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A food systems perspective: how Global Burden of Animal Diseases links to the Global Burden of Crop Loss

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Summary

Food systems comprise the interconnected webs of processes which together transform inputs (land, labour, water, nutrients, genetics, to mention just a few) into outputs including nutrition and revenue for human societies. Perfect systems do not exist and rather our global food systems operate in the presence of hazards, biotic and abiotic alike, and within the constraint of limited resources to mitigate these hazards. There are therefore inefficiencies in the system which lead to losses of: monetary, nutritional, health and environmental value as well as create additional negative externalities in the health, social, and environmental spaces. Hazards to health in our food system do not respect arbitrary distinctions between 'crop' and 'livestock' sectors, which are highly interconnected. These linkages exist where one sector provides inputs to another or through substitution effects where supply in one sector influences demand in another. The One Health approach advocates investigating the intersectoral hazards in a highly interdisciplinary manner. This paper provides a conceptual framework for how the methodologies developed by the Global Burden of Crop Loss and Global Burden of Animal Diseases initiatives may be integrated to generate burden estimates for hazards in our food systems, which better account for interconnectivity and move us towards an improved understanding of the food system aligned with the interdisciplinary nature of the One Health approach. The case study related to maize and poultry sectors linkages in the context of a wider public and environmental health are presented.

Keywords

Animal health – Crop Loss – Crop production – Food systems – GBADs – GBCL – Global Burden of Animal Diseases – Global Burden of Crop Loss – Maize – One Health – Poultry – South Africa.

Introduction

Meeting the growing demand for food while reducing the environmental impact of agriculture is one of the defining challenges of the Anthropocene. In response to population increase, urbanisation, and growing consumer expectations, food systems will need to produce significantly more to feed the world population as it heads towards 9 billion around 2050 [1-3]. These food systems currently account for a third of anthropogenic greenhouse gas emissions, projected to increase by 30–40% by 2050 [4], and it is imperative to reduce the environmental impact of agriculture to maintain ecosystem function [5].

Food systems comprise interconnected processes which transform inputs (land, labour, water, nutrients, to mention just a few) into outputs which create nutrition and revenue for human societies. A 'perfect' food system would allow this transformation to happen efficiently without waste or losses. However, perfect systems do not exist, and global food systems face biotic and abiotic hazards, which impose inefficiencies on the system and lead to monetary, nutritional and environmental losses.

Strategies to reduce the impact of hazards across the food system are needed to reduce losses and mitigate environmental degradation whilst improving nutritional and economic outcomes. There is an urgent need for robust data-driven evidence on the scale and nature of these hazards to inform decisions on investments and interventions to achieve this. A body of work exists on estimating the burden of hazards in the food system [6-8], but standardised robust methodologies which allow comparisons between hazards or production systems are lacking.

A developing partnership between Global Burden of Crop Loss (GBCL) and Global Burden of Animal Diseases (GBADs) aims to fill this gap through the quantification of the losses caused by socio-economic, biotic and abiotic factors on an 'ideal', hazard-free production system. This approach will quantify the cost of preventable food production losses to highlight key hazards for policy decisions [9,10]. This developing methodology is inherently inter-disciplinary, recognising the significant interaction between major pillars of the food system, and utilises complementary theoretical frameworks to integrate the mapping of hazards between crops and livestock.

In this paper we identify synergies between Food Systems and One Health approaches, introduce the GBCL and GBADs approaches to burden assessment and elaborate on the linkages between these approaches. To further illustrate these linkages, we then present a case study of the linkages of maize and broiler production sectors in South Africa prior to consider the challenges and opportunities which lie ahead for this kind of approach.

Food Systems and One Health approaches

While Food Systems comprise the multiple inputs, activities and outputs involved in bringing a food product from field to fork, One Health expands the concept to explicitly include human, animal and ecosystem health impacts of these processes. Food systems activities span production, processing, packaging, distribution, retail and consumption and are linked to the ecological, economic, social and political context within which they occur [11]. A food systems approach acknowledges the complexity of these systems and the inherent trade-offs between different food system functions. Food systems themselves are a key driver of health outcomes, both positive and negative, across the three domains of humans, animals and the environment [12].

The One Health concept brings important contributions to the Food Systems approach, being: '*an integrated, unifying approach which aims to sustainably balance and optimise the health of people, animals and ecosystems*' [13]. Both One Health and a Food Systems approaches recognise the inter-dependence between humans, animals and the wider environment. While One Health explicitly aims to optimise health of humans, animals and the environment, a food systems approach would focus on the maximisation of human nutritional and economic outcomes. The application of a One Health lens to create success metrics for food systems on a sustainable aquaculture case study illustrates the potential for the integration of these two concepts.

Applying a unified One-Health–Food-Systems approach to the understanding of hazards within the system requires us to conceptualise the fundamental dynamics of the processes within the system, the interactions with externalities including environment and feedback loops which are present. Building upon our sector-specific knowledge and process models, the integration of crop and livestock sectors into an integrated process model brings us closer to a true representation of a complex dynamic of the food-system.

GBCL approach

GBCL aims to support food security by generating actionable estimates of crop losses and identifying the underlying causes, in order to support better decision making across the plant health and food system. Research suggests that pests alone account for a significant loss of approximately 20–40% in major crops [14,15]. Crop loss disrupts the availability and affordability of essential agricultural outputs, leading to compromised human and livestock nutrition and increased food prices while placing more pressure on already limited environmental resources such as land to bridge the gap caused by suboptimal production.

While it is clear that reducing yield losses due to biotic or abiotic factors, especially in the context of growing population number, represents a major opportunity to increase food production with minimal futher environmental impact, we lack robust evidence on the problem to mobilise action. Data on the scale, scope, spatial patterns, and drivers of loss are outdated, lacking in granularity, not shared, or missing altogether. This evidence gap poses a significant challenge for decision makers, hindering their ability to identify the most critical problems and evaluate the returns on their investments. GBCL aims to bridge this knowledge gap by providing an evidence-based assessment of crop losses, identifying the specific crops affected, and analysing the factors contributing to these losses. The ultimate goal is to provide stakeholders in the agricultural sector, including research donors, policy makers, and industry with the information they need to make informed decisions.

We define the economic burden of crop loss as the value of crops lost to hazards, plus the costs of control measures employed to mitigate losses, including inputs and labour (Figure 1). The crop loss envelope is calculated as the gap between actual production and a hypothetical attainable yield in the absence of hazards. Attainable yield (Ya) is the yield achieved under economically optimal practices with minimal limitations due to the weather during the growing season [16-18]. Attainable yield in context (AYIC) as GBCL defines it, represents an upper threshold for a particular crop can be achieved given local context including climate, water availability, expected nutrient inputs and socio-economic context of the area including predominant agronomical practices. Hazard-specific burdens are then estimated through the attribution of the overall burden to specific abiotic (e.g. drought, flood, etc.) and biotic (e.g. weeds, fungi, bacteria, viruses and other pests) causes. Understanding and effectively managing these various factors is crucial for optimising crop yields and ensuring the resilience and sustainability of food systems.

GBADs approach

GBADs shares with GBCL a vision where decision makers are provided with robust, standardised burden data to inform investment decisions. Analogous to GBCL, the GBADs initiative aims to achieve this vision through a gap analysis approach; to quantify and attribute the losses sustained in the livestock sector from infectious diseases, non-infectious diseases and external hazards (i.e. extreme climatic events, predation, theft). This gap analysis developed by GBADs, is referred to as the ‘Animal Health Loss

Envelope' (AHLE) [19] and forms the boundary of any hazard-specific attribution, while removing the risk of double counting hazard-specific impacts as may occur in a 'traditional' summative burden estimate [19].

The approach allows for the current state of production to be compared to an ideal production level to assess the 'gap' that the burden of loss has on the livestock sector (Figure 2). Locally relevant values are affixed to the total liveweight biomass 'on the hoof' and to the yielded livestock source products and these outcomes are quantified in economic terms which allows for compatibility between systems and with the GBCL approach. The animal health loss envelope and the scenario of perfect health are also populated by context-specific data, taking into account factors such as genetics and husbandry approaches [20].

Hazard specific burdens are attributed within the AHLE according to their relative impacts of different diseases and conditions. In order to undertake such attribution in a standardised way, animal health ontology [21] has been developed to ensure interoperable and clear definitions of animal health concepts and relationships. Additionally, attribution methodologies have been developed which specifically incorporate the association between disease states and the synergistic or antagonistic impacts of co-morbidities [22].

Defining the value of an AHLE is important as it allows risks to be evaluated and ranked. Limited financial resources, whether on an individual farm, within a development agency or government, means quantifying risks allows interventions to demonstrate a return on investment. This complements the management of small scale or macro food systems and improves resilience through reducing the economic impact of disease in the most financially efficient way.

Linkages between GBCL and GBADs

Our approach recognises that the two largest components of food production, the crop and livestock sectors, are inter-connected and rely on a highly inter-dependent input-output relationship. The methodological alignment between GBCL and GBADs allowed us to develop a conceptual framework for integrating assessment of the two sectors, which will support a pioneering food systems approach to burden assessment. Given the tangible connections, illustrated in a conceptual case-study of maize and poultry in South Africa below, it is evident that hazards, whether they originate within crops or livestock systems, have wide-spread impacts across the food system. Crop production and related residues provide inputs to livestock sector, the availability, quality and price of crop production, therefore have a direct impact on livestock productivity. Conversely, livestock bi-products (manure, meat and bone meal) provide fertiliser to the crop sector and in many parts of the world, livestock are harnessed to provide traction for the management, production, harvest and distribution of crop-sector products. Crop and livestock products may hold a substitutional relationship based on elasticity of demand or driven by regulatory pressures.

For example, the European Union ban on meat and bone meal as feed input to poultry and pig production between 2001–2021 resulted in a corresponding increase in the soybean import over this period, demonstrating a strong substitutional relationship between these sectors [23]. The hazards present in crops or crop residues can lead to direct health impacts on livestock (e.g. aflatoxicosis and copper toxicity), while hazards originating in livestock bi-products, for example manure application leading to increases in soil cadmium, chromium, copper and zinc, can have consequential impacts on plant health [24,25]. As a result of the interconnectivity between the two industries, the crop and livestock sectors experience a plethora of identical hazards which effect productivity, including aflatoxins resulting in food waste as well as causing toxicity for livestock and humans, disease outbreaks, extreme weather events, environmental contaminants and other. Where these hazards have direct impacts across both sectors the burden of the hazard can be attributed within both sectors for a more accurate burden estimate to guide policy decisions.

For example, the abiotic hazard of climate change will create impacts across crop and livestock sectors. Changing weather patterns will result in vector and pathogen distribution changes, which may potentially increase their geographic range or the number of generations completed. An increase in heat, as well as water deficit or excess stresses, has potential in reducing yields [26,27]. A reduction in cereal yield is forecasted in certain localities, which may lead to resource competition between the human and animal nutrition. Such competition and resource limitation may impact lead to the favouring of livestock breeds with a higher feed conversion ratio. These breeds, however, may in turn suffer from increased burden of non-communicable disease, for instance limb deformities associated with faster growing poultry breeds.

The high-level conceptual framework provides a simplified representation of the linkages between parts of the food system as well as environmental and human health (Figure 3). The capability to model hazards which impact both crop and livestock sectors will provide a novel platform for the management of problems which affect the two sectors concomitantly.

Impact

Both GBCL and GBADs aim to support evidence-based decision making and could be used to great advantage by local, national, and global policy makers (Figure 4). Collaboration between these initiatives accounts for interconnectivity between the food system sectors to provide robust empirical evidence on the scale of factors contributing to the crop and livestock losses, identifying the synergies and trade-offs associated with hazard mitigation and contributing to a greater understanding of the wider implications of losses caused by biotic and abiotic hazards in the food system.

Decisions may relate to hazard control strategies, subsidisation approaches, or development of adaptation strategies. For example, it may turn out to be more cost effective for governments to subsidise crop protection strategies upstream, than to pay for the consequences for the downstream impacts (e.g. on nutritional quality, economic loss, water security, greenhouse gas emissions and biodiversity loss) [28]. The relative costs of preventative *versus* prophylactic strategies have been well defined for the impact of invasive species [28]. This awareness can support the allocation of appropriate resources and enable comparison with other potential investment opportunities, including the potential to stimulate increased private or public sector investment in agricultural hazard mitigation.

At the farmer level, communicating the risk of losses caused by stresses (e.g. extreme climate events or disease) can empower farmers to take timely action and implement appropriate mitigation strategies. Recent studies in South Africa and Kenya [29,30] have found that most smallholder livestock farmers are not resilient to droughts, although adaption strategies had proven beneficial adoption was still low. These studies highlight the need for appropriate support and policy alignment, although if which can be supported by integration of the GBCL and GBADs.

The estimates of loss created through the GBCL and GBADs will enable improved risk assessment, potentially supporting credit applications and the development of appropriate insurance products for farmers. The loss estimates generated through these initiatives may also provide additional data on which disease freedom dossiers may be developed, opening up improved export channels for commercial operations, enhancing market access and trade opportunities.

A proactive approach to hazard mitigation based on data may mitigate the negative impacts on food systems, optimising and balancing human nutritional, health and economic outcomes as well as the health of animals, people working with the animals, and the ecosystem in line with the One Health approach.

Maize and poultry sector linkages in South Africa

GBCL and GBADs has been appointed to collaborate on the One Food programme, a partnership between United Kingdom and South African governments which aims to apply an 'all hazards' approach to mapping hazards within the food-system. The focus of the project is to integrate models produced by GBCL and GBADs to estimate the burden of hazards across the crop and livestock sectors. It utilises an exemplar crop (maize) and livestock value chain (poultry meat) as a basis for exploration of hazards.

In the first year of the three-year project, key processes and drivers were analysed to produce a conceptual model of the linkages between crop and animal sectors in food systems. The GBCL attainable yield estimation method assesses crop production in context of local conditions using AgMIP's Global Gridded Crop Model Intercomparison project Phase3a model ensemble. We calculated model attained yields in each location run on historical climatologies between 1996–2015 [31]. On average, 28% of pre-harvest yield is lost to biotic and abiotic factors. In some years, such as during the 2015/6 drought, this figure is much greater, reaching over 50% losses. On average, post-harvest losses incurred during drying, storage, and transport stages, is estimated at 15% according to data in the Africal Post Harvest Loss Information System (APHLIS). Approximately half of maize produced in South Africa is used for human food products and almost half is used as livestock feed, with a small amount used for industrial purposes. Maize-based animal feed makes up the majority of diets by volume in the poultry sector. The broiler industry is the second largest maize market in South Africa [32] (Figure 5).

The combined crop and livestock hazard mapping approach can provide valuable insights into issues which affect both systems. For example, some fungal pathogens of maize cause in-field crop losses in the form of ear and stalk rot, and can also be transferred into maize processing systems as mould growth can occur after harvest during storage, both in and on the food [33]. These mould growths can lead to mycotoxin synthesis which poses risks to both livestock and human health. Through further economic modelling in partial equilibrium framework, this collaboration will quantify the variability of losses and hazards, and investigate their impact on the volume and cost of maize and poultry products. Links will be created with South African partners to improve input datasets to models and drive useful, local, insights which in turn, will inform policy.

Challenges, data requirements and future directions

As a partnership we aspire to provide accurate estimates on food system losses, to increase the efficacy of research in hazard surveillance, hazard response, and epidemiology. Through the alignment of the GBCL and GBADs programmes, we are working together to create synergistic methodologies, which will enable us to derive these improved results. This partnership can provide a holistic and well-rounded view of the problems faced in food production and so we must continue to interlink our results in the coming years to accelerate our understanding of losses in the food system. Through our work to date, we are investigating ways to improve the efficiency of evidence collection and these processes can be shared across programmes to increase our available data pool for modelling.

The success of this partnership is dependent upon the availability of this data to drive models to create meaningful outputs which can improve the depth of evidence available for decision making around food system hazards [27]. Data provision can be a barrier to modelling because many levels of food system are not yet fully equipped to accurately capture all inputs and outputs of food production [34]. Through the integration and alignment of our two initiatives, we can ensure that the FAIR data principles are at the forefront of food systems approaches. Through a commitment to the FAIR principles, our initiatives will provide an open platform for a truly global and community driven effort to tackle the greatest economic and environmental burdens which impact the food system [9].

Conclusions

Scientific estimates on crop and livestock loss and economic impact are pivotal in food systems. They raise awareness, drive targeted interventions, secure resources, and enhance resilience, resulting in reduced price volatility, improved market access, and a reliable food supply. Estimations of losses and associated health hazards have thus far been approached in a sector specific manner. The collaboration described in this paper is an example of a shift towards a holistic, One Health–Food Systems approach which will allow optimal decision-making from a societal perspective.

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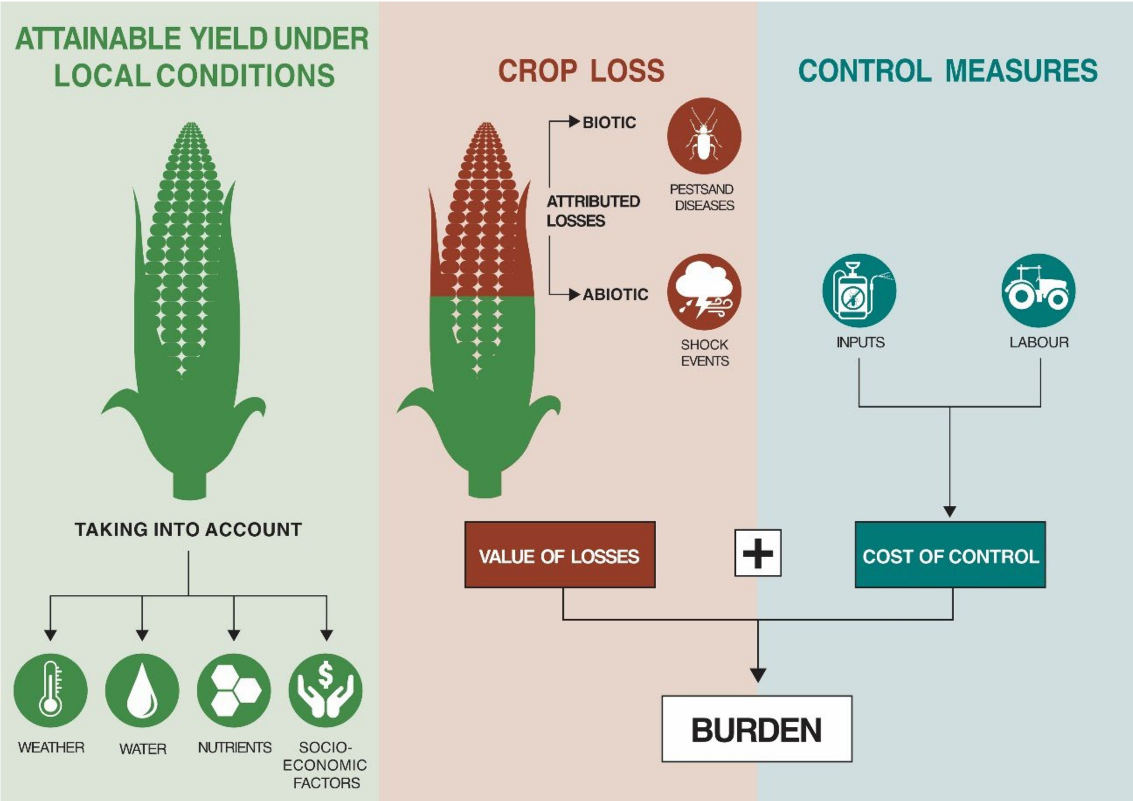

Figure 1

Global Burden of Crop Loss conceptual framework

It is representing the factors considered in the assessment of attainable yield under local conditions, crop loss, and attributing losses to biotic and abiotic factors. The value of crop losses is combined with the cost of control to mitigate hazards in the field into the calculation of the burden

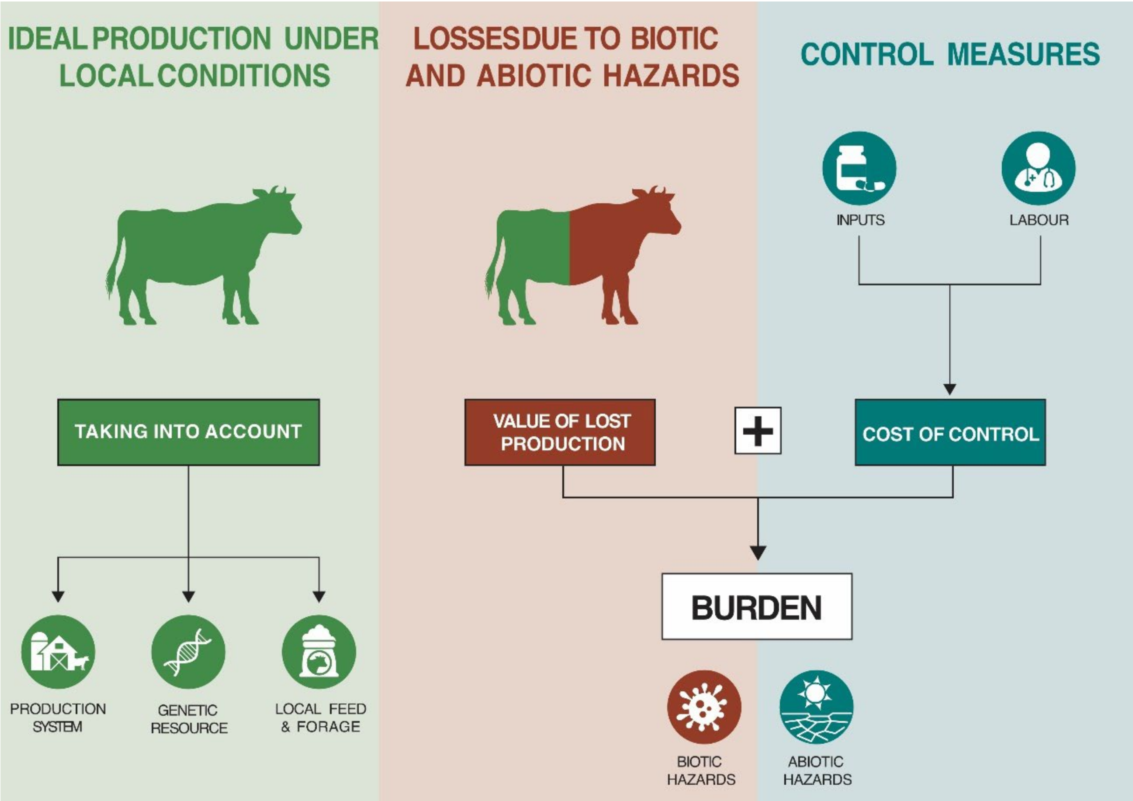

Figure 2

Conceptual framework of the Animal Health Loss Envelope developed by the Global Burden of Animal Diseases programme

The optimal production considering local factors is represented by the green cow outline, the burgundy outline represents lost production value which in addition to the cost of control equals overall burden which can be attributed to biotic and abiotic factors

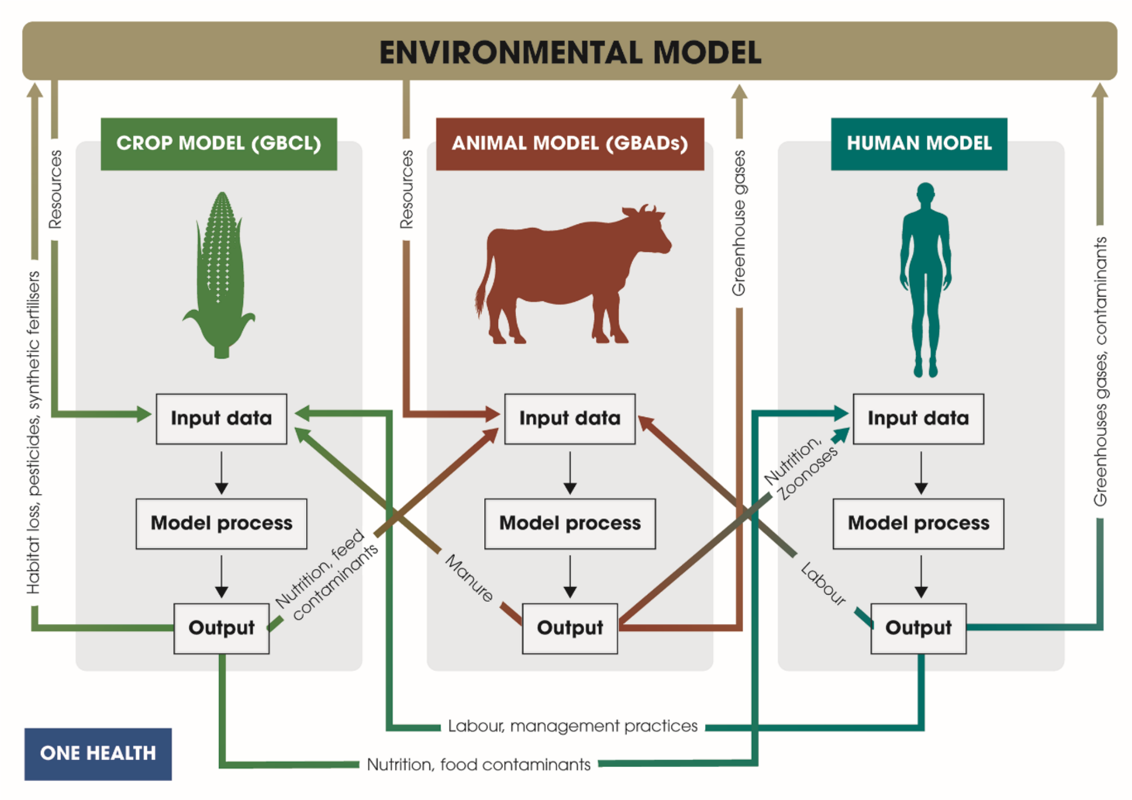

Figure 3

Conceptual framework depicting the interconnections and feedback loops among Global Burden of Crop Loss (GBCL) modelling, Global Burden of Animal Diseases (GBADs), and human systems

The figure illustrates the linkages between inputs and outputs in these modelling sectors, emphasising their relationship with the environmental model

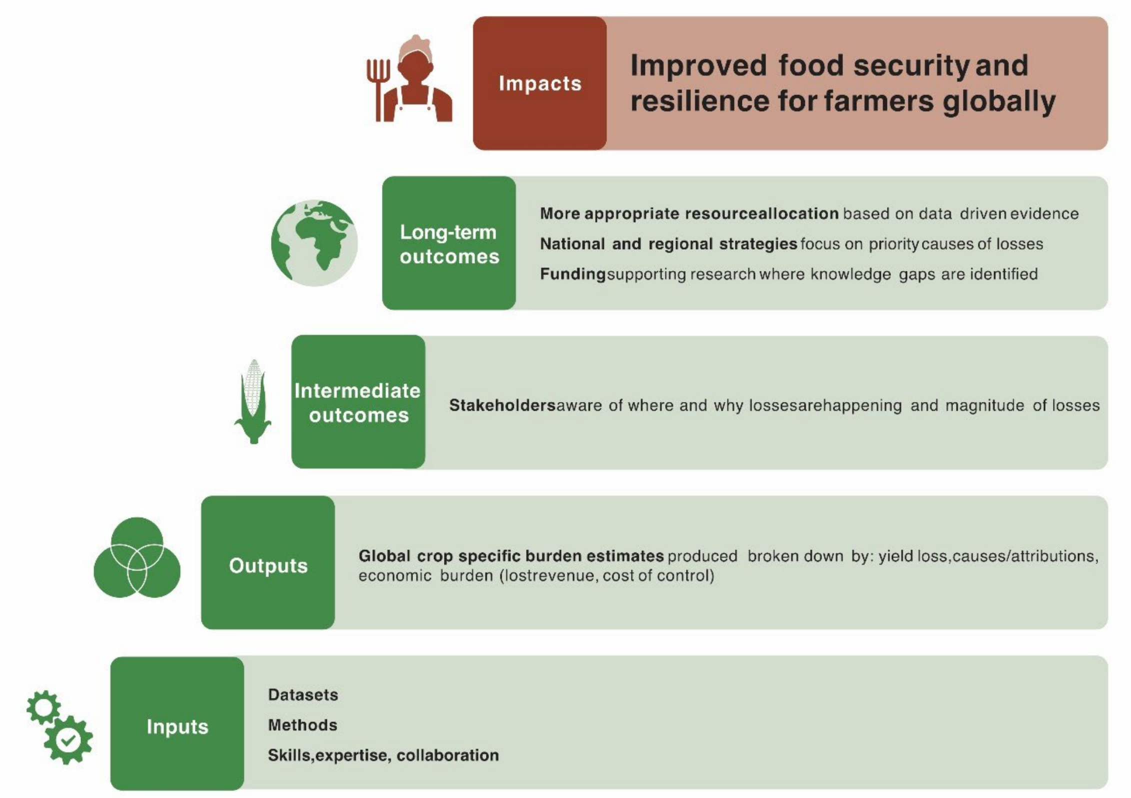

Figure 4

Illustration of the synergistic impact of Global Burden of Crop Loss and Global Burden of Animal Diseases modelling frameworks within a One Health system to aid informed policymaking, engaging stakeholders as intermediate and long-term outcomes, and providing improved food security and resilience for farmers globally

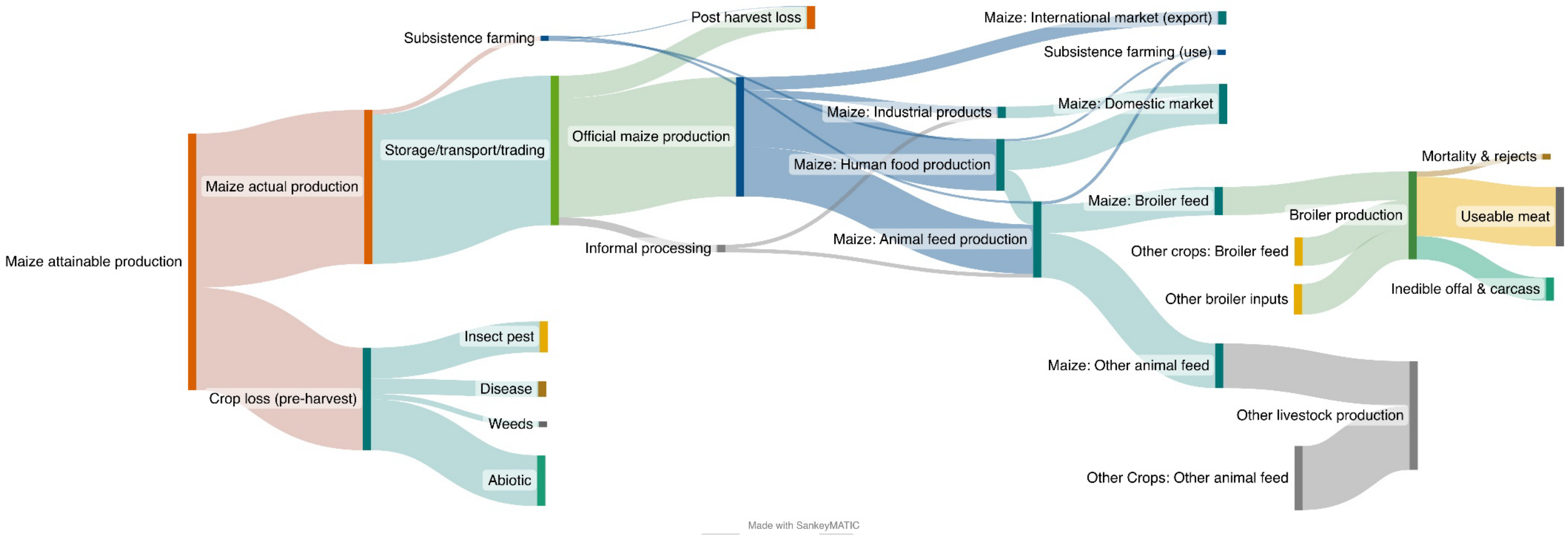

Figure 5

A combined conceptual Sankey diagram showing the link between maize and poultry sectors in South Africa

The preliminary estimates in this figure represent flows between sectors and were formulated using both accessible public data sources and approximations in cases where data was lacking, emphasising the need for cautious interpretation