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Nurturing Resilient Urban Animal Agriculture for Food Security in Sub-Saharan Africa: A Triad Approach to Social, Economic, and Environmental Sustainability

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Abstract

Urban animal agriculture (UAA) in sub-Saharan Africa is a sustainable solution to address urban food insecurity and malnutrition due to population growth. However, it faces challenges such as gender inequality, climate change, inadequate legislation, and environmental degradation. UAA aims to enhance household food security and alleviate poverty but also faces environmental issues such as resource competition, water resource strain, improper manure management, greenhouse gas emissions, noise, and nuisance. Implementing gender-climate smart urban agriculture concepts can promote social sustainability. Sustainable UAA requires semi-intensive silvopastoral and mixed crop and livestock systems, which reduce agriculture's environmental impact and enhance local food production. Supporting small-scale urban farming initiatives and collaboration between farmers and local authorities can build resilience in urban animal agriculture communities. In conclusion, a triad approach is needed for sub-Saharan Africa to harness the potential of UAA for food security, livelihood enhancement, and environmental protection.

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1. Introduction

The UN predicts that by 2050, 70% of the global population will live in urban areas, with sub-Saharan Africa experiencing the fastest urbanization (UN, 2018). The region's population is projected to reach 1.5 billion by 2030, 2 billion by 2050, and 3.5 billion by 2100. Urbanization is expected to double between 2020 and 2030, triple between 2020 and 2050, and quadruple between 2020 and 2100, reaching 2.5 billion (UN, 2022). This rapid urbanization is characterized by food deficits and poverty, increasing the risk of climate change (Zhang *et al.*, 2023; Satterthwaite *et al.*, 2010). The global per capita intake of animal protein is expected to rise, with a higher rate of increase in developing economies than in developed ones (Lal, 2020). Meat consumption is projected to rise from 133 million to 452 million tons between 1980 and 2050, with 86% of this increase occurring in developing countries. Urbanization in sub-Saharan Africa is expected to significantly increase animal protein demand, necessitating a focus on animal production to meet the needs of the growing urban population (Njoh, 2003). Hence, urban planning should consider self-sufficiency and increase urban animal agriculture production to meet future living and food

security demands Urban Animal Agriculture (UAA) is a sustainable and productive land use for rearing livestock and poultry in cities, serving as a potential food security and income strategy (Zezza and Tasciotti, 2010; De Zeeuw *et al.*, 2011; FAO, 2014; Porter *et al.*, 2014). There has been a drive that emphasizes its integration with urban economic and ecological systems, allowing urban residents to work as laborers and utilize resources such as manure for compost and urban waste management (Tajonar *et al.*, 2022). UAA is gaining popularity as malnutrition shifts from rural to urban areas due to lack of protein, making it crucial to offset food insecurity, especially in developing countries (FAO, 2007). The debate on sustainable urban animal agriculture in sub-Saharan Africa is complex and multifaceted, influenced by social, economic, environmental, and policy factors (Davies *et al.*, 2021; Ekeocha *et al.*, 2021). Climate change is a significant factor in this debate, as urban populations increase food demand (Tuts 2011). Strategies to offset food deficits for urban dwellers include promoting sustainable urban animal agriculture (Cokall-King, 2012). Understanding the social, economic, environmental, and policy implications is crucial for successful implementation of these strategies. Urban agriculture touches on all three pillars of sustainability: economics, society, and environment (Enete and Achike, 2008; Graefe *et al.*, 2008; Vagneron, 2007). Urban animal husbandry is vital for fulfilling the need for protein, providing staples such as meat, dairy, eggs, and fish, and increasing urban food security (Brinkley and Kingsley, 2017).

Micro-livestock in urban animal agriculture is vital for promoting sustainable practices in urban areas (Klapwijk *et al.*, 2020). These animals, including poultry, rabbits, guinea pigs, and insects, can contribute to resilient urban food systems (Camps-Calvet *et al.*, 2015; Coles and Costa, 2018; Hardman *et al.*, 2018). However, the challenges of sustainable urban animal agriculture in Africa, with its rapidly growing urban population, are unique. The changing climate presents sociocultural, economic, and environmental challenges, making it essential to address these (Amer *et al.*, 2022) ^[5]. Sustainable urban animal husbandry can help mitigate climate change and enhance the resilience of disadvantaged urban populations (Nyathi and Mlambo, 2024). Future research should focus on enhancing household resilience to adverse environmental conditions and exploring strategies to improve urban livelihood resilience. This approach can mitigate the social, economic, and environmental impacts of climate change and contribute to a more sustainable future for urban animal agriculture.

Climate change is predicted to exacerbate global social and gender disparities, and gender equality must consider enhancing both men's and women's resilience to climate change (UN Women, 2023a). Gender inequality is a significant issue in urban animal agriculture because the majority of urban animal farmers are women (IPCC, 2014). Gender disparities in urban animal rearing are exacerbated by climate changes. (Dankelman, 2010). To achieve social sustainability, gender-smart climate-resilient urban animal agriculture concepts can be implemented, promoting equal urban animal agriculture production for all. Climate change affects food security in African cities, affecting urban animal agriculture, while gender disparities in resource distribution and insensitive policies hinder it (UN Women, 2023b). Gender Climate-Smart Urban Agriculture (G-CSUA) in Sub-Saharan Africa aims to empower women in urban agriculture,

reduce gender disparities, and improve access to resources (Deakin, 2012).

Urban planning policies should foster a gender- and socially inclusive agenda, promoting sustainable urban animal agriculture and resources for urban farmers, particularly women and marginalized groups (Lemaire and Kerr 2017). Gender equity in climate change issues and services is hindered by a lack of understanding of gender-specific adaptation strategies and capacities (Duong *et al.* 2016; Nelson and Huyer 2016; Jost *et al.* 2014; Gumucio *et al.* 2018 2019; Climate Change 2020), which could have significant socioeconomic and environmental implications for sustainable urban animal agriculture. Silvopastoral systems sequester carbon, whereas mixed systems reduce synthetic fertilizer use, minimizing greenhouse gas emissions. (FAO, 2022; Thornton and Herrero, 2015; Clark & Nicholas, 2014). Semi-intensive silvopastoral and mixed crop-livestock systems are essential for sustainable urban animal agriculture. Semi-intensive silvopastoral systems utilize the ecological functions of trees and agricultural products, reduce the environmental footprint of agriculture, and boost local food production (FAO, 2022). Mixed crop and livestock systems are crucial for long-term food security in urban climate-smart animal production systems (Thornton & Herrero, 2015). Urban agroforestry can enhance sustainable urban animal agriculture by integrating woody species with other urban planning initiatives, thereby promoting sustainability, multi-functionality, and resilience for urban animal farmers (Gül, 2022). Muara *et al.* (2021) proposed a framework for mixed crop-livestock systems, considering individual management methods, land use change, and practices. Crop-livestock integration is a climate-smart practice that enables more efficient land and livestock use.

Inadequate planning of urban animal agricultural operations can result in adverse environmental effects that worsen ecological and health conditions (McKinney, 2002). The long-term viability of urban food systems is at risk due to environmental degradation. Although urban animal husbandry is effective in meeting the food needs of urbanites, it can also raise environmental issues (Bairoch 1988). Urban food production is accelerated by the growing urban population, underscoring the unsustainable use of natural resources and the necessity of climate-smart animal husbandry techniques in urban environments (Hardoy *et al.*, 2001). According to Kellett and Larbi (2021) and Buck (2014), "green urbanism" suggests striking a harmonic balance between urban life and the natural world. This study explores the intricate interplay between urban animal agriculture, socioeconomic dynamics, and environmental sustainability in sub-Saharan Africa, focusing on climate change adaptation. This study seeks to identify strategies for balancing the social, economic, and environmental needs of urban animal agriculture for sustainable development. Urban animal agriculture (UAA) is an excellent way to address environmental and socio-economic problems, but its absence in urban planning has resulted in unsustainable urban transformations that have created numerous challenges.

2. Urban animal agriculture influx: a conceptual framework for sustainable adaptation

A diagrammatic representation of the relationship between climate change impacts, the urban animal agriculture system, vulnerability and resilience, and adaptation and mitigation strategies is presented in Figure 1. Climate change has direct,

indirect, socio-economic, and environmental effects on urban animal agriculture (IPCC 2020). Urban animal agriculture (UAA) is a crucial sector in urban areas that aims to improve household food security and alleviate poverty. The complex relationship between climate change, UAA, and sustainability is highlighted through a framework that emphasizes the need for interdisciplinary approaches, innovative solutions, and collaborative governance to ensure sustainable and resilient urban food systems (UFS). Climate change poses significant challenges to UAA, affecting its social, economic, and environmental aspects. Adaptation to these changes is crucial for the survival of poor urban resource utilizers who rely on backyard animal production for animal-related products and food for their livelihood (Grossi *et al.*, 2019).

Direct effects include heat stress, mortality, changes in feed quality, increased disease prevalence, water scarcity, and effects on animal reproduction and fertility (Polley *et al.*, 2013; Altizer *et al.*, 2013; Thornton *et al.*, 2009; Wand *et al.*, 1999) [4]. These effects also affect the access to clean water. The indirect effects of climate change include changes in urban planning and land use, increased food prices and reduced access to animal products, shifts in consumer demand (Adger *et al.* 2005) [2], impacts on veterinary services and animal health management (Magiri *et al.* 2021), and changes in waste management and manure disposal (Elbasiouny *et al.* 2020).

Climate change indirectly impacts animals by altering habitats due to temperature and precipitation changes (Thornton *et al.*, 2009), leading to the loss of food, shelter, and breeding grounds, and disrupting food webs due to climate-driven changes in prey populations and distribution (Blois *et al.* 2013; Vondracek, 2005) [18]. Climate change impacts disease and parasite dynamics (Petney *et al.*, 2021), affecting animal health and potentially leading to

evolutionary changes and genetic diversity loss (Portmann *et al.*, 2024). Animal agriculture leads to increased greenhouse gas emissions, water pollution, land degradation, reduced biodiversity, changes in urban ecosystems, and increased risk of zoonotic diseases and public health impacts (O' Sullivan *et al.*, 2019; Scanes, 2018; Moore and Palmer, 2005; Wessel *et al.*, 2004). These interconnected effects necessitate a comprehensive and integrated approach to mitigation and adaptation (Grossi *et al.*, 2019).

Urban agriculture offers numerous benefits, including improved household food security due to less market fluctuations (Obosu-Mensah, 1999), which are largely attributed to women, and additional income from surplus sales and food expenditure savings, potentially enabling women to gain more independence but also being highly dependent on resources (Hovorka, 2003). UAA can enhance food security by improving access to food and increasing income if there is equal participation of men and women (Korth *et al.* (2014). Animal-reared products can prevent hunger and malnutrition while increasing household cash income (Zezza and Tasciotti 2010). Urban animal producers can save money by limiting food purchases, selling or trading their products, preventing malnutrition, and improving food security. The socio-economic challenges of animal agriculture include income losses for urban farmers, reduced employment opportunities, increased poverty, and food insecurity (Vågsholm *et al.*, 2020), negative impacts on urban-rural livelihoods and economies (Mougeot, 2005), and changes in social and cultural practices (Ninsheka *et al.*, 2024).

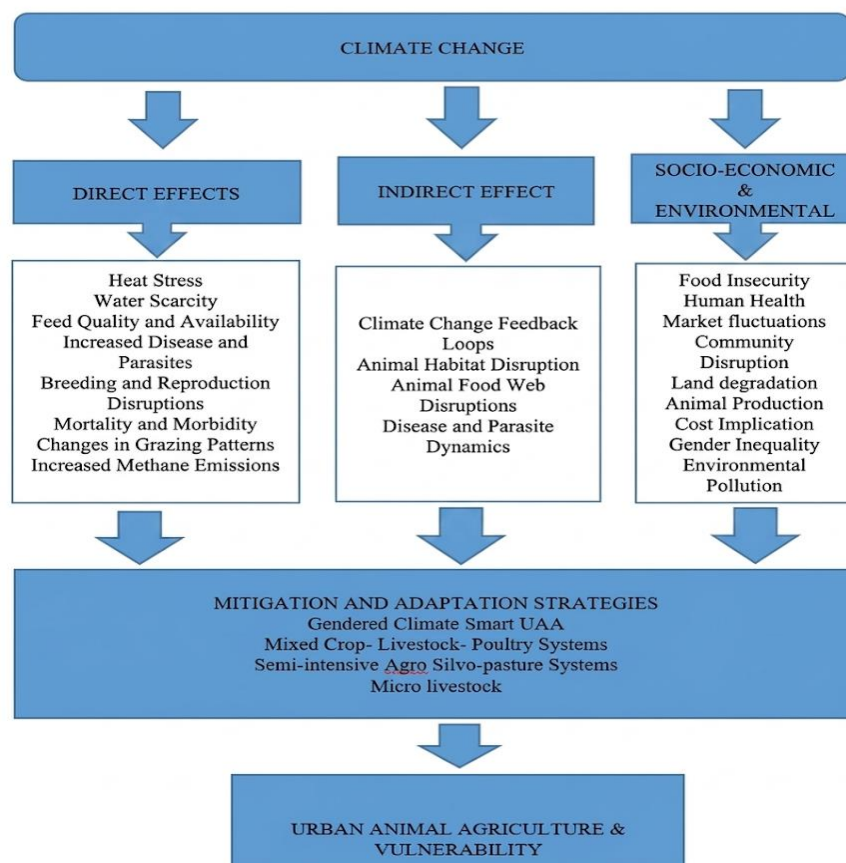


Fig 1: Direct, indirect, socio-economic, and environmental effects of climate change on urban animal agriculture

Climate-induced environmental stressors, such as heat, disease, and water stress, impact UAA, making animal rearing based on adaptive strategies and coping mechanisms critical in this context (Ansa *et al.*, 2024; Egerer *et al.*, 2021; Freedman, 2015). To reduce vulnerability to climate change, urban animal agriculture improvement strategies should enhance climate-smart adaptive and coping mechanisms in animal husbandry practices (Srinivasarao *et al.* 2020). Heat stress, caused by elevated temperatures and humidity, can significantly decrease productivity and fertility (Gonzalez-Rivas *et al.* 2020; Wasti *et al.*, 2020; Fereja, 2016; Chiang *et al.*, 2008).

Warmer temperatures cause changes in precipitation patterns and increased evaporation, leading to water scarcity, which affects livestock hydration and feed quality (Henry *et al.* 2012). Drought and temperature changes significantly affect the quality and availability of feed crops, which can lead to nutritional deficiencies and decreased productivity ((Kumar *et al.*, 2020; Abdurehman and Ameha, 2018) ^[1]. Additionally, climate-related stress can impact reproductive cycles, fertility, and breeding success, leading to increased mortality and morbidity rates due to extreme weather events, heat stress, and disease ((Thornton *et al.*, 2015; Baylis and Githeko, 2006) ^[13].

Integrating mixed crops and animals has been shown to be essential for sustainable urban animal agriculture (Behere *et al.* 2013; Thornton and Herrero 2015). Strategies for mitigation and adaptation include climate-smart farming techniques, such as agroforestry and conservation agriculture, animal breeding and genetics that promote climate resilience, feeding plans and nutrition designed to address heat stress and water scarcity, and manure and waste management to help reduce greenhouse gas emissions (Sejian *et al.*, 2012). A successful urban animal agriculture response to climate change necessitates an integrated approach to maximize synergistic effects and minimize harm (Gashure *et al.*, 2024). Urban agriculture systems may become more robust to climate change, lessen their environmental effects, and increase their overall sustainability via the use of gendered climate-smart animal husbandry practices (Bousfield *et al.*, 2024) ^[19].

Urban animal housing can mitigate climate change by providing shelter from extreme weather events, regulating temperature through insulation, and managing humidity through ventilation systems (Roka *et al.*, 2020). Climate-smart housing in urban animal agriculture includes ventilation, cooling, insulation, water harvesting, sustainable construction materials, and manure management systems to regulate temperature, reduce heat gain, conserve water, and minimize waste and emissions (Mlambo, 2024). Climate-smart sustainable urban agriculture housing offers numerous benefits, including improved animal health, reduced emissions, enhanced resilience to climate change, and increased food security (Amole and Ayantunde, 2016) ^[6].

3. Gender-climate smart urban animal agriculture: a pathway to socially sustainable cities

Climate change is causing socioeconomic and environmental instability in urban animal agriculture (Kapitza *et al.*, 2021) and disproportionately affects women in sub-Saharan regions (Assan, 2014; Dima and Ogunmokun, 2001). Women often play specific roles in food provision, household management, livestock, and land management in African cities (Meinzen-Dick *et al.*, 2016; Meinzen-Dick *et al.*, 2012; Opio, 2003).

Climate change affects the food system as a whole, affecting food production, consumption, and consequences, including livelihoods and diets. Within food systems, men and women play different roles, but women's autonomy, resources, and services are restricted by structural inequality. These disparities impact how men and women perceive and are affected by climate change. Studies on gender dynamics in urban animal agriculture are less extensive than those in rural agriculture (Musa *et al.*, 2024; Midamba and Ouko, 2024; Masanja *et al.*, 2023; Neway and Zegeye, 2022; Midamba *et al.*, 2022). Gender analysis is an essential assessment tool for understanding the complexities of urban animal agriculture systems in terms of sustainability; however, it should not be taken for granted (Dima and Ogunmokun, 2001). Depending on the circumstances, urban animal agriculture can have both positive and negative effects on men and women (Chiweshe and Bhatasara, 2021). Given their greater responsibilities, women typically benefit from urban agriculture (Berejena 1999) ^[15]. To thrive in urban animal agriculture, it is necessary to understand the interplay between gender dynamics and agricultural practices. This underscores the need to concentrate research, policy, and action planning on gender, recognizing gender disparities, examining the advantages of urban agriculture for households—especially women—and contrasting it with other forms of economic and social opportunities (Kingsley *et al.*, 2021). According to a growing body of evidence from various sources, empowering urban women in animal agriculture can lead to socioeconomic benefits for themselves, their households, and communities (Duflo, 2012; Gates, 2014; Kabeer & Natali, 2013; Klasen, 2018; World Bank, 2011).

The link between climate change, gender issues, and urban animal agriculture has been largely overlooked, but its significance is becoming increasingly evident because of food insecurity in urban areas. Figure 2 shows the interplay between urban animal agriculture, gender, climate change effects, and food security in cities. This study contributes to the debate on new approaches to tackle food insecurity in urban areas by presenting an innovative conceptual framework for the role of urban animal production underpinned by micro-livestock to enhance food security in urban households. This framework acknowledges the interrelatedness of gender, climate change, urban animal agriculture, and food security, with their dynamics being complex and rooted in social, economic, and institutional factors.

Food insecurity, gender inequality, and climate change are challenges in sub-Saharan Africa, impacting food dynamics posed by the expansion of urban populations. This study hypothesizes that gender dynamics influence both urban animal agriculture and climate change risks, with differential impacts on men and women. Gender disparities in climate knowledge and urban animal agriculture negatively affect sustainable food security in the country. Addressing these inequalities can promote urban food security. Urban animal farmers' adaptation to climate change depends on their perceptions and knowledge of climate change among men and women. Pathways to Food Security: A Gendered Conceptual Framework for Climate Change and Urban Animal Agriculture abandons previous assumptions and focuses on interdependent socioeconomic and environmental factors. A holistic approach is needed to address these adversities and their impact on urban food security, as these factors are interdependent and require a holistic approach.

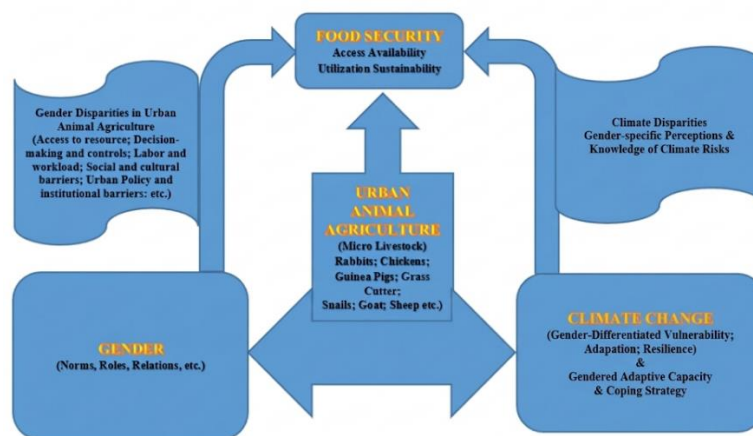


Fig 2: Pathways to Food Security: A Gendered Conceptual Framework for Climate Change and Urban Animal Agriculture

Micro-livestock rearing can mitigate food insecurity, promote gender equity, and address climate change challenges. The gender gap in livestock production and climate change impacts contributes to vulnerability and food insecurity in urban areas, particularly among women. The UAA is a vital livelihood that is vulnerable to climate change. Low animal productivity in urban areas is due to gender disparities and climate change impacts, resulting in limited food availability and high malnutrition levels. Interventions that address these disparities and the adverse effects of climate change can enhance urban food security. Therefore, addressing gender disparities in urban animal agriculture and climate change can significantly improve food security in cities.

Over the past few decades, animal agriculture in sub-Saharan Africa has shown that a gender-sensitive approach focusing on providing women with opportunities and options can lead to better decisions for their families, food welfare, and communities. This approach should focus on combating disparities in decision-making, resource allocation, and climate information over neutral gender policies, as climate change impacts gender and socioeconomic status (Angula 2010) ^[7]. However, gender is not sufficiently considered in most climate change policies and initiatives (Bryan *et al.* 2024). Failure to implement these measures might worsen gender disparities in urban food systems by placing more strain on women's work, time poverty, control over their income, and ability to make decisions. Making urban food systems resilient to the effects of climate change requires

women's efforts (Lee-Smith, 2003). Fostering a culture that values women's empowerment and gender equality is crucial for boosting the resilience of the urban food chain. Building equitable power dynamics and dismantling inflexible gender stereotypes are necessary. Further studies are required to prioritize systemic obstacles and identify gender-transforming strategies that work for sustainable urban animal agriculture.

Gender inequality is a significant issue in sub-Saharan Africa's urban animal production, which is exacerbated by climate change (Jerneck, 2018). By implementing gender-smart climate-resilient urban agriculture concepts, social sustainability can be achieved, promoting equal urban animal agriculture production for all and bridging the gap (Huyer, Gumucio, *et al.*, 2021; Kabeer, 1999). Climate change is affecting food security in African cities and urban animal agriculture, while gender disparities in resource distribution and insensitive policies hinder urban agriculture. Gender-Climate Smart Urban Agriculture (G-CSUA) in Sub-Saharan Africa aims to empower women in urban agriculture, reduce gender disparities, and improve access to resources such as land, water, credit, and markets (Dankelman, 2010; IPCC, 2014). Figure 3 shows that 35% of the population in the selected cities are farmers, with 2/3 being women. This suggests that urban farming is a livelihood strategy used more by women than by men. The data aim to demonstrate the large presence of UA in African cities, with a case study as an example.

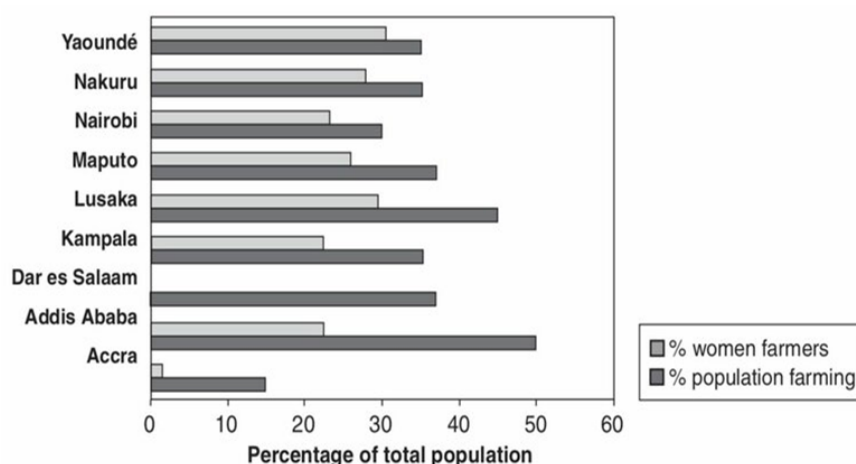


Fig 3: Percentage of urban residents engaged in farming in specific metropolitan areas in Sub-Saharan Africa (Blaustein, 2019) ^[17].

Climate change research shows significant gaps in understanding the adaptive strategies and capacities of men and women in urban agricultural settings (Dankelman, 2010; IPCC, 2014). Addressing these gaps is crucial for promoting social sustainability and achieving Sustainable Development Goals. Therefore, gender-sensitive approaches to urban agriculture planning and policy are necessary to ensure that the needs and priorities of women and marginalized groups are addressed, leading to more sustainable and equitable outcomes (Castro-Nunez *et al.*, 2024). Studies conducted on climate change reveal substantial gaps in understanding the adaptive strategies and capacities of both men and women, as well as the technologies, practices, and environments that empower women's (Duong *et al.* 2016; Duong *et al.* 2017; Nelson and Huyer 2016; Jost *et al.* 2014; Gumucio *et al.* 2018, 2019; Climate Change 2020).

Identifying context-specific technologies and supportive measures, as well as recognizing trade-offs and co-benefits that advantage women and promote gender equality in agriculture and rural development, is challenging. Despite the development of approaches that integrate gender into climate change technologies and services, a gap persists in understanding gender-specific adaptation strategies and capacities. Gender-specific adaptation strategies are crucial for urban animal agriculture to effectively address urban food insecurity (Nelson and Huyer 2016).

In sub-Saharan Africa, successful initiatives in urban animal agriculture should include women-led urban animal agriculture cooperatives, climate-resilient agriculture training programs, urban agriculture policy reforms, and private sector partnerships that support women-led urban agriculture (Hovorka, 2003). Sustainable urban animal agriculture (SUAA) has the potential to bridge the gender gap by offering benefits for women (Phiri *et al.*, 2022), assuming they can effectively utilize it. However, it is essential to consider the differences in priorities and adoption capabilities between men and women, such as men preferring large ruminants and women preferring small stock. Gender differences also exist in adaptation strategies (Osman and Ayanlade, 2024), with men focusing on community interventions and women preferring practical improvements, such as chicken and rabbit production or diversified revenues. Emphasizing gender equality can benefit sustainable urban animal agriculture; however, there has been inconsistent success in narrowing gender inequalities across various sectors, including urban agriculture (Matsila, 1999). Addressing the complex issues of discriminatory legislation, outdated practices, and gender stereotypes, particularly in urban settings, may prove challenging. Women in Sub-Saharan Africa face a significant challenge in promoting urban agriculture and poverty reduction due to discrimination against them, as they are the primary custodians of urban food production and food security in the region. The unavailability of resources for urban women to participate in urban agriculture development initiatives compromises urban animal production (CCAFS & FAO, 2013).

Involving women in urban agriculture production can contribute to reduced vulnerability, increased food security, and improved household income (Niñez, 1985). Strategies involving women's participation in urban agriculture should be instrumental in ensuring food security (Odenyo *et al.*, 2002). Gender-sensitive policies should be proposed, targeting women as the focal points of urban food production (FAO, 2013). High priority should be given to the education

and training of urban women to reduce poverty and enhance food security (Kiguli, 1995). Gender responsiveness in urban animal climate-adaptation initiatives is essential for sustainable development. Research indicates that women who engage in urban agriculture encounter difficulties due to their limited access to climate information (Ssewakiryanga, 2002). Strengthening women's adaptation capacity and supporting more inclusive, resilient urban agriculture systems are necessary (Bryan *et al.*, 2024). Training and education are essential for sustainable urban animal agriculture, with efforts to intentionally target gender to boost the proportion of women participating in training programs (InIA/CIID, 1999).

Broad-based training for urban women is crucial for developing a strong urban food production base and empowering them to make a living from urban agriculture (Hasna, 1998). Addressing gender gaps in resource allocation and implementing gender-sensitive policies are crucial for the well-being of women and their households in urban settings (Mundi, 1999). Women should not only be seen as victims of climate change but also as active actors and proponents driving mitigation and adaptation measures in urban animal agriculture, particularly where women are the majority of farmers. Technical education can improve the intelligence of urban women farmers, leading to increased food production (Hovorka 2001).

The focus on climate-resilient urban animal agriculture should be gender-sensitive, involving private sector engagement for women-led initiatives and inclusive policies (Tegegne *et al.*, 2002). Understanding women and gender equality is crucial for policymakers to provide relevant information on urban animal agriculture planning (Hovorka 1998). Climate change affects both men and women differently, determining their capacity to respond to crises such as food insecurity. Women are often more vulnerable to climate change, and gender identity is a key contributor to susceptibility to climate change.

Policies addressing gender-variegated susceptibility are necessary to adapt to climate stressors (Bogalech 1998). Sustainability will be undermined if gender differences in urban animal agriculture continue to grow invisibly, even when women make up a sizable share of the workforce and frequently lack decision-making authority. Gender-responsive interventions are essential to achieve sustainable urban development goals, increase animal production, and promote equitable urban animal agricultural development. Future studies must focus on developing and gaining knowledge about models of urban agriculture that take gender into account, as well as on building extension staff's ability in the field of urban agriculture.

4. Sustainable Urban Animal Agriculture: Harnessing the Power of Semi-Intensive Silvopastoral Systems for Climate Adaptation

The increasing urbanization in Sub-Saharan Africa necessitates innovative and adaptable urban animal production strategies to address the precarious food situation of impoverished urban inhabitants in the region. Due to climate change, Sub-Saharan Africa will continue to encounter several obstacles to the successful implementation of urban agriculture and livestock and poultry husbandry (Nazarian *et al.*, 2024; Lwasa *et al.*, 2022; Dodman *et al.*, 2019). Semi-intensive silvopasture integration has the potential to address challenges in urban agriculture, livestock,

and poultry production (Kumare *et al.*, 2024). However, owing to the diverse urban settings across Africa and socioeconomic and environmental differences, it remains uncertain whether silvopastures can provide co-benefits and mitigate animal production challenges. Different agroforestry strategies may be suitable for various metropolitan settings because of these factors. Conversely, women's roles in agroforestry strategies are increasingly recognized as a means to enhance food security in urban households (Kiptot *et al.* 2012; Rocheleau and Edmunds, 1997).

Agro-semi-intensive silvopastoral systems integrate cattle, trees, and agricultural crops for small-scale animal agriculture (Zerssa *et al.*, 2021). It can manifest in various forms, such as permanent cultivation with zero grazing, a combination of cultivated and grazing areas proximal or distal to homesteads, and permitting animals to graze on previously cultivated land (Kiptot *et al.*, 2012). This system is suitable for dairy cattle, sheep, and goats. Semi-intensive silvopastoral systems combine forestry and grazing of domesticated animals on pastures, fodder plant fences, and trees, integrating animal and plant training (Swamy and Tewari, 2017). Semi-intensive silvopastoral systems are crucial in sustainable urban agricultural practices, as they utilize the ecological functions of trees and agricultural products, reduce the environmental impact of agriculture, and enhance local food production (Shepherd 2021). Agroforestry Systems (AFS) are strategic interventions to improve urban food systems, food security, nutritional status, protect natural capital, increase sustainability, and contribute to equitable, healthy, and affordable urban food systems (Clark & Nicholas, 2014).

Urban agroforestry can enhance sustainable urban animal agriculture by integrating woody species with other urban planning initiatives that promote sustainability, multi-functionality, and resilience among urban animal farmers (Place, 1994). Figure 3 illustrates a potential silvopasture with urban households operating pig and chicken production enterprises in the area. These systems can increase urban farming productivity by providing multiple products on the same land area. In this instance, the garden provides forage for pigs and chickens, thereby reducing feed costs. Urban households can enhance their livelihoods, contribute to environmental sustainability, and improve their communities by incorporating silvopasture systems into pig and chicken production enterprises.

Urban semi-intensive silvopastoral systems can improve the production of specialty foods, crops, and animals by combining tree growth with livestock production, often in pasture systems with trees planted in clusters (Swamy and Tewari, 2017). This approach addresses issues related to urban livestock and poultry keeping in sub-Saharan African cities. It requires knowledge of livestock management, agronomic, horticultural, and silvicultural practices. Silvopasture designs are flexible, allowing for numerous combinations of animal, tree, and forage species (Kurgat *et al.* 2020). Non-sustainable animal-rearing practices are a global problem because they erode soil, degrade landscapes, and contribute to climate change (Conway and Nieman, 2021). In comparison to traditional methods, semi-intensive

silvopastoral systems provide advantages and support the livelihoods of urban livestock and poultry producers (Gül, 2022). Relative to other animal production techniques, these systems have a higher Benefit Cost Ratio and restore soil, ecosystem, and feed demands. Semi-intensive silvopastoral systems prioritize sustainability, consistent income for urban households, and alignment with Sustainable Development Goals (Nair, 1989). The system can improve animal integration and reduce difficulties in urban and peri-urban livestock management (Vos & Bellù, 2019).

Exploring indigenous multipurpose fodder trees (MFTs) to enhance ecosystem services and provide supplemental fodder (Balehegn 2017). MFTs offer a diverse forage mix, increased pasture yield, high-quality fodder, reduced parasite loads, improved soil fertility, extended grazing season, and increased carrying capacity (Zaralis *et al.*, 2019). Trees provide shade, stimulate grass growth, and contribute to soil fertility and structure, thereby promoting pasture growth. Silvopasture systems can enhance animal feed production, promote livestock health, and increase farm productivity (FAO 2022). Silvopasture systems significantly improve nutrient cycling within the system, reducing soil erosion, increasing water infiltration, improving soil health, reducing nutrient pollution, providing shade, and acting as buffer strips (Solorio *et al.*, 2017). Tree roots stabilize soil, reduce runoff and sedimentation in waterways, absorb and filter rainwater, and act as buffer strips, contributing to improved water quality, biodiversity, and ecosystem services, while maintaining productive agricultural land (Vincent, 2008).

Urban animal and food production systems must adapt to climate change and face challenges in their successful implementation. Agroforestry techniques, such as silvopasture, can help address these issues and enhance food security by integrating livestock or poultry with trees (Swamy & Tewari, 2017). Urban agroforestry can reduce exposure to heavy metals and PAHs, as crops are integrated with woody perennials, shrubs, and animals (Jose & Dollinger, 2019). However, further research is required to fully understand the potential risks associated with raising cattle and poultry in urban agroforestry systems (Brewer & Gaudin, 2020). Urban animal and food production systems must be innovative and adaptable to meet the challenges of urbanization in the future. Promoting fodder production in silvopasture systems is essential to address feed shortages caused by climate change and to develop sustainable urban food systems (Jose and Dollinger, 2019).

Women are increasingly at the forefront of efforts to increase urban animal production, and silvopasture systems have gained prominence as a means of addressing gender imbalances in urban animal agriculture (Lemes *et al.* 2021). By providing specialized fodder browse in semi-intensive silvopastures, women can improve animal nutrition and reduce the shortage of fodder caused by climate change, improving the food situation in urban areas (Kiptot *et al.* 2012). Climate-smart urban animal husbandry and food systems can effectively utilize both male and female expertise. Women are skilled at producing fodder trees, which can supply micro-livestock with food during dry seasons (Franzel *et al.* 2014).



Fig 4: Silvopasture -pig production enterprise for poor urban farmers (Salati, 2023)

Figure 4 depicts Joel Salatin's silvopasture pig system, where pigs are integrated into a grass-based, tree-supported farming landscape. Pigs naturally forage on pasture, rooting and grazing in a controlled manner that enhances soil aeration and nutrient cycling, while poultry in the background benefit from shared space and residual feed. This system exemplifies regenerative, low-input animal agriculture, demonstrating how livestock can be used as ecological tools to improve land health, recycle nutrients, and produce food sustainably with minimal environmental degradation.

5. Integrated Urban Agriculture: Mixing Crops and Livestock for Climate Adaptation and Sustainable Animal Production

Mixed crop-livestock systems, in which crops and livestock are raised in the same enterprise in urban areas, are crucial for smallholder production in Africa south of the Sahara (Swain and Teufel, 2017). These systems can enhance agricultural production, provide food security, help urban farmers adapt to climate change, and offer mitigation benefits (Roessler *et al.*, 2016). Mixed production systems combine perennial and annual crops, livestock, and fisheries and are the predominant farming methods in low- and medium-income countries (Lupindu *et al.*, 2012). Diversification in mixed systems can mitigate climate change risks to food production systems by enhancing the resilience of livelihoods and food security.



Fig 5: Sustainable Small-scale mixed crop-poultry -livestock systems in urban agriculture

Mixed crop/livestock/poultry systems (Figure 5) are prevalent in developing nations, where livestock and poultry are raised, and the risk is distributed among various enterprises (Azage Tegegne, 2004) ^[10]. The image illustrates a mixed small-livestock system in which young goats and poultry share the same grazing space. Goats browse selectively on shrubs and ground vegetation, while the chicken forages for insects and spilled feed, contributing to natural pest control and nutrient recycling. This close integration enhances resource-use efficiency, improves soil fertility through manure deposition, and supports low-cost, climate-resilient animal production, making it well suited to smallholder and urban or peri-urban farming systems. Climate change can impact these systems and facilitate adaptation through livestock adaptability and access to alternative feed resources, such as insects.

The trend towards agricultural specialization can disconnect crop and livestock farming at the farm level, leading to environmental externalities (Garrett *et al.*, 2020). Integrated

crop-livestock systems can mitigate water quality risks in urban spaces by reducing the loss of suspended solids and nutrients (Faust *et al.* 2018). Structural changes and permeable watershed development with vegetative buffers can mitigate pollutant sources, but their impacts are unclear. Incorporating vegetative buffers and biomass can improve water quality in urban environments (Holland *et al.* 2004; Mallin *et al.* 2009). Climate-smart urban animal production systems have the potential to significantly improve food security in sub-Saharan Africa while addressing climate change risks. However, their full potential requires appropriate technological development, institutional transformation, and legislative frameworks for urban planning.

Climate change affects mixed-system agricultural operations; however, little is known about its effects on urban animal agriculture. Muara *et al.* (2021) proposed a framework for mixed crop-livestock systems from three perspectives: individual management methods, land use change, and

practices (Thornton & Herrero, 2015). They also suggested that crop-livestock integration can be a climate-smart practice that enables more efficient land and livestock use. The usefulness of mixed crop-livestock systems in urban settings as a climate change mitigation technique must be further investigated.

Aquaponics technology has the potential to be integrated into a combination of crop-livestock systems in urban agriculture (Verma *et al.*, 2023). Aquaponics is a sustainable agricultural technique that combines fish farming and cropping with hydroponics to address global food security challenges. Combining aquaponics with other material production-recycling networks may yield symbioses (Cohen *et al.*, 2018), increasing the long-term potential of aquaponics as a resilient food production system for urban agriculture. Owing to space limitations in urban areas, aquaponics in a mixed crop and livestock setting can be an intensive, sustainable urban food production method to meet the demands of the cities' growing population. Aquaponics offers sustainable improvements in food production efficiency and material inputs, using nutrients and water more efficiently than aquaculture (Goddek *et al.*, 2015). Its closed-loop, ecosystem-inspired design, combined with low-impact energy and fish feed sources, resembles a natural ecosystem (Wu *et al.*, 2019). Urban areas are incorporating mixed crop and livestock enterprises, such as aquaponics, urban dairy farms, and poultry and vegetable farms (Bordignon *et al.*, 2024).

Aquaculture and poultry integration enhances resource efficiency, reduces crop failure risk, provides additional food sources, and generates additional income for poor farmers, thereby promoting diversification in aquaculture farming (Laghari *et al.*, 2023). Integrated fish-livestock farming, a method practiced in sub-tropical climates such as China and Taiwan, has been observed in tropical countries (Sharma and Olah, 1986). Further ecological network analysis is required to test this hypothesis. This approach could reduce the material inputs required for fish and crop growth. Ansa and Jiya (2002) evaluated *Oreochromis niloticus* growth using an integrated fish cum piggery system, revealing daily growth rates of 0.29 and 0.24 g/day and extrapolated yields of 302 and 242 kg/ha during 70-day culture. Proper management and selection of crop-livestock-fish enterprises act as an interactive domain for sustainable development and food security in urban areas.

Urban agriculture enterprises may include rabbitry and gardens, which involve keeping rabbits and growing vegetables (Barthel and Isendahl, 2013) ^[12]. Pig and sweet potato farms raise pigs and sweet potatoes. Goat and tomato farms raise goats and tomatoes (Eigenbrod and Gruda, 2015). An integrated rooftop farm combines crops such as herbs, lettuce, and strawberries with livestock such as chickens or bees. Backyard farms involve raising chickens, ducks, and rabbits, and growing various crops. Community gardens with livestock involve community members growing crops and raising livestock (Armstrong 2000). Urban farms with agroforestry integrate crops with livestock and agroforestry practices, thereby promoting sustainable farming. Integrated urban goat farming in mixed crop-livestock urban agriculture uses goats to fertilize crops with manure, urine, microgreens, bucket gardens, tree seedlings, and urban greenery. Urban goats can consume leftover crop products from the value chain, promoting a circular economy, facilitating the flow of nutrients, and supporting the ecosystem. Chickens can be

integrated into goat production by utilizing leftover feed, hatchlings, worms, and ectoparasites such as ticks from goat droppings. Goat farming diversifies urban livelihood systems by aiding seed dispersal and integrating with other livestock productions.

Mixed crop-livestock systems are the best for carbon sequencing, which is a major driver of global climate change (Hayli *et al.* 2014). They can increase global food production while lowering greenhouse gas emissions when replacing grazing systems with these systems. Improved forage technology in mixed crop-livestock farming systems can address sustainability and environmental challenges, such as increased groundwater drainage, soil carbon, and subsoil acidification (Ershadi *et al.*, 2020). To create effective strategies for climate-smart urban animal farming systems, the entire urban food system approach should consider these aspects and their effects on livelihoods, the environment, and production (Mirzabaev *et al.*, 2023). Climate-smart food systems consider the consequences, relationships, and gender roles of those involved in the animal and agricultural value chains to ensure sustainability.

6. Small but Mighty: Micro Livestock's Role in Sustainable Urban Animal Agriculture and Climate Change

Food security is a growing concern in an uncertain global era, and micro-livestock can enhance local food security by reducing dependence on distant supply chains and providing a reliable source of nourishment (McCarthy *et al.*, 2018). Micro-livestock can revolutionize urban agriculture by promoting sustainability, space efficiency, and ethical farming practices (Qiu *et al.*, 2024). Micro-livestock are revolutionizing urban agriculture by providing fresh eggs, milk, and meat to urban dwellers in limited spaces, thereby contributing to local food production (Mhlanga, 2024). Backyard homesteading enthusiasts are embracing micro-livestock, raising miniature chickens, goats, and rabbits in their own spaces to achieve greater self-sufficiency and a direct connection to their food sources, allowing them to enjoy fresh eggs, milk, and meat (Hardouin, 1995). These small animals demonstrate that size does not matter in contributing to food production. Whether small-scale farmers, urban gardeners, or those interested in ethical and sustainable food sources, micro-livestock offers a promising solution for sustainable future (Bouvier, 2015) ^[20]. Micro-livestock is gaining popularity in local markets and community initiatives, with small farmers, urban gardeners, and homesteaders collaborating to exchange products and promote local sustainability and food resilience (De Wilde, 1991).

Micro-livestock farming is a small-scale agricultural practice that involves rearing small animals in confined spaces with minimal resources while generating high-value products (Thys, 2001). This type of animal husbandry typically includes rabbits, guinea pigs, chickens, ducks, geese, turkeys, fish, bees, and insects (Hardouin, 1995; De Wilde, 1991). The objective of micro-livestock farming is to produce high-value items such as meat, eggs, dairy, honey, or specialty items, often utilizing locally sourced or recycled materials (Ogunjimi *et al.*, 2012). Micro-livestock species are a potential solution to address the growing demand for animal products in the urban areas of sub-Saharan Africa (Akinnusi, 1998). With the rapid expansion of human populations in urban areas, the production of animal products has not kept

pace, rendering micro-livestock an essential source of animal protein (Adinya, 2006). The discussion emphasizes the necessity of promoting alternative sources of animal protein in urban areas to address the current food supply shortages. As space for traditional livestock species, such as cattle, becomes limited, micro-livestock farming presents a more suitable option for urban animal agriculture (Assan, 2014). By focusing on micro-livestock urban farming, impoverished urban households can enhance their livelihoods through increased productivity and access to appropriate inputs and services (De Wilde, 1991). However, this should be implemented using a climate-smart approach that optimizes animal product production and food security on a sustainable

and environmentally sound basis (Bradshaw 2013). The significance of considering micro-livestock farming as a substantial component of livestock production systems is indisputable. Sustainable urban animal agriculture can be achieved through the rearing of micro-livestock, such as rabbits, chickens, guinea pigs, quails, insects, honey bees, fish, and aquaponics, as well as micro-dairy (Hardouin, 1995; De Wilde, 1991). These animals offer high-protein meat, low space requirements, minimal waste production, and low maintenance. Figures 6, 7, and 8 depict examples of micro-livestock: Nigerian farming of giant African land snails, guinea pigs, and grass cutters (*Thryonomys*), which can provide protein for urban dwellers.



Fig 6: The Giant African Snail (*Lissachatina fulica*) (Nwajei, 2017; Mead, 1961).



Fig 7. The guinea pig or domestic guinea pig (*Cavia porcellus*) (Spotomo et 2007)



Fig 8. Grass cutter (*Thryonomys*) Farming in Nigeria (Agricdemy.com 2018) ^[3]

Micro-livestock farming in urban areas offers numerous benefits, including high-quality protein production, year-round availability, minimal waste generation, low resource usage, and space efficiency (Hardouin, 1995). This sustainable method contributes to food security, environmental sustainability and community development. It focuses on selecting and breeding animals suitable for urban environments, considering factors such as climate resilience and space efficiency. Proper disposal of manure and waste is crucial, as is educating the community on the benefits of micro-livestock farming. These systems serve local markets, consumers, and communities by integrating multiple species, crops, and activities for resilience (Ekanem and Umoh 1997). To address the challenges faced by urban micro-livestock farmers, effective strategies should be developed, including noise and odor concerns, regulatory frameworks, waste management practices, and community education. Implementing these strategies can help urban micro-livestock farmers navigate challenges, develop sustainable agricultural systems, and foster a sense of community among farmers (Assan, 2014b).

Micro-livestock are particularly well-suited to local urban conditions, exhibiting a high degree of resistance to diseases and parasites while also being capable of surviving limited feed and water shortages characterizing urban agriculture (Cicogna *et al.*, 1992). Such adaptations have resulted from natural selection over numerous generations, making them essential components of successful livestock production in the face of climate change. Although Sub-Saharan Africa boasts a rich micro-livestock genetic pool, the extensive reserves in urban areas are at risk of being eradicated by recurrent droughts caused by climatic variability (Assan, 2014). Micro-livestock provide a means of meeting the basic needs of poor urban families, providing them with access to protein and a nutrient-dense diet, while also serving as a primary or supplemental source of income, as their output volume often exceeds that which is needed for home consumption (Assan, 2014b). Micro-livestock farming in urban areas offers significant advantages in terms of economy, society, and ecology (Thys, 2001). In societies where the head of the household is traditionally accorded precedence, micro-livestock can provide a means of accessing protein for the poorest households.

Urban animal agriculture, which involves keeping micro-livestock in backyards, offers a diverse range of nutrient-dense animal products, providing a balanced diet and income (Ekanem and Umoh 1997). Micro-livestock are advantageous because of their rapid reproduction, disease resistance, adaptability to limited feed, and low maintenance requirements (Hardouin, 1995; De Wilde, 1991). They can withstand feed and water shortages, making them essential for cattle production in the face of climate change (De Wilde, 1991). However, data on micro-livestock studies related to climate change are scarce and often absent from urban food systems (Clotey and John, 1981). Micro-livestock can serve as a foundation for development initiatives focusing on urban nutrition, income generation, and protein intake, making them particularly valuable for resource-poor urban farmers who rely on these animals for their livelihood in expensive urban areas (Assan, 2014).

Urban agriculture, particularly micro-livestock farming, faces gendered consequences, particularly for women (Assan, 2014). Women are predominantly involved in farming and micro-livestock production in Africa, and

addressing the influence of climate change on their production could lead to increased economic potential for women (Doss, 2018). However, access to resources, land, credit, and training can be challenging for women, and social and cultural norms can impact their participation. Micro-livestock empowers urban women by providing income, independence, and decision-making power (Kariuki *et al.* 2022). However, access to resources, land, credit, and training can be challenging for female farmers in the region. Gender-sensitive approaches promote equal participation, address gender-specific challenges, and promote inclusive decision-making in micro-livestock activities (Doss *et al.*, 2018). Training and capacity-building programs are provided for both genders, and policy and regulatory support encourage women's participation in micro-livestock activities. Gender dynamics affect breeding stock availability and micro-livestock output, and considering gender dynamics in micro-livestock care may lead to better progeny. Addressing the information vacuum in the literature can complement the current conversation about women's roles in micro-livestock farming and help ensure that management activities related to micro-livestock farming are consistent with gender dynamics (Harris-Coble *et al.*, 2022). This could improve the promotion of micro-livestock farming.

7. Sustainable Urban Animal Agriculture: Mitigating Environmental Impact and Promoting Eco-Friendly Practices

Urban animal agriculture is gaining popularity in sub-Saharan Africa because of food security and sustainability concerns (Badami *et al.*, 2015)^[11]. This technique contributes significantly to climate change mitigation, strengthens the resilience of vulnerable citizens, and increases urban food system resilience. However, it can have both positive and negative effects on environmental sustainability (Nyathi and Mlambo, 2024). Positive impacts include supporting local food systems by reducing transportation emissions, utilizing food waste as animal feed, promoting biodiversity through diverse animal breeds, and raising awareness of sustainable agriculture and animal husbandry practices (Prasanna *et al.*, 2024; Çakmakçı *et al.*, 2023; Aubert *et al.*, 2016)^[9]. Urbanization and environmental sustainability are interconnected, with cities being praised for their energy and transportation efficiency. However, they can also be hotspots for pollution, waste production, and greenhouse gas emissions (Qiu *et al.*, 2024).

Urban animal agriculture has significant negative impacts on environmental sustainability, including competition with other land uses, straining water resources, improper manure management, greenhouse gas emissions, noise, and nuisance (van Oort *et al.*, 2024; Butler, 2012; Bryld, 2003). To combat these issues, strategies such as proper manure management, regenerative agricultural practices, feed optimization, water conservation through recycling, and waste reduction through recycling and composting programs have been suggested (Qiu *et al.*, 2024). These measures aim to minimize water pollution and waste from livestock enterprises by promoting efficient production systems, reducing nitrogen and phosphorus excretion, and minimizing environmental waste. This highlights the need for a multi-pollutant perspective in water pollution assessments to improve water quality, considering animal types and spatially explicit input. In rivers, pigs, chickens, and cattle account for 74–88% of the nutrients and oocysts (Li *et al.* 2022).

Environmental issues have emerged due to human use of natural resources, and the promotion of urban agricultural production can create growing ecological and human health problems (Khanam *et al.* 2023). The long-term sustainability of urban food systems is threatened by environmental pollution (Gogoi *et al.*, 2018). Capital- and technology-intensive farming systems have been productive and competitive, but they also bring economic, environmental, and social problems. The continued human population growth in urban areas has led to the intensification of urban food production, fueling concerns about the unsustainable use of natural resources (Maja *et al.*, 2021).

Urban animal farming contributes to climate change by exacerbating greenhouse gas emissions, primarily methane and nitrous oxide, and contaminating waterways with manure and fertilizer runoff, causing eutrophication, and harming aquatic ecosystems (Bousfield *et al.*, 2024) ^[19]. It causes land degradation, soil erosion, nutrient depletion, biodiversity loss, and air pollution due to ammonia and particulate matter emissions, which negatively impact air quality and human health (Li *et al.* 2022). It also contributes to habitat destruction and fragmentation (Lwankomezi & Kaganga, 2024). A multi-faceted approach is needed to reduce environmental gas emissions from urban animal agriculture (Bieluczyk *et al.*, 2024) ^[16]. This includes efficient manure management systems, biogas capture systems for renewable energy, and feed optimization to reduce enteric fermentation in animals. Encouraging urban planning that integrates animal agriculture with green spaces, enhances carbon sequestration, and provides farmers with training on sustainable practices and technologies to reduce emissions is crucial (Hannah *et al.* 2020).

Effective governance plays a critical role in making urban animal agriculture sustainable (Wheeler & Beatley (2014). Planning for sustainability in urban development should focus on building livable, equitable, and ecological communities (Wheeler *et al.*, 2013). The concept of "green urbanism" proposes a harmonious balance between urban life and nature (Kellett and Larbi, 2021; Buck, 2014). Urban animal agriculture has led to a significant increase in environmental pollution owing to the exploitation of productive resources. The development of the urban livestock production sector has resulted in the accumulation of large amounts of domestic animal waste, causing water contamination and obnoxious odors. McKinney (2002). Odor pollution can cause health hazards due to gases such as ammonia, hydrogen sulfide, and methanethiol. Livestock waste contains pathogenic microorganisms that can lead to environmental contamination (Bairoch 1988). Regulatory measures for animal waste disposal should be more stringent to prevent catastrophes and maintain waste management cost-effectiveness (Brown *et al.* 2009). Inorganic fertilizers found in animal manure, household waste, plant materials, crop residues, and compost can affect soil fertility. Animal agricultural waste can be recycled through composting, dehydration, and incineration, with the most efficient method being biologically active systems of aerobic and anaerobic digestion.

8. Future-Proofing Urban Animal Agriculture for a Changing Climate

The future of urban animal agriculture holds both promise and concerns, including the sustainable sourcing of feed that guarantees access to nutritious food while minimizing

environmental impacts. Further research is necessary to address these issues, as suggested in this study. Focusing on the development of innovative solutions for urban animal agriculture to adapt to climate change is critical in this regard. The modernization of agriculture through digitization and technology can be utilized to improve productivity, efficiency, and sustainability in urban animal agriculture while promoting gender equality, youth empowerment, and social inclusion. The focus areas for sustainable urban animal agriculture in sub-Saharan Africa include strengthening urban-rural connections and developing supportive policies and regulations. Urban animal agriculture can only be sustainable if partnerships are fostered with private sector entities to generate knowledge and innovations that enhance the skills and capacities of urban animal farmers.

Owing to environmental concerns exacerbated by climate change, animal waste reduction, circular economy principles, and scaling up successful initiatives for broader impact should be prioritized. These areas aim to address emerging challenges and opportunities while promoting food system resilience. The ultimate goal is to foster partnerships and promote sustainable urban animal agriculture in the region. The future of sustainable urban animal agriculture in sub-Saharan Africa is based on a triad approach to social, economic, and environmental sustainability, which will enhance resilience and improve livelihoods, food security, and environmental stewardship. Raising livestock and poultry in cities is a subsector that requires close examination in an evolving climate because of its multiple objectives and effects on ecosystem health and human well-being. Future research should focus on reducing the impact of climate change, evaluating innovative feeding, housing, and waste disposal methods, examining urban food policy and governance, and incorporating precision in urban animal agriculture. Promoting sustainable urban animal farming, integrating UAA into urban planning, and prioritizing education and training programs for urban animal farmers can significantly enhance social, economic, and environmental sustainability in urban areas.

9. Implications

Urban animal agriculture (UAA) is an excellent way to address environmental and socio-economic problems, but its absence in urban planning has resulted in unsustainable urban transformations that have brought numerous challenges. Urbanization in sub-Saharan Africa presents both opportunities and challenges, including economic growth, food insecurity, environmental degradation, and climate-related disasters. This study explored the relationship between urban animal agriculture, socio-economic dynamics, and environmental sustainability in this region, focusing on climate change adaptation. Urban sustainable food production is becoming increasingly important because of advancements in climate change, sustainability, and food security. Urban agriculture offers numerous advantages, including increased food security, reduced carbon footprints, self-employment, and environmentally friendly farming practices. However, it also faces challenges such as waste management, limited water supply, limited land availability, and a lack of knowledge and expertise.

Urban animal agriculture has a positive outlook because of its incorporation into urban planning, the growing importance of locally and sustainably produced food, gender- and climate-smart urban development, and its ability to empower

urban dwellers and communities. Gender inequality has compromised the optimization of urban animal production, which is exacerbated by the effects of climate change. Implementing gender-smart climate-resilient urban agriculture concepts can promote social sustainability, equal animal production, and bridge the gap in food security in urban areas. Strategies involving women in urban animal agriculture can reduce vulnerability, increase food security, and improve household income, making it crucial to ensure food security in the future.

To achieve sustainable urban animal agriculture, it is essential to implement climate-smart animal agriculture, adaptive water urban management systems, and sustainable farming methods supported by appropriate urban legislation and a holistic approach. Addressing the challenges of resource unavailability and environmental degradation requires innovative and climate-smart poultry and livestock strategies for sustainable nutrient management. Nature-inspired solutions, such as silvopasture and mixed crop-livestock systems, can advance appropriate nutrient management strategies that leverage eco-innovation to reduce greenhouse gas emissions, optimize resource use, and align with the social, economic, and environmental sustainability goals of urban agriculture. Micro-livestock farming in urban areas offers high-quality protein, year-round availability, minimal waste, low resource usage, and space efficiency, contributing to food security, environmental sustainability, and community development.

A comprehensive approach to urban animal agriculture (UAA) in sub-Saharan Africa, incorporating socio-economic and environmental factors and implementing appropriate urban legislation, can ensure sustainable UAA. This approach, which includes climate-resilient animal husbandry practices, prolific micro livestock, gendered climate-smart agriculture policies, and climate change adaptation, can lead to a more food-secure, environmentally conscious, and resilient future for urban generations. This study highlights the importance of a triad approach to social, economic, and environmental sustainability to enhance food security, income generation, and urban economic growth.

In conclusion, this study underscores the critical importance of fostering a resilient and sustainable urban animal agriculture sector in Sub-Saharan Africa. By balancing social, economic, and environmental considerations, urban animal agriculture can play a vital role in enhancing urban food security, improving livelihoods, and promoting environmental health. The triad approach adopted in this study highlights the interconnectedness of these three pillars and demonstrates that a holistic strategy yields multiple benefits. As the region continues to urbanize, prioritizing sustainable urban agricultural practices that support the well-being of both people and the planet is essential. By doing so, we can create a more food-secure, equitable, and environmentally conscious future for generations to come.

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