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Intensification by Small Scale Dairy Farmers - A Review of the Drivers, Externalities, and Interventions in Kenya

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Abstract

This review examines the dynamics of sustainable intensification in Kenya's smallholder dairy sector, emphasizing its impact on productivity, externalities, and the potential for environmental resilience. This study demonstrates how smallholder farmers manage labour demands within the context of increasing demand for dairy products to make strategic choices in farm management. The inclusion of better feed management and crossbreeding together with improved animal health are thought to produce the potential to subjectively increase milk yields as well as to reduce emission of greenhouse gases (GHG). The calculated value of the production model coefficient, 2.11, means that input resources can be optimized to increase milk production by 16.3% without incurring incremental costs at the same time as economizing on production costs by 4.4% without a decrease in productivity. However, rapid intensification also involves externality such as loss of our natural habitat through loss of biodiversity, polluted water, loss of trees through deforestation, and use of antibiotics, which unearths the sustainability issues. The review also shows that climate change, population, urbanization, increase in living standards, and advancements in reproductive technologies as key drivers of dairy intensification. Given this global and Sub-Saharan Africa (SSA) demand for livestock products, it is only suitable that the concept of sustainable intensification (SI) emphasizes the challenge of producing more with a limited production base whilst at the same time conserving the environment. Adoption of climate-smart livestock practices, enhanced pasture management, and breeding of low methane emitting animals are key strategies that must be pursued to decrease emissions

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and enhance the adaptive capacity to climatic risks. This study concludes that sustainable intensification can enhance smallholder dairy productivity, improve livelihoods, and contribute to food security. However, effective policies to regulate antibiotic use, reduce environmental impact, and protect biodiversity must be set. It is therefore important for sustainable practices that would ensure that the sector is sustainable and meets the global food needs regarding population and economic development.

Keywords: *Dairy production, intensification, sustainable, small scale*

Introduction

Strategies for intensification of smallholder dairy farming include feeding quality and quantity, crossbreeding to increase yields, and proper health management of cattle to reduce GH emissions (Khatri-Chhetri & Wilkes, 2020; Hakuzimana et al., 2021). Kenyan dairy sub-sector alone accounts for roughly 4% of the country's GDP and provides income, food security, and employment to millions of people (Ochenje & Shikuku, 2023; Ericksen & Crane, 2018). Smallholder farmers in highland areas of Kenya contribute nearly 80 per cent of total milk production in the country due to the key role played by sustainable dairy farming to enhance productivity and resiliency to climate change influences (Momanyi and Pepela 2024). Semi-commercial unit of dairy production usually exists in small areas, the farms may have few pure or crossbred cows ranging from 1 to 5 cows. Production changes due to differences in the agroecological and socio-economic regions (Omotoso et al., 2023). Smallholders FAR incorporate dairy cattle in the intensive maize-growing systems and, while the most common number of livestock was 1 to 3, some smallholders grow other cash crops like coffee or tea to supplement their dairy income (Mukiri et al., 2021; Bosire et al., 2019). Advantages of this system include the reuse of wastes for example the manure that is used to fertilize crops and the minimization of feed losses (Hamunyela et al., 2024). Animal clustering helps in disease control and there is less challenge in parasite control as pointed out by Cramer and Ericksen (2020).

The dairy value chain in regions such as Africa and Latin America is a key sector with a high potential for sustainable intensification (Slayi et al., 2024). To achieve sustainability, it is necessary to enhance livestock management efficiency and reduce greenhouse gas emissions (Kiribou et al., 2024). The rising human population across Sub-Saharan Africa continues to drive demand for food while decreasing available arable land, making sustainable intensification an essential strategy (Brandt et al., 2023; Schoneveld et al., 2024).

Drivers of Smallholder dairy intensification

The improvement in the productivity of smallholder dairy farming systems across East Africa has been eased by different agricultural development programs to generate the growing demand for dairy produce (Momanyi & Pepela, 2024). Low soil fertility and climate change impact on intensification of agricultural production which is still acknowledged as an important soil fertility means for improved income for smallholder farmers, as stated by Van der Lee et al. (2024). This approach is crucial for increasing output and realizing sustainable environmental production in the livestock systems in the region (Hamunyela et al., 2024).

The rising demand for meat and other livestock products popularly known as the livestock revolution is a result of increased population density, urbanization, newly attained income levels, and nutrition changes from an expanding middle class (Bosire et al., 2019; Schoneveld et al., 2024). However, due to this demand pressure, several issues have been noted about foods, especially with increased meat production through intensive livestock systems, food safety and sustainability have increasingly become of concern as these systems integrate vertically into food value chains (Ngigi and Ahmed, 2024). Population pressure and soil degradation are constraining factors inhibiting integrated agricultural productivity enhancement, resulting in resource competition or land-use change that hampers livelihoods and incomes in many regions (Brandt et al., 2023; Cramer & Ericksen, 2020).

World population growth, rapid Urbanization, Rise in Income, and Economic Development

The global human population will be approximately more than seven point nine billion and nearly nine point seven billion people by 2050 and much of this numerical strength will be noted particularly among African people according to Oke (2024). In Sub-Saharan Africa (SSA) the population is projected to reach over 2.4 billion by mid-century due to high fertility rates and the continued growth of urban areas (Bosire and Rao, 2023). Urban growth especially in developing nations will lead to close to 5 billion people living in urban areas by 2030 changing the pace of consumer expenditure as well as food production systems (Kiribou et al., 2024).

Projected consumption levels of milk and dairy products between now and 2030 seriously threaten to outpace the current level of milk production threefold. This increase is driven by population growth, rising incomes, urbanization (**Figure 1**), and shifts in dietary preferences (Hamunyela et al., 2024). The increasing human population coupled with an increasing call for animal protein will demand an increase in farming system efficiency and productivity specifying in SSA where milk production is part of the rural income (Mukiri & Musau, 2023; Ojango et al., 2017). Because of the positive relationship between individual consumption of livestock products and per capita income, it is expected that as incomes rise in all the regions the consumption of milk and dairy products will become even more ingrained in the daily diets of people (Cramer & Ericksen, 2023).

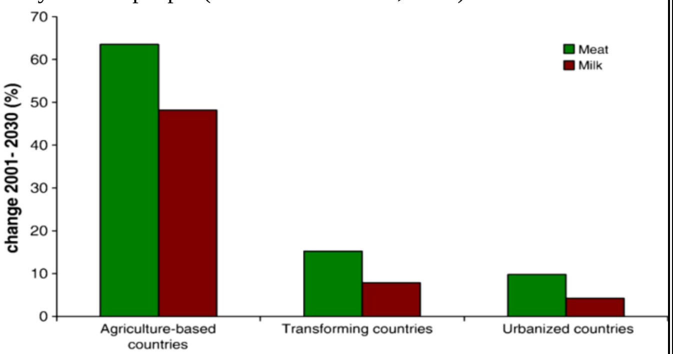

Figure 1. Projected changes in demand for livestock products, 2001 – 2030,
Source*:* Adapted from IAASTD (2009).

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Availability of Improved Genetic Resources and Reproductive technologies

In the view of Mwanga (2020), enhancing milk yield in smallholder dairy farms is a complex and multi-faceted process that can be achieved through feed management, efficient implementation of farm operations, and genetic improvement. Appropriate means of sale improvement as well as artificial insemination (AI) technologies have been adopted by small smallholder farming industry where about 44 % of farmers practice AI mainly to enhance breed quality (Ojango & Mrode, 2023). Technologies like sexed semen and embryo transfer have helped breed development for different agroecological and socio-economic systems with a focus on drought tolerance and management (Hamadani et al., 2024).

The applications of genomic technology have enhanced milk yield, quality, and diverse performance (Chawala et al., 2021). Sire selection is one of the genetic tools applied effectively to increase the yield of dairy cattle but at the time presents challenges like reduced fertility, high incidences of metabolic-related disorders, and short productive life of animals from high-yielding breeds (Brito et al., 2021; Bett, & Bebe, 2017). Current patterns of selection utilize genomic information to enhance production profiles while controlling negative impacts on animal welfare (Silva et al., 2024). As consumer demand changes, goals and selection criteria for dairy farming have evolved from increased milk yield to improved production technology and better product quality (Kirea et al., 2023). Current dairy production objectives address animal care and well-being, food safety, and readability stressing the societal impacts of production practices (Ngigi & Ahmed, 2024).

Climate change

Climate change is essentially defined as long-term shifts in climate, which have major and far-reaching effects on the livestock production systems throughout the world. These have an impact on diet, animal output, and feed supply chain, especially due to a rise in atmospheric CO_2, atmospheric temperature, and changes in rainfall levels (Bogale & Bekele, 2023). Livestock-dependent communities are most at risk in SSA where recent droughts have caused as much as 60 per cent loss of livestock in the affected regions (Tilahun et al., 2023). Higher temperatures also influence the re-emergence and transmission of vector-borne diseases resulting in enhanced winter-carrying capacities of vectors and pathogens (Auma & Radeny, 2023). Estimated annual enteric methane emissions (Kg CH_4 animal^{-1} year^{-1}) from the primary domesticated livestock species are shown in **Figure 2**.

Livestock generates about 14.5% of the global human-induced greenhouse gas (GHG) emissions (Germer et al., 2023). But better farming techniques can go a long way in decreasing the emission levels and even technical changes could lower these emissions by 41% (de Haan, 2016). Such interventions are proper feed handling and preservation, ideal breeding practices, as well as soil carbon sequestration through sustainable land management practices (Hakuzimana et al., 2021).

The existing livestock production systems in SSA are extensively marginated and constrained by low productivity coupled with high emission rates because of compromised feed quality and health status of the animals (Cramer et al., 2023). Resource utilization is a critical consideration when enhancing the sustainability of these systems (Ng'ang'a, & Girvetz 2021). Adaptive portfolio decisions, including production system improvements like water management enhancements and breeding for inherent resistance to shocks like droughts, have effectiveness against climactic change volatility (Oloo et al., 2023). These strategies also provide the potential for reducing GHG emissions including diet change, selecting animals with low methane producers, and the use of microbial treatment (Maindi et al., 2020).

They acknowledged that climate-smart livestock practices could go a long way in improving the impacts of climate change and at the same time increase productivity. Such practices in combination with knowledge transfer and technologies need policy support to reduce climate risks while achieving food security in SSA (Ntinyari & Gweyi-Onyango, 2020).

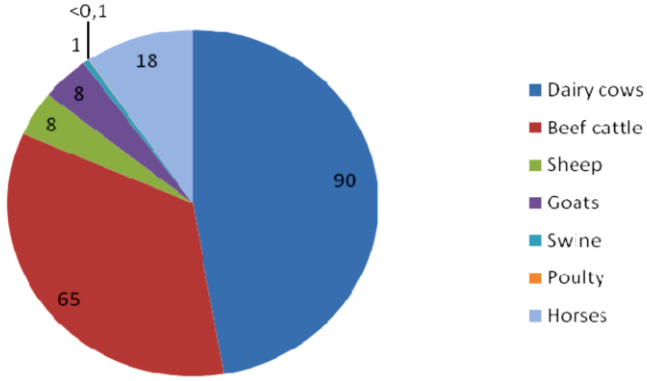

Figure 2: Estimated annual enteric methane emissions (Kg CH_4 animal^{-1} year^{-1}) from the main domesticated livestock species.

Source: Van Zijderveld et al., (2011)

Table 1. 1Mitigation strategies for methane production from ruminants

S. no.	Different strategies to reduce methane emissions from farm animals
1	Improved genetic selection to produce low methane-producing animals
2	Efforts must be taken to reduce the livestock population
3	Improved nutrition by providing high-quality feed and strategic supplementation of essential nutrients
4	Improving grassland management
5	Ensuring proper health and care through upgraded veterinary practices
6	Increasing the proportion of concentrate feeding
7	Diet modification through ammonia and molasses feeding to reduce methane
8	Oil and ionophore supplementation e.g., monensin and tannin
9	Defaunation and rumen microbial intervention
10	Reducing the manufacture of livestock products
11	Employing advanced technology to reduce methane production

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Source: Sejian *et al.* (2010)

Externalities of Smallholder Intensification and Interventions

Loss of Biodiversity

Intensification of smallholder dairy farming will lead to increased demand for animal feeds such as pastures, fodder, and fish protein. This demand can exacerbate deforestation, land degradation, and overexploitation of marine resources, which negatively impact biodiversity and ecosystem services (Momanyi & Pepela, 2024). It demonstrated that in SSA smallholder agriculture plays a significant role that leads to deforestation, decline in the stock of soil carbon, and wildlife habitats (Sekaran et al., 2021).

Marine ecosystems are at high risk such that fishmeal is used for producing high-protein feed to the animals. Overfishing to meet this demand has significant ecological consequences, affecting fish populations and disrupting marine food chains (Ng'ang'a & Girvetz, 2021). To address this, other protein sources, for example, insect proteins and other residual products from the fish industry are being considered (Carsan and van der Lee, 2024).

Water Pollution

Livestock farming contributes to water pollution through nutrient runoff, especially nitrogen and phosphorus, which cause eutrophication and reduce oxygen levels in aquatic ecosystems (Grout et al., 2023). Of these, the management of manure and recycling of nutrients are proven ways of reducing these effects. For instance, the use of integrated farming methods that involve animals and crops such as the feeding of livestock manure to crops will enhance water management (Ampadu & Adomako, 2023).

Deforestation

The effects of livestock on the issue of biodiversity and consequent deforestation depend on the production density, species of the livestock, and the regional environment. Where livestock production generates new habitats, intensity promotes forest clearance to grow feed crops such as pastures and croplands for animal feed, which adds to deforestation and biodiversity loss (van Berkum & Dengerink, 2023). Therefore, Agrosilvopastoral systems that combine crop, fodder production, and rearing of livestock and trees, are a sustainable form of production as they help build the soil structure, reduce soil erosion, and provide other sources of income (Hamadani & Shabir, 2024).

Increased Use of Antibiotics in Dairy

Intensification increases the incidence of bacterial diseases e.g. mastitis for which antibiotics are used in dairy farming. Antimicrobial resistance (AMR) is an emerging public health challenge that is spearheaded by the livestock industry (Baker et al., 2022). Therefore, the efficient control of AMR demands the government's effort to discourage the uptake of antibiotics using probiotics, regular vaccinations, and strict farm hygiene practices (Dong, 2021).

Increased Cost of Production

Smallholder zero-grazing systems provide the biggest value recovery on investment costs but call for the highest costs compared to bulk production feed requirements and close supervision (Kibiego et al., 2023). Such strategies as expanding pastures as part of the production units, storing excess feeds as hay or silages, and new formulations of dairy meals using locally available feed resources (Stroebel, 2023). Efficient resource use and minimizing waste are critical, so that, the farm can increase its profit as indicated by current efficiency.

Conclusions

i. Sustainable smallholder dairy intensification can contribute to climate change reduction and its effects on smallholders and also an effective source of world food security if the regulatory policies protecting the production environment and health of the people are generated and effectively monitored.

ii. Climate change, rise in demand for milk and its by -by-products as the world's Human population increases, economic growth, increase in urbanization and development of reproductive technologies are the key drivers for sustainable smallholders' dairy intensification.

iii. Positive externalities of sustainable smallholder dairy intensification are, the source of both direct and indirect employment, source of income to the dairy farmers and the input suppliers, and source of revenue to the government while negative externalities are loss of biodiversity.

Recommendations

i. The Government should enforce various existing policies to regulate the appropriate use of antibiotics in animals. This includes the setting of withdrawal periods to eliminate antibiotic residues in animal products and the encouragement of other methods such as the use of probiotics, immunization, and better barriers to the spread of bacterial infections than using antibiotics.

ii. Smallholder farmers should be encouraged to use sustainable intensification to reduce cases of land degradation. Such practices include enhancing the methods of pastures, appropriate feeding and conservation of the excess feeding stuff, diet management for decreasing methane, production of silvicultural crops, and livestock farming for improving biodiversity and carbon deposits.

iii. One of the key findings of the study is that there is a need to support and sustain education and training programs for smallholder farmers to enable them to put into practice good standards of sustainable dairy farming. This includes information exchange on the optimal use of resources, disease management, artificial insemination and other reproductive procedures, and agro-technologically sustainable farming methods.

Conflict of interest

The authors have no conflict and accept the manuscript to be submitted for publication.

References

1. Ampadu, B., & Adomako, T. (2023). The Impact of Agricultural Practices on Environmental Sustainability in Ghana. A review. *Journal of Sustainable Development, (8),70*.
2. Auma, J., & Radeny, M.A.O. (2023). Strengthening the adaptive capacity of livestock systems in East Africa. CGIAR Working Paper.
3. Baker, M.G., French, N., & Hales, S. (2022). A Review of Potential Public Health Impacts Associated with the Global Dairy Sector. GeoHealth.

DOI: 10.5281/zenodo.14741016

4. Bett, B. K., & Bebe, B. O. (2017). Use of Animal information and trait preferences for making breeding decisions on smallholder dairy farms. *East African Agricultural and Forestry Journal*, *82*(2-4), 214-226.
5. Bogale, G. A., & Bekele, S. E. (2023). Sustainability of agroforestry practices and their resilience to climate change adaptation and mitigation in sub-Saharan Africa: a review. *Ekológia (Bratislava)*, *42*(2), 179-192.
6. Bosire, C. K., Rao, E. J. O., Muchenje, V., Van Wijk, M., Ogutu, J. O., Mekonnen, M. M., ... & Hammond, J. (2019). Adaptation opportunities for smallholder dairy farmers facing resource scarcity: Integrated livestock, water, and land management. *Agriculture, Ecosystems & Environment*, *284*, 106592.
7. Bosire, C. K., Rao, E. J. O., Muchenje, V., Van Wijk, M., Ogutu, J. O., Mekonnen, M. M., ... & Hammond, J. (2019). Adaptation opportunities for smallholder dairy farmers facing resource scarcity: Integrated livestock, water, and land management. *Agriculture, Ecosystems & Environment*, *284*, 106592.
8. Bosire, C.K., & Rao, E.J.O. (2023). Population Growth and Urbanization Impacts on Dairy Demand in Sub-Saharan Africa. Agriculture, Ecosystems & Environment.
9. Brandt, P., Hamunyela, E., & De Bruin, S. (2023). Forest disturbance in Kenyan montane forests: Implications for livestock systems. *Land Use Policy*.
10. Brito, L. F., Bédère, N., Douhard, F., Oliveira, H. R., Arnal, M., Peñagaricano, F., ... & Miglior, F. (2021). Genetic selection of high-yielding dairy cattle toward sustainable farming systems in a rapidly changing world. *Animal*, *15*, 100292.
11. Carsan, S., & van der Lee, J. (2024). Sustainable Livestock Intensification: Balancing Productivity and Environmental Health. OAPEN Library.
12. Chawala, A. R., Sanchez-Molano, E., Dewhurst, R. J., Peters, A., Chagunda, M. G., & Banos, G. (2021). Breeding strategies for improving smallholder dairy cattle productivity in Sub-Saharan Africa. *Journal of Animal Breeding and Genetics*, *138*(6), 668-687.
13. Cramer, L., & Ericksen, P.J. (2020). Current situation and future scenarios for livestock management systems in East Africa. *CCAFS Working Paper*.
14. Cramer, L., & Ericksen, P.J. (2023). The Role of Livestock in Meeting Future Food Demand in SSA. *CCAFS Working Paper*.
15. Cramer, L., & Ericksen, P.J. (2023). The role of livestock in meeting future food demand in SSA. CCAFS Working Paper.
16. Dong, L. (2021). Toward resilient agriculture value chains: challenges and opportunities. *Production and Operations Management*, *30*(3), 666-675.
17. Ericksen, P. J., & Crane, T. A. (2018). The feasibility of low emissions development interventions for the East African livestock sector: Lessons from Kenya and Ethiopia. *ILRI Research Report*.
18. Germer, L. A., van Middelaar, C. E., Oosting, S. J., & Gerber, P. J. (2023). When and where are livestock climate-smart? A spatial-temporal framework for comparing the climate change and food security synergies and tradeoffs of Sub-Saharan African livestock systems. *Agricultural Systems*, *210*, 103717.
19. Grout, L., Baker, M.G., & Hales, S. (2023). Public Health Impacts of Environmental Pollution from Livestock Systems. GeoHealth.
20. Hakuzimana, J., Munyambonera, D. J., & de Dieu Habimana, J. (2021). The Carbon Footprint of Smallholder Dairy Farming In Sub-Saharan Africa: A Review. *International Journals of Sciences and High Technologies*, *25*(1), 476-506.
21. Hamadani, A., & Shabir, S. (2024). Innovations in Agrosilvopastoral Systems to Combat Land Degradation. Elsevier.
22. Hamadani, H., Hamadani, A., & Shabir, S. (2024). Artificial intelligence in animal farms for management and breeding. In *A Biologist's Guide to Artificial Intelligence* (pp. 167-182). Academic Press.
23. Hamunyela, E., Herold, M., & De Bruin, S. (2024). Sustainable Intensification of Dairy Production in Sub-Saharan Africa. *Global Food Security*.
24. IAASTD (International Assessment of Agricultural Knowledge, Science and Technology for Development). (2009). Agriculture at a Crossroads: Global Report. Island Press, Washington, DC.
25. Khatri-Chhetri, A., Wilkes, A., & Odhong, C. (2020). Mitigation options and finance for transition to low-emissions dairy in Kenya. *CGIAR Research Program on Climate Change Agriculture and Food Security (CCAFS) Working paper*.
26. Kibiego, K.W., Wambugu, C., & Wanyoike, F.M. (2023). Economic Viability of Zero-Grazing Systems in Smallholder Dairy Farming. Food and Agriculture Organization (FAO) Report.
27. Kihoro, E., Vernooij, V., Schoneveld, G., Crane, T., & Vellema, S. (2024). Does dairy intensification threaten livelihood diversity in East Africa? *Global Food Security*, *41*, 100770.
28. Kirea, J. A. (2023). *Factors influencing smallholder dairy cattle productivity in Tigania East sub-county, Meru County* (Doctoral dissertation).
29. Maindi, N. C., Osuga, I. M., & Gicheha, M. G. (2020). Advancing climate smart agriculture: adoption potential of multiple on-farm dairy production strategies among farmers in Murang'a County, Kenya. *Livestock Research for Rural Development*, *32*(4), 63.
30. Momanyi, D., & Pepela, F. (2024). An Assessment of Kenya's Sustainable Smart Dairy Farming: Trends and Scenario Analysis. KIPPRA Working Paper.
31. de Haan, C. (Ed.). (2016). *Prospects for livestock-based livelihoods in Africa's drylands*. World Bank Publications.
32. Mukiri, J., & Musau, E.M. (2023). Enhancing Milk Production in Sub-Saharan Africa through Sustainable Practices. CGIAR Working Paper.
33. Mukiri, J., Musau, E.M., Nzogela, B.K., & Paul, B.K. (2021). Assessing environmental impacts of smallholder dairy intensification in Tanzania. CGIAR Working Paper.
34. Mwanga, G. G. (2020). *Machine learning models for predicting decisions to be made by small scale dairy farmers in Eastern Africa* (Doctoral dissertation, NM-AIST).
35. Ng'ang'a, S.K., & Girvetz, E.H. (2021). Trade-offs and Synergies of Climate Change Adaptation Strategies

DOI: 10.5281/zenodo.14741016

among Smallholder Farmers in SSA. Regional Sustainability.

36. Ngigi, M., & Ahmed, M.A. (2024). The evolving role of smallholders in the livestock value chain: A case study from East Africa. *Taylor & Francis.*
37. Kiribou, R., Bedadi, B., Dimobe, K., Ndemere, J., Neya, T., Ouedraogo, V., & Dejene, S. W. (2024). Urban farming system and food security in sub-Saharan Africa: Analysis of the current status and challenges. *Urban Agriculture & Regional Food Systems*, *9*(1), e70007.
38. Ntinyari, W., & Gweyi-Onyango, J. P. (2020). Greenhouse gas emissions in agricultural systems and climate change effects in Sub-Saharan Africa. In *African handbook of climate change adaptation* (pp. 1-25). Cham: Springer International Publishing.
39. Ochenje, I., & Shikuku, K. (2023). Integrated agriculture and aquaculture (IAA) system, livestock breeds and improved feeding as prioritized innovations for reducing emissions in Kenya’s food systems: Assessing scaling potential using six-step criteria.
40. Ojango, J. M., Mrode, R., Okeyo, A. M., Rege, J. E. O., Emerge-Africa, K., & Chagunda, M. G. G. (2017). Improving smallholder dairy farming in Africa. In *Achieving sustainable production of milk Volume 2* (pp. 371-396). Burleigh Dodds Science Publishing.
41. Ojango, J.M.K., Mrode, R.A., & Okeyo, A.M. (2023). Improving smallholder dairy farming in Africa through genetic innovations. Taylor & Francis.
42. Oke, M. (2024). Land Use Conflict Between Farmers and Herdsmen: Implication for Agricultural and Rural Development in Nigeria. Sciforum.
43. Oloo, R. D., Ojango, J. M., Ekine-Dzivenu, C. C., Gebreyohanes, G., Mrode, R., Mwai, O. A., & Chagunda, M. G. (2023). Enhancing individual animal resilience to environmental disturbances to address low productivity in dairy cattle performing in sub-Saharan Africa. *Frontiers in Animal Science*, *4*, 1254877.
44. Omotoso, A. B., Letsoalo, S., Olagunju, K. O., Tshwene, C. S., & Omotayo, A. O. (2023). Climate change and variability in sub-Saharan Africa: A systematic review of trends and impacts on agriculture. *Journal of Cleaner Production*, *414*, 137487.
45. Sejian, V., Maurya, V. P., & Naqvi, S. M. (2010). Adaptive capability as indicated by endocrine and biochemical responses of Malpura ewes subjected to combined stresses (thermal and nutritional) in a semi-arid tropical environment. *International Journal of Biometeorology*, *54*, 653-661.
46. Schoneveld, G., Vernooij, V., & Kihoro, E. (2024). Livelihood diversification and socio-economic adaptation in Sub-Saharan Africa. *Global Food Security*, *41*, 100770.
47. Sekaran, U., Lai, L., Ussiri, D. A., Kumar, S., & Clay, S. (2021). Role of integrated crop-livestock systems in improving agriculture production and addressing food security–A review. *Journal of Agriculture and Food Research*, *5*, 100190.
48. Silva Neto, J. B., Mota, L. F., Londoño-Gil, M., Schmidt, P. I., Rodrigues, G. R., Ligori, V. A., ... & Baldi, F. (2024). Genotype-by-environment interactions in beef and dairy cattle populations: A review of methodologies and perspectives on research and applications. *Animal Genetics*, *55*(6), 871-892.
49. Slayi, M., Zhou, L., Nyambo, P., Jaja, I. F., & Muchaku, S. (2024). Communally established cattle feedlots as a sustainable livelihood option for climate change resilience and food security in sub-Saharan Africa: a systematic review. *Frontiers in Sustainable Food Systems*, *7*, 1325233.
50. Stroebel, A. (2023). Socio-Economic Complexities of Smallholder Ruminant Livestock Production Systems in SSA. University of the Free State.
51. Tilahun, G., Bantider, A., & Yayeh, D. (2023). Analyzing the Impact of Climate-Smart Agriculture on Household Welfare in Subsistence Mixed Farming System: Evidence from Geshy Watershed, Southwest Ethiopia. *Global Social Welfare*, *10*(3), 235-247.
52. van Berkum, S., & Dengerink, J. (2023). Transition to Sustainable Food Systems: The Dutch Circular Approach. Wageningen University.
53. Van der Lee, J., Klerkx, L., & Bebe, B.O. (2024). Intensification and upgrading dynamics in emerging dairy clusters in East Africa. *OAPEN Library*.
54. Van Zijderveld, S. M., Gerrits, W. J. J., Dijkstra, J., Newbold, J. R., Hulshof, R. B. A., & Perdok, H. B. (2011). Persistency of methane mitigation by dietary nitrate supplementation in dairy cows. *Journal of Dairy Science*, *94*(8), 4028-4038.

DOI: 10.5281/zenodo.14741016