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# How the Global Burden of Animal Diseases links to the Global Burden of Crop Loss: a food systems perspective

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## Summary

Food systems comprise interconnected webs of processes that together transform inputs (land, labour, water, nutrients and genetics, to mention just a few) into outputs such as nutrition and revenue for human societies. Perfect systems do not exist; rather, global food systems operate in the presence of hazards, biotic and abiotic alike, and under the constraint of limited resources to mitigate these hazards. There are, therefore, inefficiencies in these systems, which lead to losses in terms of monetary, nutritional, health and environmental values and create additional negative externalities in the health, social and environmental spaces. Health hazards in the food system do not respect arbitrary distinctions between the 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 article provides a conceptual framework for integrating the methodologies developed by the Global Burden of Crop Loss and Global Burden of Animal Diseases initiatives to generate burden estimates for hazards in food systems that better account for interconnectivity and foster an improved understanding of food systems that is aligned with the interdisciplinary nature of the One Health approach. A case study related to maize and poultry sector linkages in the wider context of public and environmental health is 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 growing world population, predicted to reach 9 billion by around 2050 [1-3]. These food systems currently account for one-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 that transform inputs (e.g. land, labour, water, nutrients) into outputs that 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 that create inefficiencies and lead to monetary, nutritional and environmental losses.

Strategies to reduce the impact of hazards across food systems are needed to reduce losses and mitigate environmental degradation while 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 these objectives. A body of work exists on estimating the burden of hazards in the food system [6-8], but standardised robust methodologies that allow comparisons between hazards or production systems are lacking.

A developing partnership between the Global Burden of Crop Loss (GBCL) and the Global Burden of Animal Diseases (GBADs) aims to fill this gap through the quantification of 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 and thus inform policy decisions [9,10]. This developing methodology is inherently interdisciplinary, 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.

This article identifies synergies between food systems and One Health approaches, introduces the GBCL and GBADs approaches to burden assessment and elaborates on the linkages between these approaches. To further illustrate these linkages, it presents a case study on the linkages of the maize and broiler production sectors in South Africa. Finally, it considers the challenges and opportunities that lie ahead for this type 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 the 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 food systems approaches recognise the interdependence of 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 conceptualising the fundamental dynamics of the processes within the system, interactions with externalities, including environment, and associated feedback loops. Building upon sector-specific knowledge and process models, the integration of the crop and livestock sectors into an integrated process model comes closer to a true representation of the complex dynamics of the food system.

## The Global Burden of Crop Loss 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 plant health and the 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 a growing population, represents a major opportunity to increase food production with minimal further environmental impact, there is a lack of robust evidence 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.

The economic burden of crop loss is defined as the value of crops lost to hazards, plus the costs of control measures employed to mitigate losses, including inputs and labour (Fig. 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 is the yield achieved under economically optimal practices with minimal limitations due to weather during the growing season [16-18]. Attainable yield in context, as GBCL defines it, represents an upper threshold for a particular crop that can be achieved given local context encompassing 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) 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.

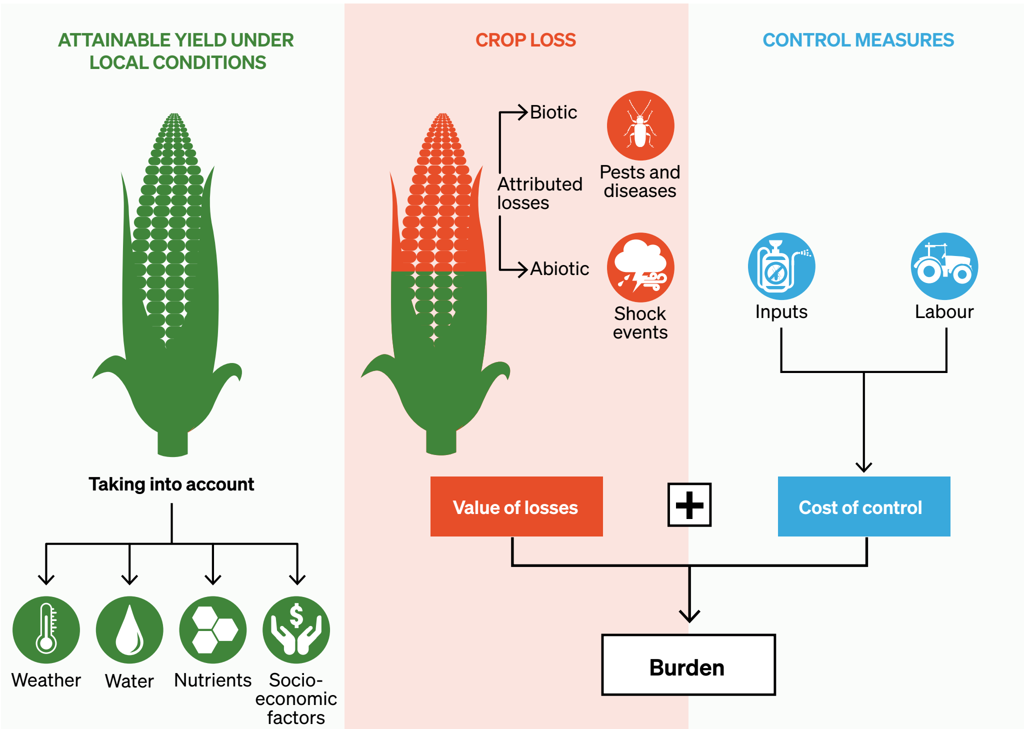


**Figure 1**

**Global Burden of Crop Loss conceptual framework**

The illustrated framework represents the factors considered in the assessment of attainable yield under local conditions as well as Crop Loss Envelope and the attribution of losses to biotic and abiotic factors. The calculation of the burden combines the value of crop losses with the cost of controls to mitigate hazards in the field

## The Global Burden of Animal Diseases approach

GBADs shares with GBCL a vision of providing decision-makers 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 creates in the livestock sector (Fig. 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, allowing for compatibility between systems and with the GBCL approach. The AHLE 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 the 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 that specifically incorporate the association between disease states and the synergistic or antagonistic impacts of comorbidities [22].

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

## Linkages between the Global Burden of Crop Loss and the Global Burden of Animal Diseases

The approach presented in this article recognises that the two largest components of food production, the crop and livestock sectors, are interconnected and rely on a highly interdependent input–output relationship. The methodological alignment between GBCL and GBADs allowed the development of a conceptual framework for integrating assessment of the two sectors that will support a pioneering food systems approach to burden assessment. Given the tangible connections, illustrated on page 179 in a conceptual

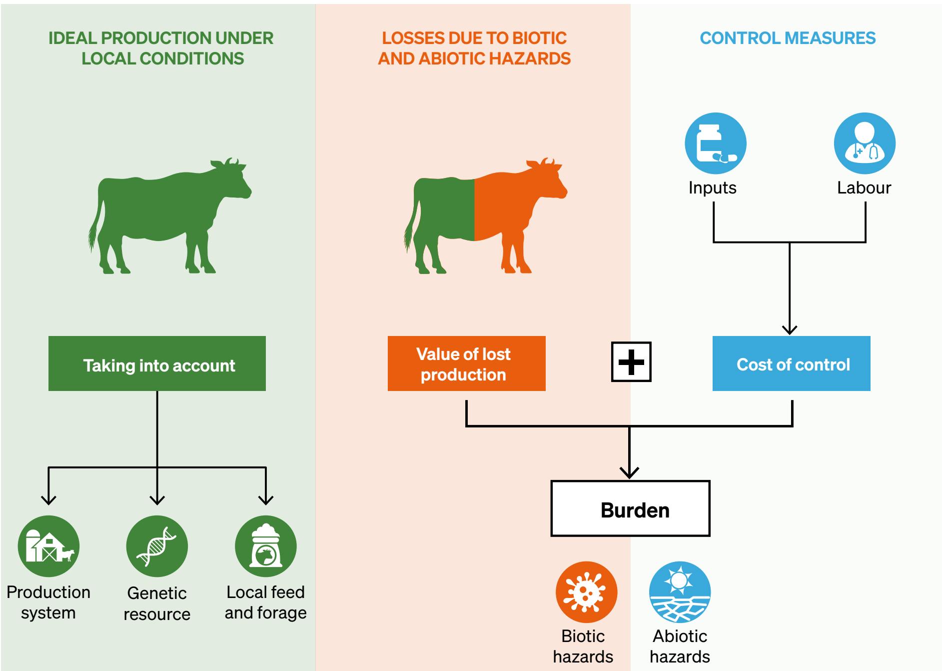


**Figure 2**

**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 orange section represents lost production value, which, in addition to the cost of control, equals overall burden. This burden can be attributed to biotic and abiotic factors case study of maize and poultry in South Africa, it is evident that hazards, whether they originate within crops or livestock systems, have widespread impacts across the food system. Crop production and related residues provide inputs to the livestock sector, and therefore the availability, quality and price of crop production have a direct impact on livestock productivity. Conversely, livestock by-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 and 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 by-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 that affect productivity, including aflatoxins resulting in food waste and causing toxicity for livestock and humans, as well as disease outbreaks, extreme weather events, environmental contaminants and more. 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.

As an example, the abiotic hazard of climate change will create impacts across the crop and livestock sectors. Changing weather patterns will result in vector and pathogen distribution changes, potentially increasing their geographic range or the number of generations completed. An increase in heat, as well as water deficit or excess stresses, has the potential to reduce yields [26,27]. A reduction in cereal yield is forecasted in certain localities and may lead to resource competition between human and animal nutrition. Such competition and resource limitation may result in 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 between environmental and human health (Fig. 3). The capability to model hazards that impact both

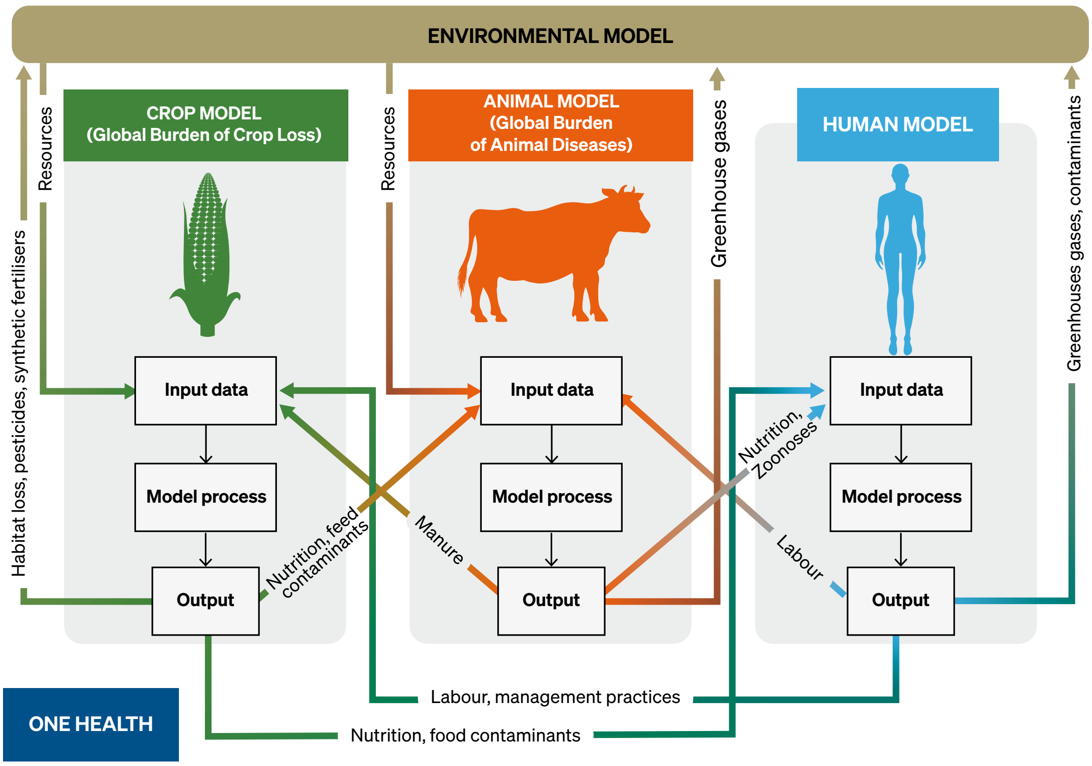


**Figure 3**

**Conceptual framework depicting the interconnections and feedback loops between Global Burden of Crop Loss, Global Burden of Animal Diseases and human systems models**

The figure illustrates the linkages between inputs and outputs in these modelling sectors, emphasising their relationship with the environmental model the crop and livestock sectors will provide a novel platform for the management of problems that 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 (Fig. 4). Collaboration between these initiatives accounts for interconnectivity among the food system sectors to provide robust empirical evidence on the scale of factors contributing to crop and livestock losses, thus 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 of the downstream impacts (e.g. regarding nutritional quality, economic loss, water security, greenhouse gas emissions and biodiversity loss) [28]. The relative costs of preventive *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 adaptation strategies had proven beneficial, adoption was still low. These studies highlight the need for appropriate support and policy alignment, all of which can be supported by integration of GBCL and GBADs.

The estimates of loss created through GBCL and GBADs will enable improved risk assessment, potentially supporting credit applications and the development of appropriate

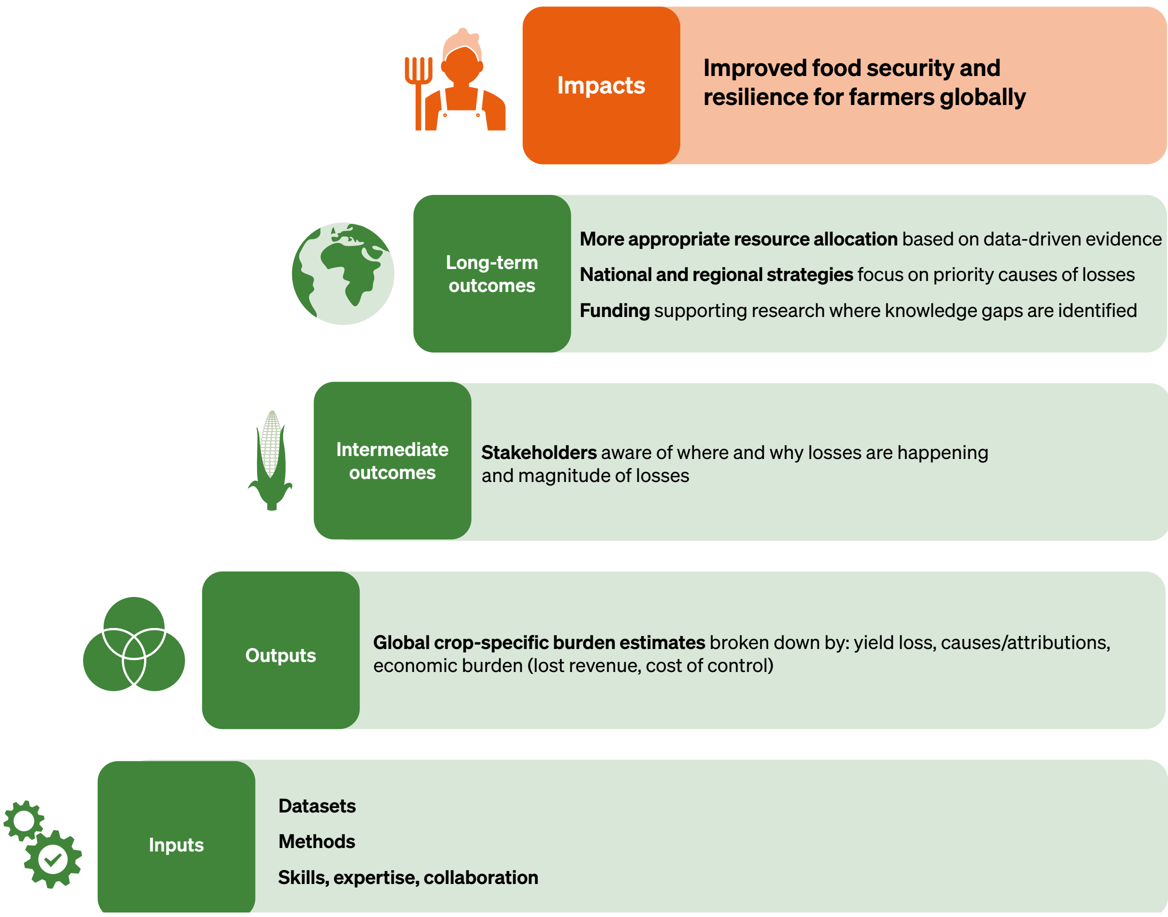


**Figure 4**

**Illustration of the synergistic impact of the Global Burden of Crop Loss and Global Burden of Animal Diseases modelling frameworks within a One Health system to aid informed policy-making, engage stakeholders in intermediate and long-term outcomes, and provide improved food security and resilience for farmers globally**

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 and enhancing market access and trade opportunities.

A proactive approach to hazard mitigation based on data may lessen 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 animals, and the ecosystem in line with the One Health approach.

## Maize and poultry sector linkages in South Africa

GBCL and GBADs have been appointed to collaborate on the One Food programme, a partnership between the United Kingdom and South African governments that 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 a 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 the crop and animal sectors in food systems. The GBCL attainable yield estimation method assesses crop production in context of local conditions, based on local climate, availability of water and expected nutrient input. In the preliminary phase this was achieved using the Agricultural Model Intercomparison and Improvement Project's Global Gridded Crop Model phase 3a data ensemble to calculate multi-model mean. The team calculated attainable yield in each location based on historical climatologies between 1996 and 2015 [31]. On average, 28% of pre-harvest yield is lost to biotic and abiotic factors. In some years, such as during the 2015–2016 drought, this figure is much greater, reaching over 50% losses. On average, post-harvest losses incurred during drying, storage and transport stages are estimated at 15% according to data in the African Post Harvest Loss Information System [32]. 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 [33] (Fig. 5).

The combined crop and livestock hazard mapping approach can provide valuable insights into issues that 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 food [34]. These mould growths can lead to mycotoxin synthesis, which poses risks to both livestock and human health. Through further economic modelling using a partial equilibrium framework, the GBCL–GBADs–One Food collaboration will quantify the variability of losses and hazards and will 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 that, in turn, will inform policy.

## Challenges, data requirements and future directions

The GBCL–GBADs partnership aspires to provide accurate estimates of food system losses, in order to increase the efficacy of research in hazard surveillance, hazard response and epidemiology. The alignment of the GBCL and GBADs programmes aims to create synergistic methodologies that will enable these improved results. This partnership has the potential to provide a holistic and well-rounded view of the problems faced in food production, and therefore its results must be continually interlinked in the coming years to accelerate understanding of losses in the food system. The partnership's work to date has investigated ways to improve the efficiency of evidence collection, and these processes can be shared across programmes to increase the data pool available for modelling.

The success of this partnership is dependent upon the availability of these data to drive models to create meaningful outputs that can then 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 the food system are not yet fully equipped to accurately capture all inputs and outputs of food production [35]. Through the integration and alignment of the two initiatives, it is possible to ensure that the FAIR data principles – findable, accessible, interoperable, reusable – are at the forefront of food systems approaches. Through a commitment to the FAIR principles, the initiatives will provide an open platform for a truly global and community-driven effort to tackle the greatest economic and environmental burdens that 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 article is an example of a shift towards a holistic, One Health–food systems approach that will allow optimal decision-making from a societal perspective.

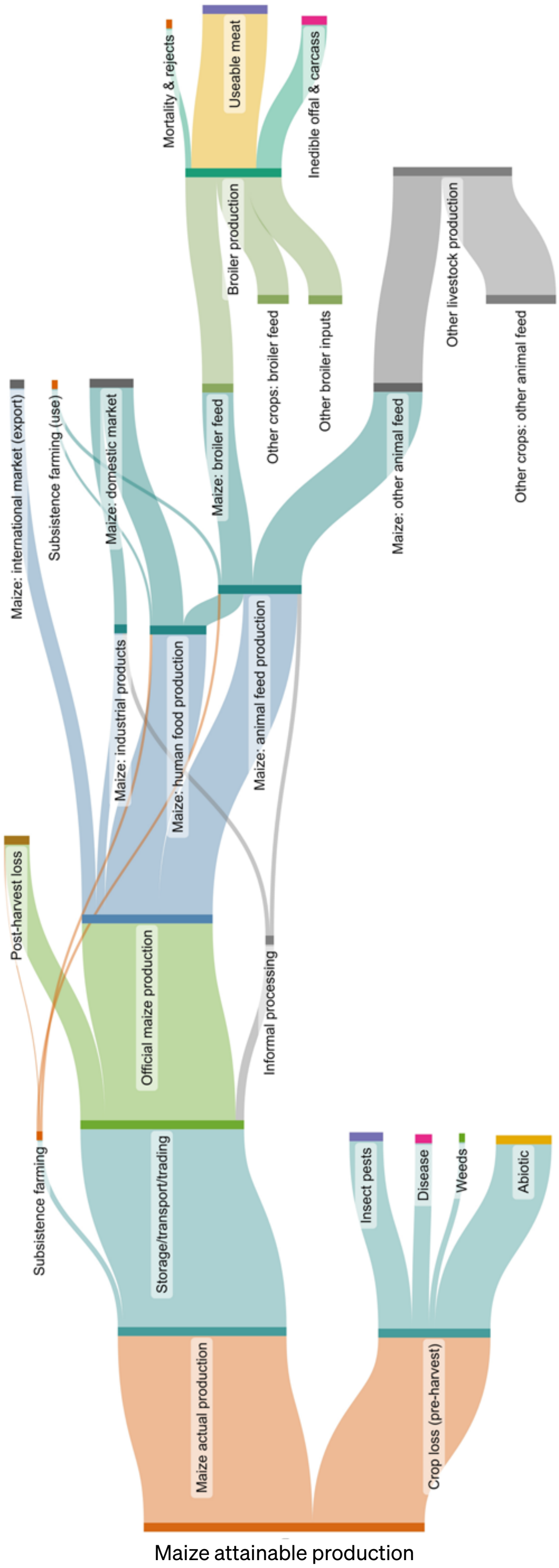


**Figure 5**

**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, underlining the need for cautious interpretation

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# Les liens réciproques entre l'impact mondial des maladies animales et le fardeau mondial des pertes agricoles : la perspective des systèmes alimentaires

A.M. Szyniszewska, K.M. Simpkins, L. Thomas, T. Beale, A.E. Milne, M.E. Brown, B. Taylor, G. Oliver, D.P. Bebber, T. Woolman, S. Mahmood, C. Murphy, B. Huntington & C. Finegold

## Résumé

Les systèmes alimentaires sont des réseaux de processus interconnectés qui concourent à transformer des intrants (terre, main-d'œuvre, eau, nutriments et génétique, pour n'en mentionner que quelques-uns) en extrants tels que des aliments et des revenus pour les sociétés humaines. Il n'existe pas de système parfait ; les systèmes alimentaires mondiaux sont exposés en permanence à des dangers de nature tant biotique qu'abiotique et contraints par les ressources limitées consacrées à l'atténuation de ces dangers. Les problèmes d'efficacité sont donc inéluctables ; ils entraînent des pertes de valeur tant monétaire que nutritionnelle, sanitaire et environnementale, et génèrent de nouvelles externalités négatives dans le domaine de la santé ainsi que dans l'espace social et dans l'environnement. Les dangers sanitaires présents dans le système alimentaire ignorent les distinctions arbitraires entre les secteurs agricole et d'élevage, lesquels sont fortement interconnectés. Ces liens se manifestent lorsqu'un secteur fournit des intrants à l'autre et, par l'effet de substitutions, lorsque l'offre dans un secteur influence la demande dans l'autre. L'approche « Une seule santé » préconise d'adopter une méthode fondée sur l'interdisciplinarité pour enquêter sur les dangers intersectoriels. Les auteurs décrivent le cadre conceptuel de l'intégration des méthodes des initiatives « Fardeau mondial des pertes agricoles » et « Impact mondial des maladies animales » dans le but de produire des estimations de la charge induite par les dangers des systèmes alimentaires qui prennent davantage en compte leur inter-connectivité et donnent lieu à une meilleure compréhension des systèmes alimentaires, en cohérence avec le caractère interdisciplinaire de l'approche « Une seule santé ». Est également présentée une étude de cas portant sur les liens entre la culture du maïs et l'élevage de volailles dans le contexte plus large de la santé publique et environnementale.

## Mots-clés

Afrique du Sud – Fardeau mondial des pertes agricoles – GBADs – GBCL – Impact mondial des maladies animales – Maïs – Perte agricole – Production agricole – Santé animale – Systèmes alimentaires – Une seule santé – Volailles.

# Cómo se relaciona el impacto global de las enfermedades animales con el impacto global de las pérdidas de cosechas: una perspectiva de los sistemas alimentarios

A.M. Szyniszewska, K.M. Simpkins, L. Thomas, T. Beale, A.E. Milne, M.E. Brown, B. Taylor, G. Oliver, D.P. Bebber, T. Woolman, S. Mahmood, C. Murphy, B. Huntington & C. Finegold

## Resumen

Los sistemas alimentarios comprenden redes interconectadas de procesos que, conjuntamente, transforman insumos (tierra, mano de obra, agua, nutrientes y genética, por mencionar solo algunos) en productos como alimentos e ingresos para las sociedades humanas. No existen sistemas perfectos; más bien, los sistemas alimentarios mundiales funcionan en un entorno de peligros, tanto bióticos como abióticos, y con las restricciones impuestas por los limitados recursos disponibles para mitigarlos. En estos sistemas se observan, por tanto, ineficiencias, que provocan pérdidas en términos monetarios, nutricionales, sanitarios y ambientales y que crean externalidades negativas adicionales en los ámbitos sanitario, social y ambiental. Los peligros para la salud en los sistemas alimentarios no atienden a distinciones arbitrarias entre los sectores agrícola y ganadero, que están muy interconectados. Estos vínculos surgen cuando un sector proporciona insumos a otro o a través de efectos de sustitución en los que la oferta de un sector influye en la demanda de otro. El enfoque de «Una sola salud» aboga por investigar los peligros intersectoriales de manera eminentemente interdisciplinaria. En este artículo se ofrece un marco teórico para la integración de las metodologías desarrolladas por las iniciativas dedicadas al impacto global de las pérdidas de cosechas y al impacto global de las enfermedades animales a fin de obtener estimaciones de los peligros en los sistemas alimentarios que tengan más en cuenta la interconexión y fomenten una mejor comprensión de los sistemas alimentarios acorde con el carácter interdisciplinario del enfoque de «Una sola salud». En este sentido, se presenta un estudio de caso relacionado con los vínculos entre los sectores del maíz y las aves de corral en el contexto más amplio de la salud pública y ambiental.

## Palabras clave

Aves de corral – GBADs – GBCL – Impacto global de las enfermedades animales – Impacto global de las pérdidas de cosechas – Maíz – Pérdida de cosechas – Producción de cultivos – Sanidad animal – Sistemas alimentarios – Sudáfrica – Una sola salud.

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