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Integrating Livestock with Crops and Forestry for Sustainability

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Global per capita consumption of animal protein is set to rise, particularly in developing economies, leading to a dramatic increase in meat consumption from 133 million tons in 1980 to 452 million tons by 2050. Notably, 86% of this increase, or 279 million tons, is expected to occur in developing countries. The expansion of animal-based agricultural systems, which cover 45% of the Earth's land area, presents significant challenges. These systems contribute substantially to agricultural emissions, including greenhouse gases such as nitrous oxide (N2O) and methane (CH4), and account for 8% of global water usage. The livestock sector is largely comprised of resource-

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constrained smallholders in developing nations. Environmental impacts arise from the lack of integration with other agricultural and forestry practices, disrupting the natural cycles of carbon, water, nitrogen, phosphorus, and sulfur. This disruption leads to increased emissions of N2O and CH4, water contamination, land degradation, and biodiversity loss. To address these challenges and support the United Nations' Sustainable Development Goals (SDGs) related to poverty reduction (SDG #1), hunger alleviation (SDG #2), clean water and sanitation (SDG #6), and climate action (SDG #13), it is essential to integrate livestock with crop and tree farming. Strategies to improve sustainability include incorporating pastures into crop rotations, using controlled grazing techniques, practicing agro-forestry such as alley cropping, and implementing systems like ley farming. Additional measures include precision feeding and protein matching to reduce enteric fermentation, repurposing emissions of CH4 and N2O, and effective manure management. Addressing greenhouse gas emissions through diverse approaches, reducing product wastage, minimizing antibiotic use, and restoring rangelands to enhance soil carbon storage are also critical for achieving sustainable livestock practices.

Keywords: Food security; ecological footprint; sustainable development goals; farming systems.

1. INTRODUCTION

The process of animal domestication starts around the 12th millennium BP (Zeder, 2008) commencing with dogs and subsequently extending to ruminants like goats, sheep, and cattle. Chickens were domesticated around 10,000 years ago, with oxen and horses following suit to serve as work animals for agriculture and transportation (Rutledge and McDaniel, 2011). Throughout history, the cultivation of crops and the raising of livestock were intertwined practices. However, in the mid-20th century, the separation of these activities has given rise to environmental concerns such as soil degradation, water eutrophication, greenhouse gas emissions, and biodiversity loss (Peyraud et al., 2014).

The isolated rearing of livestock has proven to be unsustainable both economically and ecologically (Broom et al., 2013). This issue becomes more pronounced due to the increasing demands of a growing and prosperous global population. Balancing the need for food security with the imperative of mitigating agriculture's negative environmental impact presents a significant challenge. A contributing factor to this dilemma is the simplification of agro-ecosystems, leading to reduced diversity in farming systems across various scales – from soil to landscape (Lemaire et al., 2014, Marchão et al., 2024, Oliveira et al., 2024, Monteiro et al., 2024).

The detrimental environmental effects attributed to livestock practices can be addressed through good management approaches (Dalibard, 1995). The separation of livestock from crops and trees in certain climates and landscapes has resulted in decreased farm-level diversity and subsequent environmental consequences. This loss of biodiversity not only disrupts the interconnected cycles of carbon, water, nitrogen, phosphorus, and sulfur (Lal, 2010) but also impacts the interactions between livestock and land use changes (Steinfeld et al., 2006).

To mitigate the risks associated with this decoupling, which have considerable implications for climate change due to the high global warming potential of CH4 and N2O, integrating livestock with crops and trees emerges as a solution. Strategies like establishing vegetation buffers in agricultural fields (e.g., agro-forestry or alley cropping) enhance biodiversity, conserve soil and water, and lessen the environmental impact of livestock practices on the same land (Goldstein, 2012).

This article seeks to explore several key objectives: like examining the potential and challenges of using livestock to address food and nutrition needs for a growing population; discussing the theoretical foundation of integrating livestock, crops, and trees to promote farming system biodiversity; exploring sustainable grassland management options for food and climate security; and lastly, suggesting improved livestock management strategies for tropics.

2. EXPLORING THE POTENTIAL AND CHALLENGES OF MEETING THE GROWING HUMAN POPULATION'S FOOD AND NUTRITIONAL NEEDS THROUGH LIVESTOCK REARING

Concerns about widespread famine intensified during the 1950s and 1960s due to rapid population growth (Ehrlich, 1968) with the global population rising from 2.56 billion in 1950 to 4.34 billion by 1980. The Green Revolution of the 1960s significantly boosted cereal crop yields, easing immediate famine fears (Pingali, 2012). However, the global population has since soared to 7.8 billion in 2020, with projections of 9.8 billion by 2050 and 11.2 billion by 2100 (UN, 2019b). Despite these advances, around 733 million people remain at risk of undernourishment (FAO, 2024) and approximately 2 billion suffer from malnutrition due to deficiencies in protein, micronutrients, and vitamins (Ritchie and Roser, 2019). The expansion of agro-ecosystems to feed the growing population has led to biodiversity loss, water depletion, contamination, air pollution, and increased greenhouse gas emissions. The livestock sector plays a crucial role in addressing hunger and malnutrition, but the concurrent rise in both human and animal populations raises concerns about the sustainability of these systems.

Human population growth has surged from 10–20 million at the advent of settled agriculture to approximately 7.8 billion in 2020 (UN, 2019a). Similarly, domesticated livestock populations have increased significantly. Despite a decline from 1.4 billion in 2011, the cattle population remained around 1 billion in 2019 (The Economist Global Livestock Counts, 2011, Shahbandeh, 2019). Global chicken stocks are estimated at 19 billion, with sheep and pig populations each around 1 billion. Demand for animal-based products is expected to double by 2050 due to rising affluence and changing diets (Herrero, 2009, Rojas-Downing, et al., 2017). The bovine population is projected to grow from 1.9 billion in 2010 to 2.64 billion by 2050 (Rosegrant et al., 2009, Thornton, 2010). While the global human population grows at 1.2% annually, livestock populations are expanding at 2.4%, with distribution influenced by various biophysical, socio-economic, and cultural factors (Gilbert, 2018).

With rising livestock populations, global meat production is projected to increase from 229 million tons in 2000 to 465 million tons by 2050, and milk production is expected to grow from 580 million tons to 1,043 million tons (FAO, 2006, Steinfeld et al., 2006). Currently, 60 billion land animals are used worldwide for meat, eggs, and dairy, potentially exceeding 100 billion by 2050 (Yitbarek, 2019). Meat consumption in developing countries rose from 47 million tons in 1980 to 132 million tons in 2002, and is projected to reach 326 million tons by 2050. Developed countries are expected to see an increase from 86 million tons to 120 million tons (NAS, 2015). By 2050, production increases are projected to be 290% for pig meat, 200% for sheep and goats, 180% for beef, 700% for poultry, and 90% for eggs (Yitbarek, 2019). Milk production will also rise, with each liter of milk generating about 3 kg of GHG emissions (Reay and Reay, 2019).
Livestock play a significant role in climate change, both contributing to and being impacted by it. Integrating livestock with crop and tree farming offers a solution for environmental restoration (Janzen, 2011). This approach leverages the benefits of livestock farming—such as providing essential nutrition and addressing various forms of hunger—to promote sustainable management of crops and trees while reducing environmental impacts (Herrero and Thornton, 2013). Applying ecologically sound principles to animal husbandry can also enhance ecosystem services, particularly in vulnerable but economically important rangelands (Havstad, 2007).

3. CONCEPTUAL BASIS OF INTEGRATING LIVESTOCK WITH CROPS AND TREES

The integration of livestock with crops and trees offers a conceptual basis for addressing the environmental challenges posed by the livestock sector while contributing to sustainable agricultural development. The following key points elaborate on this integration:

Environmental Footprint of Livestock: Livestock use 30% of the Earth's entire land surface as permanent pastures; 33% of arable land is used to produce feed for the livestock (FAO, 2006) and thus livestock have a large environmental footprint in terms of climate change, reactive nitrogen mobilization, and plant biomass appropriation (Smith, 2013). Addressing these challenges is essential for maintaining the planet's "safe operating space."

Reducing GHG Emissions: Greenhouse gas (GHG) emissions from the livestock sector, particularly methane (CH4) and nitrous oxide (N2O), can be mitigated through integrated systems. Selecting site-specific sustainable livestock production methods is crucial for reducing or mitigating emissions. Additionally, developing policies that support climate change adaptation and mitigation strategies is essential (Rojas-Downing, 2017).

Balancing Supply-Side and Demand-Side: Emissions from the livestock sector are influenced by both supply-side (production) and demand-side (consumption) factors. While addressing supply-side emissions is important, it's equally crucial to consider demand-side measures. Consumer preferences for plant-based diets and leaner meats can significantly contribute to emission reduction, surpassing the impact of supply-side measures (Herrero et al., 2013).

Ruminant Production Challenges: Ruminant production systems face challenges such as methane emissions, land inefficiency, feed-food competition, and degradation of ecosystems due to grassland conversion. Strategies to address these challenges include raising animals on non-edible feed, utilizing marginal lands for grazing, and reducing GHG emissions.

Site-Specific Integration for Synergies: Integrating crops, livestock, and trees in agroforestry systems can lead to synergies between agricultural production and environmental quality (Lemaire et al., 2014). For example, alley cropping, silvopastoral systems, and other integrated approaches can improve food security, enhance soil fertility, and provide additional benefits like fuel wood and fodder.

The integration of livestock with crops and trees presents a holistic approach to addressing the environmental challenges associated with the livestock sector. By adopting sustainable and site-specific practices, it is possible to achieve a balance between agricultural production, environmental preservation, and the fulfillment of societal demands. This integration contributes to the overall goal of advancing sustainable development while supporting the United Nations' Sustainable Development Goals.

4. OPTIONS FOR SUSTAINABLE MANAGEMENT OF GRASSLANDS FOR FOOD AND CLIMATE SECURITY

Sustainable management of grasslands for both food and climate security is crucial in the face of changing environmental conditions. Here are key options for achieving this goal:

Site-Specific Approaches: Given the diverse socio-economic and biophysical conditions across regions, site-specific strategies are essential for the sustainable intensification of livestock systems. Tailoring management practices to the unique characteristics of each area can optimize productivity while minimizing environmental impacts.

Importance of Grasslands and Savannas: Livestock-based systems and grasslands play a vital role in global land use. Grasslands cover a substantial portion of Earth's surface, especially in savanna ecoregions. These areas are susceptible to climate change impacts, such as altered phenology, water availability, and fire dynamics (Devi, 2010). Understanding and managing these factors are critical for enhancing net primary productivity. Eco-intensification efforts should focus on restoring soil functions, conserving water resources to mitigate drought risks, and introducing improved forage species with higher nutritional quality (Herrero, et al., 2013, Provenza et al., 2019).

Adapting to Climate Change: Climate change is already affecting agro-pastoral production. Practices like multi-paddock (MP) grazing have shown promise for sustainable intensification. MP grazing at high stocking rates has been observed to improve soil organic carbon (SOC) content, cation exchange capacity, and microbial diversity compared to conventional grazing methods (Teague, et al., 2011).

Positive Impact of Holistic Grazing: Holistic planned grazing, such as high intensity, short duration (HDSD) grazing, has demonstrated positive effects on soil carbon stocks. Studies have shown that rotational grazing with periods of high-intensity grazing followed by exclosure can increase soil carbon compared to continuous grazing or annual burning practices. While multi-paddock grazing can be effective, its feasibility depends on regional conditions. However, Hawkins (Hawkins, 2017) concluded that only rangelands with higher precipitation have the resources to support MP grazing at a high stocking rate. Sustainable management of grasslands is essential for ensuring food and climate security. By adopting site-specific approaches, understanding environmental drivers, and implementing eco-intensification practices like multi-paddock grazing, it's possible to enhance productivity while mitigating the negative impacts of climate change on grassland ecosystems.

5. IMPROVED MANAGEMENT OF LIVESTOCK IN THE TROPICS

Improved management of livestock in tropical agroecosystems is crucial for enhancing productivity and reducing environmental impacts. Innovative approaches that combine livestock and farming practices can yield numerous benefits. Here's an overview of key strategies and considerations:

Co-Benefits of Crop-Livestock Integration: Combining crops and livestock within the same landscape can yield co-benefits, such as enhanced soil fertility, pest control, reduced risks of runoff and erosion, increased livestock production, and sustained crop yields. Ley farming and pasture cropping are examples of such integrated approaches.

Ley Farming and Pasture Cropping: Ley farming involves rotating crops with light grazing of legumes, providing benefits like improved soil nitrogen, carbon sequestration, weed control, and enhanced livestock and crop production. Pasture cropping is the practice of sowing winter-active cereals into native perennial pastures, benefiting both crop and livestock production.

Challenges and Critical Factors: While ley farming offers numerous benefits, successful implementation requires addressing challenges like pasture establishment, managing competition between crops and pastures, and choosing appropriate legume species based on site-specific conditions.

Agroforestry Integration: Integrating livestock with croplands and forests can yield complementary benefits. For instance, growing trees like Acacia albida on farmlands in Sub-Saharan Africa enhances soil fertility, provides shade for livestock, and contributes to agroforestry systems that support sustainable land management.

Reducing Rangeland Degradation: Widespread adoption of integrated systems can mitigate the risks of rangeland degradation, as demonstrated by successful practices in China (Hou et al., 2008). This approach can help maintain ecosystem health and enhance productivity. India's example illustrates how integrated systems can reduce the land area needed for livestock production. By efficiently integrating livestock into agricultural systems, even densely populated regions like India can support a significant livestock population without extensive pasture land (TAAS, 2019).

Benefits of Integrated Systems: Integrated crop-livestock systems offer economic and ecological benefits, especially in developing tropical countries. These systems can create additional income streams (De Haan, et al., 2001) act as safety nets for marginalized farmers, enhance assets, and alleviate malnutrition. However, they require careful management of resources.

Sustainable Management Considerations: Integrating livestock requires additional land, water, nutrients, and forage resources. Prudent management is essential to minimize environmental footprints while maximizing economic and social benefits. A balanced approach, considering technical, institutional, and human dimensions, is crucial for success (Tarawali, et al., 2011, Lal, 2020, Peyraud et al., 2016, Rutledge et al., 2011).

6. CONCLUSIONS

Intensive farming, designed to satisfy the rising demands of an increasingly affluent human population through high-input practices on limited land, offers both benefits and challenges. While intensification of crop and livestock systems has significantly boosted per capita food production since the 1960s, the environmental impact of the livestock sector remains a concern. It is crucial to tackle issues like soil degradation, water and nutrient use efficiency, eutrophication of water bodies, air pollution, and the risks associated with global warming.

Despite the achievements in food production, a significant portion of the global population—820 million individuals—are vulnerable to undernourishment, with more than 2 billion people facing malnutrition due to protein, micronutrient, and vitamin deficiencies. The goal of sustainable agriculture is to adopt technologies that enhance production, reduce the environmental burden of food systems, and mitigate the potential risks of diseases associated with intensive livestock farming.

An effective approach to producing sufficient nutritious food while also preserving the environment is the site-specific integration of livestock with crops and trees. This approach, known as eco-intensification, aligns with several Sustainable Development Goals (SDGs) including Zero Hunger (#2), Good Health and Wellbeing (#3), Clean Water and Sanitation (#6), Climate Action (#13), and Life on Land (#15). Neglecting such an option could lead to increased environmental pollution, further deterioration of natural ecosystems, heightened human-wildlife interactions, and potentially more frequent and severe crises like the COVID-19 pandemic. Promoting sustainability for smaller-scale producers, developing policies that encourage responsible consumption of animal products, and evaluating the environmental impacts of various livestock-based production systems. Embracing innovative approaches like integrating livestock with crops and trees holds the potential to address both the need for increased food production and the imperative to protect and enhance the environment.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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