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PERSPECTIVE

SUSTAINABLE DEVELOPMENT OF CROP-LIVESTOCK FARMS IN AFRICA

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ABSTRACT

Crop-livestock farms across Africa are highly variable due to in agroecological and socioeconomic factors, the latter shaping the demand and supply of livestock products. Crop-livestock farms in Africa in the 21st century are very different from most mixed farms elsewhere in the world. African crop-livestock farms are smaller in size, have fewer livestock, lower productivity and less dependency on imported feed than farms in most countries of Europe, the Americas and the intensive agricultural systems of Asia. This paper discusses the role African crop-livestock farms have in the broader socio-agricultural economy, and how these are likely to change adapting to pressures brought on by the intensification of food systems. This intensification implies increasing land productivity (more food per hectare), often leading to more livestock heads per farm, producing fertilized feeds in croplands and importing feed supplements from the market. This discussion includes (1) the links between crop yields, soil fertility and crop-livestock integration, (2) the increasing demand for livestock products and the land resources required to meet to this demand, and (3) the opportunities to integrate broader societal goals into the development of crop-livestock farms. There is ample room for development of crop-livestock farms in Africa, and keeping integration as part of the development will help prevent many of the mistakes and environmental problems related to the intensification of livestock production observed elsewhere in the world. This development can integrate biodiversity, climate change adaptation and mitigation to the current goals of increasing productivity and food security. The inclusion of broader goals could help farmers access the level of finance required to implement changes.

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1 THE SOIL FERTILITY QUEST

Low crop yields (below 1 $t \cdot ha^{-1}$) and low fertilizer use are still a widespread reality in Africa. Over the past 40 years, there have been numerous attempts and heavy investments in research and development to increase fertilizer use to reduce the human impacts of food shortages[1]. Development agencies have been promoting the use of animal manure to improve soil fertility, under the premise that this would be a good motivation for efficient use of an otherwise neglected resource. However, studies have shown that recycling of manures alone has limited potential to increase crop productivity to the levels required in the continent to achieve food self-sufficiency[2]. Research has shown though, that there is room to improve the composting process in order to conserve more nutrients in manure[3]. In many cases accumulation of manure is achieved where livestock are confined, and this resource is often poorly managed leading to nutrient losses especially that of nitrogen. Techniques for more effective capture, storage and use of livestock manure are urgently required to increase the returns from this manure and from the purchase of off-farm nutrients. Creating specific incentives that mitigate climate change (by reducing emissions of the greenhouse gases N_2O and CH_4) may help improve manure management systems in rural areas[4]. A recent focus of development has shifted toward the promotion of bio-digesters that lead to a net loss of carbon due to CH_4 leakage from the mixed farm[5]. The volumes of manure currently managed are only sizable in commercial dairy farms and represent an important concern as major sources of pollution in urban and peri-urban crop-livestock systems[6].

Nutrient balances in many African countries are negative because of the nutrient mining nature of small-scale agriculture with low fertilizer use. One of the main reasons for the low yields in Africa is related to this low and spatially variable input use; only exceeding 50 $kg \cdot ha^{-1}$ N in a few countries with subsidized programs, such as in Malawi[7]. Increasing agriculture and livestock production in Africa will undoubtedly increase the rate of on-farm nutrient losses if the current trends continue, and therefore planning for intensification must look to avoid the past mistakes made in agricultural systems of mid and high-income countries. For example, the intensification of livestock production in the European Union has been associated with biodiversity loss due to landscape fragmentation, and the deterioration of soil, air and water quality, and increased GHG emissions[8]. These effects are caused by high livestock densities and widespread fertilizer use which lead to increased ammonia emissions, N deposition and nutrient losses to waterbodies. Similar trends are observed in China where the increasing demand of animal protein has led to the expansion of large-scale landless livestock operations in addition to small backyard mixed farms[9]. Both systems have poor manure management practices and this has led to the pollution of major rivers in China. Although the scale is different, in Africa the intensification of livestock production not only accelerates nutrient turnover but is also a conduit for import of external nutrients since many African mixed farmers purchase small amounts of forage, cereal milling byproducts and mineral supplements as soon as livestock production becomes commercial. In view of the risk associated with intensification, future crop-livestock farms must be integrated, aiming to close nutrient cycles by (1) efficiently using the biomass produced and recycling all livestock waste, (2) ensuring that stocking rates do not exceed the productive capacity of the land, and (3) avoiding the import of excessive amounts of feeds that create farm and regional economic dependencies, which should be feasible due to their small scale. Avoiding these imports is also important as farms and regions that are heavily reliant on imported feed are more exposed to market fluctuations and supply chains vulnerabilities.

The intensification of crop-livestock farms has to integrate the biomass and nutrient flows between cropping and livestock activities (shown schematically in Fig. 1) to lead to sustainable outcomes. The evolution of this intensification process, motivated by economic drivers, determines changes in the scale of production and the integration of biomass and nutrient flows due to changes in the management of livestock and their feeding systems. At low levels of intensification (Fig. 1(a)), livestock are fed mostly in grasslands, and the flows of biomass and nutrients to croplands are limited. Increasing livestock numbers require increased feed supplies from croplands (Fig. 1(b)), with opportunities for tighter crop-livestock integration through the recycling of manure. Further intensification often leads to more specialization and a shift in the feed supply from grasslands to croplands, and the subsequent need to manage soil fertility with external inputs (Fig. 1(c)). The most intensive form of crop-livestock farm relies heavily on external inputs and shows less integration of biomass and nutrient flows at farm level, and results in on-farm and sometimes regional nutrient surpluses (Fig. 1(d)).

Different stages of this intensification process and different degrees of integration between crop and livestock activities can be found across the globe and at different points in time. The last stage of intensification needs to be avoided though, due to the high costs of externalities highlighting why policies are needed to help protect broader production and environmental goals. The intensive system is often more efficient to produce food, but without effective policy, it creates problems with surpluses in farm and regional nutrient budgets.

2 DEMAND FOR LIVESTOCK PRODUCTS

As the lifestyles of Africans become more affluent with the rise of

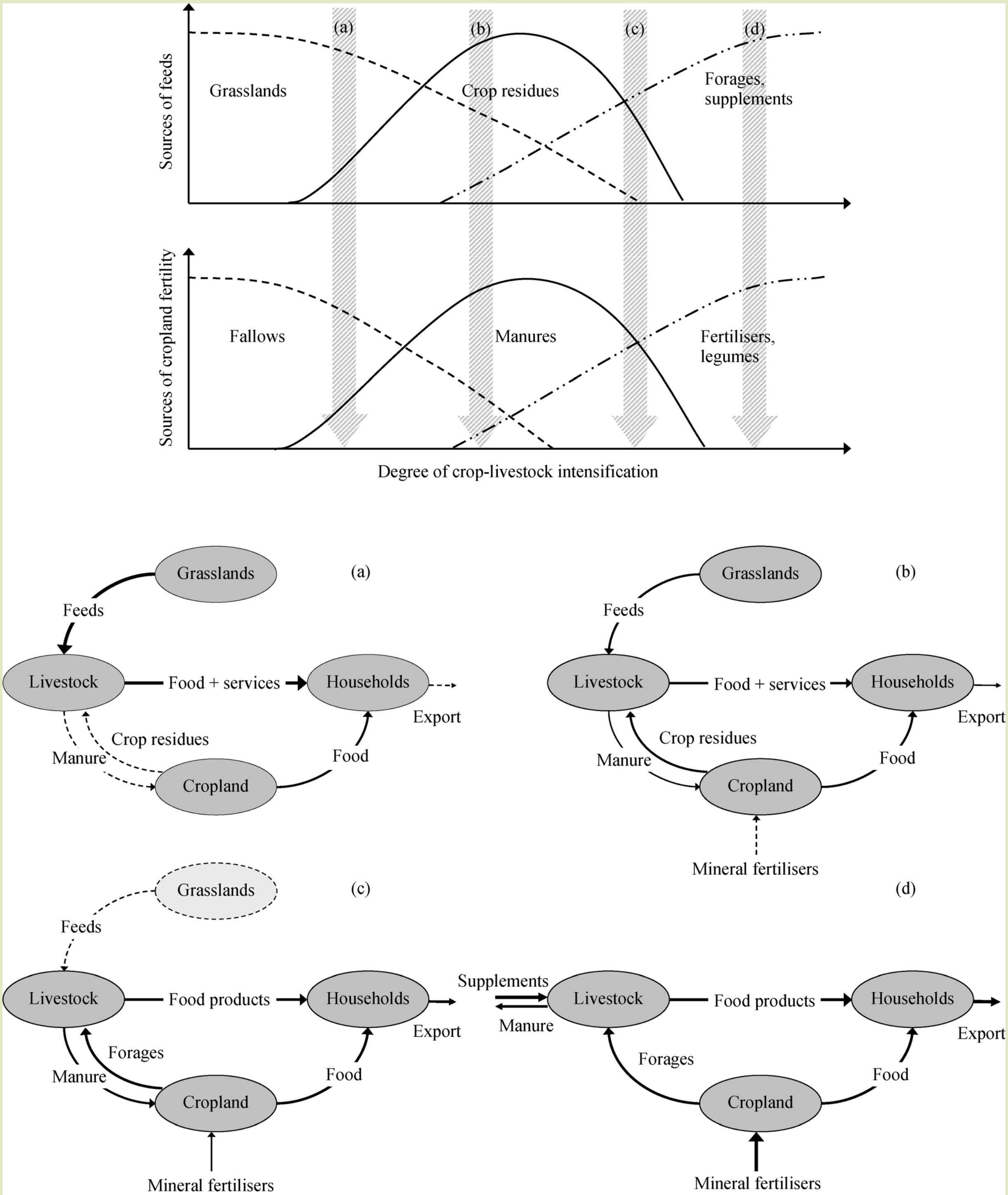

Fig. 1 Schematic representation of the intensification of crop-livestock systems indicating the sources of feeds and sources of soil fertility along a hypothetical intensification gradient (concept adapted from Fernandez-Rivera and Schlecht[10]). Four examples show the magnitude of the biomass and nutrient flows. (a) Low levels of intensification and of integration, most feed is provided by grasslands, and the fertility of croplands relies on fallows; (b) more intensive livestock production creates stronger feed biomass and manure flows; (c) higher stocking densities require the more specialized production of feeds on croplands and an increase in external inputs, opportunities for integration are high; and (d) at high levels of intensification, external inputs are more important for maintaining high levels of production and exports in detriment to the integration of biomass and nutrient flows.

the middle class[11], increased demand of milk and meat will require intensification of livestock production in order to improve self-sufficiency. This intensification of crop-livestock farms though, will create additional pressures on natural ecosystems, such as land use change, loss of forest cover and soil degradation, all of which will cause a reduction in the carbon sink[12]. Low-emission development strategies could help increase production while concurrently contributing to climate change mitigation. This development should aim to preserve soil health and rebuild soil fertility, thus removing carbon from the atmosphere and aiding in climate change mitigation. Also, this development must include human nutritional and social goals, so that the greening of crop-livestock farms benefits the communities and facilitates access to finance for poor farmers. Africa has vast areas of land that could be put into production or restored for future production of wood, crops and livestock[13], so investments now could create green jobs within the economy[14]. This is an opportunity for an alternative model of development, one that avoids the environmental burden associated with high livestock densities and high input use. Once soil, water and air are overloaded with nutrients and fine particulate matter ($PM_{2.5}$) from intensive agricultural activities, mistakes are hard to rectify, solutions are difficult to implement, expensive and are often resisted by the public[15].

Crop-livestock farms make a critical economic contribution to nutrition and income diversification[16] and in many countries livestock provides draft power for crop production. Livestock in addition can help sustain household consumption in farming systems exposed to recurrent drought[17], and therefore keeping a healthy and well-fed livestock population generates multiple benefits. However, this is not the reality in many of the small mixed farms in Africa, where a combination of high livestock densities for a given agroecology, overgrazing and climate variability lead to recurrent livestock mortality, morbidity and low overall productivity[18]. Climate change is an important stressor for livestock production, more so in the tropics where changes in temperature and increased frequency of heatwaves cause heat stress decreasing feed intake which in turn affects milk production[19]. There are however positive developments in this field, with emergency and development organizations helping communities in East Africa to increase resilience by diversifying livestock production, reducing the impacts of climate risks through landscape management, lowering stocking rates and accessing livestock insurance using a science-based approach[20]. Reducing the risk of production in crop-livestock farms is needed and more research on the potential for the commercialization of insurance could help improve land productivity and increase the opportunities for farmers to invest in sustainable management.

3 INTEGRATING BROADER GOALS TO CROP-LIVESTOCK SYSTEMS

Given the challenges faced by African crop-livestock farmers, it seems timely to integrate future development with more ambitious goals including protecting soil health, biodiversity, contributing to climate change adaptation and mitigation in addition to delivering crop and livestock products for food security and incomes. The current evidence indicates that the development of crop-livestock farms in Africa is likely to show more and not less integration of crops and livestock across landscapes in order to increase resilience to climate change and as a diversification strategy. An analysis of farms across a wide rainfall gradient (500–1200 mm) throughout East Africa showed that most farmers wanted to have more livestock, while those living in the dry areas wanted to have larger areas under cropping giving a clear indication of mixed farms as the common aspiration[16]. However, there are biological and economic limits to the expansion of mixed farming and therefore there is a role for policy to anticipate and to guide the intensification processes so that these meet multiple goals, including the delivery of environmental outcomes. In light of the expected expansion of mixed farms, new government policies are urgently required, particularly as current government policies across sub-Saharan Africa rarely include clear recommendations for manure management[21]. A good step forward would be to clearly define livestock densities and nutrient loads to the environment that are safe for people and nature.

There are many examples of beneficial crop-livestock intensification with varying degrees of integration across the African continent (Table 1). In the dry agropastoral environments of East, West and Southern Africa, crop-livestock integration mostly occurs at a landscape scale, providing multiple opportunities and challenges. Integration of cropping into the agropastoral systems of Borana in southern Ethiopia is an example of climate change adaptation[22], with the limits to further integration imposed by land degradation due to overgrazing. The combination of crop and livestock farming improves food security and incomes in West Africa because small ruminants contribute significantly to reducing the seasonality of cash flows[23]. In northern Zimbabwe, integration allows management of landscape-scale nutrient flows that make crop production possible in otherwise infertile lands, while crop residues are critical to sustain livestock through the dry season[24].

Engaging in dairy in southern Mali was perceived as an opportunity to increase farm profits with greater crop

Table 1 Increasing degree of crop-livestock integration of African farms, with examples of farm benefits and environmental challenges derived from the coexistence of crop and livestock activities

Type of system	Location	Farm benefits	Environmental challenges	Reference
(Agro)pastoral	Borana, Ethiopia	Adaptation, income diversification, risk management	Land degradation, overgrazing, biodiversity loss	[22]
Agropastoral	West African Sudano-Sahelian region	Income diversification, adaptation	Exposure to drought	[23]
Cropping with livestock	Murewa, Zimbabwe	Manure, income diversification	Exposure to climate variability	[24]
Agropastoral to mixed crop-livestock diverse	Kenya, Tanzania	Income and farm diversity	Erosion, biodiversity loss	[16]
Dairy extensive	Sikasso, Mali	Increase profits, manure	Land degradation, heat stress	[25]
Dairy semi-intensive	Western Kenya	Livestock nutrition, soil fertility	Manure concentration	[26]
Dairy intensive	Central and Western Kenya	Increase profits, market integration	Deforestation, land use conversion	[12]
Mixed crop-livestock urban and peri-urban	Urban and peri-urban, Niger	Income and nutritional diversity	Nutrient pollution, zoonoses	[6]

production through the recycling of increasing volumes of manure[25]. The intensification of crop-livestock farms in Mali must include not only pulses, but also the genetic improvement of local breeds which have currently low productivity. Urban and peri-urban farming systems in West Africa supply an important share of the crop and animal products to these burgeoning cities. In Niamey, Niger, very small farms produce vegetables, cereals and large and small ruminants which contribute importantly to household income and nutrition but also to the concentration of biomass and nutrients that create major sources for environmental pollution[6]. Further development of urban and peri-urban farms across Africa requires sound policies and guidelines for manure management that also incorporates targets to limit the risk of zoonoses[18].

Mixed intensive farming is widespread in the highlands of Kenya, where small farm sizes force farmers to cultivate most of their land and to feed livestock with feeds collected from various places due to the limited availability of grazing land. A study showed that the biomass produced in these mixed farms and the nutrients available from manure to recycle on-farm are insufficient to produce acceptable crop yields, and that improvements in manure management can only have small positive effects[26]. Analyzing biomass flows in and around the largest montane forest of Kenya, another study indicated that the shortages of feeds on dairy farms are frequently offset through forest grazing, which reduces the capacity of the forest to store carbon and deliver other critical ecosystem services[12].

4 OUTLOOK

Most crop-livestock farms in the African continent keep fewer livestock and have less land compared to the operations found in high-income countries. These African farms have higher labor inputs and rely less on commercial feed imported from other regions or countries. Given the productivity of mixed farms in Africa is often low (e.g., dairy cows produce less than 1500 L of milk per lactation), many African countries are net importers of animal-derived products such as milk powder and cheese. Changing this reality will require fast adoption of technology (e.g., fodder conservation to regulate seasonal feed fluctuations and milk processing technologies to reduce losses), which needs to be adapted to the African context to minimize the reliance on foreign industry for key inputs and knowledge. The transformation of mixed farms should also rely more on green energy (solar, hydro and wind) to reduce the dependency on fossil fuels, with farming practices adapted to harness local plant and animal diversity.

Crop-livestock farms could benefit from the climate change mitigation schemes since there are many initiatives that are designed to offset carbon emissions, contributing to food security and halting land degradation such as the UNEP Decade of Ecosystem Restoration. Restoring degraded lands will certainly help reduce the pressure on existing croplands and will be an investment in future food self-sufficiency for the

African youth. Productive crop-livestock farms can generate employment, especially if a processing industry develops around villages, towns and cities. Keeping livestock and cultivating crops will also be critical to climate change adaptation since all the evidence indicates that farm and landscape diversity helps farmers stabilize income[16] and recover from shocks[17].

There is ample room for development of crop-livestock farms in Africa, and keeping integration as part of the development will help prevent the environmental problems observed elsewhere in the world. This development can integrate more goals than just increasing productivity, and the inclusion of broader goals could help farmers access the level of finance required to implement changes. The most important next steps will be for African farmers and their decision makers to decide what development route best fits their societal goals and world vision. Given the challenge presented by climate change, strategies that relies on the exploitation of African plant and animal diversity and green energy for production and processing are the most promising. In particular, the more widespread cultivation of specific African grasses such as brachiaria (*Brachiaria humidicola*) and Napier grass (*Pennisetum purpureum*) can help deliver on these multiple goals. Brachiaria produces strong biological nitrification inhibitors in their rooting system[27], and that is why this grass can be used to produce forage and to control nitrogen losses and NOx emissions. Napier grass in another productive native African grass that can be cultivated in steep terrain and thanks to its excellent nutritional properties and suitability for fodder conservation it can be used to manage feed shortages during the dry season contributing to reduce the carbon footprint of intensive dairy farms[28]. In any option, smallholders need to have access to knowledge, the required assets and inputs to manage their land in a way that is, in the long-term, economically and environmentally sustainable.

Compliance with ethics guidelines

Mariana C. Rufino, Charles K. K. Gachene, Rodrigue V. C. Diogo, James Hawkins, Alice A. Onyango, Ousmane M. Sanogo, Ibrahim Wanyama, Gabriel Yesuf, and David E. Pelster declare that they have no conflicts of interest or financial conflicts to disclose. This article does not contain any studies with human or animal subjects performed by any of the authors.

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