue to experience seasonal hunger despite enhanced productivity as a result of SAI. They report that women and men coffee farmers who adopted SAI practices, had similar yields and level of intensification. Nevertheless, female-headed households were more likely to be food-insecure than households with male managers. While the reasons for this are poorly explored and remain nebulous, the higher dependency ratio (106 vs 82) of households headed by women, combined with more limited access to agricultural inputs, were singled out as the main factors leading to food insecurity.

Gender differences in productivity were also identified in some contexts. A study exploring gender differences in technology adoption and agricultural productivity in Malawi (Tufa et al. 2022) found that female-managed plots were 18.86% less productive than male-managed plots. The significant productivity gap between female- and male-managed plots was attributed to several factors, including differences in asset endowments, labor productivity and household dependency ratio, as well as the soil characteristics of plots. Results showed that female-managed plots were likely to be less fertile, steeper, and shallower than plots managed by men.

Similar results were also documented in central Malawi, where the promotion of soybean-maize rotations along with appropriate soil and crop management techniques led to larger maize yields, mostly among wealthier, male-headed households (Van Vugt et al. 2018). However, this result was also attributed to the low quality of soils in Dowa, where the majority of women participants came from. The fact that plots managed by women tend to have lower yields than those managed by men is generally attributed to unequal access to agricultural inputs. However, size and quality of land are highly gendered, and women often farm smaller and less fertile plots (Fischer et al. 2021a; Lovell et al. 2020**).** However, Tufa et al. (2022) remark that even when the resources managed by women and men are similar in both quantity and quality, limited agency and participation in decision-making heavily constrain women's capacity to make the best use of these resources.

It is surprising that despite the recent surge of attention to gender and nutrition, this is a neglected topic in SAI research. Schindler et al. (2016) show that the positive impact of SAI on nutrition has mainly been attributed to increased agricultural production, resulting in increased income and therefore in access to the necessary means to diversify the diet. Cyamweshi et al. (2022) argue that the focus of crop associations on legumes either as cereal legume rotations or intercropping contributes to important nutritional outcomes, since legumes are often high in nutrients. Legumes are also gendered crops, meaning that they are often controlled by women. This further enhances the nutritional potential of crop associations.

Improvements in the nutritional status of women measured through the Women's Dietary Diversity Score (WDDS) are reported in two articles. Baye et al. (2022) found that in households that practiced irrigation, women were found to have more diverse diets and higher intakes of Vitamin C and calcium than women in non-irrigating households. The statistically significant interaction between irrigation and season illustrates the buffering effect that irrigation can have on the seasonality of diets and energy/nutrient intakes.

Fischer et al. (2020) provide a more complex gender assessment of women's nutritional status in the context of SAI in Kenya by demonstrating that the adoption of push-pull technologies (PPT) has a positive impact on nutrition, and that the interaction of women's empowerment with technology adoption maximizes the positive effect. The results suggest that women's empowerment is a vital determinant of dietary diversity. As their empowerment increases, they have greater knowledge of nutrition and health and the power to make decisions, control income, and more time to exercise their knowledge in their caregiving practices. The positive impact of women's empowerment on the Women's Dietary Diversity Score is not only relevant to women themselves but can also impact the health of their family and the development of the next generation.

A few articles were also found that acknowledged the untapped potential of SAI on nutrition as a result of gender-blind or "exploitative" interventions, meaning that they reinforced rather than challenged the pre-existing gender-discriminatory normative system. For instance, Nischalke et al. (2017) found that women's lack of involvement in agro-forestry in Ethiopia meant that the use of forests as a source of food was neglected, despite the fact that the local inhabitants, especially the men, still had considerable knowledge about edible, (e.g., fruits) medicinal, and aromatic plants. Gender norms played an important role in shaping local livelihood systems and perceptions of wild plants. Indeed, forests were seen as male territory, where men mainly collected firewood for sale and grew coffee in the buffer zone. As a result, the tremendous biodiversity of the forest was not reflected in the study participants' diets.

5.3. Gendered access to resources, a constraint for SAI practices

According to some authors, SAI might magnify existing gender inequalities in access to land and resources. Some articles show how higher productivity and incomes could lead to the disempowerment and dispossession of women. This is a typical gender power dynamic whereby male farmers capture the land traditionally farmed by women for home consumption and/or take over the production of traditional women's crops to expand their own income (Fischer et al. 2017). A shift towards a more intensified system could negatively affect women (Salmon, et al. 2018). For instance, in Malawi, (Mponela et al. 2020**)** women's preference for growing legumes, intercropped with maize, largely reflects the social norm that legumes, including groundnuts, are "women's crops" (Nakazi et al. 2017; Orr et al. 2015 in Mponela et al. 2020). This is usually the case when legumes are grown for subsistence needs. A shift in control from women to men usually occurs when the legumes acquire a market value, thus changing status from being a subsistence to a commercial crop. Men's participation then increases but largely relies on women's knowledge for efficient management.

A gender assessment of the dairy value chain in Kenya (Katothya et al. 2017 in Mottet et al. 2018) found that women contributed most of the labor in small-scale intensive production systems but did not own the cows, which resulted in limited decision-making power and poor access to resources and opportunities. Salmon et al. (2018) quote a review of African backyard poultry

systems to illustrate that it was mostly men who made decisions and controlled the income, despite women providing the majority of care (Guèye, 2000). A clear risk emerges from the literature, therefore, that SAI interventions may increase the workloads of women and girls without commensurate enhanced access to and control of benefits from increased production.

Negative impacts on women's access to land is found by Huat et al. (2020) in their analysis of farmers' perceptions of water control systems in Mali. In undeveloped inland valleys, mixed farmers' groups (i.e., containing both men and women) were the main users (75%) followed by groups of men (15%) and groups of women (10%). The situation differed significantly in inland valleys developed using spate irrigation or controlled submersion, where the groups of men were the most dominant with 56% and 50%, respectively, compared with the groups of women at 0% and 11%, respectively. Thus, following inland valley development, men's access to land increased while women's access decreased. Water control facilities also affected access to land by migrant populations. Indigenous farmers were the most dominant in 55% of the undeveloped inland valleys, while mixed groups of indigenous and migrant farmers were the most dominant in more than 50% of the inland valleys developed using spate irrigation and controlled submersion, showing that inland valley development did increase access to land by migrant farmers.

This result confirms frequent reports that the construction of a water control facility reduces women's access to lowland use. One explanation for the fact that inland development reduces access to land by women is that in Mali, plots are allocated to individuals within the farm by a male elder following patrilineal inheritance. The most fertile lands are managed by men. Women are allocated the less fertile or more unreliable plots through their husbands or the male farm managers at the beginning of the growing season.

6. Structural constraints to gender-inclusive SAI

This chapter provides a critical review of the main gender constraints found by research about gender and SAI. It emerges that discriminatory social structures and norms shaping the gender division of labor, roles and responsibilities in rural societies, agriculture, and food systems are powerful constraints to gender-equitable SAI adoption and the distribution of benefits. Research highlights the following as the main gendered challenges and constraints:

- Women's weaker resource rights and insecurity of tenure;
- Women's limited participation in intra-household and collective decision-making;
- Difficult access to and control over the labor-saving technologies, mechanization, and irrigation that often accompany SAI packages;
- Male bias in extension systems and agricultural institutions.

Thus, from the household to the community and to a broader policy context, women face marginalization and exclusion. A more comprehensive analysis and conceptualization of how normative and institutional constraints are addressed and negotiated by women and men in their interaction with SAI is only found in a very few articles.

6.1. Gender-transformative approaches in SAI research and development

Only three articles adopt a comprehensive gender-transformation approach in the analysis of SAI and address the structural causes of gender inequalities, rather than merely focusing on the symptoms. These articles explore how the interaction of gendered social norms and structures at different institutional levels inhibit women's capacity to invest in and benefit from SAI. They also explore potential entry points for gender-transformative pathways built on Kabeer's social relations framework 1994 (Fischer et al. 2021a). This establishes four key institutional sites for conducting a gender analysis: market, community, government, and household. Each site embeds official and deep-seated rules and norms, which shape gendered patterns of resource distribution, participation, and relations of authority, ownership, and control. Gender inequality results from the dynamic interaction between all four sites. Changes toward more equity in one location may influence changes in other sites or give rise to tensions.

Fischer (2022) adopts a framework to show how gender-transformative approaches differ from standard gender approaches to SAI initiatives. She argues that gender transformation is about addressing existing discriminatory gender norms when researching and delivering technologies, studying how intra-household power dynamics affect the adoption of SAI, and involving different actors at multiple levels.

A critical perspective in the analysis of the factors perpetuating gender and youth-based inequalities in access to SAI is provided by Mdee et al**.** (2021). They argue that an identity-labelling approach (e.g., "women" or "youth" or "vulnerable groups" (such as people living with HIV/AIDS))

does not allow us to capture the structural processes of class relations, resources control and power that shape and intersect identity-based disadvantage. This homogeneous and superficial view of women and youth usually translates into the definition of specific or targeted projects for them. However, this might ignore the diversity of social and gender relations in agrarian households and fail to address more complex structural disadvantages. They conclude that without a more comprehensive understanding of increasing differentiation within and between rural households, it is unlikely that policy will be able to respond to making agricultural intensification more inclusive.

6.2. Tenure insecurity and inequalities in access to and control over land

Access to and control of assets are key for achieving the sustainable intensification of agriculture, food security and nutrition, and broader poverty reduction. Evidence is mounting that women's control of assets contributes to positive development outcomes, including greater food security and better nutrition, and more just, resilient, and sustainable food systems for all.

Secure access to land and water is vital for stimulating investment in these resources and related ecosystems (CGIAR, 2018). Sustainable intensification requires access to and control of sustainable production and management. Where women and men farmers do not have access to and control over land and natural resources, sustainable intensification is much harder, if not impossible.

Gender inequalities in access to and control over land are the most significant underlying factors constraining women's adoption of SAI practices. Looking at the interaction of SAI and land-based institutions, Fischer et al. (2021) remark that SAI conceptualizations of agricultural land use have failed to investigate their implications for prevailing inequitable land tenure systems. They argue that, while the literature has broached the question of how tenure insecurity negatively influences farmers' willingness to adopt SAI — even more so as climate change increases land pressure — gender and land equity issues have remained unaddressed. As an example, Yahaya et al. (2018) identified land ownership in northwestern Ghana as a major factor influencing participation in SAI technologies, which is in line with findings by Manda et al. (2015), Kassie et al. (2015) and Teklewold et al. (2013). As SAI is a long-term investment, non-landowners lack the incentive to invest in land. Yet the gender implications of this finding are not further discussed.

Fischer et al. (2021a, quoting Loos et al. 2014: 356) state:

"Without specific regard for equitable distribution and individual empowerment (distributive and procedural justice) agricultural intensification cannot legitimately claim to be sustainable."

Their research demonstrates that women's insecure tenure due to inequitable access to and control over land constitutes a profound obstacle to their engagement with SAI. Land-based institutions interact and mediate SAI processes and outcomes. Therefore, gendered negotiations

over SAI adoption are primarily located in gendered struggles over land. The patriarchal bargain varies depending on the local system, whether matrilineal or patrilineal.

For instance, in patrilineal Ghana, customary male control over land also implies control over labor and crops. This means that men are the primary decision-makers on whether to adopt SAI, which technology to choose, and on which plot to test it. Women were found to have little room for negotiation (Fischer et al. 2021a), and when they engaged in SAI testing on male-controlled land, men did not encourage them to adopt the practice.

This finding is confirmed by Piemontese et al. (2021), who found in their study of sustainable land and water management (SLWM) in Uganda that a rigid patriarchal customary land system, where decisions are taken by the older men of the clan, often represses the initiative to implement SLWM by women in favor of traditional practices. Conversely, in matrilineal Malawi, where the land is retained within the matrilineage, women are found to have more bargaining power in adoption and management decisions.

Likewise, In Cambodia land tenure security was recognized as a key factor in determining the adoption of conservation agriculture (CA); insecure tenure by either men or women may decrease interest in implementing CA. Short-term land management arrangements constrain the adoption of CA as its short-term benefits are minimal. Farmers with insecure land tenure arrangements might prefer investments that bear immediate profits rather than increasing the production potential of their soil. Since women tend to have less secure tenure than men, and their name is frequently not registered in ownership documents, whether formal or informal, they tend to be less interested than men in CA practices (Sumner et al. 2015). In Vietnam, there are clear differences in technological adoption between plots on which men have decision-making power (e.g., male-managed and jointly managed) and plots that are female-managed. On average, male influence increased adoption of SAI by 15% (Lovell et al. 2020).

Even in contexts where women enjoy access to and control rights over land, outcomes of SAI adoption can be uncertain as women frequently engage in small-scale experimentation on their plots that are smaller and often less fertile than those held by men (Fischer et al. 2020). Khatun et al. (2020) studied how in palm oil intensification in Ghana, gender shaped all the mechanisms of access to both land and resources and thus to adoption of SAI, with male farmers holding rights to larger areas of land and having preferential access to extension support. An interesting finding also came from Vietnam, where female-headed households farmed 0.50-hectare plots, on average, compared with the 0.65-hectare plots farmed by male-headed households. In households run by a couple, the average land size managed by the woman and the man was 0.56 and 0.66 hectares, respectively. In addition, female-managed plots were likely to have greater soil health problems (e.g., salinity, lack of fertility) which constrained the adoption of reduced tillage.

The interaction of SAI with customary systems is also a key research area. Yami et al. (2018) highlight the important role played by informal institutions in Uganda in enhancing farmers' investment in sustainable crop intensification (SCI) interventions. The customary system

facilitates access to land through inheritance, land rentals, and labor-sharing arrangements. However, informal institutions tend to be biased against non-clan and female members of the community. Some informants (33%) raised concerns over the gender implications of the customary land tenure system in excluding girls from inheritance based on the belief that they will get married and move away. This means that women, and especially girls, have far fewer rights and hence incentives to adopt SCI in the surveyed areas of Uganda. (Yami et al. 2018). At the same time, Fischer et al. (2021a) acknowledge the importance of customary institutions as sites for women to exert their collective agency and negotiate access to land for farming.

6.3. Limited participation of women in decision-making about SAI technologies

The ability of women to engage in decision-making in the SAI context is largely affected by intersectional factors, such as marital status and age; women's diverse access and control rights; awareness of new practices; gender division of labor; sense of agency; and whether broader support is provided by extension and research institutions. Gender decision-making traditionally takes place in two domains: within households and in public spaces. Though women's ability to participate in decision-making varies hugely by context, it is broadly recognized that key decisions concerning farm investments are largely male dominated. Mutenje et al. (2019) highlight the following:

"*Promoting women's active participation in intra-household decision-making is a critical step that would strengthen the ability of smallholder farmers to select a combination of suitable climate-smart agriculture options*." (Mutenje et al. 2019: 22).

For Theriault (2017), women have less bargaining power than men, which limits their access to and control over household resources, affecting their incentive to make investments for their plots.

Upadhyay et al. (2020) show that in northern Vietnam (e.g. Phu Tho), women play a central role in pest/disease monitoring, the selection of planting material, and overall crop management. Yet even in settings where women assume an equal (or larger) role than men in cassava crop management, they take on a relatively minor role in making integrated pest management (IPM) decisions. This differs in Tay Ninh, where women are regularly employed in off-farm activities, manage their own finances, and influence pest management decision-making at the household level. An in-depth analysis of intra-household decision-making over the use of shelling machines in Tanzania shows how male predominance in decision-making is the prevalent pattern. This is likely to be so, even in contexts where new gender norms around jointness or inclusive family-based decisions have started to emerge. The male-predominant role in decision-making is more difficult to relax in contexts where mechanization is part of SAI packages.

Tufa et al. (2022) also document that unequal participation in decision-making in Malawi was a key structural factor leading to lower productivity among female-managed plots than among male-managed plots. They suggest that efforts to close the gender productivity gap in SAI should

go beyond attempting to create equal access to resources towards addressing the underlying causes of gender inequalities. This requires using gender-transformative approaches to strengthening women's decision-making capacity and negotiation skills, along with challenging existing discriminatory gender norms.

An important finding that confirms the importance of addressing women's weak bargaining power in intra-household decision-making is discussed by Mutenje et al. (2018). The study found that women household heads, especially in matrilineal Malawi and Mozambique, were capable of mobilizing family labor and adopting complex SAI packages. The fact that they could exert decision-making power over resource use and labor allocation led to successful adoption.

The Water, Land and Ecology, (WLE) Program has found that intra-household dynamics need more attention in SAI research design, data collection and analysis, as well as in development programs, to avoid ineffective interventions (CGIAR 2018). In-depth anthropological analysis of smallholder farming systems could contribute to improving the design of SAI interventions. (CGIAR, 2018) According to Fischer et al. (2022), these are the key questions to be considered at the household level:

- Who acquires new knowledge and skills?
- Who decides on inputs, varieties, and land use?
- How are labor requirements distributed?
- Who reaps the benefits of increased productivity?

These and other questions are important in designing the dissemination and scaling up of SAI technologies to ensure that women benefit equally from the resulting opportunities.

A gendered analysis of intra-household decision-making entails a thorough understanding of the different norms that inform the process and of how this process is actually perceived and performed by women and men. An interesting and in-depth analysis of gendered decision-making patterns over the use of mechanization is provided by Fischer et al. (2021b). The research found that men from male-headed households said that they took the majority of decisions alone or jointly. Women from the same households ranked joint decisions first, husbands' decisions second, and their own decisions last. Where more active female labor was available in households, willingness to rent a shelling machine decreased significantly. The same correlation was not found in households with available male labor. Men's high decision-making power was associated with land ownership, income control, and with the perception that looking for machine services or for hired labor requires leaving the house.

People interviewed also mentioned a new emerging trend toward more joint decision-making. However, this was not reflected in the quantitative data. Key informants described two gender norms in this respect which — although contradicting each other — both endorsed men's authority: i) women should not challenge their husband's suggestions, but rather support them.

Women who speak first may be perceived as dominating their husband; ii) A woman can make suggestions to her husband. However, in all cases, the man is the ultimate decision-maker. A few people also mentioned households in which important agricultural decisions are taken at family meetings (vikao vya familia). The authors caution that the analysis of "joint decision-making" in the survey is incomplete as it is not clear whether this involved meaningful negotiation or just sharing information about male-determined decisions. In conclusion, they argue that such decision-making patterns will hardly change, as they are influenced and reinforced by the rigid patriarchal norms embedded in all institutional structures.

Conversely, in Malawi, Fischer et al. (2021a) found that the strong ideology of jointness has actually led to more gender-equitable decision-making patterns. "Jointness" is the main narrative promoted by the extension system in the country, and all extension staff have embraced the message that women and men "should do things together". This means that all activities, both productive and reproductive, should be shared, and all key decisions concerning what to grow and how to invest family resources should be open to negotiation and consensual.

With regard to community-based decision-making, some of the examples provided above show how women's voices in collective management institutions, such as water user associations, (WUAs) tend to be weak. However, the issue of women's participation in community-based decision-making concerning adoption of SAI in the context of common property resources, such as agroforestry or water management projects, has not been identified through research.

However, the importance of fostering women's collective agency to harness their knowledge and raise their voices in SAI processes is recognized as a key empowerment and leadership pathway.

6.4. Women's access to labor-saving technologies, mechanization, and irrigation

These important constraints for women are discussed by several articles about gender and SAI. Mechanization is a sub-topic of SAI and is sometimes also included as a complementary intervention of SAI packages. It is an issue of critical importance for women. Lack of farm mechanization means high labor drudgery that affects women disproportionately and especially those who are household heads. Estrada-Carmona et al. (2020) affirm that improved access to appropriate, low-cost, labor-saving technologies (e.g. through access to oxen and ploughs), while considering the potential labor demand that alternative practices such as conservation agriculture can pose to farmers is particularly relevant for women, especially in the Western Province of Zambia, where the percentage of female-headed households is greater than the national average (CSO, 2012; see also Cole et al. 2015).

Baudron, et al. (2015) identify farm power (quantity and quality) as a major limiting factor on productivity in many farming systems of sub-Saharan Africa. However, labor availability is uneven across countries and most importantly, the quality of labor has deteriorated as a result of an ageing population (stemming from rural-urban migration, and HIV/AIDS) and the subsequent

increase in the number of female-headed households among smallholder farmers, which are excessively labor-constrained. Baudron et al. (2015) suggest the adoption and dissemination of small, multipurpose, and inexpensive sources of power such as two-wheeled tractors (2WTs) in combination with the promotion of energy-saving technologies such as conservation agriculture (CA), as a key pathway to SAI in sub-Saharan Africa.

The so-called feminization of agriculture often means that women are left to manage their farms with very limited inputs and support and often compensate for the lack of male labor by increasing their own workloads. According to Farnworth et al. (2017, male outmigration in Vietnam has forced women to take over traditional male responsibilities in rice operations, including irrigation, land preparation, dredging field canals, pest management, pest identification, pesticide spraying, fertilizer application, and hauling of paddy sacks. However, women found all these activities very difficult to manage without male support.

Women's limited access to farm and agricultural inputs such as seed, herbicides and farming equipment is also mentioned by Wairegi et al. (2018). They report that in Ethiopia, even if men gave women coffee trees and land to establish coffee, households with female-managed coffee owned less spraying equipment (26.4% vs 38.1%), fewer wheelbarrows and carts (16.4% vs 25.1%) than households where the coffee was managed by men.

Institutional gender constraints to accessing machinery are pervasive and cut across all institutional sites, namely household, community, market, and extension system. In an in-depth gender analysis of the dissemination and adoption of shelling machines in Tanzania, Fischer et al. (2021 b) show that deep-seated patriarchal norms that govern the distribution of resources, responsibilities, and power across all institutional domains, impede women's effective involvement in mechanization.

Decision-making about the use of machinery is heavily male-dominated. The high cost and poor availability of shelling machine services are also identified as key factors that limit their use among the rural population. Women's limited mobility further hampers their ability to access machinery services outside the household, as this is perceived to be a man's responsibility. However, women farmers were found to be more interested in manual labor as they use the maize cobs as fuel. Sometimes, female hired laborers are given the cobs as part of their payment for manual shelling. Women's need for unbroken cobs therefore discourages mechanization. This also demonstrates how women's specific needs and preferences are overlooked in machine designs, thus limiting adoption. The small number of women engineers in the country is also part of the problem.

A study that assessed differentiated gender perceptions of risks and impacts related to different agricultural innovations in Tanzania found that intra-family conflicts were triggered by the introduction of maize threshers. Since threshing is normally women's responsibility, men's refusal to let women use the machines was a cause of tension (Schindler et al. 2016).

With regard to irrigation, Lefore et al. (2019) found that women in sub-Saharan Africa are typically limited in the extent to which they can access and benefit from advanced irrigation technologies

and practices following adoption by a household. Men often exclude women in the household from information and extension services, appropriate more expensive agricultural assets in the household, direct the use of technologies to men's plots, and are more likely to control and benefit from production sales with advanced irrigation technologies. Women also often have limited decision-making power over when and how small-scale technologies are used across seasons and water sources. In many cases, women confront cumbersome customary requirements that reduce their access to family land on which to farm. These intra-household power dynamics further reduce the ability of, and incentives for, women to invest in irrigated production.

Research in the Eastern Gangetic Plains (CGIAR 2018) found that gains in irrigated areas and increases in agricultural production largely accrue to a small minority of relatively privileged people; the vast majority are landless and remain poor. In Nepal, despite government subsidies for tube wells and pump sets, the procedures to access the scheme are cumbersome, and social networks are needed to push through applications. This makes it challenging for female-headed households to access these entitlements.

Even well-intended pro-women policy reforms often fall short because the contextual social dynamics are not well understood. Women's membership in collective irrigation schemes is frequently constrained, even where national policy supports their participation. Among the many factors that militate against women's participation, the most notable include rules that make membership contingent on land ownership, inconvenient timing or location of meetings, and social norms that limit women's active participation in public forums. When gender quotas are enforced, women are often reluctant to speak in public meetings or see no advantage in participating. They would rather pursue more informal channels to achieve their objectives (Yami 2013; WLE 2017a; Karn et al. Forthcoming)

6.5. Male bias in extension systems and agricultural institutions

Male bias in extension systems is identified as a crucial constraint in limiting women's adoption of SAI practices. Extension services barely target socially or economically marginalized groups and remain stuck in a top-down technology-transfer approach. Farmer-to-farmer or community-to-community knowledge exchange and learning processes are still more the exception than the rule. According to Farnworth et al. (2018) women's lack of self-identification with the concept of innovation is a consequence of their exclusion from extension services.

Khatun et al. (2020) found that in palm oil intensification in Ghana, male farmers are able to access support from local extension services because they are often in direct contact with local government extension officers.

Women's limited contact with extension services is often due to lack of education and to barriers to accessing local agricultural cooperatives or government extension officers (Brown P. et al. 2021; Muriithi et al. 2018). In Vietnam, extension workers prefer to interact with male farmers, and they

usually wrongly assume that information will be shared with other family members; this rarely happens unless it is proactively supported by extension workers through the adoption of family-based approaches. In a sample, only 21% of women received training compared with 50% of men (Lovell, et al. 2020). Lack of a focus on gender transformation in extension activities is also documented in Ghana, where rural extensionists tend to reinforce existing gender norms and inequality in access to resources and decision-making by translating the practices and their labor requirements into a pre-existing gender order (Fischer et al. 2021a).

Oyetunde-Usman (2022), noted that constraints to technology adoption among women are pronounced across all stages of technology adoption, which include awareness, tryout, and continued adoption. These constraints are similar to the ones faced in traditional agricultural practices such as, for example, difficulties of access to and use of agricultural inputs; insecure land tenure; access to credit, markets, institutions, and human and physical capital. Fischer et al. (2021b) also found that the lack of women engineers in Tanzania is a factor that limits attention to women's needs in machine design.

In Asia, both Vietnamese and Lao women attribute their deficient knowledge of crop protection to limited access to resources, training, or information. (Upadhyay et al. 2020). Agroecological knowledge and practices differ between men and women and among households along a gender continuum. Women's knowledge is often relatively slight, and they have a limited role in pest management decision-making at most sites, yet they play a prominent role in the selection of propagation material and favor agroecological practices. In southern Vietnam, women guide household-level IPM decision-making, but their poor agroecological knowledge further enables the diffusion of insecticide-based pest control locally.

Mulema (2019) analyses the factors that constrain women' participation in the different stages of the agricultural research process in Ethiopia. The results showed that input in production decisions, autonomy in plot management, membership of farmers' groups, the ability to speak in public, as well as access to information, extension services, education and land size, all enhanced women's participation, while cultural norms hindered women's empowerment and engagement in research.

To successfully scale up SAI technologies, agricultural development actors need to reach out to a diverse group of farmers, including women and men of different ages and different social groups. Extension efforts are frequently targeted at men, which means that women have unequal access to the same information. With regard to gender-related constraints, attention should be paid to identifying the most vulnerable groups in those communities and to the scaling of technologies that provide benefits specifically for these groups. Gramzow et al. (2018) document how the inclusion of both women and men from married couples in Training of Trainers (ToT) activities was key to accelerating technology adoption and dissemination.

Studies (e.g., Ragasa et al. 2014) show that technology adoption can be enhanced and made more sustainable when dissemination efforts are broadened to target both husband and wife within a

household. Fischer (2022) recommends that extension implements household approaches to create a space for women and men's heterogenous preferences to be considered in negotiations, and to facilitate adaptation within households. She mentions the gender-balance tree developed by the Gender Action Learning System (Mayoux and Oxfam Novib, 2014) as an important tool in this repertoire. Fischer et al. (2021a) also mention the household approach, which is being implemented by the Department of Extension in Malawi as a flagship gender-transformative approach to extension.

Little access to extension and agricultural institutions also means that women's traditional knowledge often remains unrecognized. Hence, its value and potential remain untapped, despite the fact that complex interactions of agrobiodiversity and agroecosystems are always mediated by smallholder and gendered knowledge systems (Zimmer et al. 2015).

For instance, Kuria et al. (2019) argue that gender has a significant influence on farmers' knowledge of soil quality indicators and soil management practices, suggesting that soil and land restoration interventions that recognize gender-sensitive entry points are likely to be more effective than gender-blind approaches. Bharucha et al. (2021) also argue that land rehabilitation projects globally are gender blind and fail to address gender-differentiated aspects of land degradation by ignoring women's knowledge, priorities for land restoration, and resource needs.

Overall, few articles emphasize the importance of harnessing the traditional knowledge of women and men in smallholder farm households. In Nepal, women have difficulties in acting on their agroecological knowledge (Jewitt 2000 cited in Timberlake et al. 2022). Estrada-Carmona et al. (2020) recommend a gender-sensitive ecosystem services approach to assess local knowledge from women and men and ascertain which SAI services and their sources are most important to them. A third article criticizes the lack of men and women's, but especially women's traditional knowledge, used in fighting pests in agriculture in Vietnam and Laos (Upadhyay et al. 2020).

Women's groups can offer an opportunity for the successful delivery of extension services (Kristjanson et al. 2014 in Salmon et al. 2018). In an assessment of SAI of cereal production in Burkina Faso, it was demonstrated that addressing a male bias in extension services by engaging with women's groups, along with improving women's access to resources (including credit and equipment) and income, contributed to greater gender equality of interventions (Theriault et al. 2017 in Salmon, et al. 2018).

As stated by Flora (2021**),** women's organizations could prove useful in adapting and developing SAI technologies for both female- and male-headed households. Fischer et al. (2021a) also highlight the important role of women's collective action in counterbalancing knowledge gaps in SAI.

Moreover, Gramzow et al. (2018) found that women-dominated groups in Tanzania tended to outperform men-dominated groups in caring for their demonstration plots. The reason for the gender-specific differences observed here can perhaps be attributed to leadership style. Women-dominated groups often had moderate leaders, while in some of the men-dominated villages,

strong leaders supported the dissemination of innovations, but in most cases, strong leaders dominated the groups too much, which led to the decreasing involvement of other group members.

Innovation platforms (IP) offer opportunities for gender integration in research activities. Schut et al. (2016a) observed that a large share of the current Humid Tropics IP activities focusses on the (participatory) testing and adaptation of technologies (e.g., intercropping) at local levels. Here there is increasing attention to the non-technological dimensions of agricultural innovations such as nutrition and gender. However, these platforms are rarely integrated into R4D activities.

Smallholder farmers in general are constantly faced with limited credit facilities that affect the adoption of SAI practices, and in many cases women have even less credit facilities than men. Theriault et al. (2017) analyze how credit access also remains crucial for cash purchases of yield-enhancing and yield-protecting inputs, especially for women who have limited economic control within the household.

7. Conclusions

We conclude in our review that research up to now has produced rather contradictory evidence about the effectiveness and potential of SAI to enable smallholder farmers to improve their livelihoods, and for it to fulfill the enormous expectations related to food security and the recovery of natural resources in this time of climate change. This finding is consistent with the conclusions of several other literature reviews on SAI mentioned in section 3.

SAI technologies are not gender neutral as regards labor and capital requirements, empowerment, or economic benefits and costs. Some may worsen women's conditions while others may increase their workloads. SAI might increase existing gender inequalities in access to land and resources. This is because technologies are developed either with only male farmers in mind, or, if focused on women, they overlook how the gender division of labor and women's unequal access to decision-making in the household influences adoption. For example, the design of a mini tiller that can also be operated by a woman (Paudel et al. 2020) may increase production of the commodity. But if the overall time that women need to spend doing household and reproductive work and also operate these machines is not considered, women's workloads may increase too much. Therefore, SAI technological innovations should always consider social, economic, and cultural factors, and not focus exclusively on a single technological innovation or the yield of specific crops.

SAI technologies require new ways of working with farm systems and involve a reallocation of men's and women's resources (Farnworth et al. 2015). They have implications for labor requirements, time use, and investment decisions, and may negatively impact the ability to manage a variety of crops, wild plants, and animals for household food security. This is especially relevant for research about how women's workloads are affected by the adoption of SAI

technologies. It is not enough simply to measure the time that women need to invest in a specific technology, but a broader focus also has to capture shifts in the labor allocation of women's other productive tasks because of the adoption of SAI technologies.

The potential of SAI technologies as innovative approaches to food production that protect the soil while increasing resilience to climate change is important, but the risk of further soil deterioration remains.

"*Fertilizer access is not on its own sufficient for sustainable soil management*" and "*crop stover is preferred as feed … rather than to amend the soil*" (Tu et al. 2022: 13).

Many studies also focus on short-term research pilots and fail to capture the viability and impact of these technologies over the long term. The reality of rural households and how they transition to SAI is still not fully understood. Long-term studies suggest that environmental, productive, and social sustainability may not be easy to maintain and are not guaranteed over long periods of time (Snapp et al. 2018; Rietveld et al. 2022). The changing demand for certain agricultural products in the market, for example, can lead to the production of new kinds of crops, which in turn may increase the income of some smallholder farmers but may disadvantage others and change the whole dynamic of SAI adoption at the local level.

Lower intensity of labor and higher yields are seen when CA is adopted with the appropriate machinery and nutrient- and pest-management practices, which helps mitigate any labor increases in weeding, harvesting, and threshing (Montt et al. 2020). Yield increases are not guaranteed with CA, as CA is a mix of practices best implemented in combination. Moreover, it requires a waiting period for soil quality to recover and a specific mix of chemical inputs, machinery, and skills to produce higher yields and actually reduce labor. As implemented in Ethiopia, Kenya, Malawi, Mozambique, and Tanzania, all three principles of CA are seldom applied together. Disadoption could be the result of the fact that CA benefits take time to materialize (Jat et al. 2018). After accounting for the selection process in CA adoption, we find that CA actually increases the demand for labor. This is consistent with findings from Teklewold et al. (2013) that take a broad look at CA and its effect on labor in Ethiopia.

According to Haggar et al. (2021) the literature supports the notion that low adoption often results from promotion of a technological package that does not meet farmers' production conditions and objectives. Agricultural policies often encourage short-term productivity and adoption-focused interventions that disregard the diversity of African smallholder farms and long-term sustainability goals. Facilitating farmers' adaptation of conservation practices to their own conditions and capabilities, by means of farmer-participatory experimental approaches, is presented as a potential way forward.

Social sustainability remains a neglected dimension of SAI, although SAI is inherently about the future and sustaining or improving human welfare across generations. Consequently, researchers and development specialists increasingly call for more inclusive SAI, with increased engagement of women and youth (see Grabowski et al. 2020). Promising approaches for finding gender-

relevant conclusions and realizing the real impacts of SAI are ecosocial system models or so-called network approaches that observe a combination of technical, ecological, and social impacts (Timberlake et al., 2022; Estrada-Carmona et al., 2020; Flora, 2021) and the participatory monitoring of SAI interventions over long periods of time.

Our review has shown that socially sustainable SAI interventions need to take into account that SAI adoption patterns are strongly influenced by gender differences and depend on specific crop or animal types, management, and labor requirements. Rural women can be key agents of socioecological changes, but they need to be addressed directly by institutions and extension services, and their workloads need to be reduced. Women's organizations can facilitate collective action for the adoption of SAI technologies by helping to overcome important constraints such as access to technologies; land, water, and other natural resources; and markets and financial services. A strong focus needs to be on equal benefits from SAI innovations for women and men in smallholder farm households. When incomes are improved, SAI interventions need to ensure that men do not appropriate all the benefits for themselves.

Many research studies still do not include gender or women at all (74 % of all the articles found). Only 14 % of the articles were gender relevant. Another 12 % included one or another gender aspect but did not have a systematic gender analysis. 8 % of the gender-relevant articles only included women who were heads of households, while 9.4 % also included women of different ages in male-headed households. Intersectional research about gender and generational aspects is still emerging.

Women are often conceived as a homogeneous category; some articles do not even differentiate between women who are household heads and women from couple households. Other intersectional dimensions, e.g., age, social status, ethnic identity, etc., are rarely considered in the literature. However, it emerges clearly that women household heads typically have more bargaining power, greater control over assets and decision-making, and can be better agents of change towards SAI than women in male-headed households. Many households led by women are reported to be keen to learn and to see SAI as a viable solution to enhancing food security and nutrition and to coping with climate-related stresses. However, they face critical labor and resource constraints that must be addressed to enable them to choose and combine multiple practices that can lead to long-term benefits. For instance, evidence is mounting that manure application is often too labor-demanding. Some evidence is also provided that when women farm managers are empowered, they can mobilize family labor or access labor-saving technologies and other incentives that enable them to adopt complex packages, often including a combination of land- and water-management components, crop associations and diversification, and organic fertilizers.

Most research does not seem to be interested in the perceptions of farmers themselves about SAI technologies, and even less in differences in perceptions between women and men of different age groups in rural households. There is still a lack of information about how different members of small farming households actually perceive SAI and its impacts on their livelihoods.

This seems to reflect prejudice on the side of researchers about the “unscientific nature” of small farmers' perceptions vs. scientific findings, or even about whether smallholder farmers with little education are able to think critically and perceive what is going on at the local level. A majority of articles still focus exclusively on quantitative methods to measure technical details. However, the most relevant articles about gender and SAI use either mixed quantitative and qualitative research methods or mainly participatory qualitative methods.

7.1 Major trends in recent research

The suitability of SAI for diverse African smallholder farming systems has been contested. The dispute has mainly focused on yield benefits, financial investments required, whether labor savings are achievable, and the quantity of crop residues available for use as surface mulch. Overall, there is limited understanding of how different technologies or packages are most suitable for specific socio-ecological contexts, farming and food systems, and household characteristics. This has resulted in top-down solutions and limited adoption and scaling-up. Labor shortages are reported to be an important constraint for SAI technology adoption in Africa, especially when zero tillage is not complemented by the application of herbicides. Gender-differentiated labor shortages or labor-hiring practices need to be considered, especially for tasks such as weeding. Labor entails the work of boys, girls, women, and men, and has different implications for each of them, but this is not documented in detail. Women’s labor is often not interchangeable with men’s labor. Women are paid less and since they have many tasks in the household, their work may be less secure.

Many articles consider that SAI enhances food security and nutrition through increased yields, which means that surplus can be sold in the market, thus boosting income. However, this assumption is contested, as others argue that such impact has not been adequately documented and that inefficiency in food and market systems might jeopardize food and nutrition outcomes. Gender analysis contributes to questioning the productivity-food-security-nexus by showing how food security and nutrition outcomes are always mediated by multiple factors, including the way women and men negotiate access to and control over resources, income, and benefits.

7.2 Emerging themes

One topic emerging is that investments in SAI often only offer long-term benefits (Snyder et al**.** 2022). This is a critical constraint to adoption as small farmers, and particularly women, might be unable to invest in technological packages that have financial and labor costs but no immediate benefits. Insecure tenure might further discourage long-term investments in land. There is also

ample evidence that the labor costs of CA are too often borne by women, who are already overburdened and unable to take on additional labor without compromising their health and precarious livelihood systems. In those contexts, measures must be adopted that address and minimize those tradeoffs.

However, evidence also shows that in matrilineal societies like Malawi and Mozambique, farm households with female heads are more likely to invest in a combination of climate-smart agricultural (CSA) practices (i.e., improved maize varieties, soil and water conservation, and cereal-legume diversification) with medium- to long-term benefits, despite the high labor requirements. This is because women tend to adopt less risky but more labor-intensive CSA technologies if they have decision-making power over their own labor allocation (Mutenje et al. 2019).

Another emerging theme in research in Africa is a focus on the perceptions of young people about SAI as well as on generational challenges and their impact on agricultural intensification. Again, several of these studies focus on low yields in SAI adoption even among young people (Lindsjö et al. 2020 and 2021), but some new studies focus more than before on social dynamics and SAI, on the intersections between gender and age, and on exclusion from SAI technologies (Zulu et al. 2021 and 2022).

Many of the reviewed studies about generational challenges point to the growing population and the demand for increased employment opportunities within the agricultural sector, as well as to the mounting pressure on the always-less-fertile land available for agriculture and the need to protect and recuperate natural resources. In Malawi for example, where 85 % of the population is rural and most of the population is young, life expectancy for older farmers has nearly doubled recently (Lindsjö et.al. 2021). The lack of social security imposes a strong interdependence between generations, because young people need to care for old people in their family. Most conflicts within families are reported to be land related, as old people withhold their land longer or prefer to rent out or even sell land instead of transferring it to the younger generations.

One of these recent studies (Zulu et al. 2021) tried to create standard SAI indicators for detecting inequalities in specific socio-cultural contexts. “Locally appropriate indicators” for gender and age in SAI as well as data collection methods, instruments and practices are generated through participatory contextualization processes as a means to proposing alternative research methods. Local contextualization of SAI indicators through participatory processes have led to the participatory indicator development (PID) approach (Gujit, 1998; Fraser et al. 2006; Reed et al. 2008 quoted by Zulu et al. 2021), a framework with four categories of gender and intergenerational inequities in SAI productive resources: agency, empowerment, capacity, and achievements. The important conclusion is that in order to get holistic and reliable information, one needs to interview multiple members of the household (men, women, male and female youth).

Another emerging theme is research and development with a gender-transformative approach to SAI. Fischer (2022) proposed a whole working session with agricultural extensionists about how to "weave gender into SAI interventions" with a gender-transformative approach. Fischer et al. (2021 b) have also applied a gender-transformative lens to qualitative research methods about "SAI and gender-biased land tenure systems". The authors focus on four institutional domains — household, community, market, and government — that shape gender relations and their outcomes and identify how these institutions engrain and perpetuate gender inequality in Ghana and Malawi, how they relate to land use intensity in comparison, and how a gender-transformative approach to SAI could tackle and change these mechanisms. An important conclusion is the need to assess the gender implications of new technologies and their potential to transform existing gender inequalities.

Another emerging theme is how to address gendered institutional constraints in gender research. For instance, the extension system is still highly male-focused and male-dominated. Extension messages continue to reinforce existing gender norms and technologies designed with a male farmer in mind. Nevertheless, opportunities are identified in women's collective action and by using women's informal networks and social capital to disseminate knowledge and innovations. Institutional innovations in extension systems, through the use of household methodologies for example, are also singled out as key drivers of gender-transformative SAI. A focus on customary systems and how they mediate gendered access to SAI also emerges as an important research area in the search for transformative solutions.

8. Recommendations for future gender and SAI in agriculture research and development

This review has shown the need for more evidence about how gender and SAI technologies interact. More participatory and qualitative research is needed to unveil gender power dynamics by including the perceptions of women and men of different ages in smallholder farming households and not only the perceptions of male or female household heads. Although a focus on female-headed households is important, the preferences of women within male households should also be considered, and the same is true for the preferences of young women and men. Rather than a focus on one or a few particular technologies, which may not reveal the gendered impacts of the technologies, an ecosocial systems approach is recommended.

On the one hand, many more small research projects should be undertaken to obtain detailed empirical knowledge from different sites. In particular, the different parts of the production cycle should be examined with a gender lens: e.g., land preparation by manual vs. animal traction; weeding; residue management; crop diversification; gendered crop choices; post-harvest

processing; and food and nutrition security. More evidence about how gender and SAI technologies interact could contribute to a better understanding of gender differences in the adoption of intensification strategies; this is crucial for designing effective policies to close the gender gap while sustainably enhancing farm productivity in the context of climate change.

On the other hand, more long-term research is needed that has a broader focus on a farm-to-field-to-landscape and an ecosocial-system approach, and on the perceptions of different members of small farming households of different gender and ages, in order to evaluate the potential of SAI for productive, ecological, and social sustainability and for improving the livelihoods of all the family members of these households.

Only one article by Farnworth et al. (2017) explored the use of nitrogen fertilizers in the tropics and argued that negative externalities of imbalanced inorganic nitrogen use impact most strongly on women and children. A more balanced use of nitrogen is critical for delivering better gender outcomes in relation to health and livelihoods. More evidence from other case studies is needed about this important aspect.

More research is required about emerging themes, such as the Implications of land ownership for the adoption of SAI by women, especially in relation to long-term investments. Sharp differences have been identified between matrilineal and patrilineal societies, with the latter embedding a more rigid normative patriarchal system that impedes women's engagement in SAI. But regardless of the type of customary system, gender struggles over land within households and communities always mediate access to SAI, and this aspect needs to be researched in more areas.

The institutional and policy frameworks that shape SAI initiatives should be more strongly considered in research. Very often the focus is strictly on technology, without considering the broader institutional context, how this informs technology development, and what socio-institutional innovations are needed to promote gender-transformative SAI initiatives. More research on the gender-transformative potential of SAI is needed.

Several recommendations emerge for development action and the design of SAI innovation packages for smallholder farmers to assure social sustainability and to avoid unintended negative gender impacts. Among relevant social and gender indicators, the following should be considered: 1) local gender preferences for technologies, crops, varieties or animals; 2) the purpose of production; 3) the level of investments vs. the level of benefits of SAI technologies (immediate and longer-term) for each smallholder farm household; 4) additional incentives offered besides technical advice to improve access to resources, mechanization, financial services, value chains, etc.; 5) the distribution of benefits from SAI adoption between men and women in each small farming household; 6) workload changes for different family members when adopting SAI technologies and compensation measures for rural women; 7) resources offered to support local rural women's organizations.

According to Fischer et al. (2022), these are the key questions to consider at the household level in relation to SAI packages:

- Who acquires new knowledge and skills?
- Who decides on inputs, varieties, and land use?
- How are labor requirements distributed?
- Who reaps the benefits of increased productivity?

Fischer et al. (2019) identified three gender-linked pathways to nutrition in SAI:

- Women's enhanced participation in agricultural decision-making, which means that they can influence intra-household decisions over allocation of food, health, and care;
- The promotion of a healthy balance of time between income-generating activities and household maintenance and caregiving;
- The general improvement of their own health (e.g., through less exposure to agricultural chemicals) and nutritional status (e.g., through less expenditure of energy).

Gender-transformative approaches to SAI interventions are about addressing existing discriminatory gender norms when researching and delivering technologies. They require studying at local levels to see how intra-household power dynamics mediate SAI adoption and involve different actors at multiple levels. Without a more comprehensive understanding of increasing differentiation within and between rural households, it is unlikely that policy will be able to respond to making agricultural intensification more inclusive (Mdee et al. 2021).

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