

The critical importance of planned small ruminant livestock health and production in addressing global challenges surrounding food production and poverty alleviation

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Supplementary Figure 1. A scheme operates in southern Malawi, whereby villagers are provided with four female and one male goats. The first five kids produced must be passed on to neighbouring villagers to establish new herds; together forming producer groups. Small ruminants in the region are commonly perceived as short-term economic reserves, but ensuring efficient productivity through planned animal health management is nevertheless important. The animals shown in the image belong to the founding member of the local group, who also acts as a model producer, demonstrating best practice in khola design, nutritional management (note the herbage hanging from the roof to avoid wastage) and infectious disease control. Shortly before this picture was taken, tropical cyclone Idai hit the region, destroying much of the village. Income from these goat herds was critical in rebuilding the community. Small ruminant production is generally resilient to disasters such as this, due to their high reproductive turnover.



Supplementary Figure 2. These Merino cross Romney hoggets in the South Island of New Zealand look healthy and uniformly well grown. Nevertheless, their growth rates are routinely monitored because in the absence of subsidy support, profitability of agribusinesses depends on meeting targets for efficiency of conversion of pastures to meat. These animals are not meeting the high targets that have been set for the flock. The main disease causes of suboptimal production efficiency in pastorally managed livestock are trace element deficiencies and gastrointestinal nematode parasitism. The need for sustainable management of these challenges is obvious, hence anthelmintic resistance mitigation is an integral part of planned animal health management for this flock.



Supplementary Figure 3. The Malabari goat breed has been genetically selected for large litter sizes. The Malabari herd in the southern Indian state of Kerala shown in the image rears just 1.0 kid per doe per year. Weights are well below arbitrary breed standards; kidding is all year round; and the mean age of adult does is ~3 years due to involuntary culling because of failure to re-breed (Sargison *et al.* 2017). In this case, failure to meet pragmatic production targets that are commensurate with the animals' genetic potential (let alone adequate to meet the demands of global food security) arose as a consequence of animal husbandry constraints and seasonal protein undernutrition, compounded by nematode parasitism. Benzimidazole resistance was detected in *Haemonchus contortus*, showing the need for better understanding of the principles of sustainable helminth parasite control within the southern Indian context. It is important to understand the true costs of goat production in seasonally resource poor environments, while also considering its impact on the overall ecosystem in which the animals are placed.



Supplementary Figure 4. The sheep flock shown in the image belongs to a village smallholder family in the state of Tamil Nadu in southern India. Until recently, this family derived subsistence income from keeping a few ducks and a buffalo. In common with many smallholders in the region, they now own a flock of about 50 ewes, the income from which has allowed them to “build a more substantial house and to educate three daughters”. This is in keeping with the United Nations Sustainable Development Goals, and the flock serves as an example in the local community, encouraging a move from subsistence to commercial small ruminant farming. The system works because of an appreciation of why these animals are kept; to convert free grazing provided by tracts of Government land to meat for sale for human consumption. Achieving these goals efficiently in a way that is sustainable requires iterative planned animal health management, which is provided in this case by a knowledgeable and enthusiastic private veterinary surgeon (Lalljee *et al.* 2018). The role of small ruminants in improving livelihoods is recognised by policy makers in the region, where a “four goat scheme” has operated for several years, providing millions of animals to landless women villagers. The success of this scheme depends on production efficiency being adequate.



Supplementary Figure 5. This goat herd is part of a mixed farming enterprise in the Punjab province of Pakistan, which also includes dairy cattle and buffalo herds and about 100 acres of wheat, rice and vegetable crops. Planned animal health management needs to account for the integrated role of the goats in this mixed agricultural system. Animal health infrastructures in the region are good and literacy rates are very high, providing a unique opportunity for improvement in livestock production efficiency through planned animal health management, including the sustainable use of antimicrobial drugs.



Supplementary Figure 6. The rate of movement of people from rural districts to cities is high in most LMIC. This creates opportunities for hitherto neglected peri-urban small ruminant production in poverty alleviation and in providing societal benefits through productivity, market participation and provision of nutritious food. The sheep flocks shown in the city of Lahore are being kept for slaughter during religious festivals, when their value will be highest. Peri-urban small ruminants are predominantly kept by women, affording a means of empowerment, provided that there is capacity for improved production efficiency. However, the achievement of these benefits presents complex challenges, such as the risk of spread of zoonotic infections (for example, large street dog populations scavenging on dead animals account for a high prevalence of hydatid disease) and the frequent dependence on pharmaceutical remedies for the control of production limiting diseases. The women shepherds are transitory and difficult to access with regards to education on the topic planned animal health management. Many of the animals shown in the image would have been sourced from markets in neighbouring Afghanistan, raising concerns about transboundary disease transmission.



Supplementary Figure 7. The sheep and goats shown in this image belong to villagers in the Punjab province of Pakistan. They are being tended by three shepherds while grazing on cereal crop aftermaths, utilising otherwise wasted herbage resources in the production of meat. Advice on animal health management is provided by their paravet (shown to the right of the image) and is focussed primarily on parasite control, reflecting the importance of helminths and haemoprotozoa in the region. The control of gastrointestinal nematodes typically involves regular treatments using Punjab Livestock and Dairy Development Department approved and supplied drugs (albendazole tablets at the time of the image). A more sustainable approach to gastrointestinal nematode control requires application of understanding of the farming system and environment, and inferences on the relationship between pasture contamination, the availability of infective larvae and the accumulation of infection in animals. The availability of infective larvae on the dry and open swards shown in the image should be low, but the animals also grazed on a green oasis created by the overflow from an irrigation pump immediately behind where the picture was taken, where egg contamination, the rate of larval development and the availability of infective larvae would be high. This illustrates the importance of understanding the whole farming system in which the small ruminants belong. Literacy rates among livestock keepers in this region are high, and educational programmes on animal health planning need to be delivered accordingly.



Supplementary Figure 8. Scoring of conjunctival mucous membrane colour, referred to as FAMACHA, provides a simple and effective means of engagement with smallholder small ruminant keepers. The image shows the use of a mobile phone application to record the FAMACHA scores along with production data for peri-urban goats in the Blantyre district of southern Malawi. In this setting and depending on the season, FAMACHA scores are a poor index for the targeted selective treatment of haemonchosis; due to other causes of anaemia, such as age, nutritional status and co-infecting parasites (haemoprotozoa and fleas).