Understanding Livestock Yield Gaps for Poverty Alleviation, Food Security and the Environment

The LiveGAPS Project

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Executive summary

The BMGF and other donors and development agencies need to target investments in the livestock sector in ways that are likely to maximize the impacts for broad numbers of producers and consumers. Estimating and understanding how to measure and trigger productivity changes in livestock systems is essential for better defining the technological and investment needs in the livestock sector. Estimates of livestock yield gaps are not available and these are necessary for developing feasible scenarios of how the production of different livestock commodities might evolve in the future, how systems might change and what would be the resource use implications and their costs, both for donors and for public and private entities in target countries. Productivity and yield gap analyses will also help define the most appropriate technology entry points for different livestock species: health, nutrition, genetics, policy levers, others. This information will contribute to making informed investment decisions and target technologies in the livestock sectors of developing countries.

Main findings

1. Our study suggests that dairy yield gaps in Ethiopia and India range between 65-350% depending on the type of intervention package implemented. In both cases, benchmarking production against the top 10% of producers demonstrated that yields could be tripled. However, when implementing efficiency frontier studies, we found that potentially more modest gains would be achievable at the herd level.
2. Our projections demonstrate that it would be possible to increase production further that the existing baseline projections to 2030 for India and Ethiopia would suggest. For example, dairy production in India is projected to increase by a factor of 65% to 2030. Our results show that with improved feeding and promoting changes in the herd structure towards more cross-breeding and or buffalo production, milk production could increase between 112-130% by 2030.
3. Ethiopia has higher yield gaps than India, but also as a result of a lower baseline. Ethiopian dairy production is expected to grow by 84% to 2030 under baseline conditions. Alternative scenarios demonstrated a positive, but more variable production response, ranging from 97-242% depending on the improvement strategy selected. Packages of interventions including better feeding, crossbreds and others led to the highest potential gains. These results were confirmed by our benchmarking studies.
4. A very strong and statistically significant link between market access and farm performance was found for most sites. This suggests that efforts to improve market access should be an important component of policies to close yield gaps.
5. Biomass constraints could be critical for the development of the ruminant livestock sector in India and Ethiopia. In these situations achieving production targets with less, more productive animals might be desirable.
6. Increasing milk production will require both an increase in the quantity of feed available and more efficient use of existing resources. This is especially important as the smaller indigenous livestock breeds are replaced by larger crossbred cattle and buffalo with higher energy requirements.
7. A shift away from the use of cattle and buffalo for draught purposes will make more feed resources available for dairy production in India. However, a decrease in the total size of the national dairy herd may still be required to increase total production.
8. Cross-breeding is a good option to increase milk productivity, but this will only work if higher quality feed is available.

9. Herd management and species composition for milk production is a key strategy to maximize milk production in India.
10. There is significant potential for increasing small ruminant production through practices to reduce mortality and strategic sowing of improved fodders. Cross-breeding in these systems was shown to be relatively ineffective, but a package with the three interventions demonstrated to have the potential to increase productivity five-fold. These results translated in a potential doubling of small ruminant meat production to 2030 relative to 2010.
11. The interactions between improved nutrition and improved reproduction and reduced mortality could be used as a way of increasing total system productivity while protecting livestock assets.
12. The most profitable feeding interventions tested are not necessarily those with the highest productivity. This needs to be accounted for when designing dairy improvement programmes.
13. In all cases and for all species and location, packages of interventions performed better than single interventions for increasing productivity and profitability of livestock production.
14. The smallholder poultry sector in Ethiopia could potential supply a significant amount of meat and eggs, especially if improved interventions are applied. In contrast, the strength and the accelerated growth of the industrial poultry sector in India is likely to dominate poultry production in the next 20 years. Nevertheless, localised livelihoods benefits of improved extensive poultry production are likely to be continue to be important in places.
15. Ethiopia: The regional mean annual egg offtake for a small sized farm for the baseline was 21.7 eggs. The largest increases in regional egg offtake rates were from the dual interventions of vaccination and supplementary feeding (48.4) and crossbreeding and housing (46.2).
16. The dual intervention of vaccination and supplementary feeding consistently returned the greatest percentage increase in net profits above the baseline value for each of the different sized farms. However, the cost of providing supplementary feed can be highly variable, dependent on many localized issues. The dual intervention of vaccination and housing frequently provided the greatest increases concerning total bird offtake rates, however the percentage increase in net profits as a result of this intervention was relatively much lower, due to the cost associated with providing daytime housing.
17. Market incentives and value chain development will be essential to ensure farmers can intensify their production.
18. Investment in projects targeting improved feed management should be a priority. Without these, the impacts of many other interventions (genetics, health) will be small. This should include fodder markets and biomass value chains, apart from on-farm interventions on improved fodders.
19. Further research on herd management and manipulation of herd structures is necessary.

Introduction

Livestock play a significant role in rural livelihoods and the economies of developing countries. They are providers of income and employment for 1.3 billion producers and others working in, sometimes complex, value chains. They are a crucial asset and safety net for the poor, especially for women and pastoralist groups, and they provide an important source of nourishment for billions of rural and urban households. These socio-economic roles and others, are increasing in importance as the sector grows due to increasing human population, incomes, and urbanisation rates (Herrero et al 2009, 2010, 2013a).

The demand for livestock products in developing countries is projected to double in the next forty years as a result of the drivers mentioned above. There is a need to ensure that the smallholder sector is able to respond to sustainably supply the volumes of livestock products required to meet the increased consumption, thus increasing their incomes, protecting their assets and consuming wholesome diets. We need a sustainable livestock revolution in action. Therefore, understanding how the contribution of smallholders livestock farmers might evolve in the future is needed for better implementing poverty reduction and nutritional security strategies.

The developing world produces 41% of the milk, 72% of the lamb, 50% of the beef, 59% of the pork and 53% of the poultry globally (Steinfeld et al 2006, Herrero et al 2010, 2012). These shares are likely to increase significantly to 2050 as rates of growth of livestock production in the developing world exceed those in developed countries (>2%/yr and <1% /yr, respectively). Mixed extensive and intensive crop-livestock systems produce 65%, 75% and 55% of the bovine meat, milk and lamb, respectively, of the developing world share (Herrero et al 2010).

The productivity of livestock in the developing world is low, relative to its potential (Herrero et al 2013b). There are significant opportunities to increase it via adequate mixtures of technologies, policies and investments in farms and product value chains. However, until recently, the baseline data needed to adequately characterize livestock productivity levels in different parts of the developing world was either not available, nor at the level of disaggregation necessary to make informed decisions on the upscaling potential of key interventions and their impacts on productivity and household nutrition and income. This is quickly changing due to new data sources (i.e. see Herrero et al 2013b) but there is a significant need to study and synthesize the potential for productivity increases in smallholders systems for improved programmatic decision making and for targeting poverty and food security strategies.

The BMGF and other donors and development agencies need to target investments in the livestock sector in ways that are likely to maximize the impacts for broad numbers of producers and consumers. Estimating and understanding how to measure and trigger productivity changes in livestock systems is essential for better defining the technological and investment needs in the livestock sector. Estimates of livestock yield gaps are not available and these are necessary for developing feasible scenarios of how the production of different livestock commodities might evolve in the future, how systems might change and what would be the resource use implications and their costs, both for donors and for public and private entities in target countries. Productivity and yield gap analyses will also help define the most appropriate technology entry points for different livestock species: health, nutrition, genetics, policy levers, others. This information will contribute to making informed investment decisions and target technologies in the livestock sectors of developing countries.

Terms of reference

This one-year investment, commissioned to CSIRO in partnership with ILRI and UTAS, and co-developed with the BMGF Livestock Programme, aimed to:

1. Improve the existing livestock baseline productivity data in selected BMGF target countries and in Sub-Saharan Africa and South Asia in general. We developed a framework for assessing productivity in livestock systems, particularly those owned and managed by smallholder farmers. Part of this work included updating existing productivity maps for dairy, small ruminant (milk and meat) and poultry (eggs, poultry) developed by Herrero et al (2013b) for the year 2000 to the year 2010 for the specific countries and continents. We used new information from surveys and livestock monitoring systems for improving this effort. Additionally we updated the distributions of animal numbers and the share of smallholder production as part of this effort for regional level assessments, while at the farm level we used household-level analysis for estimating the productivity of dairy, small ruminants and poultry. This enabled us to determine baseline hotspots of production, shares by production system, feed demand and supply and contribution of livestock to livelihoods in the regions of interest.

2. As a second step, using state of the art livestock and household simulation models like CSIRO's IAT, RUMINANT, APSFARM and other models from partners, we estimated the impacts of best bet packages of interventions provided by key informants (genetics, nutrition, health) on livestock productivity, and farmers' incomes and nutrition in different types of production systems in two selected BMGF target countries (India and Ethiopia). This is a practical way of getting a better sense of how to exploit yield gaps in these systems, rather than assessing technical potentials. Additionally this can lead to a prioritization of key interventions in terms of production potential, costs and others.

3. The study would also assess the potential impacts of these practices if they were up-scaled broadly throughout the individual countries to 2017 and 2030. This kind of information would enable BMGF to assess the feasibility and investment needs of selected practices and would enable us to assess country level impacts on consumption of livestock products and farmers' incomes.

4. Additionally, the project would develop a dissemination portal for the data and would organize a small workshop for setting the foundations for establishing a community of practice in the field of livestock modeling and data sharing.

A schematic description of the project is presented in Figure 1.

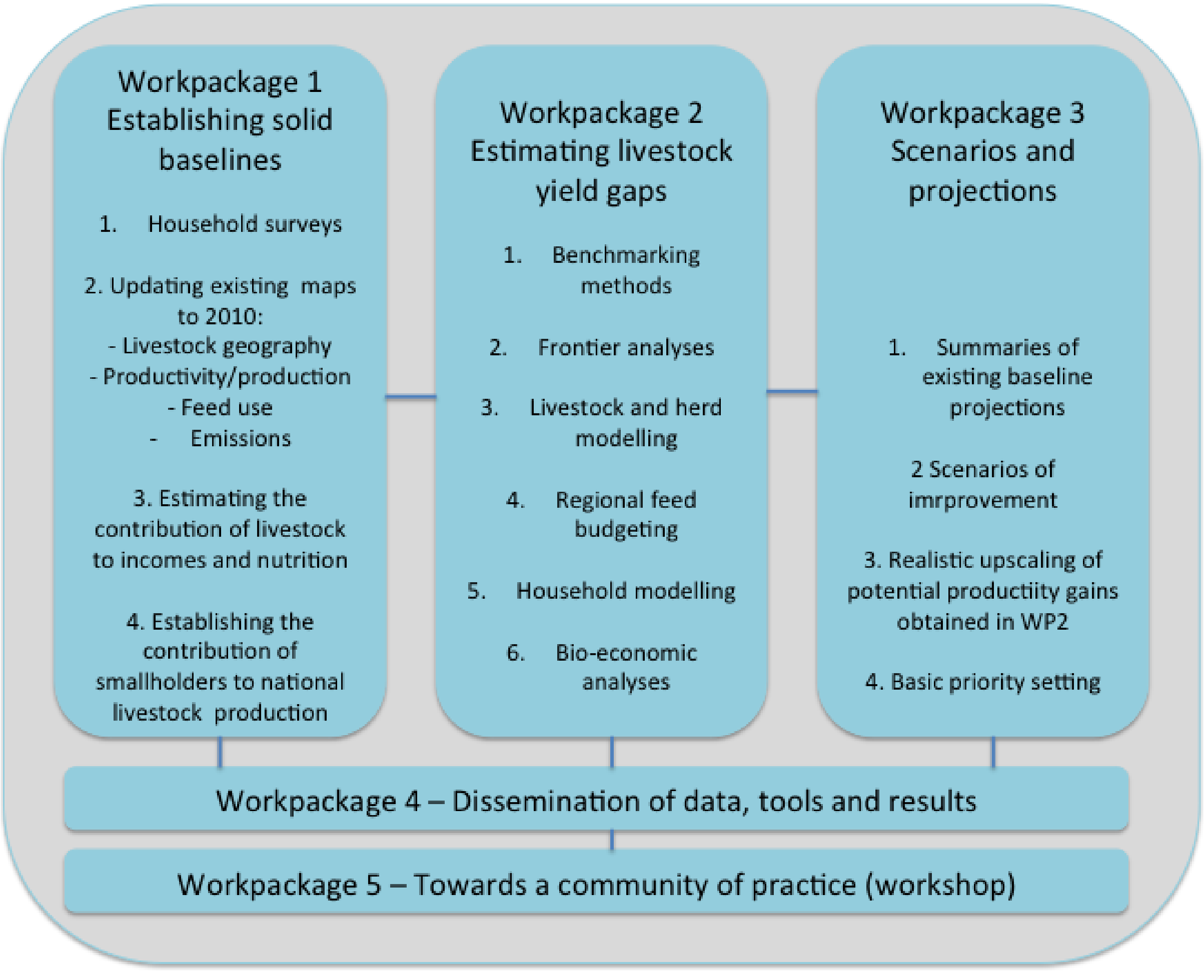


Figure 1: Schematic representation of the LiveGAPS project and its workpackages

Workpackage 1- Development and implementation of a framework for estimating productivity of livestock in smallholder systems

The framework developed for estimating livestock productivity involved a combination of empirical work, modeling, and spatial analyses. The generation of solid baselines of livestock productivity and indicators of the contribution of livestock to nutrition and incomes is only possible by combining data sources. Hence a key initial activity of the project was to develop a 'data rescue' protocol to find high quality household surveys, regional feed and livestock inventories and others that would be curated, and used to establish base productivity levels for different species and production systems in different parts of the countries under study. A description of the databases and the initial descriptive analyses is presented in workpackage 2 as part of the yield gap analyses. This information was also used to improve ongoing livestock mapping efforts wherever possible. Triangulation between data sources enabled us to establish the most likely productivity baselines for the different species and countries.

Development of livestock production maps for Sub-Saharan Africa, South Asia, India and Ethiopia

This work was based on two primary sources of information. Herrero et al (2013) published detailed global maps of livestock production, feed use, and greenhouse gas emissions and these were used as the basis for the update. This effort uses the gridded livestock data of Robinson et al (2014); which for the purpose of this study was also updated to 2010 for the regions of interest (Gilbert et al, 2015).

A general description of the methodology is presented in the next section. A livestock systems classification recently updated by Robinson et al (2011) was used as the starting point. This classification system has been widely used for studying different aspects of livestock production, such as linkages with poverty (Thornton et al 2002), environmental impacts (Steinfeld et al 2006), systems evolution (Herrero et al 2009), and livestock demographics (Robinson et al 2011, 2014) amongst others. It has many useful features for studying bio-geochemical aspects of livestock production. It distinguishes between grazing, mixed crop-livestock systems, peri-urban and industrial systems and others. These are essential distinctions for the development of mitigation and adaptation strategies in livestock systems and for understanding how the sector is likely to evolve in the future and the environmental, social and economic consequences of different pathways of growth. It is based on agro-ecological differentiation (arid, humid and temperate/tropical highland areas), which helps in establishing the composition of diets for animals in different regions and agro-agroecologies and in the future to elicit the impacts that climate change might have on feed resources and land use. We differentiated 8 different types of livestock systems in 28 geographical regions of the world for this study.

Numbers of animals for each of these systems and regions were updated from Robinson et al. (2014) for the year 2010 (Nicolas et al, under revision). For ruminants (cattle, sheep and goats), we disaggregated the dairy and beef cattle herds using livestock demographic data for total cattle, sheep and goats and the dairy females for each species, respectively, from FAOSTAT. We used herd dynamics models parameterised for each region and production system using reproduction and mortality rates obtained from extensive literature reviews to estimate herd composition. We then subtracted the number of total dairy animals from the total number for each species. This procedure enabled us to have distinct herds for the production of milk and beef.

For monogastrics (pigs and poultry), we only differentiated two systems: smallholder and industrial production systems (Robinson et al 2011, Herrero et al 2013, Gilbert et al 2015), since these are the most important ones and industrial systems exhibit most of the growth in meat production globally (Bruinsma 2003) The allocation of poultry, eggs and pork production was done on the basis of knowledge of the total product output from these two systems from national information from selected countries in the different regions, applied to the respective region. The numbers of animals contributing to the estimated animal production was also computed using herd dynamics models coupled with information on mortalities, reproduction and productivity for these two main systems for each region.

Biomass consumption and productivity estimations from different species in each region and system followed a three stage process. First, feed availability of four main types of feeds (grass, crop residues, grains, occasional feeds) was estimated. Hybrid maps of grassland productivity were developed using rain use efficiency concepts in drylands (Le Houerou et al 1988, Illius and O'Connor 1990) and EPIC model output (Havlik et al 2013) for humid and temperate regions of the world. Crop residue availability was estimated using the SPAM cropland layers (You et al 2014) and coefficients of stover use for animal feeding and harvest indexes for different parts of the world. Grain availability for animal production was taken from the FAO Commodity balance sheets and the availability of occasional feeds like cut and carry grasses and legumes was obtained from literature reviews. The second step consisted of developing feasible diets for each species in each region and production system. The proportions of each feed in the diet of each species was obtained from extensive information available in the literature and from databases and feeding practice surveys at key research centres in the world (i.e. FAO, ILRI). Data on feed quality was obtained from the databases containing regional feed composition data for each feed (Herrero et al 2008). The third step consisted of estimating productivity. For ruminants, the information on the quantity and quality of the different feeds was then used to parameterise an IPCC tier 3 digestion and metabolism model (RUMINANT, Herrero et al 2002), as described in Herrero et al (2008) and Thornton and Herrero (2010). The model estimated productivity (milk, meat), methane emissions and manure and N excretion. For monogastrics, information on feed quality was used to estimate feed intake, productivity and feed use efficiency using standard nutrient requirements guidelines (NRC 2008).

The estimation of methane and nitrous oxide emissions from manure, and of nitrous oxide from pastures followed an IPCC tier 2 approach, for each species, system and region. Further details are available in the Supplementary information.

All information on animal production (bovine milk, bovine meat, sheep and goat milk, sheep and goat meat, pork, poultry and eggs) and for grains as feed was harmonised with FAOSTAT's commodity balance sheets at national level following an iterative procedure restricted to deviate +/- 20% from the statistical data in FAOSTAT. All 200 maps can be found on the LiveGAPS website, but below we present examples of the maps for India and Ethiopia.

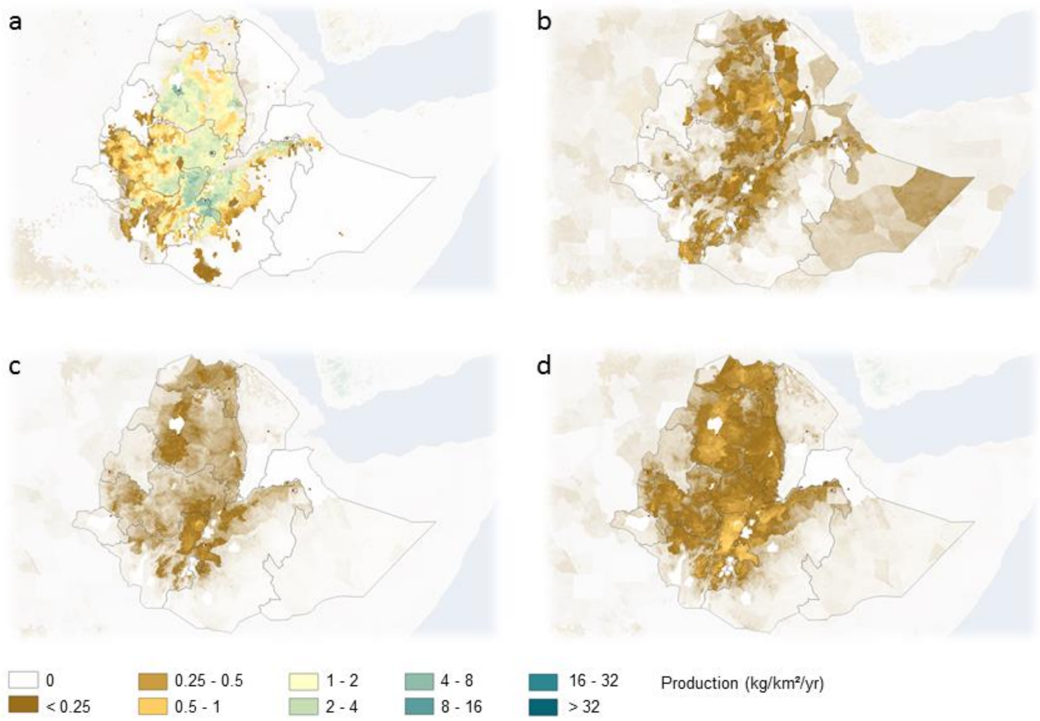


*Figure 2: Livestock production in Ethiopia, expressed in kg/km²/year **a** Milk production by cattle, **b** Meat production by small ruminants, **c** Meat production by poultry, **d** Egg production by poultry*

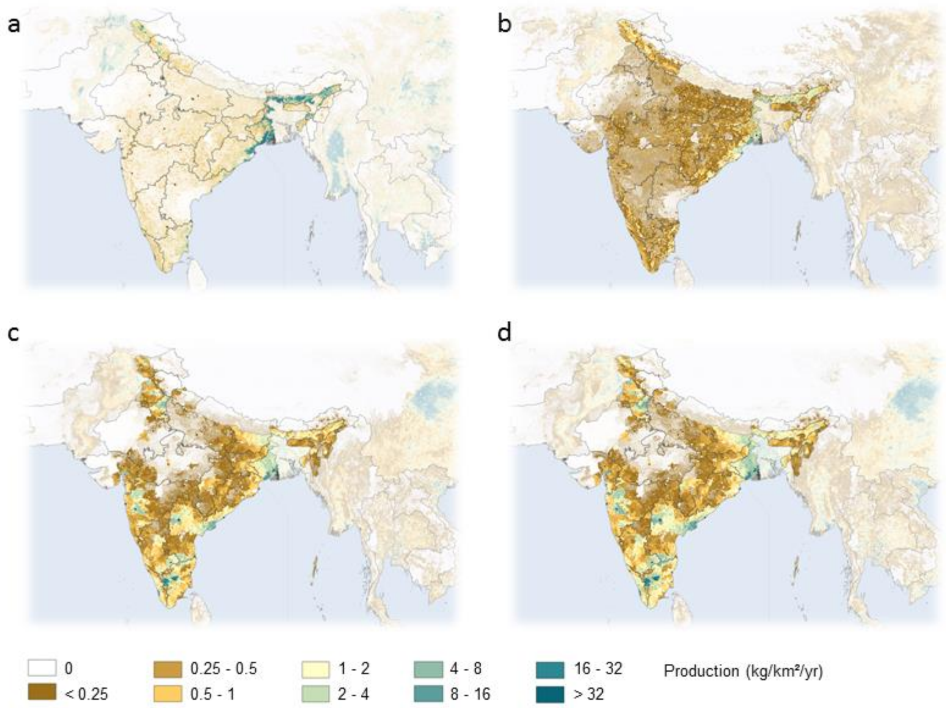


*Figure 3: Livestock production in India, expressed in kg/km²/year **a** Milk production by cattle, **b** Meat production by small ruminant, **c** Meat production by poultry, **d** Egg production by poultry*

Estimating the contribution of smallholders to livestock production in South Asia, Sub-Saharan Africa and India and Ethiopia in 2010

Knowledge of the contribution of smallholders to national and regional livestock production, and agriculture in general, is critical for designing R4D programmes and planning and targeting agricultural investments. This crucial piece of information has been elusive for some time, but recently available data on global field sizes (Fritz et al. 2015) has made possible to approximate what proportion of the production actual comes from agricultural plots of different sizes. Fritz et al. (2015) crowdsourced information from 30 thousand real data points where the plot size was estimated and trained a global model against remotely sensed land cover data to populate a global map of field sizes. The key assumption we are using is that smallholders have largely fragmented farms with small plots, and that these correspond to the areas of the maps with large concentrations of small plots: more populated areas, with better market access. Analyses of the farm surveys indicated that in India farm sizes vary between 1.6 - 3.2 ha (VDSA data) and in Ethiopia between 1.2 – 2.1 ha (LSMS data) which would indicate that farmers would have between 3-6 plots. These data are consistent with several farming systems studies in the same regions (Waithaka et al. 2006; Erenstein et al. 2010; Tittonell et al 2009, 2010). Larger plots are located in more extensive areas. The production maps we produced were overlayed with the field size map of Fritz et al (2015) and key statistics computed. These are presented in table 1.

The results suggest that areas with field sizes of less than 0.5 ha contribute to 58.7 to 68% of the production of meat and milk from ruminants. Very similar results were obtained for the whole of South Asia. For Ethiopia, the contribution of small plots to total ruminant production is higher (75.2-76.6%). Due to large areas of arid mixed systems and pastoral systems, small plots contribute still significantly, but less (43-64%) to the total production of Sub-Saharan Africa.

While these results need to be taken with caution, they are indicative of a large contribution of smallholder farmers to national and regional production.

Table 1: The total area, human population, and production per animal type, by different plot areas (tonnes)

	Area	Population	Bovine		Sheep & goats	
Field sizes	(km2)	('1000)	Meat	Milk	Meat	Milk
			South Asia			
> 100 ha	2951	1,040	4	115	1	9
2 - 100 ha	85,535	15,488	40	1,332	42	138
0.5 - 2 ha	1,359,290	424,610	847	32,067	709	2,983
< 0.5 ha	2,064,137	931,225	1,808	69,232	1,157	5,261
% production < 0.5 ha	58.8	67.9	67.0	67.4	60.6	62.7
			India			
> 100 ha	1414	669	3	100	1	4
2 - 100 ha	48,220	10,348	19	805	17	95
0.5 - 2 ha	1,008,465	303,069	493	22,489	343	1,951
< 0.5 ha	1,544,758	729,888	1,053	49,814	515	2,909
% production < 0.5 ha	59.3	69.9	67.2	68.0	58.8	58.7
			Sub-Sahara Africa			
> 100 ha	154,565	7,283	7	77	10	47
2 - 100 ha	644,940	33,303	42	524	40	209
0.5 - 2 ha	2,670,694	207,776	455	3,582	158	750
< 0.5 ha	2,416,852	282,449	890	5,611	201	786
% production < 0.5 ha	41.1	53.2	63.8	57.3	49.1	43.9
			Ethiopia			
> 100 ha	201	41	0	2	0	0
2 - 100 ha	1869	356	5	29	1	3
0.5 - 2 ha	51,264	10,346	158	874	16	65
< 0.5 ha	179,852	36,493	493	2,742	54	222
% production < 0.5 ha	77.1	77.3	75.2	75.2	76.1	76.6

The contribution of livestock to incomes, food availability and nutrition

Based on data availability assessments of a wide range of different surveys from different agricultural development-oriented efforts in sub Saharan Africa (Frelat et al., 2015), we developed a simple indicator of food security, called the food availability ratio, that can be quantified on the basis of these surveys. The indicator quantifies the ratio between food availability and household level food needs, and also quantifies the (relative) importance of different agricultural and off-farm activities for this indicator. Figure 4 displays the key components of the analysis. A simple Food Availability (FA) ratio is defined to be the ratio of total physical energy available to a household via crop and livestock production as well as food that can be purchased ('food available'; MJ-year^{-1}), to the physical energy requirements of the household ('food need'; MJ-year^{-1}). Households with FA ratio values less than 1 are thus considered food-insecure.

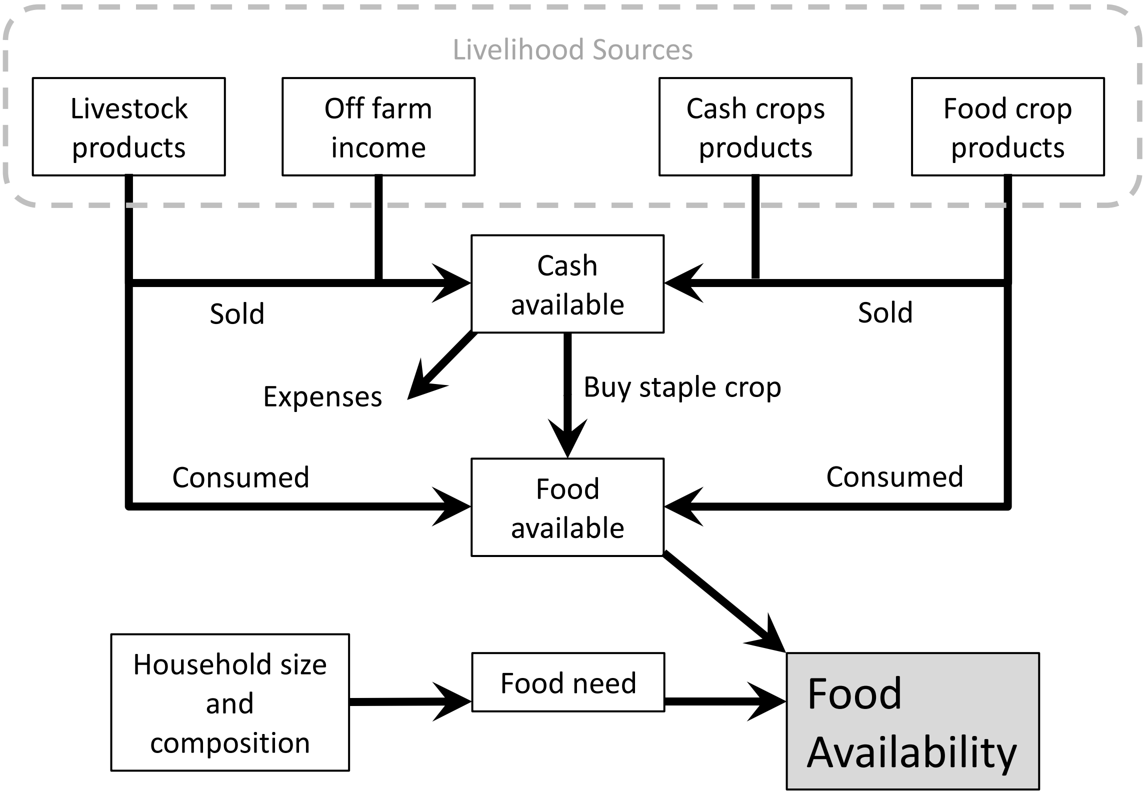
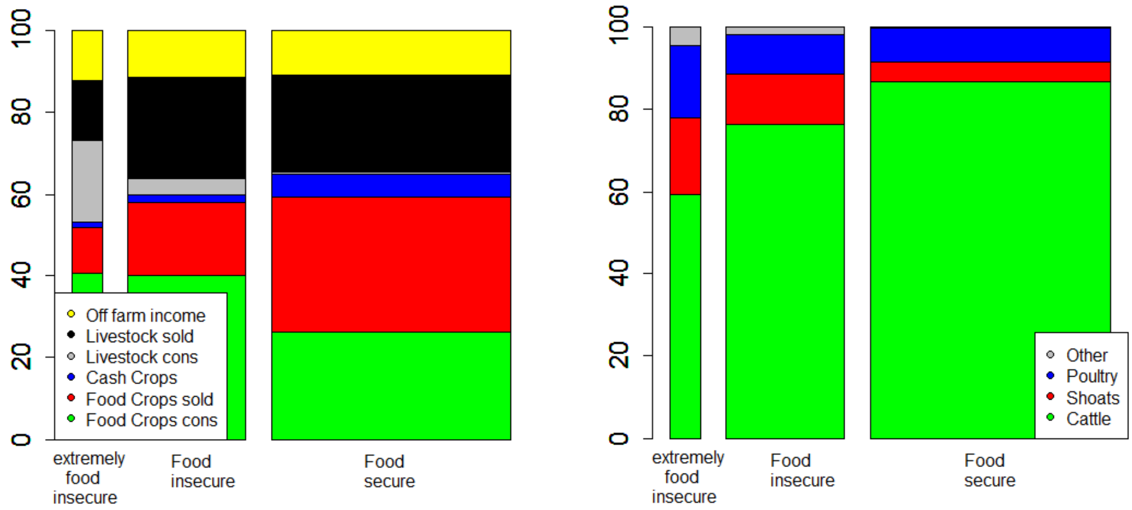


Figure 4: Simple household Food Availability calculation (Frelat et al 2015)

To estimate household 'food need', members of the household are disaggregated by gender and age classes, following FAO/WHO methodology. Energy requirements for each gender and age class are multiplied by the number of household members in each category and summed to produce the food need of the household. The FAR indicator has been shown to be a good indicator of overall household level food security (Frelat et al., 2015; Hammond et al., 2015) and to relate well to diet diversity (Hammond et al., 2015), despite the major assumption made in the calculation scheme (Figure 1).

This indicator was quantified on household characterization data available for Ethiopia. Two type of data were available: 1) survey data that tried to represent the farm household population present in a site; and 2) survey data tried to cover the spatial variations in farm households across the whole country. Type 1 data were obtained from three projects: AFRINT (http://www.keg.lu.se/en/research/research-projects/current-research-projects/afrint), CCAFS (http://ccafs.cgiar.org/) and CIALCA SIMLESA (http://simlesa.cimmyt.org/). The type 2 data were obtained from the WORLDBANK Living Standards Measurements Study, the Integrated Surveys on Agriculture (LSMS-ISA) (http://econ.worldbank.org/WBSITE/EXTERNAL/EXTDEC/EXTRESEARCH/EXTLSMS/0,,contentMDK:23512006~pagePK:64168445~piPK:64168309~theSitePK:3358997,00.html). The type 1 data available for Ethiopia (in total 1500 farm households across 7 sites) were used to quantify the variations in importance of different on and off farm activities of the simple FAR indicator within the different populations. The LSMS-ISA data of Ethiopia (3000 households across 331 sites) were used to spatially map the importance of livestock production, sales and consumption across the country.

Livestock contributes roughly 20-30% to the energy value of the FAR indicator, and this value is relatively consistent across the three farm household groups we defined (i.e. extremely food insecure, food insecure, food secure), although a shift takes place from consumption to sales of livestock product when households become more food secure (Figure 5A). Within this livestock contribution cattle play by far the most important role, while for the poorer households poultry and goats are also a key source of energy (Figure 5B).



A B

Figure 5: Contribution of different on and off farm activities to the FAR indicator (A), and the relative contribution of different livestock species to the overall livestock contribution to FAR (B)

When using the LSMS-ISA data to spatially map the importance of livestock to the FAR indicator strong spatial differences visible across Ethiopia (Figure 6). The arid, (agro-) pastoral systems of the south are clearly visible, as well as the crop based systems in the north, and the mixed systems in the central west. In combination with information on the number of farm households in a region these spatially explicit data can be used to develop targeted intervention strategies and prioritization schemes to determine what the outreach potential is of certain technological options.

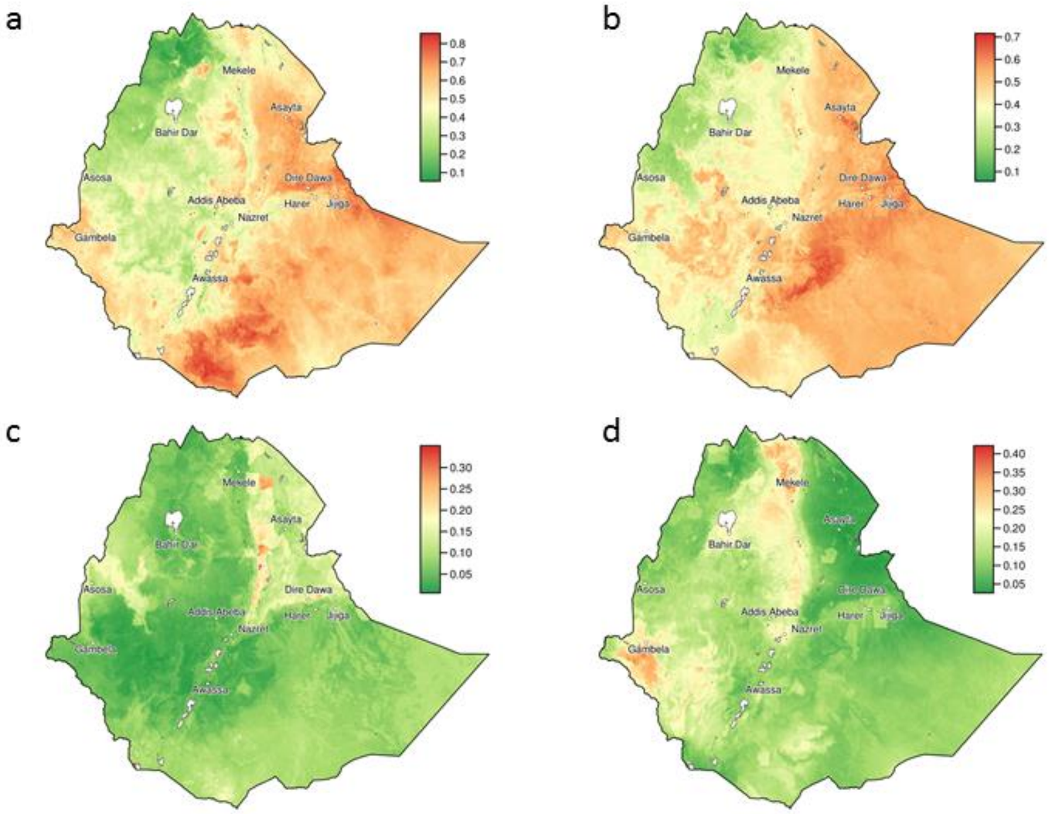
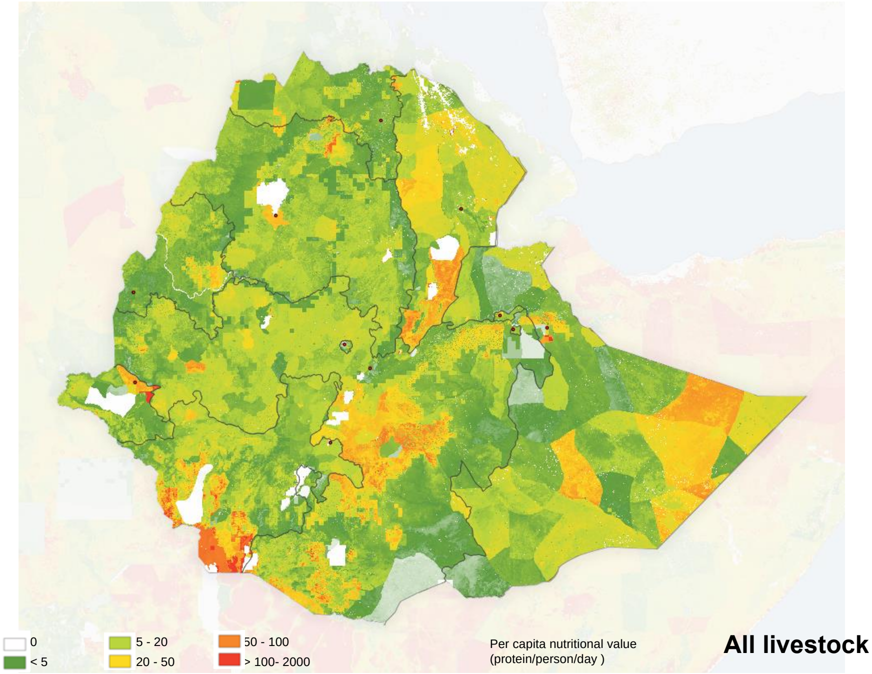


Figure 6: Relative contribution of livestock to food availability, a Relative contribution of all livestock to the overall food availability, b Relative contribution of cattle to the food available from livestock, c Relative contribution of goats to the food available from livestock, d Relative contribution of poultry to the food available from livestock

Another indicator of nutritional adequacy is the availability of protein per capita. The WHO estimates that 50 g of protein per capita derived from livestock products is adequate for maintaining a healthy diet. This indicator was estimated from the production maps for 2010 for all livestock products and the 2010 population density layers for India and Ethiopia. Continental maps for Sub-Saharan Africa and South Asia were also produced and are available in the website.

Few places in Ethiopia and India reach the threshold of 50 g of protein per capita from livestock products (Figure 7). However, a higher availability of protein from livestock can be observed in Ethiopia in comparison to India, in general terms, due to lower population densities mostly. In India, while production of most livestock commodities is higher, the large numbers of people create lower protein availabilities from livestock, with exceptions of a few places.



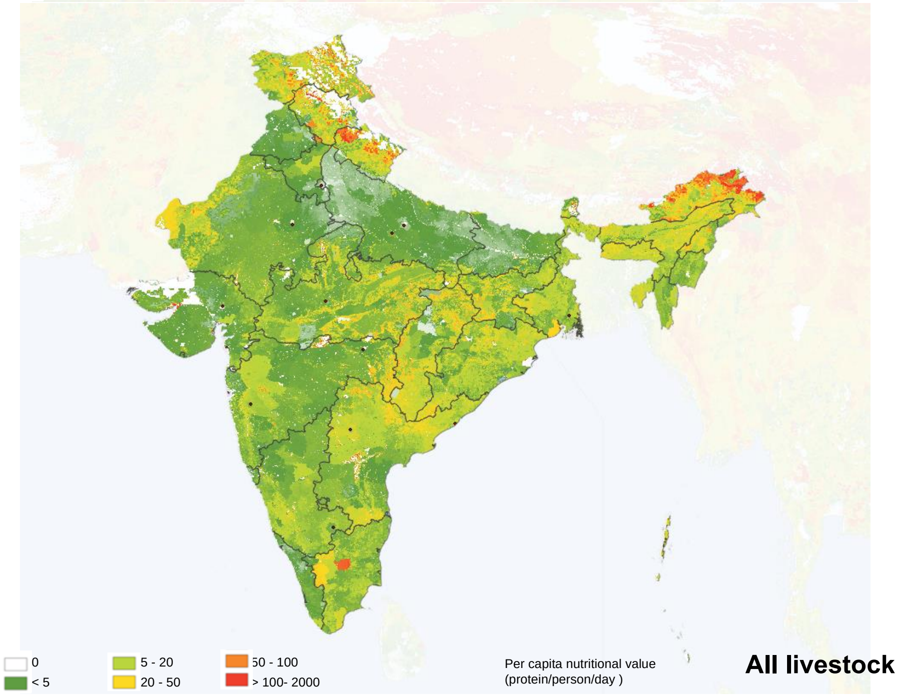


Figure 7: The contribution of livestock to protein availability per capita in Ethiopia and India 2010 (g protein per person per day). Note: the recommended consumption is a minimum of 50g/per person/d (WHO 2010).

Workpackage 2 – Estimation of livestock yield gaps

Introduction

Smallholder farming systems in Sub-Saharan Africa and South Asia are known to have substantial yield gaps (Tittonel and Giller 2013; Dzanku et al. 2015; Nin-Pratt et al. 2011, and to therefore have large potential for increasing food production. The yield gap concept is commonly used in agronomic assessments, which compare observed yields with maximum potential yields under certain agroecological conditions for a particular region. As noted by Neumann et al. 2010; Nin-Pratt et al. 2011; Dzanku et al. 2014, these potential yields are often overestimated because they are based on optimal conditions (e.g. where pests and diseases are effectively controlled) and often ignore practical regional and farm-level constraints (Rockström and Falkenmark 2000). A number of recent studies use statistical and mathematical programming approaches based on variations in observed yields, which provide more realistic yield gap estimates (Neumann et al. 2010; Dzanku et al. 2014; Tittonel and Giller, 2013; Baldos and Hertel 2012; Foley et al. 2011; Licker et al. 2010. These and other yield gap studies for Africa (Mutegi and Zingore , 2014) and the globe (Rockström and Falkenmark 2010) are, however, limited as they do not include livestock. This is a significant omission given that large share of food production in sub-Saharan Africa and South Asia that comes from mixed crop-livestock systems (Herrero et al. 2010). This assessment seeks to redress this neglect.

Variations in farm productivity arise because of differences in production environments, production technologies, and the efficiency of production processes (Lovell et al. 1994). Part of this yield gap can be closed through management decisions including more precise matching of agronomic inputs and crop requirements (technical efficiency improvement), and through the adoption of more productive technologies such as improved animal breeds (Nin-Pratt et al. 2011).

This workpackage analysed yield gaps using three different methods in order to understand the sources of variation and triangulate realistic yield gaps for the different species in the different countries. As an initial step, yield gaps based on simple bench marking from survey data were developed. Subsequently frontier analyses were performed to understand the distribution of resource use efficiency and productivity in the different regions. We concluded with an ex-ante assessment of selected interventions in selected farms using livestock, herd, and household and regional models.

Empirical yield gaps based on simple benchmarking

The usefulness of simple empirical benchmarking is to elicit the range of production attainable in a particular region. A common approach is usually comparing what the best farmers are producing against the rest. Figures 8 and 9 present the information on the average milk production of the top 10% vs the bottom 90% for different locations in Ethiopia and India.

In general terms, milk yields in India are significantly higher than in Ethiopia. This information also shows that it is possible to at least triple yields in different locations of India and Ethiopia. Even for cross-bred animals in India, there is at least a two fold difference in production between the best farmers and the rest. The best farmers are implementing 'packages' of technologies that lead to higher productivity. These include better feeding practices, improved animals, better veterinary care leading to less disease challenges, lower mortalities, etc. Secure markets for some of these producers could also explain their incentives to intensify. Only as a whole package, these levels of productivity can be attained. Attaining these conditions simultaneously for all the farmers might no be possible due to financial constraints to purchase animals and inputs, lack of areas for growing fodders, lack of labour, spatial location and others. Many of these constraints have been the subject of considerable research (Blummel et al. 2009; Kebreab et al. 2006; Herrero et al 2012 and many others).

Neverthless, this information is very useful for testing the boundaries of what is feasible in a particular region.

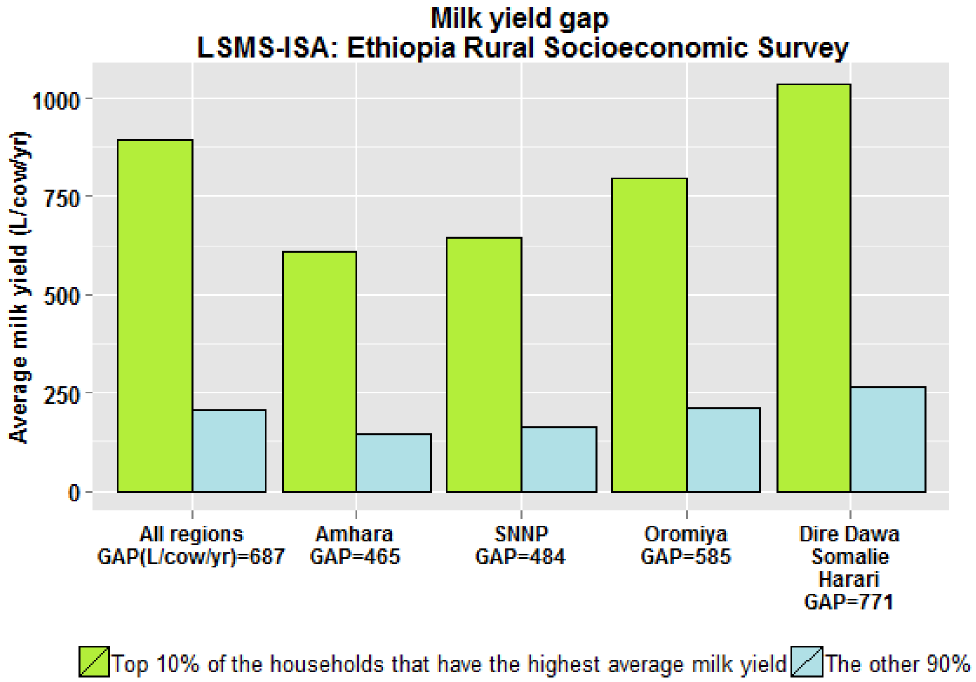


Figure 8: Milk production levels of the top 10% farmers vs the rest in different provinces of Ethiopia (LSMS survey 2012)

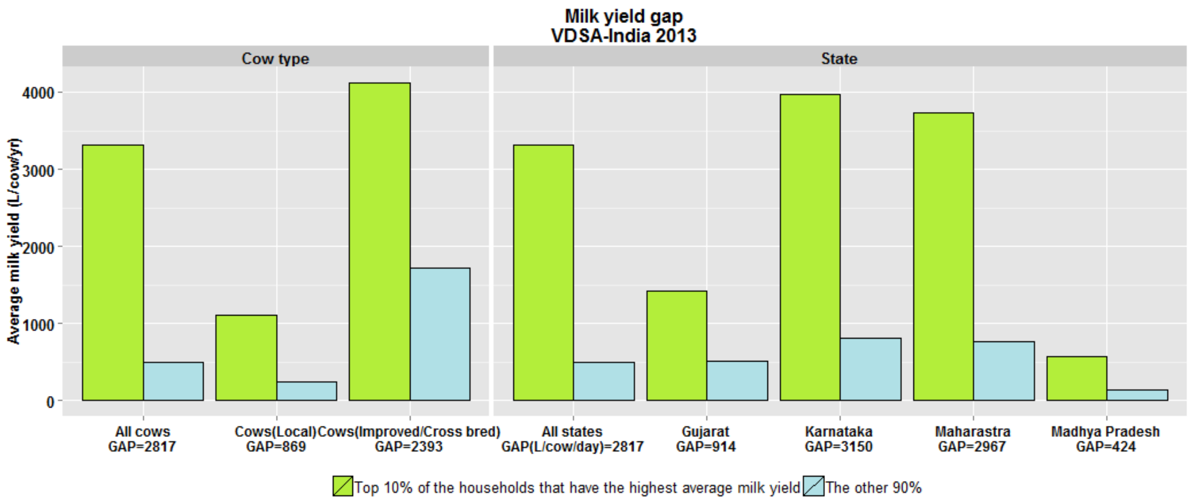


Figure 9: Milk production levels of the top 10% farmers vs the rest in different provinces of India (VDSA suvey 2013)

Yield gaps based on frontier analyses

This part of the study is concerned with improving yield gaps through improvements in the efficiency of production, and it is based on the construction of production frontiers for mixed crop-livestock smallholder farmers in Ethiopia and three countries within South Asia (India, Bangladesh and Nepal).

The production frontiers used in this study are based on the most technically efficient farms within each site, and they represent the maximum amount of output that can be produced from the existing production inputs used by each farm. To accommodate the multiple-output nature of these production systems, we estimate distance functions using a stochastic frontier analysis (SFA) estimation procedure. This is a robust methodology with sound theoretical underpinnings in production economics, which also permits the statistical testing of model specifications (Coelli et al. 2005; Bogetoft and Otto 2011). Moreover, the production frontier approach used in this study simultaneously considers all production inputs and outputs, therefore the efficiency improvements identified with this approach can be assured of increasing total factor productivity. By contrast, the improvement of partial productivity measures, which only consider one input (e.g. output per animal or per hectare), can result in greater use of inputs not captured in the measures and thereby cause total factor productivity to fall. Furthermore, because our approach does not involve adjusting proportions or levels of production inputs, the closing of gaps estimated in our assessment cannot inadvertently make farmers economically worse off. It is also the first study we are aware of that uses SFA to estimate system-wide yield gaps for mixed crop livestock smallholder production systems.

Data

This assessment relies on farm household level data from three different databases. For Ethiopia we use the IMPACTlite database prepared by the CGIAR Programme on Climate Change, Agriculture and Food Security (Rufino et al. 2013) for the Borana site, and the World Bank Livestock Standards Measurement Study (LSMS) database for the Amhara, Oromiya and SNNP sites (Figure 10). For South Asia, we relied on the Village Dynamics in South Asia (VDSA) database for two Indian sites (Andhra Pradesh and Maharashtra) and the IMPACTlite database for two further sites in India (Bihar and Haryana). The IMPACTlite database covers the 2012 calendar year, the VDSA data is from 2010 (although additional years are also available) and the LSMS data is for 2003-2004.

There is a diversity of production systems across the sites, ranging from the agro-pastoral system in Borana, characterised by large ruminant herds relative to farm land area, to the more crop-based systems in Haryana, Maharashtra and Andhra Pradesh. Farms in Bihar are characterised by a more balanced crop-livestock orientation. The livestock production rates vary across the sites. For instance, in the Ethiopian sites, the average milk production yields are between 193 and 937L/cow/yr whereas in the Indian sites, they range from 1430 to 2219 L/cow/yr. The average farm sizes of the farms under a mixed crop-livestock systems are between 1.2ha and 3.8ha in the Ethiopian sites and between 2.65ha and 3.56ha in the Indian sites with the exception of Bihar where the farm sizes are in average the smallest (0.32ha).

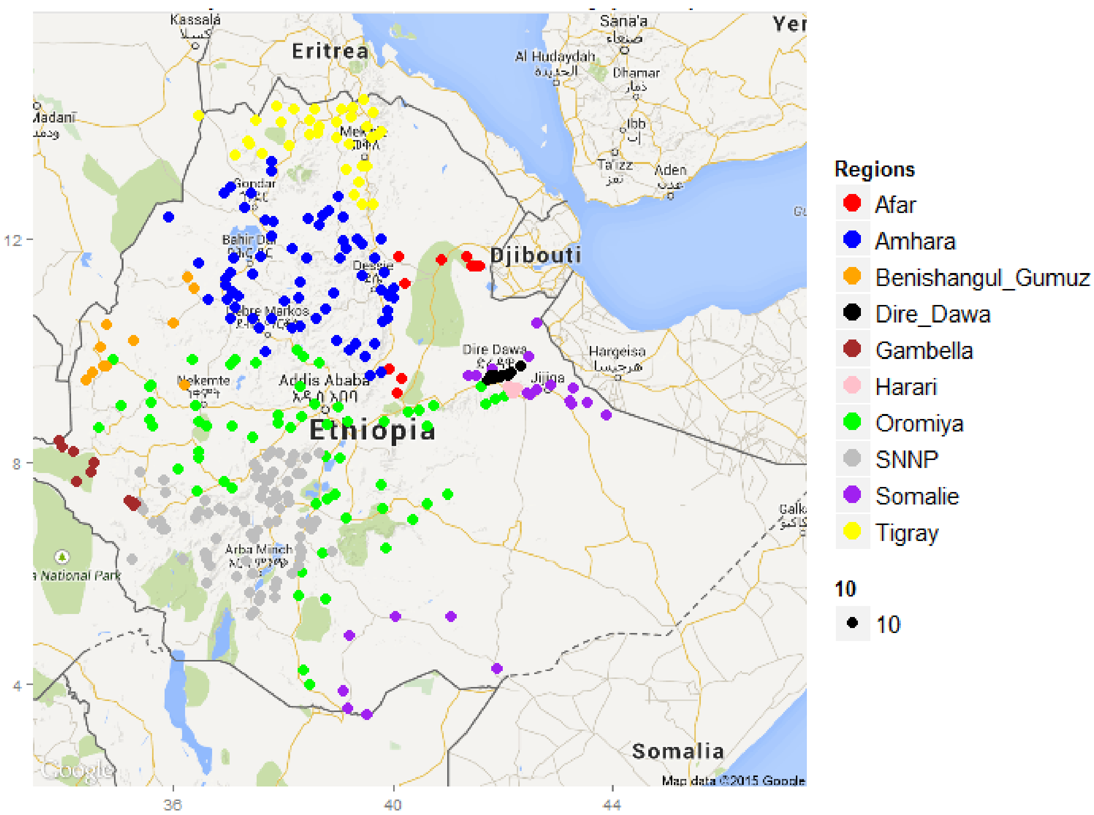


Figure 10: Locations of households within the LSMS database for Ethiopia

Results - Ethiopia

The average technical efficiency score for smallholders at each site ranges between 0.43 and 0.68 (Table 1). The efficiency scores are also expressed as potential yield gaps by converting them to percentage increases in output for each site. The yield gaps range from a 47% increase in SNNP to more than doubling of output in all other sites. These are encouraging findings, as they show there is scope to generate reasonably large increases in output with existing practices and existing levels of input use. The variance in yield gaps tends to be greater in sites with lower mean technical efficiency scores (e.g. Amhara and Borana), as shown by the coefficients of variation (CV) in Table 2. This is expected, because sites with a larger spread in performance should generally have larger yield gaps.

Table 2: Average technical efficiency & yield gap by site in Ethiopia

	Oromiya	Amhara	SNNP	Borana
Mean TE	0.44	0.38	0.68	0.43
Yield gap (%)	125	165	47	133
CV (%)	43	51	21	49

The distributions of the farm level technical efficiency scores within each site are shown in the box plots within Figure 2. There are reasonable similarities in the spread of the efficiency scores across

Oromiya, Amhara and Borana, while the farms in SNNP are more closely clustered at relatively high levels of efficiency.

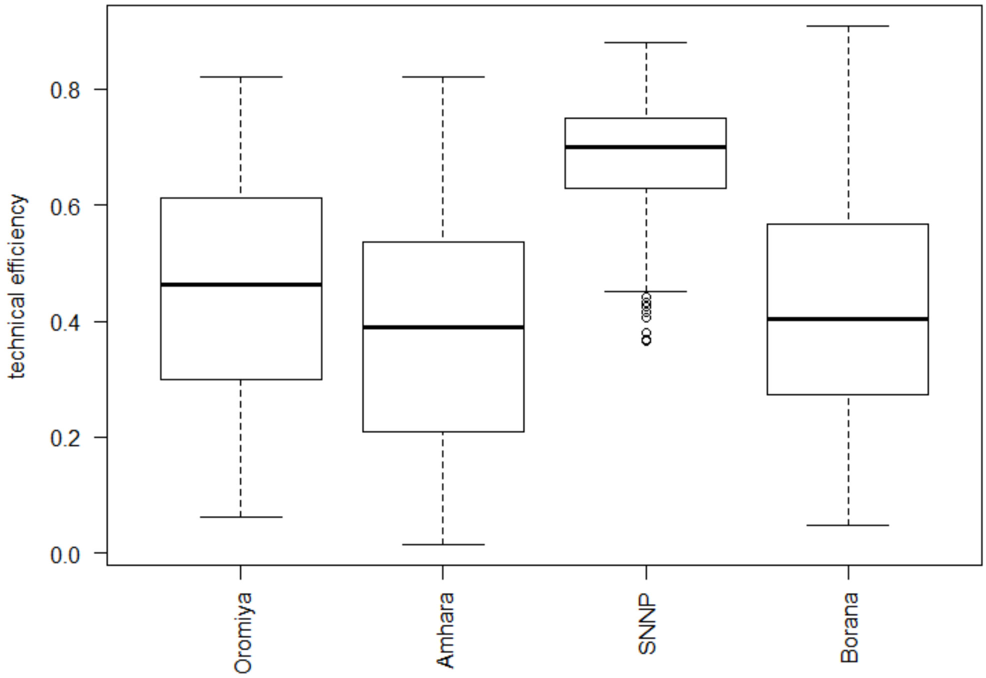


Figure 11: The distribution of farm technical efficiency for sites in Ethiopia

To further explore the potential gains from closing yield gaps, we report output targets which could be achieved by closing yield gaps, for a selection of the main livestock products in each site (Table 3). Unlike the average results reported in Table2, which give equal weighting to the farms in each site, the yield gap targets in Table 3 are calculated by dividing the baseline products for each farm by its respective technical efficiency score. While the magnitude of these changes broadly correspond to the mean yield gaps in Table 2, some differences emerge due to variations in product mixes and efficiency levels among farms. For instance, in Oromiya the potential for product expansion is higher than its average yield gap. This is because relatively more inefficient farms, with larger yield gaps, assume a greater output share of the main products in this site.

Table 3: Increased supply of main livestock and crop products (output targets) for Ethiopia. Values are percentages.

	Milk	Eggs	Meat
Borana	167	102	
Oromiya	130	201	178
Amhara	151	257	265
SNNP	49	48	30

Results – India

The average technical efficiency score for smallholders at each of the Indian sites are have relatively similar levels of efficiency, ranging between 0.6 and 0.69 (Table 4). Expressed as percentage increases in output, the aggregate site level yield gaps have a similarly narrow range from 46% to 66%. While these yield gaps are smaller than those estimated for Ethiopia, they still reveal that there is large scope to increase output with existing practices and existing levels of input use.

Table 4: Average technical efficiency & yield gap by site in India

	India Andhra Pradesh	India Maharashtra	India Bihar	India Haryana
Mean TE	0.69	0.67	0.61	0.60
Yield gap (%)	46	49	64	66
CV (%)	17	31	29	29

The box plots shown in Figure 12 reveal more detail about the distributions of technical efficiency within each site. The distributions are reasonably similar among the sites, although the spread in performance within India Maharashtra is relatively large, despite the high average efficiency for the site.

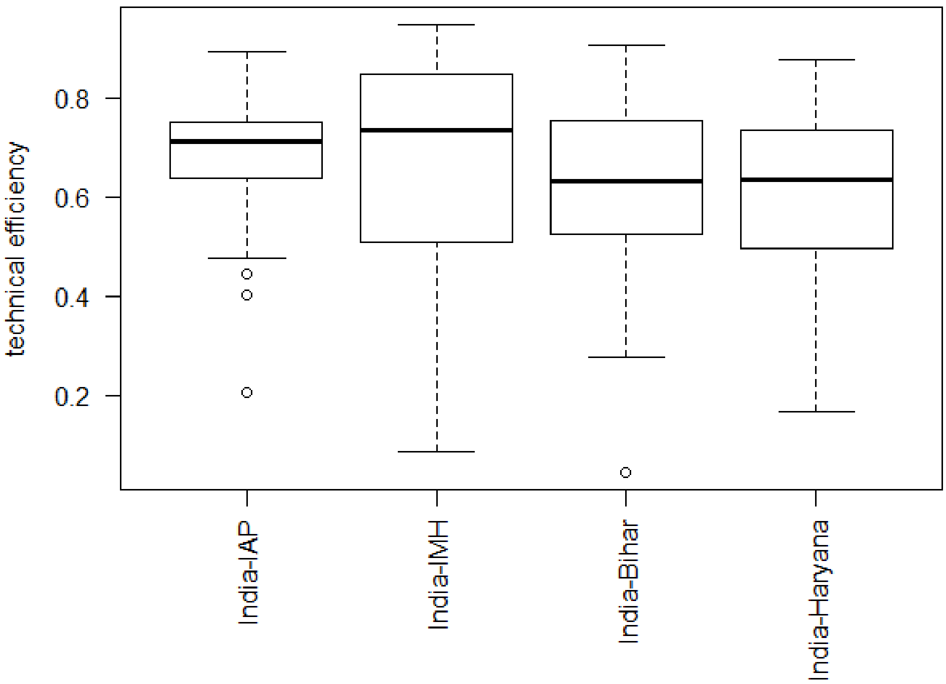


Figure 12: The distribution of farm technical efficiency for sites in India

Again, tangible benefits to food supply are provided by calculating farm output targets which could be achieved by closing yield gaps (Table 5). For these sites the potential increases in the production of specific livestock outputs of between 40% and 72%, very closely match the aggregate yield gaps reported above.

Table 5: Increased supply of main livestock and crop products (output targets) for India. Values are percent.

	Milk	Eggs	Meat
India Andhra Pradesh	45	62	
India Maharashtra	69	40	
India Bihar	72	66	68
India Haryana	55		

Discussion and conclusions

There are substantial yield gaps in the mixed smallholder farm communities assessed in this study, and closing these gaps would provide marked benefits for smallholder incomes. We estimate that there is the potential to raise the average supply of aggregate farm outputs by 47 and 165% in Ethiopia and by between 46 and 66% in South Asia. The corresponding livestock-specific increases for each region are between 30% and 265% in Ethiopia and between 40% and 72% in India. These potential improvements crop production are comparable with those from other yield gap studies. For example, in a global assessment Neumann et al (2010) estimate that crop yields are between 50 and 64% of their maximum potential, which translates to potential yield improvements of between 56 and 100%. Neumann et al (2010) used similar frontier-based methods as this study, however, their assessment as based on gridded spatial data which is likely to mask some of variability that would be present at the farm-level. In an assessment of yield gaps in African smallholder maize production across several countries, Tittonell and Giller (2013) estimated that observed yields on moderately fertile soils were between 36 and 61% of what could be attained under local conditions, which suggests that yields could be increased by between 64 and 178%.

While the estimation of yield gaps provide useful benchmarks for policy makers about potential improvements, it is equally important to understand the drivers behind these gaps. To this end, further assessment of the link between farm attributes and yield gaps would provide some possible site-specific leverage points, to help inform policy makers and extension agents in the design and targeting of capacity building programmes. In a related study Henderson et al. (2015) assessed these relationships for seven Sub-Saharan African sites covering five countries (Kenya, Uganda, Ethiopia, Senegal and Burkina Faso). The authors found a very strong and statistically significant link between market access and farm performance in most sites, particularly in more livestock-oriented sites. This suggests that efforts to improve market access should be an important component of policies to close yield gaps. Henderson et al. (2015) also found an efficiency dividend from the closer integration of crop and livestock enterprises. The benefits of integration are largely derived from the use of by-products from one enterprise in another that would usually be left unexploited. Two obvious examples are the use of manure to fertilize crops and the feeding of crop residues to animals. The benefits to integration were found to be larger for sites that were more specialized in either livestock or crop production. This finding is supported by the seminal work of McIntire, Bourzat, and Pingalii (1992), who showed that in more livestock dependent areas of Africa with low land productivity, crop production is not in competition with livestock and can provide residues for animal feed during times when pasture is less abundant. These findings could be used to help direct capacity building programs to smallholders most in need of support, as well is indicate production structures that are most likely to perform efficiently. While this study is an important first step, closer examination of and comparison of farms, including through field visits, would be needed to identify constraints and opportunities on site-by-site basis.

Finally, it is important to note that there are a number of ways to estimate yield gaps. This study relies on the *ex post* measurement of performance gaps between farms assuming no change in existing practices and technologies. Another important approach is to estimate, *ex ante*, the potential for increasing productivity by adopting new technologies, including improved varieties and breeds of crops and livestock. These approaches involve different, but complementary ways to achieve similar goals.

Yield gaps based on alternative interventions evaluated with household and regional models

Baseline production systems for household modelling

Before evaluating interventions for increasing livestock productivity it was necessary to establish baseline production for dairy animals and small ruminants in Ethiopia and India. For dairy in Ethiopia, a number of databases were available including the OPEC dataset (Duncan *et al.* 2013), the LSMS Ethiopia Rural Socioeconomic Survey (ERSS 2013), an ILRI analysis of smallholder dairy production systems in Ethiopia (Tegegne et al. 2013), and the IMPACTLite Ethiopia database. These databases had reasonably good recordings of herds sizes and milk production but were pretty poor in other characteristics such as inter-calving interval (Duncan *et al.* (2013) being an exception), which is a key factor in animal productivity in cattle systems.

Similar databases were available describing baseline dairy production systems in India. The OPEC and LSMS databases described above also contained data from several Indian states. In addition, the IMPACTlite (CGIAR research program on Climate Change Agriculture and Food Security) and VDSA (ICRISAT Village Dynamics in South Asia) databases provided details of animal numbers per household, reproduction, milk production and feeding. Information on animal numbers and production were also available at a state level from the Indian Ministry of Agriculture (MoA 2014a; MoA 2014b). Additional information on animal management, production and pricing was gained from the literature (Gupta *et al.* 2014; Kumar and Parappurathu 2014; Kumar and Kumar 2013; Meena *et al.* 2015; Rao *et al.* 2014; Singh *et al.* 2008).

Baseline productivity data for goats in Ethiopia was very difficult to obtain. The ERSS survey data had information on herd sizes, birth rates, disposals and mortality, but there was almost no data on productivity. Baseline data was supplemented by various papers published on goat production systems in Ethiopia, including Gizaw et al. (2013), Ebrahim and Hailemichael (2012), Dereje et al. (2015), Hirpa et al. (2011).

Similarly, whilst the IMPACTlite and VSDA databases provided some information on small ruminant production in India, most baseline data was obtained from the literature. Detailed information on reproduction and growth rates of sheep and goats raised in extensive grazing systems was available from Chandran *et al.* (2013); Chaturvedi *et al.* (2008); Nayak *et al.* (2008); Singh *et al.* (2009); Tailor (2012); Tanwar and Chand (2011) and Yadav and Tailor (2010).

Ethiopia

Survey data showed as much variation within regions as between regions so rather than undertake analysis on a large number of administrative regions it was decided to focus on three broad production-environment zones that aligned with the Livestock Master Plan for Ethiopia. These zones were:

(a) Highland mixed crop-livestock moisture sufficient systems zone (MRS)

(b) Highland mixed crop-livestock moisture deficient zone (MRD)

(c) Lowland grazing systems zone (pastoral and agro-pastoral) (LG).

For the dairy analysis, the lowland/pastoral systems were modelled using Borana cattle grazing natural pastures, the highland moisture deficient zone was assumed to be a rural system with some land and pasture access with crop straws and residues available, while the highland moisture sufficient zone assumed more intensive peri-urban and urban dairy systems with little access to land. In the highland zones both indigenous Zebu cattle and Zebu-European crossbred cattle were assessed.

Goats were analysed using similar zones with local breeds and crossbreds assessed in the lowland and highland moisture deficient zones and just crossbreds in the higher rainfall highland zone. The various interventions for dairy cattle and goats within each of the zones are summarized in Appendix A.

India

India can be broadly classified by state into six major agro ecological zones; arid, coastal, irrigated, rain-fed, hilly/mountainous and islands (Ramachandra *et al.* 2007). Of these, the irrigated, rainfed and arid zones are the most important for livestock production, containing around 85% of India’s ruminant population (MoA 2014a) (Table 6). The irrigated zone covers much of Bihar, Haryana, Punjab and Uttar Pradesh states and is characterised by high agricultural production. Dairy production is the main livestock enterprise, and there is a high proportion of buffalo and improved cattle breeds compared to other areas. Rice and wheat are the predominant crops. The rainfed zone covers much of central and southern India, including Andhra Pradesh, Chandigarh, Chattisgarh, Jharkhand, Karnataka, Madhya Pradesh, Maharashtra, Odisha, Puducherry, Telangana and Tamil Nadu. The major crops are coarse cereals, pulses, oilseeds and cotton. The rainfed zone is the largest agricultural zone, and home to 30% of India’s buffalo, 49% of the cattle and 51% of the small ruminants. Finally, Gujarat and Rajasthan states make up the bulk of the arid zone, along with the small union territories of Dadra & Nagar Haveli and Daman & Diu. This zone is characterised by erratic rainfall and long dry spells. The area has a large grazing resource, which supports a large number of sheep and goats – 19% of India’s small ruminant population. The main crop residues available for livestock are from wheat, pearl millet, ground nut, chickpea and mustard crops (Ramachandra *et al.* 2007). Crop residues and concentrates are fed mostly to large ruminants, and small ruminants subsist on green roughages.

Table 6: Number (millions) of bovines and small ruminants in each major agricultural zone. Data is from 2012 national livestock census.

Agricultural zone	Area (million ha)	Indigenous cattle	Crossbred cattle	Buffalo	Small ruminants
Rainfed	159	75.3	18.0	32.1	100.9
Irrigated	43	25.9	10.1	49.4	30.5
Arid	54	19.7	3.7	23.4	37.4
Hilly	59	16.4	3.8	3.0	17.5
Coastal	13	13.8	4.1	0.7	13.8
Islands	1	0.03	0.02	0.01	0.1
Total	329	151.1	39.7	108.7	200.2

The dairy sector is a major source of income for smallholder and landless farmers. Milk and other dairy products account for around two thirds of the value of the Indian livestock sector and support the livelihoods of nearly half of India's 147 million rural households (MoA 2014b; Rao *et al.* 2014). In 2012-13, India produced 132 million tonnes of milk (MoA 2014b). Half (51%) the milk produced was from buffalo, with 24 and 21% of milk production from crossbred and indigenous cattle, respectively. Around 4% of milk came from goats. This report will focus on dairy production from buffalo and cattle, using examples from the irrigated and rainfed zones. Attributes of the various production systems used for ruminants in the Indian study are described in Appendix B.

Small ruminants play an important role in improving the livelihoods of marginal and landless farmers in India, especially in the drier areas of the arid and rainfed zones. Sheep and goats provide meat, milk and wool, which can be traded or contribute directly to household food security. In 2012-13, mutton and chevron production accounted for almost 7% of the value of the livestock sector, whilst wool and hair accounted for only 0.1% (MoA 2014b). The small ruminant population is dominated by goats, which comprise 68% of the population (MoA 2014a). Indigenous sheep make up 31% of the small ruminant population, with improved, exotic sheep breeds contributing only 2%. The keeping of local goats for meat production will be the focus of the Indian small-ruminant part of this report.

Modelling interventions to address yield gaps

Interventions to address livestock yield gaps were tested using a smallholder household simulation model, the integrated analysis tool (IAT) (Lisson et al. 2010). The IAT is a spreadsheet model that integrates climatic variability, crop production, forages, livestock production, herd/flock dynamics, household economics and labour supply. Production of crops and improved forages are simulated using the stand-alone Agricultural Production System Simulator (APSIM – Keating et al. 2003) and imported into the IAT. Natural forages can also be simulated in a separate forage model or estimates of production provided as an input file. The livestock simulation model within the IAT predicts the liveweight gain and reproduction cycles for ruminant livestock under specified local feeding and husbandry practices. Simulated livestock production systems may include grazing, cut and carry feeding of forages and crop residues, and systems based completely on purchased fodders, residues and supplements. Animal production is based on energy and protein supply in the diet using the

Feeding Standards for Australian Livestock (Freer *et al.* 2007) and has been calibrated for local conditions using available data and published literature. The household economic model accounts for the key resource pools of labour, finance, land, household consumption needs and opportunities, forage and draught. It was developed to identify production, consumption and economic returns, and resource constraints associated with exploiting new forage–livestock opportunities.

The IAT model allows users to define and calibrate a baseline case against which to 'design' and test alternative crop, forage and livestock management options. The IAT also enables rapid assessment of potential production and socioeconomic impacts of changes in the system state (i.e. management, climate, soil, prices and costs). Less desirable strategies can be identified and discarded, leaving a shortlist of 'best-bet' options.

Results

Dairy - Ethiopia

Baseline dairy production was obtained from three sources of data; the LSMS database (Word Bank 2014), the OPEC database (Duncan et al. 2014), the Central Statistical Agency (CSA 2014) and the IMPACTLite Ethiopia database (Silvestri et al. 2014) and is shown in Table 7. Indigenous cattle produce yields of milk around 300 kg/year where the lactation length is 6-7 months which is equivalent to 1.4-1.6 kg/day. Only the OPEC dataset had significant numbers of crossbred cattle and yields of milk averaged 1560 kg/year with the range from 1161-2017 kg. This is a relatively high level of production reflecting this study's focus on including a significant sample of dairy farms with a strong focus on markets.

Inter-calving interval for indigenous cattle was considerably longer than for crossbred cattle. Only one database had information on inter-calving interval but the results are supported by specific research studies e.g. Alemayehu et al. (2009).

Table 7: Dairy cattle production indicators for Ethiopia

	Milk production (kg/year)		Inter-calving interval (months)	
	Indigenous	Crossbred	Indigenous	Crossbred
LSMS	336[1]		-	-
OPEC	276[2]	1556	23	16
Ethiopia	258[1]		-	-
CSA	288[1,3]		-	-

[1]Dataset does not distinguish between indigenous and crossbred but indigenous cattle make up > 90% of the statistics
[2]This dataset focuses on more market oriented dairy regions
[3]Data explicitly indicates it is net production i.e. does not include milk produced suckled by calves

Simulated milk and livestock production for the three study regions in Ethiopia is shown in Table 8 to Table 10. Baseline milk production and intercalving interval is generally consistent with the survey data. Crossbred cattle tended to have lower simulated milk production than the OPEC data. However, our baseline simulations used a basic forage diet with low levels of concentrate supplementation so it is not surprising that the milk yields are lower than the survey data, which spans all production systems.

In the Borana region, where there are relatively large herds under pastoral management and with almost no inputs, milk production is very low but returns are positive on the back of reasonable receipts from sales of cattle. Given the relatively low level of cropping in these lowland grazing regions and the access to pasture, the improvement option that we focussed on was oversowing of natural pasture with a perennial, herbaceous legume rather than feeding higher levels of concentrates and residues. The results in Table 8 show that the benefits from oversowing a legume accrue through increased cattle production rather than improvements in milk production per animal because of the genetic constraints of Borana cattle. The increased cattle productivity is a result of being able to sustain higher herd numbers, a much reduced calving interval (higher reproduction rates) and a nearly 300% increase in cattle sales. These factors combined to produce a significant increase in profit based on the assumption that the government provides the investment for pasture improvement on these communal grazing lands.

Table 8: Milk and livestock production from the Lowland Grazing region

	Baseline	Legume scenario
Herd size	26.3	38.4
Intercalving interval (months)	26	15
Milk yield (kg/year)	292	407
Animals sold	4.1	11.6
Mortality (%)	14.0	7.5
Profit (ETB)*	8,496	27,411

*Assumes the government meets the cost of pasture improvement

Table 9 and Table 10 show the effect of different interventions on dairy cattle performance in the Highland regions of Ethiopia. The rural highland dairy production system has access to some pasture (0.8 ha) and there is 1ha of cropping land that can provide cereal and/or pulse straws. This pasture needs to be supplemented with additional straw/hay where required and some crop residues and concentrates e.g. noug seed cake. The more intensive peri-urban and urban systems have almost no access to land and rely almost solely on purchased fodders, crop residues and concentrates. Herd sizes are much smaller (4-8 head) than the lowland grazing region.

Feeding natural pasture and/or low quality forages with low levels of concentrates (Baseline) to indigenous Zebu cattle resulted in low milk yields and long calving intervals (2 years). For both rural highland and intensive systems farm financial losses were projected, with the loss being greater in intensive systems where all fodders must be purchased.

Feeding higher levels of concentrates (c. 3.0 kg/day/cow of noug seed cake and wheat bran) to indigenous cows lifted productivity as cow weight and condition improved which increased reproductive performance through reduced calving interval and lower mortality. Increases in milk yield per animal were modest in response to concentrate feeding. Farm profit was positive but remained modest.

The forage improvement strategies differed between the highland rural and intensive peri-urban/urban systems. In the rural highland system 0.5 ha of the 0.8 ha of available pasture was converted to the legume forage, lablab. In the intensive dairy systems, purchased fodders shifted from cereal straws to urea-treated stovers, which are contain higher levels of protein and are more digestible. In the rural highland system, lablab offered a good alternative to concentrates in increasing milk production though calving interval was not reduced as much. Planting lablab was a lower cost alternative to feeding concentrates so profit slightly increased. Feeding urea-treated stovers to indigenous cows increased animal productivity but their relatively high cost meant that little profit was generated.

The improved genetic potential of crossbred cattle for milk production resulted in a doubling of milk yields, even on baseline diets, and farms shifted from loss making enterprises to making a small profit. However, milk production and herd productivity was still quite low, with mortalities being quite high.

Compared with indigenous breeds, crossbreds were able to express their genetic potential when feeding was improved. Milk yields increased from baseline levels of less than 900 kg/year to 1800-1900 kg/year when fed higher levels of concentrates or improved forages. This highlights the benefits of focussing on system improvements in both nutrition and genetics rather than a single component technology. Feeding concentrates at 3.0 kg/cow per day had a bigger impact on milk yield and animal productivity than feeding improved forages with small amounts of concentrates. It should be noted that a significant component of the additional benefit in the concentrate scenario was from reduced calving interval and increased sales of animals. With the reduced calving interval and lower mortality in better fed crossbred animals, a larger herd could be carried compared with the baseline. There was little difference between the rural highland and more intensive feeding dairy systems under conditions of improved feeding.

Table 9: Milk and livestock production from the Highland Moisture Deficient zone – rural highland dairy production

	Baseline Zebu	Conc. Zebu	Forage Zebu	Baseline X-bred	Conc. X-bred	Forage X-bred
Herd size	4.2	5.1	5.3	4.9	7.4	6.6
Intercalving interval (mth)	24	18	22	20	14	18
Milk yield (kg/year)	306	669	702	741	1960	1753
Animals sold	0.6	1.0	0.9	1.0	2.6	1.4
Mortality (%)	13.4	8.8	9.6	18.6	6.6	7.6
Profit (ETB)	-104	2488	3687	676	33,406	16,058

Table 10: Milk and livestock production from the Highland Moisture Sufficient zone – urban and peri-urban intensive dairy production

	Baseline Zebu	Conc. Zebu	Forage Zebu	Baseline X-bred	Conc. X-bred	Forage X-bred
Herd size	4.3	5.1	5.6	5.5	6.6	6.2
Intercalving interval (mth)	24	12	14.4	20	12	16
Milk yield (kg/year)	429	627	474	848	1885	1810
Animals sold	0.8	2.1	1.5	1.0	2.7	1.6
Mortality (%)	9.9	7.6	10.0	10.1	5.7	7.0
Profit (ETB)	-1388	4149	30	947	31,003	17,680

Dairy – India

Although there is wide variation in production levels, average milk yields of dairy animals kept by smallholder farmers are generally lower than their genetic potential (Table 11). Length of lactation is usually around 9 months for all breeds, but may be shorter for indigenous animals, especially under conditions of poor nutrition (Meena *et al.* 2015; Rao *et al.* 2014). Inadequate nutrition is the biggest limitation to increasing production, and diets of dairy animals are based largely on crop residues such as rice straw, wheat straw and maize stover. In some areas animals may also graze on communal grasslands, but only small areas are dedicated to fodder production because most agricultural land is under crops. Most farmers cannot produce enough feed for livestock from their own land and need to purchase additional feed. Dairy production tends to be higher in the irrigated zone compared to rainfed and arid areas because more feed is available.

Table 11: General production characteristics of dairy animals kept by smallholder farmers in India (Duncan et al. 2013; Meena et al. 2015; MoA 2014a; MoA 2014b; Rao et al. 2014)

Breed	Milk yield (kg/day)	Milk yield (kg/lactation)	Inter-calving interval (m)
Indigenous cattle	1-4	400-900	16-23
Crossbred cattle	6-12	1600-2200	13-18
Buffalo	3-8	1000-1500	17-19

For the irrigated zone, we simulated the effects of improving nutrition on milk production from buffalo, which are the dominant dairy animal. The baseline diet consisted mostly of crop residues and native grass, supplemented with 1.5 kg/head/day of rice and wheat bran. Supplementing she-buffalo with additional green feed or concentrates increased milk production, whilst inter-calving intervals were maintained (Table 12). The use of high energy feeds such as rice and wheat bran was the most efficient way to increase production. However, these feeds may not always be available or may be too expensive for farmers to purchase, even though they generate higher returns. While the green feed in this scenario was purchased, small plots of improved grasses may be grown around the edge of cropping land or household area, contributing to household feed resources. There are also options for forage legumes to be grown in relay with cereal crops, utilising any residual moisture at the end of the growing season. Growing rather than purchasing green feed would increase profits, though may require an increase in household labour requirements.

Table 12: Milk and livestock production from buffalo in the irrigated zone

Intervention	Herd size	Intercalving interval (m)	Milk yield (kg/day)	Milk yield (kg/lactation)	Mortality (%)	Profit (INR)
Baseline	3.9	18	4.2	1128	5.7	46,870
Improved stover	3.9	17	4.7	1260	5.1	63,462
Increased green	3.8	19	7.0	1887	5.4	75,765
Increased concentrate & green feed	3.9	18	7.9	2136	5.0	86,230
Increased concentrate	3.9	17	8.1	2197	5.3	87,159

An alternative way to improve animal nutrition is to improve the quality of existing feed resources. This can be achieved through new crop cultivars, changes to crop management and treatment of crop residues (Anandan *et al.* 2013; Bidinger and Blümmel 2007; Reddy *et al.* 2003). In the improved stover scenario, we increased the metabolisable energy content of stover by 1 MJ/kg DM. We assumed that there was no increase in cost of stover, thus there was a modest increase in profit (Table 12). However, even if the cost of cereal straw was increased, the profit would still be higher than the baseline scenario.

For the rainfed zone where indigenous cattle are the dominant dairy breed, we investigated the effects on production and profit of replacing indigenous cattle with either buffalo or crossbred cattle. Crossbred cattle and buffalo have the genetic potential to produce higher milk yields than indigenous cattle breeds (Table 11). In addition, milk from buffaloes and some exotic breeds such as Jersey cattle has a higher milk fat content, which generally attracts a higher price at sale. However, crossbred cattle and buffalo are also bigger than indigenous cattle, and require a larger amount of feed. Along with the higher milk prices, we assumed that there would be greater mating and health costs associated with switching to these breeds.

On the baseline diet of native grass and maize stover, changing breeds resulted in a small increase in daily milk production (Table 13). While milk production was higher for buffalo and crossbred cattle compared to indigenous cattle, daily yields were still low due to inadequate nutrition. In all breeds, poor nutrition also resulted in high mortality rates and long inter-calving intervals, which contributed to reduced profits. Increased profit for buffalo was largely due to the higher price of milk. In areas where a price premium is not paid for high-fat milk there would be less benefit in switching to buffalo unless milk production could be substantially increased through better nutrition. Providing concentrate feed to livestock allowed animals to express their genetic potential, increasing milk production and profit, especially for buffalo and crossbred cattle.

Table 13: Milk and livestock production in the rainfed zone. Dairy animals were fed a baseline diet of maize stover and native grass with the addition of 1 kg (low) or 3 kg (high) of bran/day

Intervention	Breed	Herd size	Intercalving interval (m)	Milk yield (kg/day)	Milk yield (kg/lactation)	Mortality (%)	Profit (INR)
Baseline	Indigenous	3.0	23	1.8	441	11.3	2,662
Baseline	Buffalo	3.3	21	2.2	559	11.8	17,587
Low concentrate	Indigenous	3.7	18	2.9	779	6.4	9,330
Baseline	Crossbred	2.5	24	3.0	801	12.3	10,301
Low concentrate	Buffalo	3.3	18	3.3	830	7.8	36,301
Low concentrate	Crossbred	3.7	19	4.2	1,137	6.7	24,483
High concentrate	Buffalo	3.8	17	4.7	1,281	5.2	42,587
High concentrate	Crossbred	3.7	18	7.2	1,954	5.3	31,283

Implications for interventions

The results from this modelling analysis suggest that significant improvements in dairy production can be achieved through better genetics and better nutrition. This is highlighted in Figure 13, which shows the increases in milk yields for the different interventions in Ethiopia. The percentage increase in milk yield of the different interventions, compared with baseline nutrition of indigenous Zebu, is shown at the top of each bar. Just improving nutrition of indigenous cattle or only switching to crossbred cattle without lifting nutrition limits potential gains. Large increases in milk production and reproductive performance come from combining interventions in nutrition and genetic gain. A similar pattern was observed with results from the Indian modelling.

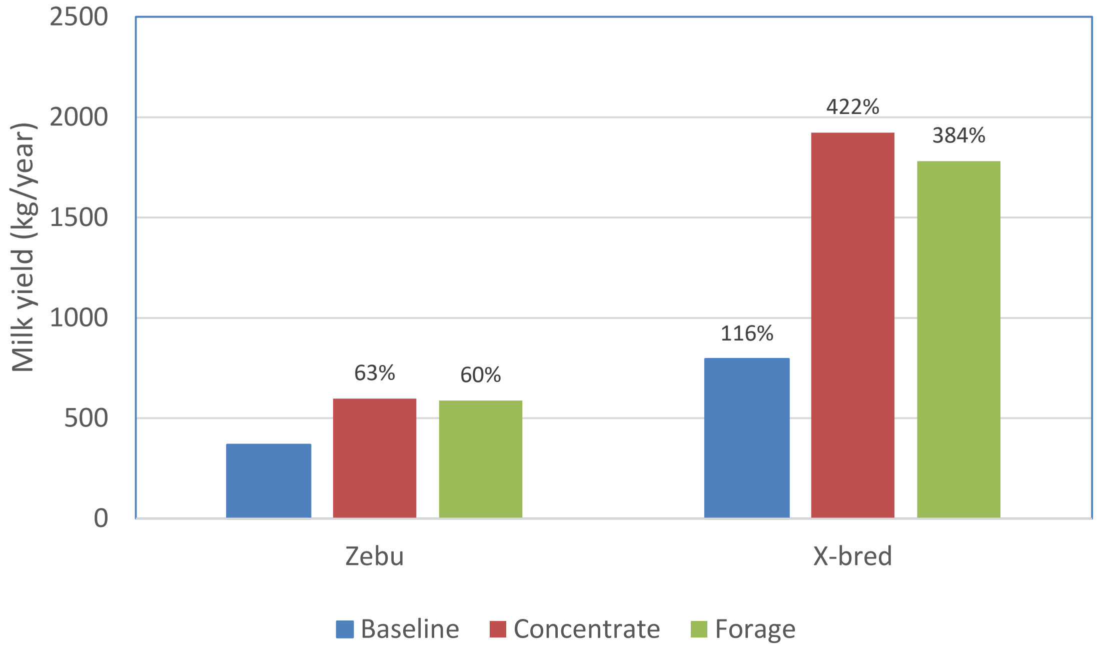


Figure 13: Increases in milk yields in response to different interventions. The values above the bars represent percentage increases relative to the indigenous Zebu receiving a baseline diet

At present, over 90% of cattle in Ethiopia are indigenous breeds (CSA 2014, ERSS 2013), and even in regions with more commercial dairy activity, crossbred animals only represent 20-40% of total dairy cattle numbers (Duncan *et al.* 2013). Similarly, half the bovine population in India is made up of indigenous cattle breeds, while crossbred and exotic cattle breeds account for only 13% - the rest are buffalo (MoA 2014a). Improving genetics is a key component of the Livestock Master Plan for Ethiopia (Ministry of Agriculture, 2014) and the Indian National Dairy Plan. In Ethiopia, there are ambitious targets to increase the number of crossbred cattle in the Moisture Sufficient systems from 450,000 head in 2014/15 to over 4,000,000 head in 2019/20. Although indigenous cattle are still the dominant breed in India, a shift towards higher-producing crossbred cattle and buffalo is already occurring. Between the 2007 and 2012 livestock censuses, the number of female crossbred cattle and buffalo increased by almost 7 million each, while the number of indigenous animals decreased.

Beef is not commonly consumed in India, and male cattle have little value to farmers except as draught animals. Across all breeds, there was a 19% decrease in the number of male animals between 2007 and 2012, which may indicate a shift away from the use of draught animals towards mechanised agriculture and an increased focus on dairy production. However, the relative value of male cattle cannot be overlooked because half the offspring produced in the dairy industry will be male calves. Because of this, transitioning from indigenous cattle breeds to buffalo instead of crossbred cattle may be a safer option for farmers since it is more likely that there will be a market for male animals.

Results from these analyses suggest that significantly increasing the milk yields of crossbred cows and buffalo through better nutrition is economically feasible if concentrates and/or improved forages are available. While the Ethiopian Livestock Master Plan is very ambitious in the targets for genetic improvement, the goal for milk production increases at an individual cow level would appear to be achievable i.e. increase from 247 litres/year for indigenous breeds to 1,053 litres/year for crossbred cows. Indeed even under feeding regimes of modest nutrition, crossbred cows should easily be able to achieve greater than 1000 litres/day.

Improved milk yields per animal require greater feed inputs and this might is likely to represent a significant constraint to realising improved dairy production in both countries. Table 14 shows the increase in feed demand per animal in response to genetic improvement and feeding strategy for the Ethiopian simulations. The most productive scenario (i.e. concentrate feeding to crossbred animals) resulted in a significant increase in feed demand compared with indigenous animals on a baseline diet (83%) or even crossbred animals on a baseline diet (73%).

Table 14: Forage and concentrate intakes (dry matter basis) for the various scenarios in Ethiopia. Rural highland and intensive systems have been averaged

	Baseline Zebu	Conc. Zebu	Forage Zebu	Baseline X-bred	Conc. X-bred	Forage X-bred
Forage intake (kg/hd/yr)	1703	1713	1807	1973	2284	2403
Concentrate intake (kg/hd/yr)	146	511	146	292	1095	292
Total intake (kg/hd/yr)	1848	2224	1953	2265	3379	2694

When these increases in feed demand are scaled up to the target numbers in the Livestock Master Plan, the challenges become apparent. Within the Moisture Sufficient zone using the target of increasing crossbred animals by 3,500,000 by 2019/20 and assuming these are fed under the concentrate scenario then an additional 5.36 million tonnes of feed has to be provided each year. Under this scenario most of the additional feed requirement is in concentrates such as wheat, corn or rice bran or whole grain (3.3 million tonnes). Currently most concentrate feeding of dairy animals is based on crop residues e.g. brans and seed cakes. Total cereal grain production in Ethiopia is around 18 million tonnes per year (USDA 2013). Bran represents about 15% of whole grain so 18 million tonnes would produce about 2.7 million tonnes of bran. Even if all the bran produced in Ethiopia was directed to dairy feeding in the MRS zone it would not meet the additional demands of 3.5 million crossbred cattle under a high production scenario. It would likely need some whole grain to be utilised in dairy feeding systems.

Similar deficits also exist for dairy production in India. At a national level, there is currently a deficit in the amount of energy available for livestock production. Increasing milk production will require both an increase in the quantity of feed available and more efficient use of existing resources. This is especially important as the smaller indigenous livestock breeds are replaced by larger crossbred cattle and buffalo with higher energy requirements. A shift away from the use of cattle and buffalo for draught purposes will make more feed resources available for dairy production. However, a decrease in the total size of the national dairy herd may still be required to increase total production.

A feed-balance assessment was used to investigate opportunities to increase milk production within the constraints of current feed resources in the states of Bihar (irrigated zone) and Odisha (rainfed zone). Based on animal numbers and average daily milk yields reported in the 2012 livestock census, daily milk production was estimated to be 19.7 thousand tonnes in Bihar and 4.7 thousand tonnes in Odisha. This equated to approximately 190 and 110 g milk per person/day in Bihar and Odisha, respectively. Results suggest that reasonable increases in milk production at a state level can be made by more efficiently feeding indigenous livestock (Table 15). Improving production of crossbred cattle in both states and buffalo in Odisha gave smaller increases because they comprise only a small portion of the population. Larger gains could be made from replacing indigenous cattle with crossbred cattle or buffalo, especially if they were fed better to achieve higher daily milk yields. The intervention with the highest increase in production, replacing half the indigenous cattle with high-yielding crossbred cattle, would increase milk availability to 250 and 230 g per person/day in Bihar and Odisha, respectively.

Table 15: Examples of interventions to increase milk production applied at a state level, assuming a constant level of feed energy available. Baseline milk production estimates are based on animal numbers from the 2012 livestock census and reported average milk yields (MoA 2014a; MoA 2014b)

Interventions	Bihar (irrigated)	Odisha (rainfed)
Baseline milk production (000 t/day)	19.7	4.7
Additional milk production (000 t/day)		
Increase production from indigenous cattle to 4.3 (irrigated) and 2.3 (rainfed) kg/h.d	2.3	1.1
Increase production from crossbred cattle to 8.1 (irrigated) and 6.5 (rainfed) kg/h.d	1.8	0.1
Increase production from buffalo to 6.1 (irrigated) and 4.6 (rainfed) kg/h.d	3.5	0.1
Increase production of crossbred cattle and buffalo	5.3	0.2
Replace 50% indigenous cattle with buffalo	1.0	1.5
Replace 50% indigenous cattle with high-producing buffalo	6.1	2.2
Replace 50% indigenous cattle with crossbred cattle	3.4	5.1
Replace 50% indigenous cattle with high-producing crossbred cattle	6.8	5.5

This highlights the need to carefully examine the whole system feed implications before embarking on a large scale dairy improvement program.

Goats – Ethiopia

Compared with dairy cattle, there is little information on goat productivity contained within the large surveys e.g. CSA 2014, ERSS 2013. There have been a number of more focussed studies on goat production systems and productivity of indigenous goats in Ethiopia and based on those studies, the general herd characteristics for the three different regions is shown in Table 16.

Table 16: General production characteristics of indigenous goats in Ethiopia (based on data from Dereje et al. 2014, Tadesse et al (2014), Gizaw et al. (2010), Hirpa et al. (2010)

	Lowland	Moisture Deficient Highland	Moisture Sufficient Highland
Herd size	20-50	15-25	10-20
Age at slaughter (m)		12 - 20	
Mortality (%)	20-30	15-25	10-20
Mature body size (kg)		22-30	
Price received (ETB)		500 for weaner, 600-700 for doe, 1000-1200 for fattened male	

Simulated production from extensive goat systems in the pastoral lowlands is shown in Table 17. Two baseline scenarios with local goat breeds were used – one with access to pasture restricted (5 ha for the herd) and a baseline where access to pasture (10 ha) would meet forage demand in most years. Under restricted forage access and a baseline mortality of 25%, goat sales and meat produced was low and even though input costs were low, costs exceeded revenue and a loss was generated. When access to forage was not restricted, a small profit was generated. Improving animal health to reduce mortalities to 10% resulted in a significant increase in sales and meat produced and profit, even with the additional input costs of veterinary treatments.

The higher productivity of crossbreds generated significantly higher returns than local breeds despite the fact that herd sizes were reduced to not increase the area of pasture required and the loans required to purchase crossbreds to improve herd genetics.

Improving forage quality and quantity through oversowing with a legume dramatically increased productivity and profit for both local breeds and crossbred goats. This was achieved through being able to carry more animals and producing more liveweight per animal. A combination of crossbred goats, legume addition and improved animal health (reduced mortality) was able to produce quite substantial profits. Demand for goat meat in recent years, particularly from Middle Eastern countries, has seen sale price of goats increase from 200 ETB to 800 – 1,000 ETB. Consequently increases in productivity can generate good returns.

Table 17: Goat production and financials for the Lowland Grazing region

Scenario	Breed	Herd No.	Births	Sales	Production (kg/yr)	Mortality (%)	Profit (ETB)
Baseline restricted	Local	36.4	16.3	7.1	96.9	26	-1,150
Baseline	Local	38.4	18.7	9.1	172.9	25	981
Low Mortality	Local	39.8	19.9	15.7	295.5	10	2,937
Baseline	Crossbred[1]	32.7	19.5	9.1	240.6	25	4,080
Low Mortality	Crossbred	38.1	24.0	19.2	403.6	10	6,811
Legume[2]	Local	56.5	30.5	15.6	344.4	25	4,705
Legume + low mort	Local	57.2	30.8	24.0	534.3	10	8,005
Legume	Crossbred	39.5	24.5	11.4	315.6	25	6,756
Legume + low mort	Crossbred	45.6	30.2	24.0	530.0	10	11,062

[1] Assumes private loans to purchase 12 crossbred goats to improve productive potential.

[2] Assumes government provides pasture improvement

It was assumed that farmers in the Moisture Deficient Highlands had access to 0.8 ha of pasture and browse that this was supplemented with low quality cereal straws or stover with no crop residues or concentrates fed to goats. Baseline mortality was assumed to be 20%. With herd sizes around 20 goats productivity was low for both local breeds and crossbred animals because of poor nutrition (Table 18). Reducing mortality was able to turn financial losses into small positive returns. Improving forage through sowing some of the pasture area to lablab was a cost-effective way of improving productivity and profit. Compared with baseline production, improved forages permitted a threefold increase in goat meat turned off.

Table 18: Goat production and financials for the Moisture Deficient Highlands region

Scenario	Breed	Herd No.	Births	Sales	Production (kg/yr)	Mortality (%)	Profit (ETB)
Baseline	Local	18.3	9.0	4.6	69.1	23	-3
Low Mortality	Local	20.7	11.4	8.7	107.7	12	257
Improved forage	Local	22.0	14.2	11.6	200.9	10	1,239
Baseline	Crossbred[1]	14.7	7.8	3.0	60.3	25	-562
Low Mortality	Crossbred	16.7	10.0	5.9	109.7	17	264
Improved forage	Crossbred	17.9	11.3	8.3	206.9	11	2095

[1] Assumes private loans to purchase 6 crossbred goats to improve productive potential.

Farmers in the Moisture Sufficient Highlands simulations had no access to pasture for their goats and all fodders had to be purchased. Baseline mortality was assumed to be 15%. Given the lack of land and pasture, it was assumed only crossbred goats would be kept and that herd sizes were around 15 head. With baseline forages based on cereal and pulse straw and animals fed adequately, a modest profit could be generated (Table 19). Improving the nutrition of goats through feeding higher quality urea-treated stover improved productivity by 25% and although profitability was still modest, it was almost three times the baseline simulation.

Table 19: Goat production and financials for the Moisture Sufficient Highlands region

Scenario	Breed	Herd No.	Births	Sales	Production (kg/yr)	Mortality (%)	Profit (ETB)
Baseline	Crossbred[1]	15.1	10.5	6.8	158.2	15	1,323
Low Mortality	Crossbred	15.9	11.2	8.9	201.3	7.7	2,307
Improved forage	Crossbred	15.8	11.2	8.9	216.8	8.1	3,520

[1] Assumes private loans to purchase 6 crossbred goats to improve productive potential.

Goats – India

Most goats in India are managed by poor farmers with limited resources, and production systems are similar in both the arid and rainfed zones. The general characteristics of the national goat herd are described in Table 20. Goats graze mainly on communal land resources - natural vegetation, common grazing land, wastelands and crop stubbles, with minimal supplementation from either green fodder or concentrates (Yadav and Tailor 2010). The main constraint facing grazing animals is a lack of feed (Gujar and Pathodiya 2008). Farmers agree that the size and condition of communal rangelands is declining due to land reclamation, overstocking and lack of management, and there is insufficient biomass and nutrients available to meet the demands of the flock (Porwal *et al.* 2006). In the baseline scenario, it was assumed that grazing animals could meet approximately 80% of daily dry matter intake requirements from communal grazing land, and this provided production outputs similar to values published in the literature.

Table 20: General production characteristics of local goats in India. Based on data from (Chandran et al. 2013; Kumar and Kumar 2013; Porwal et al. 2006)

Production characteristic	Value
Flock size (number animals)	5-50
Age of males at sale (months)	3-6
Mortality (%)	10-20
Mature female weight (kg)	20-30
Price received (INR/kg)[1]	130 for females, 160 for males

[1] average values from regression equations developed by Kumar and Kumar (2013). Values were consistent with those reported by Tyagi *et al.* (2013)

Although farmers in the baseline scenario made a small profit from goat-keeping, production levels were constrained by poor reproduction and high mortality rates (Table 21). In addition to this, male offspring weighed only 9 kg at sale, resulting in low animal prices. The results from the modelled interventions highlight the importance of adequate nutrition in improving goat production. Increasing the amount and/or quality of feed available to goats increases the number of offspring born and average daily gain of growing animals (Chaturvedi *et al.* 2010; Chaturvedi *et al.* 2003; Chaturvedi *et al.* 2006; Chaturvedi *et al.* 2012; Sankhyan *et al.* 2007; Yadav and Khan 2011). Good nutrition also contributes to lower mortality rates of both juveniles and adults. Combined, these factors lead to an increased amount of meat produced, and potentially a higher profit.

Table 21. Goat production and financials for extensive grazing systems in India

Intervention	Breed	Flock size	Births	Sales	Production (kg/yr)	Mortality (%)	Profit (INR)
Baseline	Local	10.2	4.9	2.9	32.6	25	3,251
Supplement does (wheat bran)	Local	15.2	10.2	8.7	86.0	9	1,890
Improved pasture + low mortality	Local	13.5	7.4	6.1	71.2	9	8,803
Improved pasture	Local	13.0	6.9	5.0	62.3	15	8,375
Supplement does (cereal straw)	Local	12.8	6.4	4.6	57.4	15	6,233
Supplement kids	Local	10.2	4.9	2.9	56.5	25	5,496
Free grazing	Local	8.2	5.1	4.1	49.7	11	7,838
Baseline + low mortality	Local	12.1	6.0	3.8	42.5	19	3,543

An unrestricted grazing scenario ('free grazing', Table 21) was modelled to assess the impacts of increasing the amount of feed available to goats by reducing stocking rates. By reducing the average number of breeding females from 8.3 to 5.6, the amount of biomass required to sustain the flock in this intervention was comparable to the baseline scenario. Despite a reduction in breeder numbers, both total production and profit increased. Improved nutrition caused higher reproduction rates, and lower kid mortalities meant there were more offspring available for sale. Weight of offspring at time of sale also increased.

Similar to the Ethiopian study, improving the quality of pasture by oversowing with a legume resulted in a substantial increase in both production and profit. The higher profit compared to other interventions with similar levels of production (e.g. supplementing does with cereal straw) is because no cost to the farmer was included in the model. While it may not be the case in practice, for the purpose of this exercise it was assumed that local government would meet the cost of range improvement.

Three interventions investigated the impacts of improving livestock nutrition by providing supplements to specific classes of livestock. Supplementing does with wheat bran provided the largest increase in production. However, it was also the most expensive intervention, with a smaller profit than the baseline scenario. Providing supplement to does increased kidding and survival rates, but growth of weaned offspring, and therefore sale weights, remained low. Supplementing does with poorer quality cereal straw caused a smaller increase in animal production, but due to the low cost of straw compared to wheat bran (5 vs. 18 INR/kg), it was a more profitable feeding strategy. This is an important consideration for landless farmers who need to purchase supplements, or farmers who feed crop residues and by-products to large ruminants in preference to goats. In comparison, when supplement was directed towards weaned male goats, there was little change to animal mortality, but growth rates were much higher, and animals were sold at an average of 21 kg. If resources were available, the most effective strategy might be to feed poor quality crop residues to mature does, which have relatively low energy requirements, whilst directing higher quality but more expensive supplements towards male goats, which can be sold for cash.

The impacts of disease control were also assessed in two of the modelled interventions ('baseline + low mortality' and 'improved pasture + low mortality', Table 21). In these scenarios, the baseline mortality rate was decreased, and animal vet costs were increased. Importantly, under conditions of inadequate nutrition ('baseline + low mortality'), there was only a small decrease in flock mortality rates, and due to the additional costs, there was a minimal increase in profit. Decreasing mortality rates had a much larger impact on production and income when combined with an intervention that also addressed goat nutrition. While disease is an important limitation to goat production in India, animal nutrition also needs to be addressed for interventions to be effective.

Implications for interventions

The scenarios tested in this project are consistent with the proposed interventions in the Ethiopia Livestock Master Plan (LMP) for increasing goat production. The LMP aims to improve both the goat herd population (20-60%) and the productivity of individual animals through "a 20% live weight gain, a 3 percentage point increase in dressing percentage, a 4 percentage point increase in parturition rate over 20 years and an annual increase of adult off-take rate from 4-5% are expected". When these expected increases are integrated, goat meat production is anticipated to increase by 67-123%.

The intervention strategies suggested in the LMP include:

Lowlands

- Pasture introduction with higher productivity grasses and legumes and improved rangeland management
- Reductions in mortalities through better animal health programs
- Breed improvement and selection (no AI)

Moisture Deficient and Moisture Sufficient Highlands

- Breed improvement with a focus on AI
- Reducing mortality through vaccines and anti-parasites
- Better use of fodders and crop straws and residues.

The simulations in this study suggest that the combination of improved genetics, pasture/forage improvement and reduced mortalities can increase goat productivity on an individual herd basis by greater amounts than set as objectives in the LMP.

Similar strategies to improve goat production in the extensive grazing systems of India are described in the National Livestock Mission (MoA 2015). Key features of the advisory on improving sheep and goats production include:

- Prevention of animal loss through universal deworming and a vaccination program
- Increasing the nutrition of livestock through supplementation, improved grazing resources and adequate provision of water
- Training for farmers in improved animal husbandry practices
- Breed improvement and selection (no AI)

There are significant challenges in achieving the productivity gains modelled in this project. Oversowing natural pastures on communal grazing land will require careful selection of appropriate species and developing reliable establishment techniques. Most of the grazing land in both Ethiopia and India is communal, so it will almost inevitably fall on government to improve pastures. Given the land is largely communal it can provide challenges in managing the land in the months following pasture introduction to ensure a high chance of successful establishment. Similarly, decreasing grazing pressure on communal rangelands needs a community level approach, and may require government incentives or enforcement. While decreasing flock numbers can increase both production and profit at a household level, it may be a risky practice for smallholder farmers unless animal disease and mortality is also addressed.

Improving genetics through introduction of crossbreds in a reasonable timeframe will require purchase of animals, which will likely require farmers to take out loans for animal purchase.

Despite these challenges, goats offer an opportunity to increase incomes of the rural poor and supply of meat to the market. In addition, more efficient animal production may reduce labour requirements, providing social benefits and allowing family members to work for off-farm income.

Poultry yield gap analysis

In this study, the Village Poultry Simulation Model (VIPOSIM) was used to simulate village poultry systems for both Ethiopia and India which is a dynamic deterministic model developed to simulate the dynamics of village poultry flocks. The model was developed at Wageningen University, in the Netherlands, and validated with data from Tigray, Ethiopia (Asgedom 2007). Qualitative data are used to conceptualise the model relations, whereas quantitative data are used to quantify those relationships and to define input values for a village poultry systems. Mortality is the main source of variation in flock dynamics in village poultry systems, with diseases and predation being the main causes of death. Other causes of mortality are accidents, smothering, drowning, and theft (Udo *et al.* 2006).

In this study, the model was parameterised to represent both Ethiopian and Indian backyard poultry production systems. VIPOSIM takes into account the complex and dynamic aspects of a village poultry production system by incorporating five processes related to chicken production and management (flock offtake, egg production, egg loss, egg offtake and reproduction). The model performs calculations in time steps representing reproduction cycles. Each step has a length of three months (seasonally) and the maximum number of steps in the model is twelve, which corresponds to a period of three years (Asgedom 2007). Within the model, a flock is categorized into five categories according to age and gender: i) the chicks group includes all chickens up to three months of age; ii) cockerels are male chickens older than three months but not yet adult; iii) pullets are female chickens older than three months but not yet adult; iv) hens are female adult chickens; and v) cocks are male adult chickens.

The schematic sequences of events in VIPOSIM for each time step, with the broken arrows indicating the inputs and outputs are shown in Figure 14. The input variables in VIPOSIM include chicken production and management parameters such as initial size and composition of the flock, mortality rates, bird sales, bird consumption rates, egg production, reproduction parameters (incubation and hatching), egg sales, egg loss, egg consumption rates, and bird offtake limits. These variables are related to agro ecology and husbandry conditions, and they differ across the seasons. The economic parameters such as prices of birds and eggs and costs of production are also input variables in the model. VIPOSIM categorises total costs from the input costs of labour and costs of intervention. The model also incorporates the standard deviations of each input parameter (Udo *et al.* 2006; Tomo *et al.* 2012).

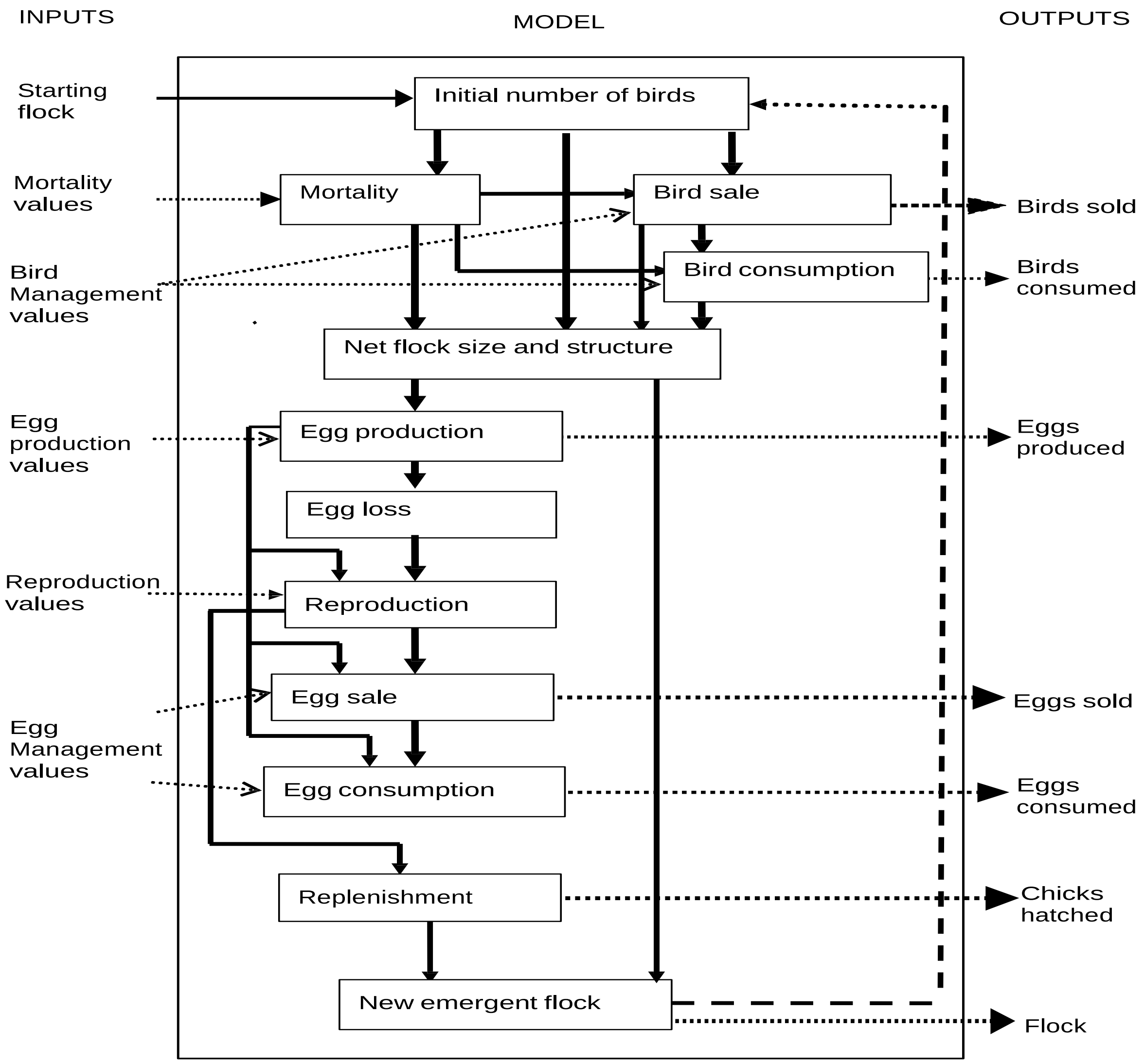


Figure 14: Schematic representation of sequences of events in the model for each time step; broken arrows represent inputs and outputs (Udo et al. *2006)*

Conceptual framework and estimation techniques

The model considers mortality, egg production, reproduction and offtake of birds and eggs. Mortality rates are by default distributed as 75% chicks, 20% growers (pullets and cockerels) and 5% adult birds. We assumed that backyard poultry producers aim to maintain bird numbers at a certain target flock size adjusted to the scavenging feed resources base. Additional birds, predominantly growers are consumed or sold depending on the season, and backyard producers aim to maintain a male:female ratio of 1:4 in their flock (Udo *et al.* 2006).

Various changes were made in order to apply the model to the conditions of the study, taking into account the limitations of VIPOSIM, the objectives of the research, and data availability. Parameterisation was based on location-specific information and knowledge of village chicken production systems in both Ethiopia and India. The VIPOSIM model requires information on production and utilisation, some of which was not available for either country. However there was more information available on production and utilisation of backyard poultry systems for Ethiopia than for India. In the case of insufficient information for Ethiopia, the original parameters developed for the VIPOSIM model were used. Parameterisation was based on the work of Aklilu (2007), Halima *et al.* (2007), Tegegne (2012) and Udo *et al.* (2006). For India, these assumptions were informed by work in Bhutan by Gyeltshen (2011) and Gyeltshen *et al.* (2013). In India available data on parameters such as flock size, mortality and bird offtake were not disaggregated by categories of chickens. Thus, the parameters needed for each category were generated based on available data and the relationship between the parameters across the categories in the default input data of VIPOSIM (Asgedom 2007) were used to validate the model. The model also categorises the parameters for bird and eggs offtake into two groups: sales and home consumption. In this study, bird offtake parameters were treated as one broad category because while there are differences in sales or consumption rates between regions within both countries, the net profits remain similar, due to price similarity of whether the eggs or birds are sold or consumed on farm.

Although VIPOSIM was designed to generate direct (bird, egg and manure offtake rates) and indirect benefits (the value of immediate availability of birds for cash and social needs), only direct benefits resulting from avoidance of bird deaths were considered in this study. The direct benefits of vaccine use could result in an improved quality of chickens, increased flock size and/or increased offtake rates. Due to the low level of quality differentiation in local markets regarding egg and bird production, and due to the difficulties in getting data on quality improvement resulting from vaccination, only direct benefits related to increased offtake of birds, eggs and manure are considered. The additional indirect benefits such as the value of the social roles of chickens that may increase due to vaccination were not estimated in the study, in part because it is difficult to assign a monetary value to these benefits (Tomo *et al.* 2012).

Model inputs and assumptions

The input parameters such as the flock size, mortality rate due to disease and/or predation, and bird offtake varied both regionally and seasonally across Ethiopia and India. The number of hens in the flock and number of eggs laid by each hen determine total egg production in a season. Eggs set for hatching, eggs damaged and eggs sold are subtracted from total production to obtain household egg offtake rates. The number of eggs per clutch, eggs lost or broken, eggs set for hatching, maximum incubation capacity of hens, and hatchability of eggs in a season determines reproduction rates in a flock (Table

22). In both Ethiopia and India the rates of these inputs varied regionally. The rates of eggs per clutch, eggs set for hatching, maximum incubation capacity of hens and hatchability of eggs in a season were determined regionally for Ethiopia from the Living Standards Measurement Study (LSMS) and the previous work of Aklilu (2007), Halima *et al.* (2007) and Udo *et al.* (2006). For India these rates were obtained from the work of Conroy *et al.* (2003) Gyeltshen *et al.* (2011; 2013) and Mandal *et al.* (2006). For example, eggs per clutch and hatchability rates in the arid and rainfed regions of India are lower than the irrigated and coastal regions, the result of a drier harsher localised climates, impacting on the general health of the flock. In turn these conditions impact on productivity levels of the flock through a scarcity of resources such as feed supplementation or the distance required for the flock to scavenge to meet nutritional needs. The total number of eggs incubated per clutch varied across India from 8 to 17, and from 6 to 17 across Ethiopia. Estimates of manure production, body weights of birds and carcass percent could not be obtained directly from field studies, and so values for these parameters were adopted from Aklilu *et al.* (2007) Halima *et al.* (2007) and Udo *et al.* (2006) for Ethiopia and from Gyeltshen *et al.* (2011;2013) for India. No birds or hens were purchased in either backyard system.

Table 22: An example of seasonal input values for hens used for the Baseline simulations for the coastal region in India

		Season 1	Season 2	Season 3	Season 4
Mortality due to	Predation (%)	2.6	1.7	2.9	2.65
	Disease (%)	2.6	2.6	2.6	2.6
	Other reason (%)	5	5	5.5	5
Bird offtake	Consumption (%)	5.87	11.9	5.05	7.41
	Sales (%)	2.68	10.2	8.1	8.0
	Egg production (eggs/clutch)	12.9	12	13.3	12.2
Egg offtake and losses	Consumption (%)	25.2	25.0	25.5	24
	Sales (%)	28.0	28.5	29.0	29.5
	Lost or broken (%)	14	13	13	14
	Egg set for hatching (%)	33	33	33	33
	Hatchability (%)	80	80	80	80

Interventions - Ethiopia

A range of interventions were undertaken for each region across Ethiopia. The interventions were explored to assess the effect on the management, productivity and profitability of backyard village poultry. The interventions for each region were; Newcastle disease vaccination (V), supplementary feeding (SF) provision of daytime housing (H), control of broodiness (B), crossbreeding (CB), and dual interventions of crossbreeding and vaccination (CB+V), crossbreeding and supplementary feeding (CB+SF), crossbreeding and housing (CB+H), vaccination and supplementary feed (V + SF), vaccination and daytime housing (V + H), vaccination and broodiness (V + B), supplementary feed and control of broodiness (SF + B) and broodiness and housing (B + H). Changes in the input parameters as a result of each of these interventions are given in Table 23 and are adapted from Udo *et al.* (2006).

Table 23: Changes in input values for the simulation of interventions and feed supplementation required.

Intervention	Change	Feed supplementation required (grams/day)
NCD vaccination	Mortality from disease 50% lower	
Daytime housing	Mortality from predation 5% of flock	80g cocks/hens, 50g cockerels/pullets
	Egg loss 2% of clutch	25g chicks
	Mortality by other reasons 50% lower	
Feed supplementation	50% more eggs	40g cocks/hens, 30g cockerels/pullets
	15% Earlier age at first egg	
Crossbreeding	15% Earlier age at first egg	
	50% more eggs per hen	
	Mortality from disease 10% higher	
	Mortality from predation 54% higher	
	One season (season 3) without clutches	
Control of broodiness	45% More eggs per hen	

Economic inputs and assumptions

The model allows the input values of extra costs per day per bird of various inputs and extra inputs for the range of interventions. The net return (profit) is calculated as the difference between the total benefits and total input costs the model also calculates the effectiveness of labour in terms of net return per labour hour. For India, the prices of the input cost of supplementary feed varied slightly between seasons and regions whereas the inputs costs of vaccination regimes and the provision of daytime housing were held constant between the regions (Table 24). Poultry offtake prices for eggs and birds varied both regionally and seasonally the offtake price for manure was held constant for each region and season (Table 3). The value of the inputs costs for each intervention was guided by Aklilu *et al.* (2007), Halima *et al.* (2007) and Tegegne (2012) as well as various poultry market reports from across Ethiopia. Generally the cost of housing and vaccination remain relatively stable, however the range of input costs regarding the provision of supplementary feeding can vary widely and are prone to fluctuations in both pricing and availability from region to region.

Table 24: An example of seasonal input values for hens used for the Baseline simulations for the coastal region in India, with standard deviation in parentheses. All values are INR

		Season 1	Season 2	Season 3	Season 4
Price of birds	Pullets and cockerels	170 (21)	160 (22)	140 (22)	120 (20)
	Hens	222 (32)	222 (30)	170 (31)	170 (29)
	Cocks	180 (22)	160 (21)	150 (22)	120 (20)
Price of eggs		3.6 (0.8)	3.7 (1.1)	4.5 (1.2)	3.8 (1.1)
Price of labour		80	80	80	80
Intervention costs					
	NCD vaccination/bird	3	3	3	3
Supplementary feed/bird					
	Pullets and cockerels	5.6	6.0	5.6	5.2
	Hens/cocks	7.1	7.6	7.2	6.9
	Chicks	2.1	1.8	1.9	2.2
Housing costs					
	Pullets and cockerels	23	23	23	23
	Hens/cocks	27	27	27	27
	Chicks	11	11	11	11

A large regional backyard producer was defined as the 90th percentile, a medium backyard producer was defined by the 50th percentile and a small backyard producer was defined by the 10th percentile from the Living Standards Measurement Data (LSMS).

Results – Ethiopia

Baseline simulations

The baseline simulations reflect the behavior of a relatively stable backyard village poultry flock these were simulated without any interventions for the three regions across Ethiopia and the outputs of annual egg offtake, which incorporates both eggs sold and consumed (Table 26) and annual bird offtake, both birds sold and consumed (Table 27). The most productive region in terms of total egg offtake is the High rainfall region for each of the various size farms. The egg offtake rates for the Arid lowlands and Medium rainfall highlands is very similar. The Medium rainfall highlands is the most productive region in terms of bird offtake rates (Table 26, Figure 15), this is partly a reflection of local regional practices where in the Medium rainfall highlands the focus of backyard producers is more on bird production as opposed to egg production (LSMS 2012).

Table 25: Baseline flock size for the regions of the Arid lowlands, Medium rainfall highlands and High rainfall zone in Ethiopia

Farm size	Arid lowlands	Medium rainfall highlands	High rainfall zone
Large	14.2	16.9	19.6
Medium	6.1	5.5	6.8
Small	2.5	2.1	2.0

Table 26: Baseline annual egg offtake (eggs sold and consumed) and bird offtake (birds sold or consumed) for the regions of the Arid lowlands, Medium rainfall highlands and High rainfall zone in Ethiopia

Farm size	Egg offtake			Bird offtake		
	Arid Lowlands	Medium Rainfall	High Rainfall Zone	Arid Lowlands	Medium Rainfall	High Rainfall Zone
Large	66.6	65.1	97.9	8.2	11.8	10.8
Medium	32.6	35.5	49.0	3.1	4.2	4.3
Small	18.9	23.7	22.4	1.4	2.8	1.8

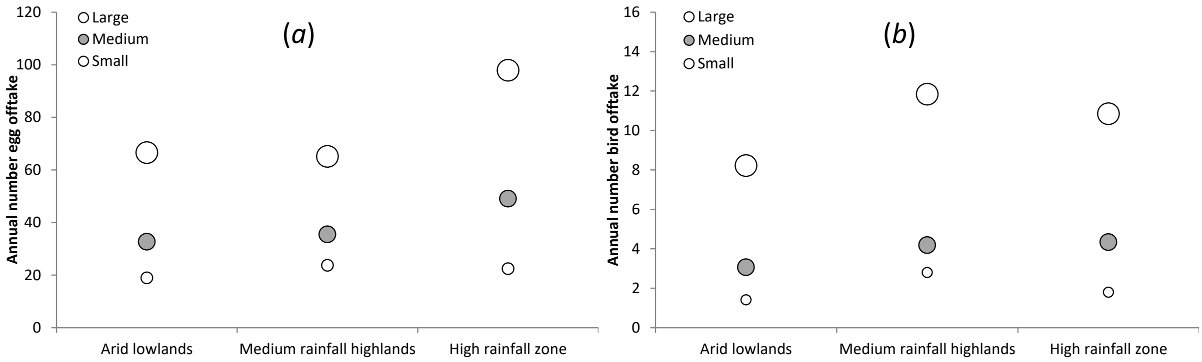


Figure 15: Baseline annual number of egg and bird offtake (sold or consumed) for the regions of Arid lowlands, Medium rainfall highlands and High rainfall zone in Ethiopia

Table 27: Baseline annual net profit (ETB) for the regions of Arid lowlands, Medium rainfall highlands and High rainfall zone in Ethiopia

Farm size	Arid lowlands	Medium rainfall highlands	High rainfall zone
Large	1359	1482	1934
Medium	584	719	1006
Small	343	380	449

The baseline net profits without any interventions for the three regions in Ethiopia are presented in Table 27 and Figure 16. Generally the net profits reflect the production trends, despite the fact that the respective prices of the offtakes (eggs, birds and manure) varied slightly regionally and seasonally. The High rainfall zone is the most economically productive, while the Arid lowlands region is the least productive in terms of net profits.

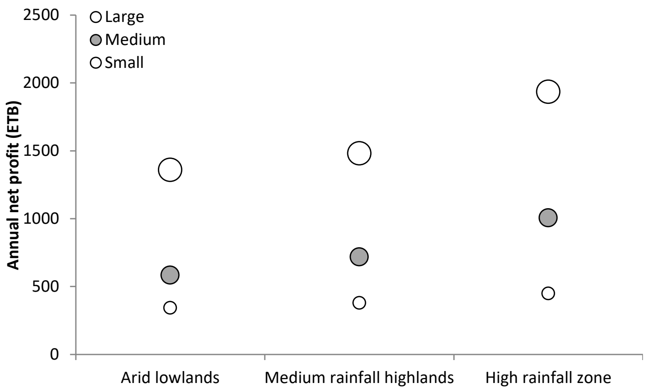


Figure 16: Baseline annual net profit (ETB) for the regions of the Arid lowlands, Medium rainfall highlands and High rainfall zone in Ethiopia

Interventions summary for Ethiopian regions

Egg offtake rates

Overall, for each region in Ethiopia there were some similar trends for each of the five interventions and the range of dual interventions for both total annual eggs and birds sold or consumed. For egg production across each of the regions, the relative responses to each intervention were similar, although greater responses were observed with both the large and medium backyard producers in comparison to the smaller backyard producers (Figure 17). Each intervention generally showed a positive response in term of egg production, supplementary feeding showed the greatest response as a single intervention as well as a combined intervention with vaccination and supplementary feeding. However, the interventions of controlling broodiness and crossbreeding were marginal in terms of increasing egg production (Figure 17).

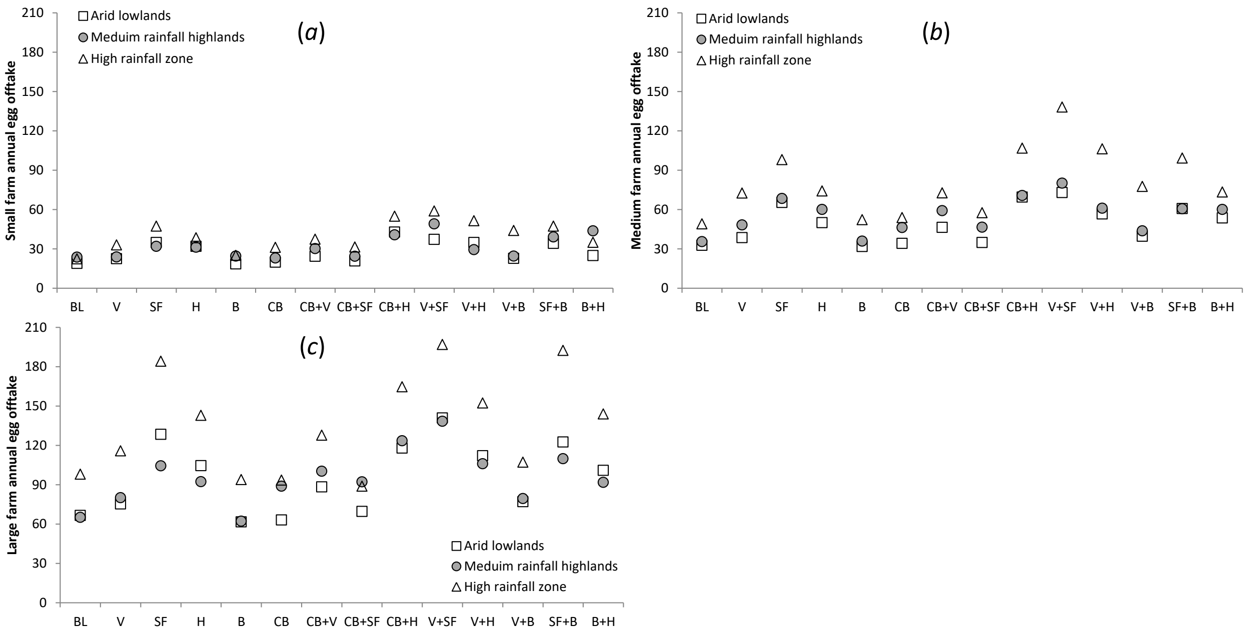


Figure 17: Annual egg offtake number for a small sized farm (a), medium sized farm (b), and large sized farm (c). For the baseline (BL), and interventions of vaccination (V), supplementary feeding (SF), daytime housing (H), control of broodiness (B), crossbreeding (CB), and dual interventions of crossbreeding + vaccination (CB+V), crossbreeding + supplementary feeding (CB+SF), crossbreeding + housing (CB+H) vaccination + supplementary feeding (V+SF), vaccination + daytime housing (V+H), vaccination + broodiness (V+B), supplementary feeding + broodiness (SF+B), and broodiness + housing (B+H) for each region in Ethiopia

The regional mean annual egg offtake for a small sized farm for the baseline was 21.7 eggs (Table 28). The largest increases in regional egg offtake rates were from the dual interventions of vaccination and supplementary feeding (48.4) and crossbreeding and housing (46.2). The smallest response was observed from the intervention of controlling broodiness (22.7) The mean percentage change of each intervention in egg offtake rates, above the baseline value were varied, the lowest percentage increases above the baseline was observed for the Medium rainfall highlands region (35%). The greatest relative increase in egg offtake rates were observed for the High rainfall region (84%) (Table 28).

Table 28: Small sized farm annual egg offtake rates, regional mean intervention response, and percentage change. For the baseline (BL), and interventions of vaccination (V), supplementary feeding (SF), daytime housing (H), control of broodiness (B), crossbreeding (CB), and dual interventions of crossbreeding + vaccination (CB+V), crossbreeding + supplementary feeding (CB+SF), crossbreeding + housing (CB+H) vaccination + supplementary feeding (V+SF), vaccination + daytime housing (V+H), vaccination + broodiness (V+B), supplementary feeding + broodiness (SF+B), and broodiness + housing (B+H) for each region in Ethiopia

	BL	V	SF	H	B	CB	CB+V	CB+SF	CB+H	V+SF	V+H	V+B	SF+B	B+H	Mean	Mean % change
Arid lowlands	19	23	35	32	19	20	24	21	43	37	35	22	34	25	28	50
Medium rainfall highlands	24	24	32	31	25	23	30	24	41	49	29	25	39	44	32	35
High rainfall zone	22	33	47	38	25	31	37	31	55	59	51	44	47	35.	41	84
Mean	22	26	38	34	23	25	31	26	46	48	39	30	40	35		
Mean % change		22	76	56	5	14	41	18	113	123	78	40	86	59		

The regional mean annual egg offtake for a medium sized farm for the baseline was 39 eggs (Table 29). The largest increases in regional egg offtake rates were from the dual intervention of vaccination and supplementary feeding (97.1). Smaller responses were observed with the interventions of broodiness (40), crossbreeding (44.7) and the dual intervention of crossbreeding and supplementary feeding (46.3). The mean percentage change of each intervention in egg offtake rates, above the baseline value are varied, the lowest percentage increases above the baseline was observed for the Arid lowlands region (54%). A greater relative increase in egg offtake rates were observed for the High rainfall zone (70%) (Table 29).

Table 29: Medium sized farm annual egg offtake rates, regional mean intervention response, and percentage change. For the baseline (BL), and interventions of vaccination (V), supplementary feeding (SF), daytime housing (H), control of broodiness (B), crossbreeding (CB), and dual interventions of crossbreeding + vaccination (CB+V), crossbreeding + supplementary feeding (CB+SF), crossbreeding + housing (CB+H) vaccination + supplementary feeding (V+SF), vaccination + daytime housing (V+H), vaccination + broodiness (V+B), supplementary feeding + broodiness (SF+B), and broodiness + housing (B+H) for each region in Ethiopia

	BL	V	SF	H	B	CB	CB+V	CB+SF	CB+H	V+SF	V+H	V+B	SF+B	B+H	Mean	Mean % change
Arid lowlands	32.6	38.6	65.4	50.0	31.8	34.2	46.4	34.9	69.5	73.0	56.6	39.5	60.8	53.6	50.3	54
Medium rainfall highlands	35.5	48.2	68.4	60.0	35.9	46.2	59.1	46.6	70.7	80.1	60.9	43.8	60.6	60.1	57.0	61
High rainfall zone	49.0	72.6	98.0	74.2	52.2	53.8	72.7	57.5	106.7	138.1	106.2	77.5	99.2	73.3	83.2	70
Mean	39.0	53.1	77.3	61.4	40.0	44.7	59.4	46.3	82.3	97.1	74.6	53.6	73.5	62.3		
Mean % change		36	98	57	2	15	52	19	111	149	91	37	88	60		

The regional mean annual egg offtake for a large sized farm for the baseline was 76.5 eggs (Table 30). The largest increase in regional egg offtake rates was again from the dual intervention of vaccination and supplementary feeding (158.6). A negative response was observed with the intervention of controlling broodiness (72.5), and marginal responses were observed with the interventions crossbreeding (81.8) and the dual intervention of crossbreeding and supplementary feeding (83.5). Regionally for a large sized farm, the mean percentage change of each intervention in egg offtake rates above the baseline was similar, varying from 42 to 46% for each of the three regions (Table 30).

Table 30: Large sized farm annual egg offtake rates, regional mean intervention response, and percentage change. For the baseline (BL), and interventions of vaccination (V), supplementary feeding (SF), daytime housing (H), control of broodiness (B), crossbreeding (CB), and dual interventions of crossbreeding + vaccination (CB+V), crossbreeding + supplementary feeding (CB+SF), crossbreeding + housing (CB+H) vaccination + supplementary feeding (V+SF), vaccination + daytime housing (V+H), vaccination + broodiness (V+B), supplementary feeding + broodiness (SF+B), and broodiness + housing (B+H) for each region in Ethiopia.

	BL	V	SF	H	B	CB	CB+V	CB+SF	CB+H	V+SF	V+H	V+B	SF+B	B+H	Mean	Mean % change
Arid lowlands	67	75	128	105	62	63	88	70	118	141	112	77	123	101	97	46
Medium rainfall highlands	65	80	104	92	62	89	100	92	124	138	106	79	110	92	98	50
High rainfall zone	98	116	184	143	94	93	128	89	165	197	152	107	192	144	139	42
Mean	77	90	139	113	73	82	105	84	135	159	123	88	142	112		
Mean % change		18	82	48	-5	7	38	9	77	107	61	15	85	47		

Regionally across Ethiopia, the means of egg offtake responses to the various interventions showed positive responses for the three different farm sizes. Generally though, greater percentage responses to the various interventions were observed with medium and smaller sized farms in comparison to the larger sized farms. Similar responses were evident for each of the different sized farms where the intervention of vaccination and supplementary feeding consistently returned the most positive response. The lowest intervention response for each of the three different sized farms was consistently the intervention of controlling broodiness, responses to the interventions of crossbreeding and the dual intervention of crossbreeding and supplementary feeding also only showed marginal gains in terms of egg offtake rates.

Bird offtake rates

Overall, for each farm size and region in Ethiopia there were some similar trends for each of the five interventions and the range of dual interventions for bird offtake rates (Figure 18). Each intervention generally showed a positive response in terms of bird offtake rates, the provision of daytime housing showed the greatest response as a single intervention and the dual interventions of vaccination and supplementary feeding and vaccination and housing consistently returned positive results for each different farm sized. However, the interventions of controlling broodiness, crossbreeding and dual intervention of crossbreeding and supplementary feeding were marginal in terms of increasing bird offtake rates (Figure 18).

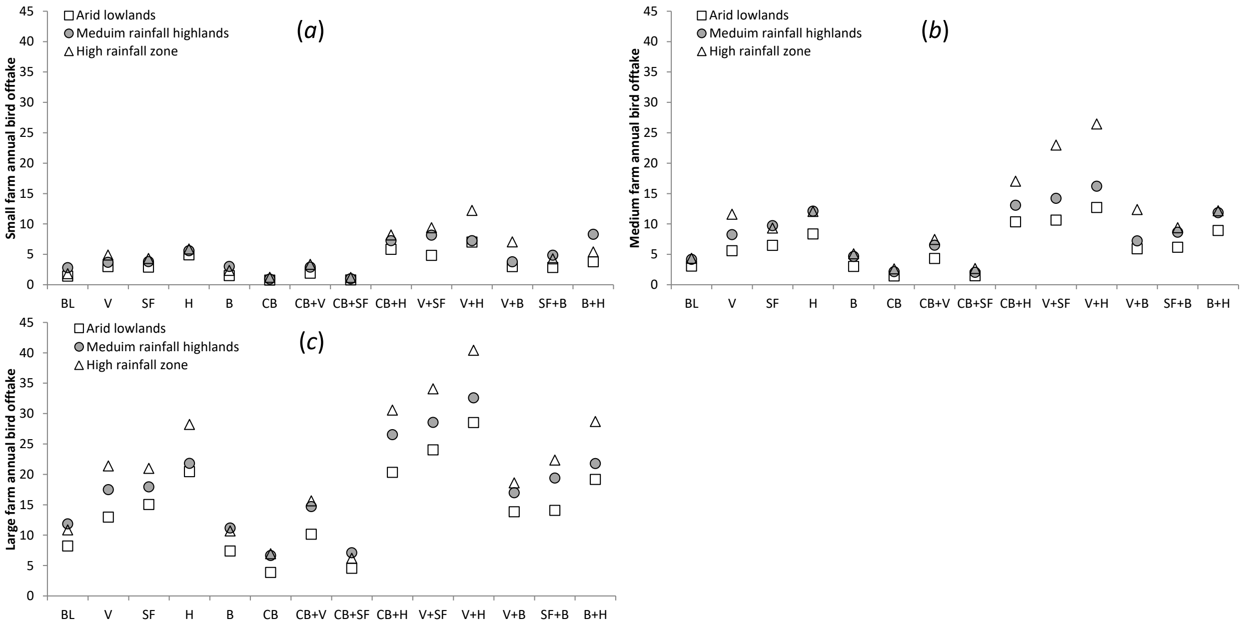


Figure 18: Annual bird offtake number for a small sized farm (a), medium sized farm (b), and large sized farm (c). For the baseline (BL), and interventions of vaccination (V), supplementary feeding (SF), daytime housing (H), control of broodiness (B), crossbreeding (CB), and dual interventions of crossbreeding + vaccination (CB+V), crossbreeding + supplementary feeding (CB+SF), crossbreeding + housing (CB+H) vaccination + supplementary feeding (V+SF), vaccination + daytime housing (V+H), vaccination + broodiness (V+B), supplementary feeding + broodiness (SF+B), and broodiness + housing (B+H) for each region in Ethiopia.

The regional mean annual bird offtake rates for a small sized farm for the baseline was 2 birds (Table 31). The largest increases in regional bird offtake rates were from the dual interventions of vaccination and supplementary feeding (7.4) and vaccination and housing (8.8) respectively. The smallest responses were from the interventions of crossbreeding and dual intervention of crossbreeding and supplementary feeding where negative responses were observed. The mean percentage change above the baseline value in bird offtake rates from each intervention varied widely, the lowest percentage increase was observed for the Medium rainfall highlands region (66%), while the greatest response was in the High rainfall zone region.

Table 31: Small sized farm annual bird offtake rates, regional mean intervention response, and percentage change. For the baseline (BL), and interventions of vaccination (V), supplementary feeding (SF), daytime housing (H), control of broodiness (B), crossbreeding (CB), and dual interventions of crossbreeding + vaccination (CB+V), crossbreeding + supplementary feeding (CB+SF), crossbreeding + housing (CB+H) vaccination + supplementary feeding (V+SF), vaccination + daytime housing (V+H), vaccination + broodiness (V+B), supplementary feeding + broodiness (SF+B), and broodiness + housing (B+H) for each region in Ethiopia

	BL	V	SF	H	B	CB	CB+V	CB+SF	CB+H	V+SF	V+H	V+B	SF+B	B+H	Mean	Mean % change
Arid lowlands	1.4	3.0	2.9	4.9	1.5	0.7	1.9	0.8	5.8	4.8	7.0	3.0	2.8	3.8	3.3	134
Medium rainfall highlands	2.8	3.7	3.8	5.6	3.0	0.9	2.9	1.0	7.2	8.1	7.2	3.8	4.8	8.3	4.6	66
High rainfall zone	1.8	4.9	4.3	5.9	2.3	1.2	3.3	1.2	8.2	9.4	12.2	7.0	4.2	5.4	5.4	198
Mean	2.0	3.8	3.7	5.5	2.3	1.0	2.7	1.0	7.1	7.4	8.8	4.6	4.0	5.8		
Mean % change		92	83	173	14	-52	36	-51	254	273	342	129	99	191		

The regional mean annual bird offtake rates for a medium sized farm for the baseline was 3.9 birds (Table 32). The largest increases in regional bird offtake rates were from the dual interventions of vaccination and supplementary feeding (15.9) and vaccination and housing (18.4) respectively. The smallest responses were from the interventions of crossbreeding (2.1) and dual intervention of crossbreeding and supplementary feeding (2) where negative responses were observed in comparison to the baseline value. The mean percentage change above the baseline value in bird offtake rates from each intervention was the same for both the Arid lowlands and Medium rainfall highlands regions (114%) comparatively, the High rainfall zone had a larger response to the various interventions (168%) (Table 32).

Table 32: Medium sized farm annual bird offtake rates, regional mean intervention response, and percentage change. For the baseline (BL), and interventions of vaccination (V), supplementary feeding (SF), daytime housing (H), control of broodiness (B), crossbreeding (CB), and dual interventions of crossbreeding + vaccination (CB+V), crossbreeding + supplementary feeding (CB+SF), crossbreeding + housing (CB+H) vaccination + supplementary feeding (V+SF), vaccination + daytime housing (V+H), vaccination + broodiness (V+B), supplementary feeding + broodiness (SF+B), and broodiness + housing (B+H) for each region in Ethiopia

	BL	V	SF	H	B	CB	CB+V	CB+SF	CB+H	V+SF	V+H	V+B	SF+B	B+H	Mean	Mean % change
Arid lowlands	3.1	5.6	6.5	8.3	3.0	1.4	4.3	1.4	10.3	10.6	12.7	5.9	6.2	8.9	6.6	114
Medium rainfall highlands	4.2	8.2	9.7	12.1	4.6	2.1	6.5	2.0	13.1	14.2	16.2	7.2	8.6	11.9	9.0	114
High rainfall zone	4.3	11.6	9.3	12.0	5.1	2.6	7.4	2.6	17.0	23.0	26.4	12.4	9.4	12.2	11.6	168
Mean	3.9	8.5	8.5	10.8	4.2	2.1	6.1	2.0	13.5	15.9	18.4	8.5	8.1	11.0		
Mean % change		119	120	181	10	-47	58	-47	249	313	378	120	109	184		

The regional mean annual bird offtake rates for a large sized farm for the baseline was 10.3 birds (Table 33). The largest increases in regional bird offtake rates were similar to both a small and medium sized farm where the largest responses were to dual interventions of vaccination and supplementary feeding (28.9) and vaccination and housing (33.8). The smallest responses were again from the interventions of crossbreeding (5.8) and dual intervention of crossbreeding and supplementary feeding (5.9) where negative responses were observed. The mean percentage change above the baseline value in bird offtake rates from each intervention varied, the lowest response was the Medium rainfall highlands (58%) and the largest overall response to the intervention was for the High rainfall zone (102%) (Table 33).

Table 33: Large sized farm annual bird offtake rates, regional mean intervention response, and percentage change. For the baseline (BL), and interventions of vaccination (V), supplementary feeding (SF), daytime housing (H), control of broodiness (B), crossbreeding (CB), and dual interventions of crossbreeding + vaccination (CB+V), crossbreeding + supplementary feeding (CB+SF), crossbreeding + housing (CB+H) vaccination + supplementary feeding (V+SF), vaccination + daytime housing (V+H), vaccination + broodiness (V+B), supplementary feeding + broodiness (SF+B), and broodiness + housing (B+H) for each region in Ethiopia

	BL	V	SF	H	B	CB	CB+V	CB+SF	CB+H	V+SF	V+H	V+B	SF+B	B+H	Mean	Mean % change
Arid lowlands	8.2	13.0	15.0	20.4	7.4	3.9	10.1	4.5	20.3	24.0	28.5	13.8	14.1	19.1	14.9	82
Medium rainfall highlands	11.8	17.5	17.9	21.8	11.2	6.6	14.7	7.1	26.5	28.5	32.6	17.0	19.4	21.8	18.7	58
High rainfall zone	10.8	21.4	21.0	28.2	10.7	6.9	15.6	6.2	30.5	34.1	40.4	18.6	22.3	28.7	21.9	102
Mean	10.3	17.3	18.0	23.5	9.7	5.8	13.5	5.9	25.8	28.9	33.8	16.5	18.6	23.2		
Mean % change		68	75	128	-5	-44	31	-42	150	180	229	60	81	125		

Regionally, each mean of bird offtake rates from the various interventions showed positive responses for the three different farm sizes. Generally however, greater responses to the various interventions were observed with the medium and smaller sized farms in comparison to the larger sized farms. Similar trends were observed with each of the different sized farms where the combined interventions of vaccination and supplementary feeding, and vaccination and housing returned the most positive results. The smallest intervention response for each of the three different sized farms was consistently the intervention of crossbreeding and dual intervention of crossbreeding and supplementary feeding.

Total net profits

Annual net profits (ETB; Ethiopian Birr) are presented in Figure 19 for the percentage change from the baseline in terms of total net profits for each sized backyard producer for the various interventions generally showed positive results. For the single interventions, the provision of supplementary feeding commonly returned the greatest increase in net profits. The control of broodiness and provision of housing was often marginal and at times had a negative impact on net profits in comparison to the baseline values. The intervention of crossbreeding had a consistently negative impact on net profits regardless of which farm size, while the dual intervention of crossbreeding and supplementary feed showed the least positive response out of all the interventions (Figure 19).

The dual intervention of vaccination and supplementary feeding consistently returned the greatest percentage increase in net profits above the baseline value for each of the different sized farms. However, the cost of providing supplementary feed can be highly variable, dependant on many localised issues. The dual intervention of vaccination and housing frequently provided the greatest increases concerning total bird offtake rates, however the percentage increase in net profits as a result of this intervention was relatively much lower, due to the cost associated with providing daytime housing (Figure 19).

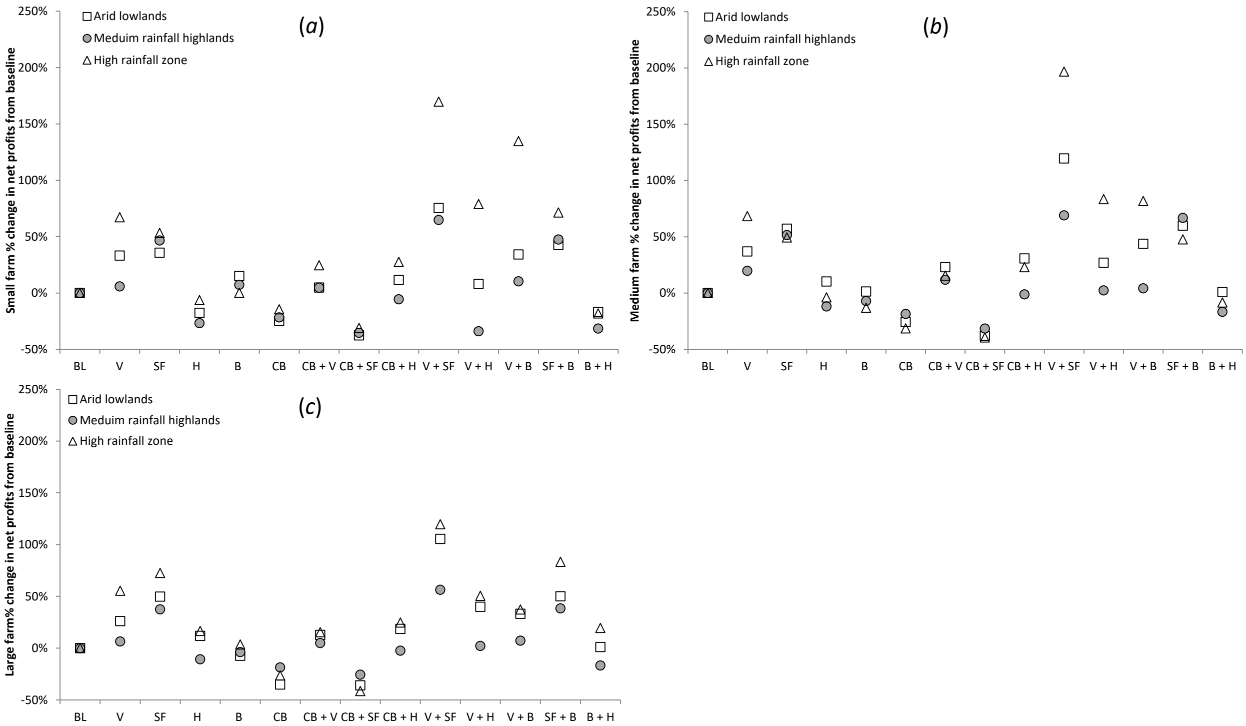


Figure 19: Annual net profits percentage change from the baseline for a small sized farm (a), medium sized farm (b), and large sized farm (c). For the baseline (BL), and interventions of vaccination (V), supplementary feeding (SF), daytime housing (H), control of broodiness (B), crossbreeding (CB), and dual interventions of crossbreeding + vaccination (CB+V), crossbreeding + supplementary feeding (CB+SF), crossbreeding + housing (CB+H) vaccination + supplementary feeding (V+SF), vaccination + daytime housing (V+H), vaccination + broodiness (V+B), supplementary feeding + broodiness (SF+B), and broodiness + housing (B+H) for each region in Ethiopia

Discussion/summary

The efficiency of a backyard poultry system is affected by many factors such as nutrition, environment, management, diseases and genetic constitution interacting in multiple ways, all of which influences the final productivity. Improvement or intervention options for a backyard poultry system can be determined by simulation models such as VIPOSIM. The VIPOSIM model integrates mortality, reproduction, egg production and offtake to assess the flock dynamic parameters. The VIPOSIM model allows an understanding of both current and future scenarios of a backyard poultry based system in both biological and economic terms, allowing backyard poultry producers to select interventions within their physical and economic resource limitations. In this study a range of interventions were undertaken for each region across India, incorporating Newcastle disease vaccination, supplementary feeding, daytime housing provided, control of broodiness and various dual interventions.

The initial model inputs of regional flock numbers generally determine the scale of the total numbers of egg, bird and manure offtake rates. This is reflected in the various sized farms, e.g. a larger farm will always produce larger offtake rates than a smaller sized farm.

Arid lowlands

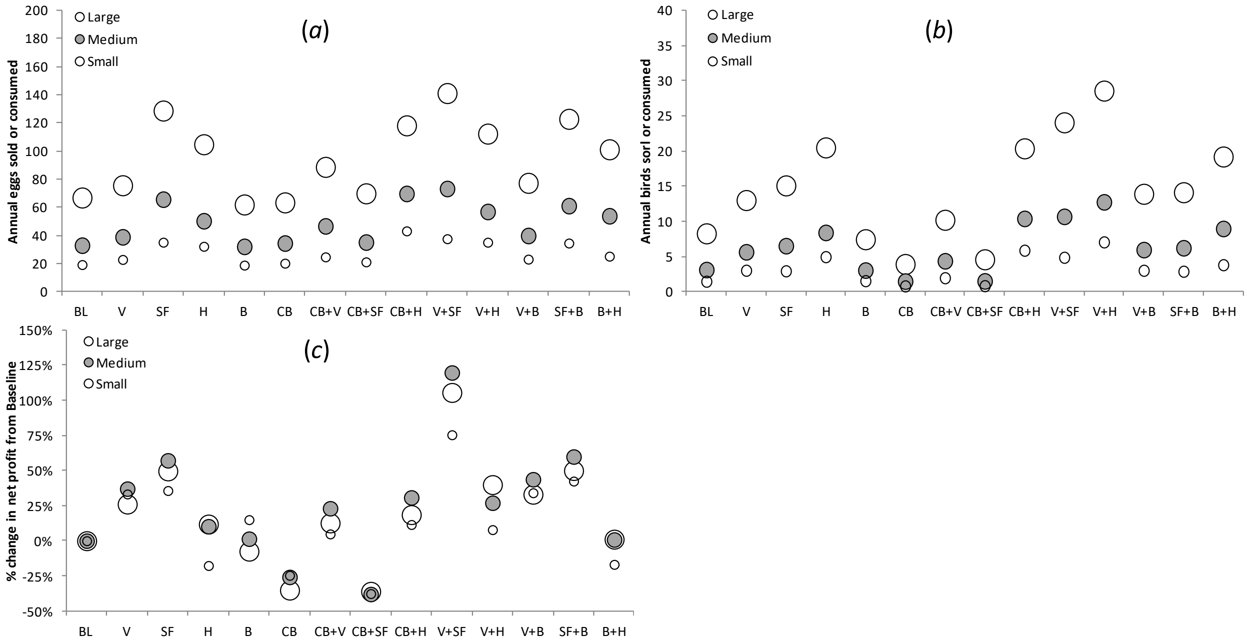


Figure 20: Annual eggs sold or consumed (a), and annual birds sold or consumed (b), and annual net profit percentage change from the baseline (c) for the baseline (BL), and interventions of vaccination (V), supplementary feeding (SF), daytime housing (H), control of broodiness (B), crossbreeding (CB), and dual interventions of crossbreeding + vaccination (CB+V), crossbreeding + supplementary feeding (CB+SF), crossbreeding + housing (CB+H) vaccination + supplementary feeding (V+SF), vaccination + daytime housing (V+H), vaccination + broodiness (V+B), supplementary feeding + broodiness (SF+B), and broodiness + housing (B+H) for the arid lowlands

Table 34: Annual egg and bird production percentage change from the baseline for the interventions of vaccination, supplementary feeding, daytime housing, control of broodiness and dual interventions of vaccination and supplementary feeding, vaccination and daytime housing, vaccination and broodiness, supplementary feeding and broodiness, and broodiness and housing for the arid lowlands

		% increase over baseline													
		Baseline	V	SF	H	B	CB	CB+V	CB+SF	CB+H	V+SF	V+ H	V+B	SF+ B	B +H
Eggs sold or consumed	90th	66.6	13	93	57	-7	-5	33	4	77	112	68	16	84	52
	50th	32.6	18	100	53	-3	5	42	7	113	124	73	21	86	64
	10th	18.9	19	84	69	-2	5	29	10	127	97	84	20	81	32
Birds sold or consumed	90th	8.2	58	83	149	-10	-53	23	-45	147	192	247	68	71	133
	50th	3.1	83	111	173	-2	-54	41	-53	238	247	315	93	101	191
	10th	1.4	111	105	249	5	-47	35	-45	314	242	398	111	101	167

Table 35: Annual net profit percentage change from the baseline for the interventions of vaccination, supplementary feeding, daytime housing, control of broodiness and dual interventions of vaccination and supplementary feeding, vaccination and daytime housing, vaccination and broodiness, supplementary feeding and broodiness, and broodiness and housing for the arid lowlands

	% increase over baseline													
	Baseline	V	SF	H	B	CB	CB+V	CB+SF	CB+H	V+SF	V+H	V+B	SF+B	B+H
90th	1359	26	50	12	-7	-35	13	-36	19	105	40	33	50	1
50th	584	37	57	10	1	-26	23	-38	31	120	27	44	60	1
10th	343	33	36	-18	15	-25	5	-38	12	75	8	34	42	-17

Medium rainfall highlands

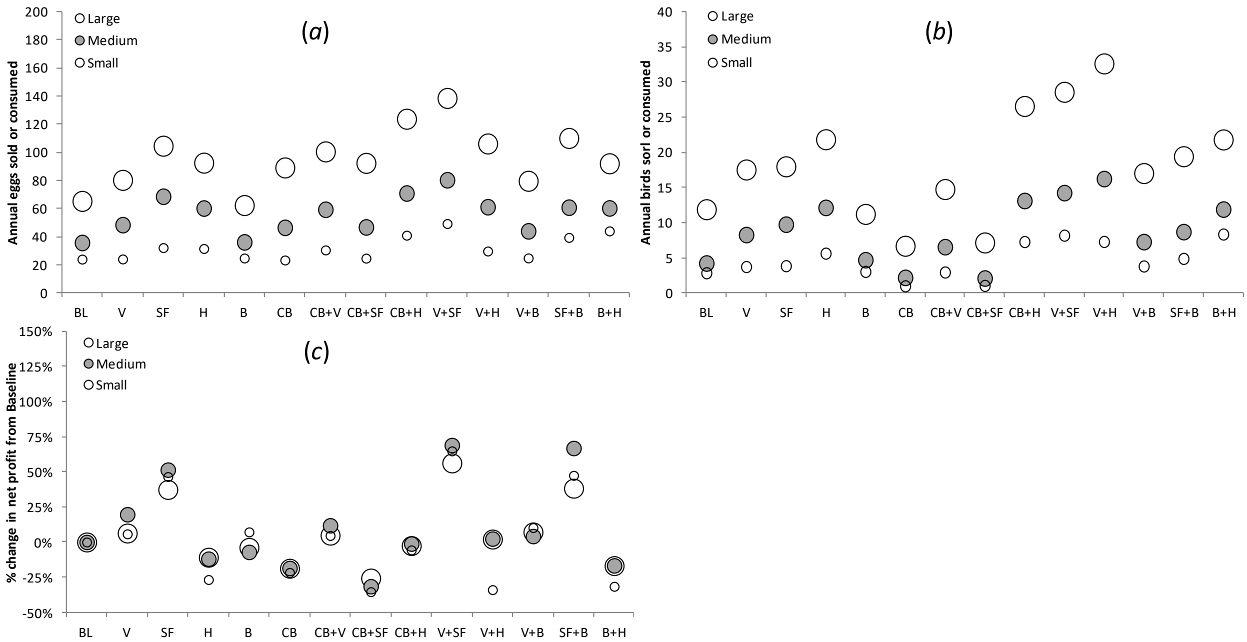


Figure 21: Annual eggs sold or consumed (a), and annual birds sold or consumed (b), and annual net profit percentage change from the baseline (c) for the baseline (BL), and interventions of vaccination (V), supplementary feeding (SF), daytime housing (H), control of broodiness (B), crossbreeding (CB), and dual interventions of crossbreeding + vaccination (CB+V), crossbreeding + supplementary feeding (CB+SF), crossbreeding + housing (CB+H) vaccination + supplementary feeding (V+SF), vaccination + daytime housing (V+H), vaccination + broodiness (V+B), supplementary feeding + broodiness (SF+B), and broodiness + housing (B+H) for the medium rainfall highlands

Table 36: Annual egg and bird production percentage change from the baseline for the interventions of vaccination, supplementary feeding, daytime housing, control of broodiness and dual interventions of vaccination and supplementary feeding, vaccination and daytime housing, vaccination and broodiness, supplementary feeding and broodiness, and broodiness and housing for the medium rainfall highlands

			% increase over baseline (BL)												
		Baseline	V	SF	H	B	CB	CB+ V	CB+SF	CB+ H	V + SF	V + H	V + B	SF + B	B + H
Eggs sold or consumed	Large	65.1	23	60	42	-5	37	54	42	90	113	63	22	69	41
	Medium	35.5	36	93	69	1	30	67	31	99	126	72	23	71	69
	Small	23.7	0	35	32	3	-3	28	3	72	107	24	3	65	85
Birds sold or consumed	Large	11.8	48	52	84	-6	-44	24	-40	124	141	175	43	64	84
	Medium	4.2	97	132	189	11	-49	56	-51	213	240	288	73	107	184
	Small	2.8	32	36	100	7	-67	4	-64	159	192	160	35	73	197

Table 37: Annual net profit percentage change from the baseline for the interventions of vaccination, supplementary feeding, daytime housing, control of broodiness and dual interventions of vaccination and supplementary feeding, vaccination and daytime housing, vaccination and broodiness, supplementary feeding and broodiness, and broodiness and housing for the medium rainfall highlands

		% increase over baseline												
	Baseline	V	SF	H	B	CB	CB + V	CB + SF	CB + H	V + SF	V + H	V + B	SF + B	B + H
Large	1482	6	37	-11	-4	-19	5	-26	-3	56	2	7	38	-17
Medium	719	20	51	-12	-7	-18	12	-31	-1	69	2	4	67	-17
Small	380	6	47	-27	7	-22	5	-35	-6	65	-34	10	47	-32

Higher rainfall zone

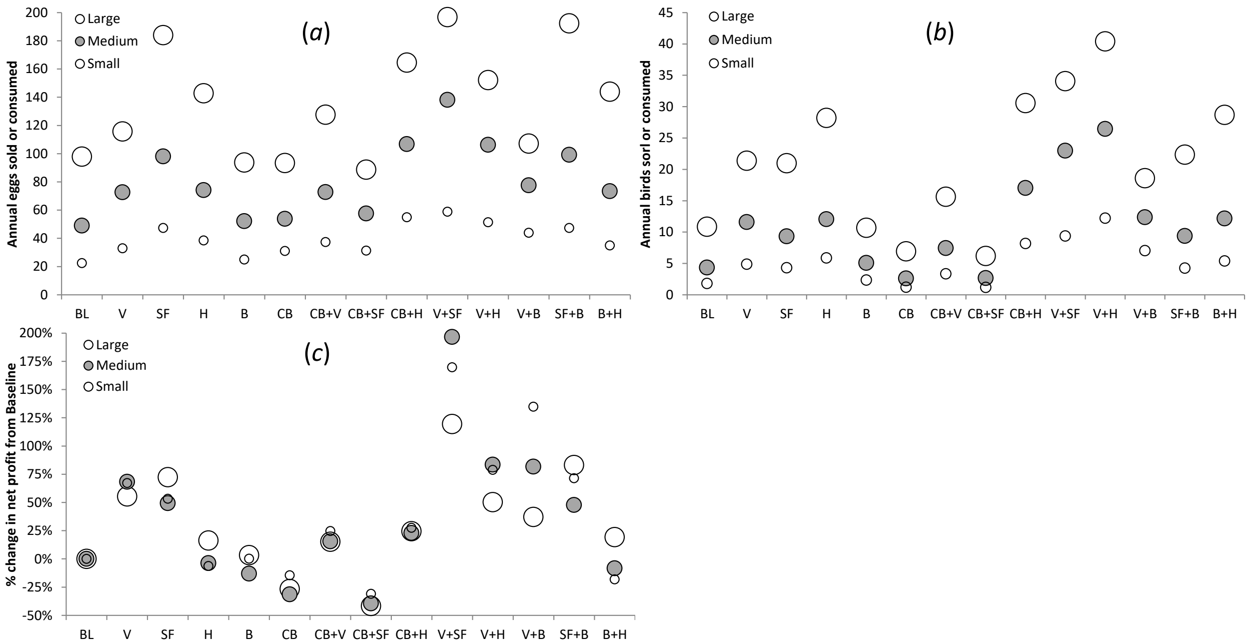


Figure 22: Annual eggs sold or consumed (a), and annual birds sold or consumed (b), and annual net profit percentage change from the baseline (c) for the baseline (BL), and interventions of vaccination (V), supplementary feeding (SF), daytime housing (H), control of broodiness (B), crossbreeding (CB), and dual interventions of crossbreeding + vaccination (CB+V), crossbreeding + supplementary feeding (CB+SF), crossbreeding + housing (CB+H) vaccination + supplementary feeding (V+SF), vaccination + daytime housing (V+H), vaccination + broodiness (V+B), supplementary feeding + broodiness (SF+B), and broodiness + housing (B+H) for the high rainfall zone

Table 38: Annual egg and bird production percentage change from the baseline for the interventions of vaccination, supplementary feeding, daytime housing, control of broodiness and dual interventions of vaccination and supplementary feeding, vaccination and daytime housing, vaccination and broodiness, supplementary feeding and broodiness, and broodiness and housing for the higher rainfall zone

		% increase over baseline													
		Baseline	V	SF	H	B	CB	CB+V	CB+SF	CB+H	V+SF	V+H	V+B	SF+B	B+H
Eggs sold or consumed	Large	97.9	18	88	46	-4	-5	30	-9	68	101	55	9	96	47
	Medium	49.0	48	100	51	7	10	48	17	118	182	117	58	102	50
	Small	22.4	47	111	72	12	39	67	40	145	163	130	96	111	56
Birds sold or consumed	Large	10.8	97	93	160	-2	-36	44	-43	182	214	273	71	106	164
	Medium	4.3	167	115	178	17	-40	72	-39	292	430	510	185	116	181
	Small	1.8	171	140	227	30	-33	86	-35	355	422	580	291	136	200

Table 39: Annual net profit percentage change from the baseline for the interventions of vaccination, supplementary feeding, daytime housing, control of broodiness and dual interventions of vaccination and supplementary feeding, vaccination and daytime housing, vaccination and broodiness, supplementary feeding and broodiness, and broodiness and housing for the higher rainfall alpine zone.

	% increase over baseline													
	Baseline	V	SF	H	B	CB	CB + V	CB + SF	CB + H	V + SF	V + H	V + B	SF + B	B + H
Large	1934	55	72	16	3	-27	15	-42	25	119	50	37	83	19
Medium	1006	68	49	-4	-13	-31	16	-39	23	197	83	82	48	-8
Small	449	67	53	-6	0	-15	25	-31	28	170	79	135	71	-18

Results - India

Baseline simulations

The baseline simulations reflect the behaviour of a relatively stable backyard village poultry flock these were simulated without any interventions for each of the six regions across India and the outputs of annual egg offtake, which incorporates both eggs sold and consumed (Table 40) and annual bird offtake, both birds sold and consumed (Table 41). The most productive region in terms of total eggs and birds produced is the Islands Region and the lowest productivity region across India is the Arid Region. The Islands Region is primarily the most productive region due to higher initial flock numbers (Table 42) and therefore production rates are generally higher, the Coastal Region is also highly productive, while the Arid and Rainfed Regions are generally poorer in terms of total production (Figure 23*a*,*b*), the result of harsher and drier climates in these Regions.

Table 40: Baseline annual egg production (eggs sold and consumed) for the Arid, Coastal, Hilly, Irrigated, Islands and Rainfed Regions in India.

Farm size	Arid	Coastal	Hilly	Irrigated	Islands	Rainfed
Large	57.5	62.4	79.9	87.9	107.0	69.1
Medium	35.1	41.3	49.6	61.1	72.1	44.7
Small	18.6	24.7	30.4	43.0	43.6	25.6

Table 41: Baseline annual bird production (birds sold and consumed) for the Arid, Coastal, Hilly, Irrigated, Islands and Rainfed Regions in India.

Farm size	Arid	Coastal	Hilly	Irrigated	Islands	Rainfed
Large	8.6	9.8	13.3	13.6	17.6	10.7
Medium	4.7	6.3	7.3	8.8	11.9	6.2
Small	2.2	4.0	3.8	6.1	6.8	3.1

Table 42: Baseline flock size for the Arid, Coastal, Hilly, Irrigated, Islands and Rainfed Regions in India.

Flock size	Arid	Coastal	Hilly	Irrigation	Islands	Rainfed
Large	7.5	7.4	12.0	8.0	13.8	8.6
Medium	5.3	3.2	7.1	4.0	10.7	6.2
Small	2.0	2.5	4.3	2.0	4.9	3.0

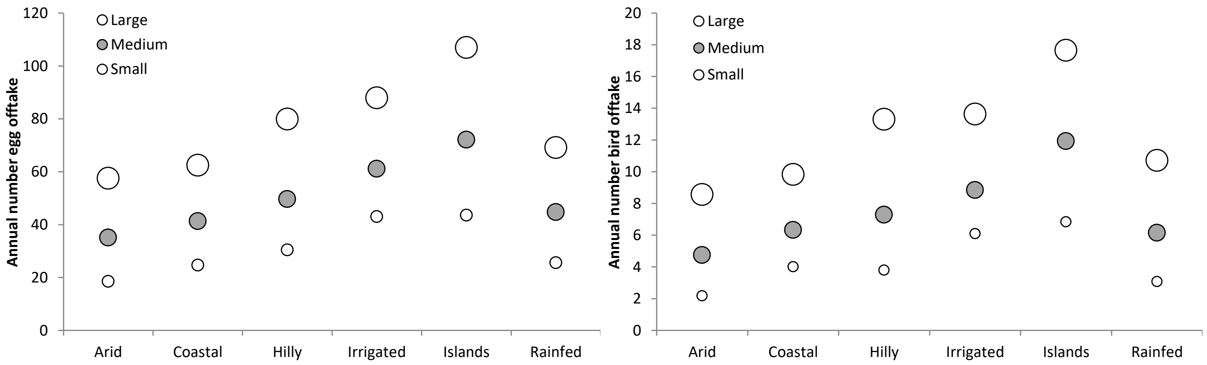


Figure 23: Baseline annual numbers of egg and bird offtake (sold or consumed) for the Arid, Coastal, Hilly, Irrigated, Islands and Rainfed Regions in India.

The baseline net profits without any interventions for each of the six regions across India are presented in Table 43 and Figure 24. Generally the net profits reflect the production trends, despite the fact that the respective prices of the offtakes (eggs, birds and manure) varied slightly regionally and seasonally. The Islands Region is the most economically productive, though again this is more a reflection of larger poultry flocks, while the Arid and Rainfed Regions are the least productive in terms of net profits.

Table 43: Baseline annual net profits for the Arid, Coastal, Hilly, Irrigated, Islands and Rainfed Regions in India.

	Arid	Coastal	Hilly	Irrigation	Islands	Rainfed
Large	1944	2511	3019	3176	3866	2671
Medium	1225	1572	1759	1963	2294	1414
Small	551	1139	875	1407	1389	780

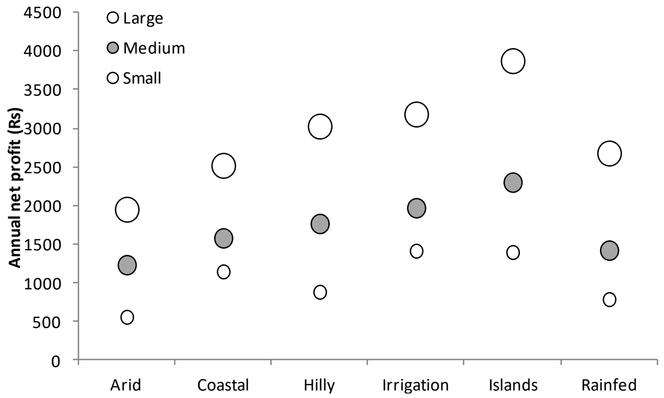


Figure 24: Baseline annual net profits for the Arid, Coastal, Hilly, Irrigated, Islands and Rainfed Regions in India.

Interventions summary for Indian regions

Egg offtake rates

Overall, for each of the six regions across India there were some similar trends for each of the four interventions and the range of dual interventions for both total annual eggs and birds sold or consumed. For egg production across each of the regions the relative responses to each intervention were similar, although greater responses were observed with both the large and medium backyard producers in comparison to the smaller backyard producers (Figure 3). Each intervention generally showed a positive response in term of egg production, supplementary feeding showed the greatest response as a single intervention as well as a combined intervention with vaccination and control of broodiness. However, the intervention of controlling broodiness was marginal in terms of increasing egg production and vaccinating the flock for Newcastle disease and only showed a small positive result (Figure 25).

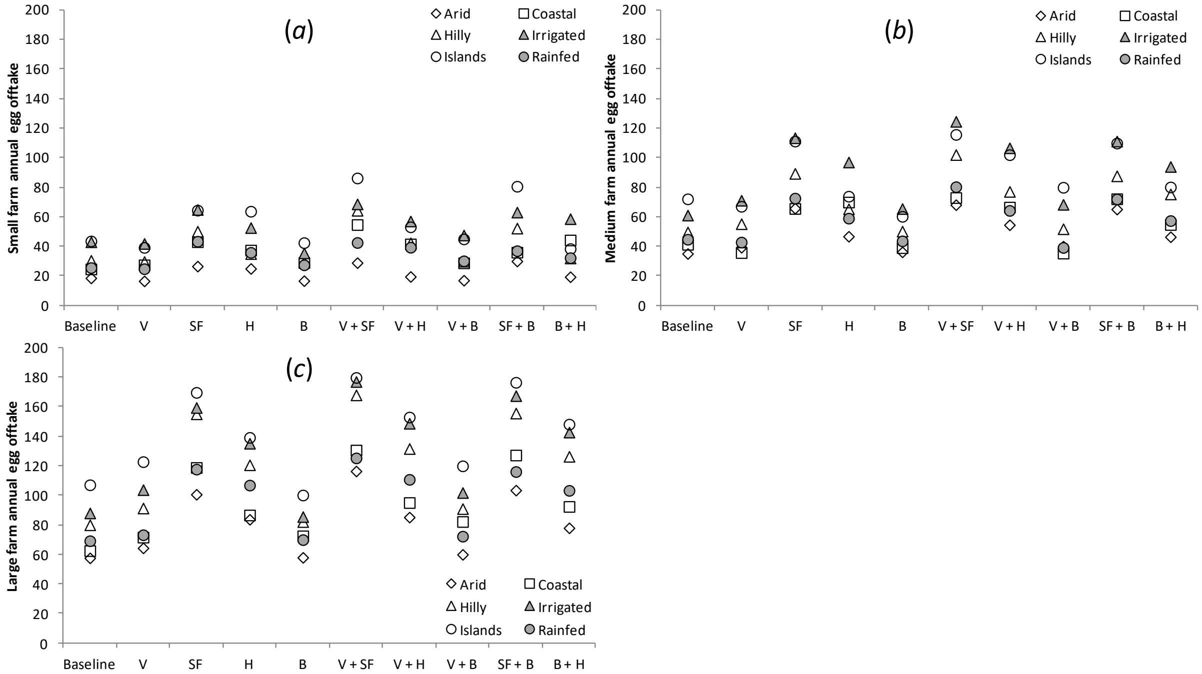


Figure 25: Annual eggs sold or consumed for a small backyard producer (a), medium backyard producer (b), and large backyard producer (c). For the Baseline and the interventions of vaccination (V), supplementary feeding (SF), daytime housing (H), control of broodiness (B) and dual interventions of vaccination and supplementary feeding (V+SF), vaccination and daytime housing (V+H), vaccination and broodiness (V+B), supplementary feeding and broodiness (SF+B), and broodiness and housing (B+H) for each region in India.

The regional mean annual egg offtake for a small sized farm for the baseline was 31 eggs (Table 44). The largest increases in regional egg offtake rates were from the interventions of supplementary feeding (48.7) vaccination and supplementary feeding (57.5) and supplementary feeding and control of broodiness (49.8). Smaller responses were observed with the interventions of vaccination (29.9), broodiness (30.1) and the dual intervention of vaccination and broodiness (33.1). The mean percentage change of each intervention in egg offtake rates, above the baseline value were varied, the lowest percentage increases above the baseline was observed for the arid region (19%). The greatest relative increase in egg offtake rates were observed for the coastal region (54%) (Table 44).

Table 44: Small sized farm annual egg offtake rates, regional mean intervention response, and mean percentage changes. For the Baseline and the interventions of vaccination (V), supplementary feeding (SF), daytime housing (H), control of broodiness (B) and dual interventions of vaccination and supplementary feeding (V+SF), vaccination and daytime housing (V+H), vaccination and broodiness (V+B), supplementary feeding and broodiness (SF+B), and broodiness and housing (B+H) for the six poultry regions of India.

Region	Baseline	V	SF	H	B	V + SF	V + H	V + B	SF + B	B + H	Mean	Mean % change
Arid	18.6	16.5	26.6	25.0	16.7	28.9	19.5	17.0	30.0	19.4	22.2	19
Coastal	24.7	27.4	43.1	37.4	29.0	54.7	41.6	28.8	36.0	44.2	38.0	54
Hilly	30.4	29.6	50.2	35.0	29.3	64.3	42.3	29.9	52.3	32.0	40.6	33
Irrigated	43.0	41.9	64.9	52.6	35.5	68.6	57.0	47.6	63.1	58.6	54.4	27
Islands	43.6	39.2	64.4	63.7	42.4	86.2	53.1	45.0	80.6	38.4	57.0	31
Rainfed	25.6	24.8	43.4	35.9	27.4	42.5	39.3	30.1	37.0	32.3	34.7	36
Mean	31.0	29.9	48.7	41.6	30.1	57.5	42.2	33.1	49.8	37.5		
Mean % change		-3	57	34	-3	86	36	7	61	21		

The regional mean annual bird offtake rates for a small sized farm for the baseline was 4.3 birds (Table 45). The largest increases in regional bird offtake rates were from the interventions of vaccination and supplementary feeding (10.1) and vaccination and housing (10.2). Regionally, a slightly negative response was observed with the control of broodiness (4.2) intervention and a minimal response form the intervention of vaccination (5.3). The mean percentage change of each intervention in bird offtake rates, above the baseline value were varied, the lowest responses were observed for the arid region (58%), irrigated region (56%) and the islands region (55%). The largest relative increase in bird offtake rates were observed for the rainfed region (98%) (Table 45).

Table 45: Small sized farm annual bird offtake rates, regional mean intervention response, and mean percentage changes. For the Baseline and the interventions of vaccination (V), supplementary feeding (SF), daytime housing (H), control of broodiness (B) and dual interventions of vaccination and supplementary feeding (V+SF), vaccination and daytime housing (V+H), vaccination and broodiness (V+B), supplementary feeding and broodiness (SF+B), and broodiness and housing (B+H) for the six poultry regions of India.

Region	Baseline	V	SF	H	B	V + SF	V + H	V + B	SF + B	B + H	Mean	Mean % change
Arid	2.2	2.3	3.0	5.0	2.0	4.5	4.4	2.6	3.6	3.5	3.4	58
Coastal	4.0	5.3	5.9	8.1	4.3	10.0	10.7	5.7	5.1	9.4	7.2	79
Hilly	3.8	5.1	6.6	7.1	4.0	10.8	10.1	5.1	6.8	6.2	6.9	80
Irrigated	6.1	7.2	8.6	10.6	4.7	11.5	13.6	8.8	8.4	12.1	9.5	56
Islands	6.8	7.6	9.0	13.5	6.7	16.8	13.3	8.9	11.9	7.9	10.6	55
Rainfed	3.1	4.0	5.6	6.8	3.5	6.9	9.2	5.0	4.4	6.4	5.8	87
Mean	4.3	5.3	6.4	8.5	4.2	10.1	10.2	6.0	6.7	7.6		
Mean % change		21	49	97	-4	133	135	39	55	75		

Workpackage 3 – Scenarios and projections

This workpackage takes the information produced in workpackages 1 and 2 and tests what would be the impacts of improve productivity on livestock product supply projections to 2030. The objective of this section is to determine an upper range of production increases in both India and Ethiopia.

Base projections for India were obtained from FAO (Alexandratos and Bruinsma 2013) for the different species. Unfortunately these were not available for Ethiopia from the same source. Hence we used the projections of the IMPACT model as presented in Herrero et al 2012, under the business as usual scenario. In both cases these base scenarios try to project relatively closely the continuation of current trends in production and herd development.

For all species we tested alternative trajectories of livestock product supply on the basis of the results found in the previous analyses. For dairy we used a combination of the projections obtained from benchmarking against the best producers, from the frontier analyses and also from the strategies tested with the livestock and household models. We chose two strategies, one that increased production beyond the current baseline trajectory to 2030 that could lead to increases in consumption and incomes for producers and a reduction in trade deficits beyond the baseline projection. As a contrast we also maintained the livestock product demand constant, with livestock production intensification decreasing the numbers of animals required to meet such trajectory. We considered this important, as in many cases biomass constraints and competition of feed with food crops might constraint the potential growth of the sector. Since these simple projections did not include land use changes, we decided to offer these two alternatives. Future studies could be planned with appropriate models that capture those dynamics.

The results for dairy in Ethiopia are presented in Table 46. In 2010, Ethiopia produced 2.94 million tonnes of milk from 9.6 million cows. The baseline projections to 2030 suggest that dairy is projected to grow at 4.2% per year, not an uncommon rate for dairy base scenarios in East Africa (Herrero et al 2012, 2014). Most increases in production occurred as a result of increases in animal numbers, but also a 25% increase in productivity contributed to increasing milk production.

Table 46: Projections for dairy production in Ethiopia under different improvement scenarios to 2030 (milk production in 000 tonnes) by production system (LG=grazing livestock, M=mixed crop-livestock system, A=arid, H=humid, T=temperate/highland)

	bv milk 2010	bvmilk 2030	milk low conc	milk high conc	benchmarking	average frontier	shifts to crossbreds with better feed
LGA	204	376	204	204	799	1470	376
LGH	6	10	6	6	22	41	10
LGT	12	22	12	12	47	87	22
MA	364	670	364	364	1425	2621	670
MH	111	203	111	111	432	795	203
MT	2024	3725	4890	6850	7916	14565	8381
Other	143	263	143	143	560	1030	263
Urban	75	139	75	75	295	542	139
Total milk	2940	5410	5806	7766	11495	9733	10066
relative to 2010		1.84	1.97	2.64	3.91	3.31	3.42
animals (000)	9600	13524	13524	13524	13524	13524	13524
yield (kg/anim/yr)	306	400	414	559	850	720	1800

Alternative scenarios suggest that there is potential to increase milk production beyond the baseline projection. Specific internventions like improved feeding (brans and others) could increase production of indigenous animals in the mixed highland systems and this would lead to an increase in total production since most of the animals are in these areas. The results from benchmarking and the frontier analyses applied to all the regions and the intervention of shifts to crossbreds with better feeding in the mixed systems in the highlands gave results of a similar order of magnitude (relative increases of 3.3-3.9 of production to 2030). This is is many ways not surprising, as the results from the best farmers include the use of packages of technologies that include cross-bred animals, better feed and reductions in mortality. Additionally, the better feeding strategies lead to improved reproductive performance. It is reassuring that 3 independent methods obtained results in a similar ballpark, suggesting that this kind of triangulation is useful for obtaining robust results. These results are more modest than those in the Ethiopian masterplan, but we might not have captured all the benefits of the different interventions tested. Still, other prospective studies, have demonstrated that increases in crop production with a combination of land expansion might be sufficient for producing the extra feed needed to accommodate these increases in production (Bowman et al 2005; Wirsenius et al 2010; Herrero et al. 2012, Havlik et al. 2013, 2014; Valin et al 2013).

Our alternative scenario of maintaining the production projection from the baseline suggested that significant reductions in animal numbers could be obtained if less but better fed animals were used as the basis for the productivity increases. Reductions in the orded of 28 to 78% were found, and this would increase resource use efficiencies and many environmental dimensions (greenhouse gasses, less land use); but this would have significant repercussions for other benefits that livestock provide (asset values, manure, traction, risk management). These considerations need to be carefully weighted in (Oosting et al).

Table 47 presents the dairy projections for India. As explained before, India is a biomass constrained country, and although many studies have demonstrated that it might be feasible to increase feed supply we designed scenarios focused on better feed management. These included supplemtnation and also modifying the composition of the national herd to maximise production. The rational for these was explained in the previous section.

Table 47: Projections for dairy production in India under different improvement scenarios to 2030 (milk production in 000 tonnes by production system (LG=grazing livestock, M=mixed crop-livestock system, A=arid, H=humid, T=temperate/highland)

	milk 2006	milk 2030 baseline	milk 2030 improved feed	Replace 50% indigenous cattle with high-producing buffalo	Replace 50% indigenous cattle with crossbred cattle
LGA	776	1280	1280	1280	1280
LGH	28	46	46	46	46
LGT	110	181	181	181	181
MA	51867	85570	133225	111242	100117
MH	16189	26708	41582	38994	55553
MT	2125	3505	3505	3505	3505
Other	13887	22912	22912	22912	22912
Urban	10604	17494	17494	24142	28428
total	95584	157696	220225	202302	212023
prod growth relative to 2010		1.65	2.30	2.12	2.22
Animals ('000)	70651	101415	101415	101415	101415
prod/animal/yr	1353	1555	2172	1995	2091

The FAO study (Alexandratos and Bruinsma 2013) project a 65% growth in dairy production in India to 2030 under the baseline scenario. We find that with judicious use of additional supplementation (which also improves reproduction) and careful decisions on animal types (switches to buffaloes or more cross breeding) it is possible to increase production by 2.1-2.3 times the level of production in 2010. Our scenarios imply better use of the existing biomass, although growth in concentrate use, and stover as projected with crop growth in the region are also expected.

Table 48 presents an alternative scenario, where India satisfies its demand for milk as stated in the baseline projection. This study confirms the findings of Blummel et al 2009 that If systems intensified and milk production per animal increased, the projected volume of demand could be met with significantly less numbers of animals. This will significantly reduce pressure on existing land resources and would lead to reduced trade-offs for water and food/feed. Additionally, the increased in mechanisation could lead to a lower need for low producing indigenous animals, which are partly used for traction. These could potentially be replaced for higher producing crossbreds or buffalo.

Table 48: Potential for reducing the numbers of animals to satisfy the same level of production projected under the 2030 baseline

	prod per animal/yr	animals needed to meet demand ('000)	% reduction in numbers of animals
baseline 2030	1555	101415	
increased concentrate + fodder	2410	65429	0.35
improved fodders	1887	83570	0.18
average frontier	2487	63384	0.38
top 10% farmers benchmark	3100	50870	0.50

The projections for small ruminants in Ethiopia are presented in table 49. Small ruminants are projected to grow at lower rates than milk production under the baseline scenario. This is partly explained by the fact that they are raised mostly in the arid grazing and mixed crop livestock systems. Nevertheless, we tested the impacts of reducing mortalities and improved forages and the combination of both, and found that further increases in production and productivity (relative to the baseline 1.53-1.99 times) could be achieved with these interventions. The package of both interventions yielded the best results. Cross-breeding by itself, did not improve the productivity parameters. Still, there are significant structural constraints to be able to implement these interventions, which will need to be accompanied by increased markets for the extra animals to be produced.

Table 49. Projections for small ruminant meat in Ethiopia under different improvement scenarios to 2030 (milk production in 000 tonnes by production system (LG=grazing livestock, M=mixed crop-livestock system, A=arid, H=humid, T=temperate/highland)

	2010 production	2030 base projection	low mortality 2030	improved forages 2030	cross-breeding + low mort + improved feed
LGA	20855	28738	35643	41541	64262
LGH	114	157	114	114	225
LGT	268	370	268	268	530
MA	15051	20741	25724	29981	46379
MH	2541	3501	3960	7387	2541
MT	34453	43840	47476	47215	34453
Other	1515	2088	1515	1515	1515
Urban	1160	1599	1160	1160	1160
total	75958	101034	115861	129182	151066
growth relative to 2010		1.33	1.53	1.70	1.99

A critical consideration for the poultry projections was to be able to distinguish between the fast growing industrial sector and the smallholder sector. We followed the approach of Gilbert et al. 2015 who found a relationship between the proportion of extensively raised chickens and their GDP growth of different countries. Since GDP growth is a variable often projected in forward-looking studies, it was possible to project for Ethiopia and India this proportion to 2030 (figure 26)

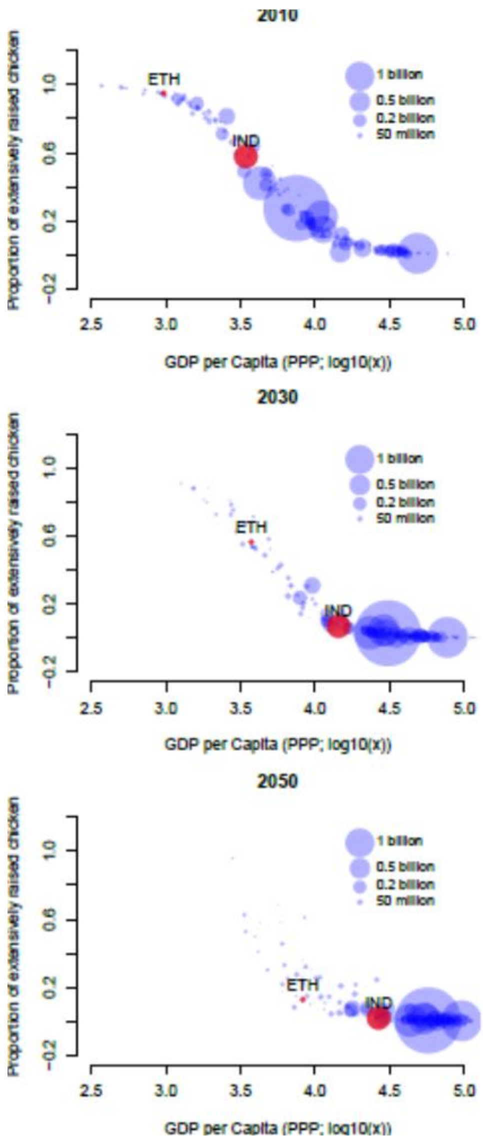


Figure 26: Projected contribution of extensively raised chickens to total country poultry production for India and Ethiopia (2010 and 2030)

The poultry sectors of both countries exhibit very different dynamics. Not only the starting point is very different (95% of poultry production still rural in Ethiopia vs 62% for India), but the speed of industrialisation to 2030 is radically different. While in Ethiopia the production of poultry products from industrial systems is projected to contribute to 42% of the national production, in India it is 95% due to its higher level of development, the potential for vertical integration of production and a dynamic agricultural sector attuned to meet its national demand.

Table 50 presents poultry and egg production for Ethiopia for 2010 and to 2030 under a variety of scenarios. It is clear that in Ethiopia the smallholder sector will maintain an important role in the supply of poultry products. This role could be enhanced significantly by the implementation of key improvements in the sector as shown in table 50. Vaccination and housing seem to be the package of interventions that most enhances poultry meat production, mainly due to reductions in mortality and faster turn-over rates, while vaccination and supplementary feeding are the best strategies for increasing egg production. Our results demonstrate that 4-fold increases in poultry meat production could be possible if some of these strategies where implemented. Egg production under similar strategies could slightly more than double with the same strategies. This would increase the future contribution of smallholder poultry to meet local demand significantly (Table 51).

Table 50: The contribution of smallholder and industrial poultry systems and projections of poultry meat and eggs in Ethiopia under alternative scenarios and their contribution to smallholder production to 2030. (CB=control of broodiness, H=housing, V=vaccination, SF=supplementary feeding, B=broodiness)

System	prod 2010 (tonnes)	prod 2030 (tonnes)	2030 cb+h (tonnes)	2030 V+SF (tonnes)	2030 V+H (tonnes)	2030 SF+B (tonnes)
smallholder						
Poultry	37240	36252	128695	134133	159510	72504
Eggs	51965	44263	94238	98725	78532	81999
industrial						
Poultry	1960	25480				
Eggs	2735	32317				

Table 51: Relative contributions of the industrial and smallholder poultry sectors to total poultry production under different interventions to 2030

	poultry meat		eggs	
	industrial	smallholder	industrial	smallholder
2030 base	0.42	0.58	0.42	0.58
2030 cb+h	0.17	0.83	0.26	0.74
2030 V+SF	0.16	0.84	0.25	0.75
2030 V+H	0.14	0.86	0.29	0.71
2030 SF+B	0.26	0.74	0.28	0.72

A contrasting situation is found in India (Table 52), with the projected growth of the sector expected in the order of 800%, and mostly coming from the growth in industrial poultry systems, both for meat and eggs. Even when interventions can improve the production derived form smallholder systems, this growth is dwarfed by the growth in industrial systems. This is not to say that these improvements would not be important for the livelihoods of smallholders, both in terms of increased incomes and nutrition.. Again, a combination of vaccination and housing seems to be the most promising intervention for increasing production. In the best of circumstances, this could double the poultry production attained by smallholders. Consistently with the Ethiopian results, vaccination and supplementary feeding appears the best strategy for increasing egg production, which could increase by 95% relative to the 2030 baseline. These increases in production would modelstly increase the contribution of the smallholder poultry sector to national production (Table 53).

Table 52: Projections of poultry meat and eggs in India under alternative scenarios and their contribution to smallholder production to 2030

System	prod 2010 (tonnes)	prod 2030 (tonnes)	2030 v+sf (tonnes)	2030 sf+b (tonnes)	2030 V+H (tonnes)
Smallholder					
Poultry	1346434	668250	1569610	1041227	1585151
Eggs	2082051	540000	1001613	867484	735097
Industrial					
Poultry	825233	6756750			
Eggs	1276096	5460000			

Table 53: Relative contributions of the industrial and smallholder poultry sectors to total poultry production under different interventions to 2030

	poultry meat		eggs	
	industrial	smallholder	industrial	smallholder
2030 base	0.91	0.09	0.91	0.09
2030 v+sf	0.81	0.19	0.84	0.16
2030 sf+b	0.87	0.13	0.86	0.14
2030 V+h	0.81	0.19	0.88	0.12

Conclusions

Our study suggests that there is significant scope for increasing the productivity and production of the dairy, small ruminant and poultry sectors in India and Ethiopia. Dairy yields in Ethiopia and India could be increased by between 65-350% depending on the type of intervention package implemented. In both cases, benchmarking production against the top 10% of producers demonstrated that yields could be tripled. However, when implementing efficiency frontier studies, we found that potentially more modest gains would be achievable at the herd level.

Our projections demonstrate that it would be possible to increase production further that the existing baseline projections to 2030 for India and Ethiopia would suggest. For example, dairy production in India is projected to increase by a factor of 65% to 2030. Our results show that with improved feeding and promoting changes in the herd structure towards more cross-breeding and or buffalo production, milk production could increase between 112-130% by 2030.

Ethiopia has higher yield gaps than India, but also as a result of a lower baseline. Ethiopian dairy production is expected to grow by 84% to 2030 under baseline conditions. Alternative scenarios demonstrated a positive, but more variable production response, ranging from 97-242% depending on the improvement strategy selected. Packages of interventions including better feeding, crossbreds and others led to the highest potential gains. These results were confirmed by our benchmarking studies.

A very strong and statistically significant linkage between market access and farm performance is found in most sites. This suggests that efforts to improve market access should be an important component of policies to close yield gaps.

Biomass constraints could be critical for the development of the ruminant livestock sector in India and Ethiopia. In these situations achieving production targets with less, more productive animals might be desirable.

Increasing milk production will require both an increase in the quantity of feed available and more efficient use of existing resources. This is especially important as the smaller indigenous livestock breeds are replaced by larger crossbred cattle and buffalo with higher energy requirements.

A shift away from the use of cattle and buffalo for draught purposes will make more feed resources available for dairy production in India. However, a decrease in the total size of the national dairy herd may still be required to increase total production.

Cross-breeding is a good option to increase milk productivity, but this will only work if higher quality feed is available

Herd management and species composition for milk production is a key strategy to maximize milk production in India

There is significant potential for increasing small ruminant production through practices to reduce mortality and strategic sowing of improved fodders. Cross-breeding in these systems was shown to be relatively ineffective, but a package with the three interventions demonstrated to have the potential to increase productivity five-fold. These results translated in a potential doubling of small ruminant meat production to 2030 relative to 2010.

The interactions between improved nutrition and improved reproduction and reduced mortality could be used as a way of increasing total system productivity while protecting livestock assets.

The most profitable feeding interventions tested are not necessarily those with the highest productivity. This needs to be accounted for when designing dairy improvement programmes

In all cases and for all species and location, packages of interventions performed better than single interventions for increasing productivity and profitability of livestock production.

The smallholder poultry sector in Ethiopia could potential supply a significant amount of meat and eggs, especially if improved interventions are applied. In contrast, the strength and the accelerated growth of the industrial poultry sector in India is likely to dominte poultry production in the next 20 years. Nevertheless, localised livelihoods benefits of improved extensive poultry production are likely to be continue to be important in places.

Ethiopia: The regional mean annual egg offtake for a small sized farm for the baseline was 21.7 eggs (Table 7). The largest increases in regional egg offtake rates were from the dual interventions of vaccination and supplementary feeding (48.4) and crossbreeding and housing (46.2).

The dual intervention of vaccination and supplementary feeding consistently returned the greatest percentage increase in net profits above the baseline value for each of the different sized farms. However, the cost of providing supplementary feed can be highly variable, dependent on many localized issues. The dual intervention of vaccination and housing frequently provided the greatest increases concerning total bird offtake rates, however the percentage increase in net profits as a result of this intervention was relatively much lower, due to the cost associated with providing daytime housing.

Market incentives and value chain development will be essential to ensure farmers can intensify their production

Investment in projects targeting improved feed management should be a priority. Without these, the impacts of many other interventions (genetics, health) will be small. This should include fodder markets and biomass value chains, apart from on-farm interventions on improved fodders

Further research on herd management and manipulation of herd structures is necessary.

LiveGaps extension

Implementation of livestock data and models in the IPA and RISE projects

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Background

The Bill & Melinda Gates Foundation's Agricultural Development Program is creating a series of monitoring and evaluation tools to track the performance of the agricultural sector and to make informed choices of the technologies that have the greatest potential for generating impacts. The work described here involved a discrete set of activities as part of two of these initiatives: 1. The Investment Priority Analysis (IPA) and the RISE indicators.

For the IPA project, a very simple set of livestock models, to complement other suites of models for the crops sector was built and populated for 4 key target countries: Nigeria, Ethiopia, Tanzania and 3 states in India.

This information was obtained from existing databases, models and the initial set of LIVEGAPS activities.

As part of RISE, dashboards of *key performance indicators* for agricultural sub-sectors, systems, or topics of interest that are representative of the sub-sector's health were built. The dashboards should be capable of diagnosing and illuminating potential strategic interventions for country governments, donors, and other stakeholders to improve the performance of the agricultural sector and its capacity to deliver the key outcomes of increased productivity and smallholder farmer income, nutrition, and women's empowerment.

BMGF helped to construct a set of similar performance indicators for the human health sector – please refer to: http://phcperformanceinitiative.org/about-us/about-phcpi for reference and the model for our activity. The dashboards are currently being envisioned for internal decision-making purposes, but may eventually be developed into a publically-accessible tool.

The funds were used to support the following activities:

1. As part of IPA:

1.1 Develop an investment planning analysis (IPA) methodology for the livestock equivalent to the IPA levels 1-3 analyses for crops (developed by Camber)

1.2 Migrate/aggregate results of LiveGAPS project for India and Ethiopia into the IPA livestock model (NOTE: This should include a selection of which LiveGAPS scenarios will be equivalent to the IPA crop packages)

1.3 Compile relevant livestock data for Tanzania and Nigeria, and integrate those data into IPA livestock model

1.4 Provision of data and models to AGDev/DEAL team.

2. As part of RISE:

2.1 Review, edit, and finalize a list of indicators for the Livestock Dashboard, including defining measurement methodology (numerators/denominators);

2.2 Suggest other relevant resources or additional literature from key partners we haven't already reviewed.

2.3 Review for accuracy the rationale narratives written by R4D in support of our indicator selection;

2.4 Suggest relevant primary and secondary data sources to populate the finalized selected indicators;

- Review for accuracy population of data per indicator (to be populated by R4D);
- Produce indicator metadata spreadsheet, written documentations, dashboard mock-ups;
- Draft narratives on data quality, missing data, and implications for missing data (what are some suggested next steps?);
- Analyze data per indicator and assist in drafting narratives;
- Assist in drafting or reviewing the Team's Memo for Bill on the Livestock Dashboard;
- Review relevant graphics made by R4D;
- Suggest key stakeholders for the Gates Foundation to convene in September to vet the draft Livestock Dashboard.

2.5 Serve as a regular technical resource and strategic advisory for continued Livestock Dashboard development.

Key findings of Livestock models for SSA countries and India (UP, Bihar, and Odisha)

Contents

Investment Planning Analysis (IPA) – Livestock section

This work contributes to the livestock modelling section of IPA initiative for India (UP, Odisha, and Bihar) and SSA countries (Ethiopia, Nigeria, and Tanzania). We constructed mathematical models using spreadsheet modelling approach to analyse LSMS and national statistics data and constructed analytical models to evaluate the potential future outcomes associated with different scenarios of change ('low lift' and 'stretch packages'), particularly those aimed at raising smallholder productivity, increasing incomes, and driving rural development. We developed mathematical models that allow conducting ex-ante analysis of effect of different levels of technological uptake and adoption rate by smallholder households on raising their income and the likelihood of meeting BMGF mortality and yield targets in different points in time. We supplemented mathematical models with simple simulation models to evaluate livestock population under different mortality, fertility and offtake assumptions. A general representation of equations of simulation models are as follow (spreadsheet model details are submitted separately as excel files):

Cattle(t) = Cattle(t - dt) + (Birth rate - Death rate - Offtake) * dt
INIT Cattle = 44187326

INFLOWS:
Birth rate = (Cattle*Reproduction rate)
OUTFLOWS:
Death rate = Cattle*Mortality rate
Offtake = Cattle*Offtake rate

Chicken(t) = Chicken(t - dt) + (Birth rate 1 - Death rate 1 - Offtake 1) * dt
INIT Chicken = 28961529

INFLOWS:
Birth rate 1 = (Chicken*Reproduction rate 1)
OUTFLOWS:
Death rate 1 = Chicken*Mortality rate 1
Offtake 1 = Chicken*Offtake rate 1

Goats(t) = Goats(t - dt) + (Birth rate 2 - Death rate 2 - Offtake 2) * dt
INIT Goats = 17851080

INFLOWS:
Birth rate 2 = (Goats*Reproduction rate 2)
OUTFLOWS:
Death rate 2 = Goats*Mortality rate 2
Offtake 2 = Goats*Offtake rate 2

Sheep(t) = Sheep(t - dt) + (Birth rate 3 - Death rate 3 - Offtake 3) * dt
INIT Sheep = 21040855

INFLOWS:
Birth rate 3 = (Sheep*Reproduction rate 3)
OUTFLOWS:
Death rate 3 = Sheep*Mortality rate 3
Offtake 3 = Sheep*Offtake rate 3

The main outputs of the IPA analysis (livestock section) can be split into three models (national SHF status and scenarios, evaluating sub-national targets, and bottom-up farm-level impact build) that combine reported data with user assumptions informed by IPA's baseline data outputs.

- **National SHF status and scenarios (Level 1):** Presents national level baseline production data for select livestock owned by smallholder farmer households (SHF hh), as well as modeled revenue effects. Through adjustments to yield, farmgate price, and mortality (for livestock), AgDev team members can forecast and contrast the production and revenue effects on SHF hh across a wide selection of Ag commodities.
- **Evaluating sub-national targets (Level 2):** Enables AgDev team members to check yield targets by breaking down the shift in yield into its component parts: yield change and rate of adoption, across four SHF segments for SSA countries and three SHF segments for India. The exercise of considering, by segment, potential yield increases per adopting households (hhs) and the number of adopting hhs allows for a more realistic estimation of potential yield changes.
- **Bottom-up farm-level impact build (Level 3):** Enables AgDev team members to model potential yield changes and their income effects on SHF hh using a combination of reported data and inputted assumptions. The model aims to better imitate farming practices by separating SHF hh into groups with different sets of practices in both the current and future states, and identifying how many farmers shift to improved practices between the two states. The outputs show income changes both averaged across all farmers and just for those changing their practices, along with the necessary inputs/on farm expenditures to realize those changes.

Key findings

The major outcome of Level 1 models are of the overall number of smallholder households that keep different livestock species and average number of livestock per household. Level 2 models allocates total number of smallholder households to four different segments in SSA countries

SSA segments:

1. Low agricultural potential; Low market potential
2. Low agricultural potential; High market potential
3. High agricultural potential; Low market potential
4. High agricultural potential; High market potential

Level 2 focuses on major livestock species such as cattle, chicken, sheep, and goat for SSA countries. The main outcomes of level 2 models are percentage of households allocated to each segment, the most likely yield and mortality changes per segment, and the likely percentage of households adopting technologies that increases yield. Similarly, level 3 models expand level 2 models by including 'low lift' and 'stretch' intervention packages to enhance livestock productivity. The main outcomes of level 3 models are changes in livestock productivity and household income per segment. In the subsequent sections, we summarize key results of level 1, 2 and 3 models per country.

Ethiopia:

- **Level 1 model:**

Table 1 summarizes the key outcomes of level 1 model in Ethiopia. Cattle, followed by chicken, sheep, goat, sheep, camel, donkey, and mule, are the main livestock species that support the livelihood of smallholder producers.

Table 40: Main livestock species in Ethiopia

Item	Approximate number of households (millions)	Livestock/household
Cattle	10.13	4.6
Chicken	7.574	5.5
Sheep	4.828	4.5
Goat	3.772	5.6
Camel	0.406	5
Donkey	4.083	1.4
Mule	0.339	1.1

- **Level 2 model:**

Table 2 summarizes key outcomes of level 2 model for cattle in Ethiopia. Percentage household represents the proportion of total households that belong to each segment. Similarly, Percentage cattle population represents the proportion of total cattle population per segment. Potential yield increase represents the likely increases in milk yield relative to baseline yield depending on adopted technologies (see section xxx for a summary on 'low lift' and 'stretch' packages). Percentage households adopting yield increasing technologies represent the likely proportion of total households in each segment to adopt yield increasing technologies by 2020. Tables 3, 4, and 5 shows similar summary for chicken, sheep, and goat, respectively.

Table 41: Key outcomes of level 2 model – Ethiopia (cattle)

Item	Seg 1	Seg 2	Seg 3	Seg 4
% households	21%	10%	51%	19%
% cattle population	29%	9%	44%	18%
Potential yield increase rate	30% to 250%	30% to 250%	39% to 283%	39% to 283%
% households adopting yield increasing technologies	3% to 6%	3% to 13%	3% to 11%	5% to 20%

Table 42: Key outcomes of level 2 model – Ethiopia (chicken)

Item	Seg 1	Seg 2	Seg 3	Seg 4
% households	23%	9%	50%	18%
% chicken population	25%	9%	48%	17%
Potential yield increase rate	22% to 180%	22% to 180%	22% to 180%	22% to 180%
% households adopting yield increasing technologies	3% to 5%	3% to 8%	3% to 10%	8% to 15%

Table 43: Key outcomes of level 2 model – Ethiopia (sheep)

Item	Seg 1	Seg 2	Seg 3	Seg 4
% households	22%	8%	55%	15%
% sheep population	27%	12%	46%	15%
Potential yield increase rate	25% to 140%	25% to 140%	32% to 167%	32% to 167%
% households adopting yield increasing technologies	2.5% to 8%	5% to 8%	5% to 8%	5% to 8%

Table 44: Key outcomes of level 2 model – Ethiopia (Goat)

Item	Seg 1	Seg 2	Seg 3	Seg 4
% households	33%	15%	38%	14%
% sheep population	44%	21%	26%	9%
Potential yield increase rate	25% to 140%	25% to 140%	32% to 167%	32% to 167%
% households adopting yield increasing technologies	2.5% to 8%	5% to 8%	5% to 8%	5% to 8%

- **Level 3 model:**

While level 1 and level 2 model provided an overview of livestock species per country and allocation of livestock households and population to different segments, respectively, level 3 models reports a more disaggregated figures in which we compare model results to BMGF productivity targets. In level 3 models, we report potential changes on livestock productivity parameter to compare it with BMGF targets, and income generated per household per livestock species. Figure 1 shows level 3 model results for cattle in Ethiopia. In figure 1, the x-axis represent segments and weighted average of all segments, the y-axis represents yield, mortality rate, and income (in USD). BMGF yield and mortality targets are plotted on the figures (if available). The bars on each figure shows model outcome based on initial data used and potential yield increase and percentage households adopting yield increasing technologies. Figures 2, 3, 4, and 5 shows level 3 model results for chicken, sheep, goat, and overall household income from livestock activities in Ethiopia, respectively.

Figure 1: Level 3 model results – Ethiopia (cattle)

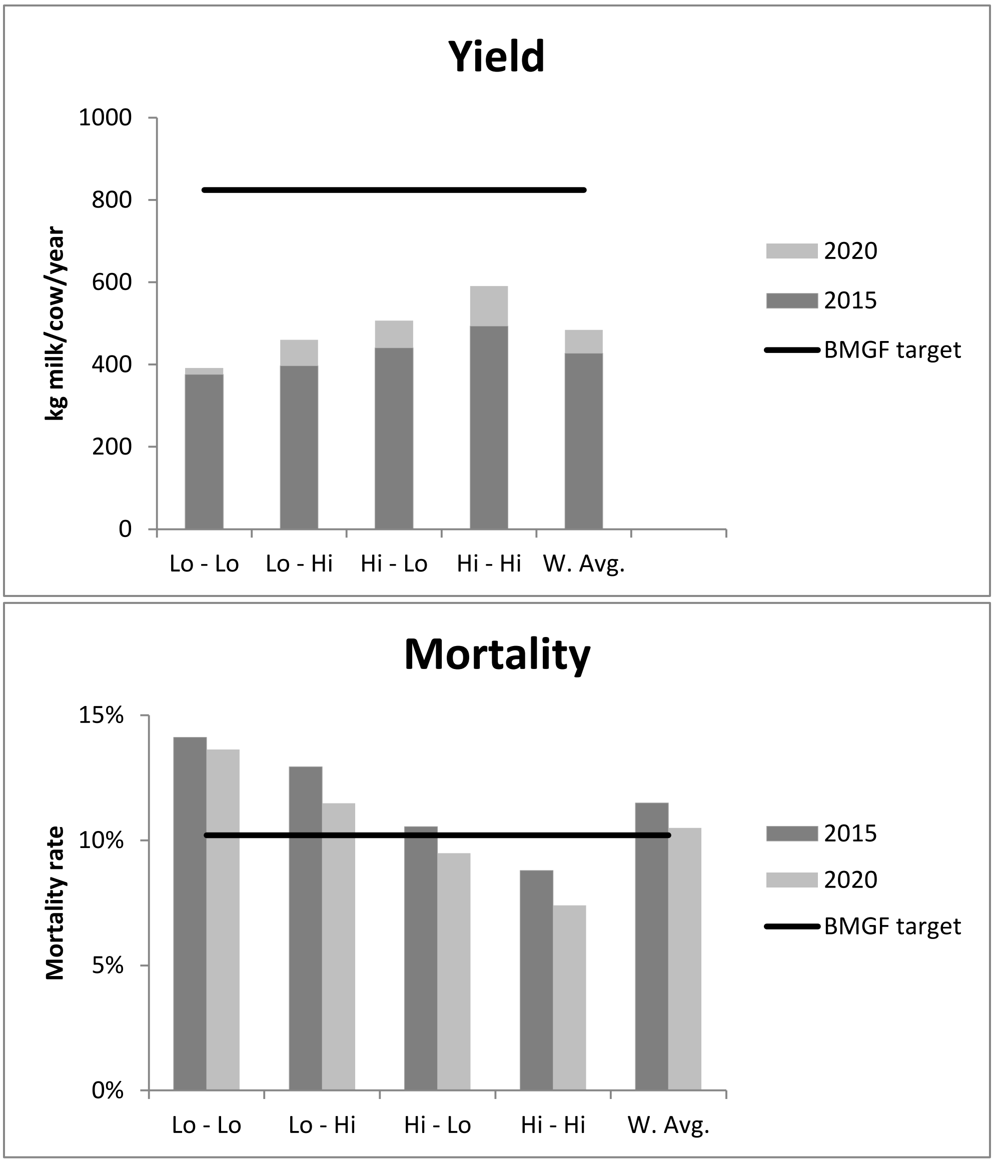
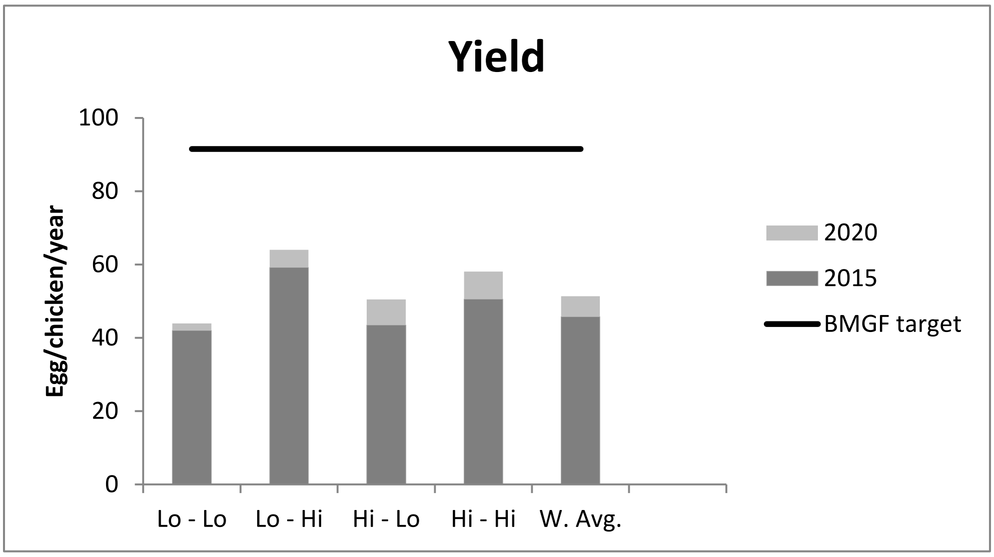


Figure 2: Level 3 model results – Ethiopia (chicken)



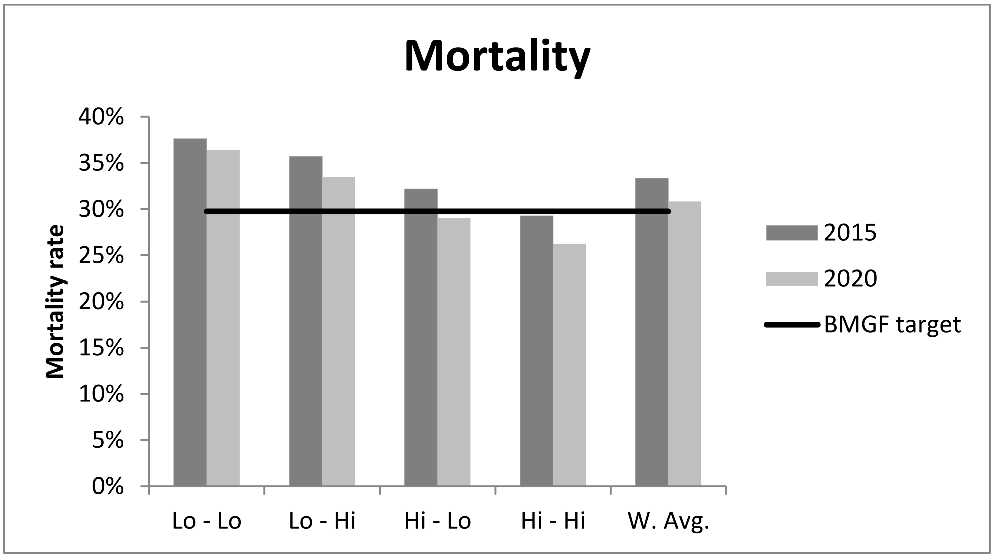
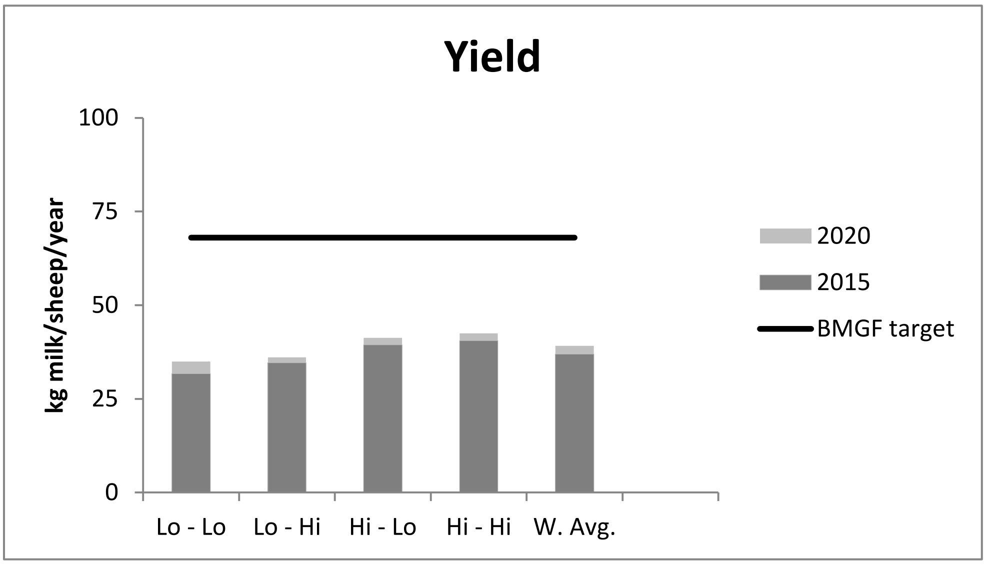


Figure 3: Level 3 model results – Ethiopia (sheep)



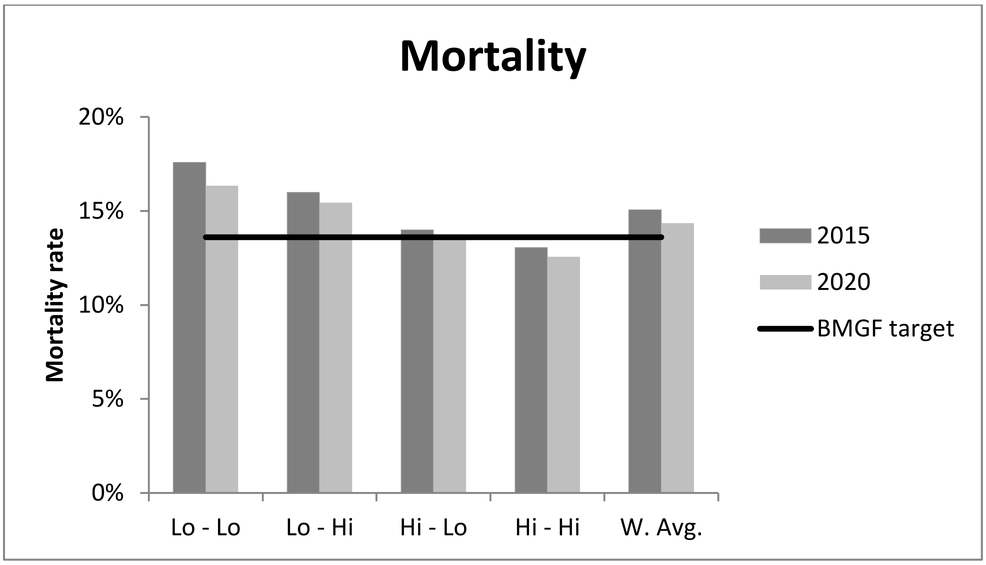


Figure 4: Level 3 model results – Ethiopia (Goat)

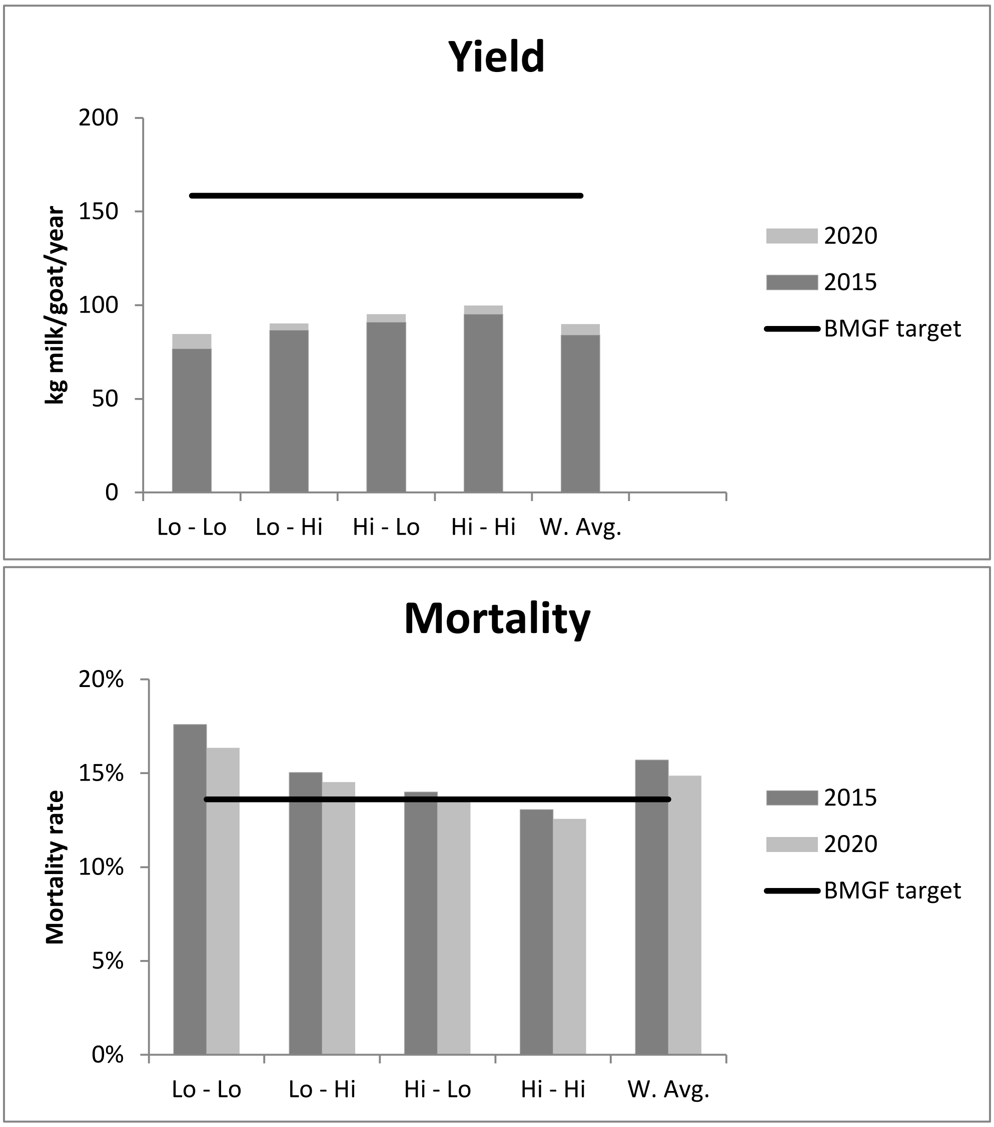
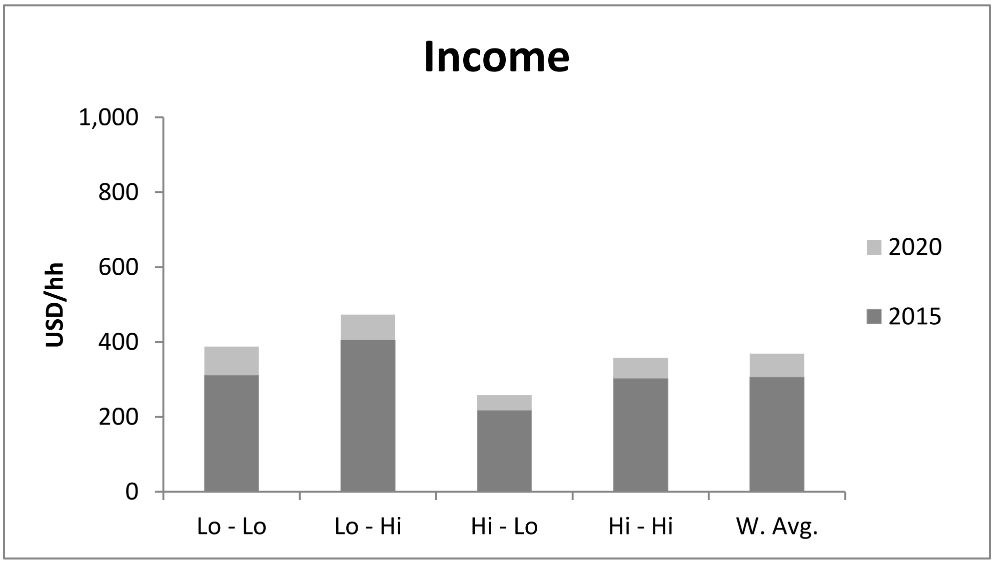


Figure 5: Level 3 model results – Ethiopia (Total livestock income per household)



Tanzania

- **Level 1 model:**

Table 6 summarizes the main outcomes of level 1 model in Tanzania. The majority of smallholder households in Tanzania produce chicken, followed by goats, cattle, sheep, ducks, pigs, and Rabbits, respectively.

Table 45: Main livestock species in Tanzania

Item	Approximate number of households (millions)	Livestock/household
Chicken	2.999	13.1
Goats	1.820	8.7
Cattle	1.393	11.3
Sheep	0.607	7.7
Ducks	0.449	8.6
Pigs	0.406	3.4
Rabbits	0.0165	5

- **Level 2 model:**

Table 7 summarizes key outcomes of level 2 model for chicken in Tanzania, followed by tables 8, 9, and 10 that reports level 2 model results for goat, cattle, and sheep, respectively.

Table 46: key outcomes of level 2 model - Tanzania (Chicken)

Item	Seg 1	Seg 2	Seg 3	Seg 4
% households	22%	15%	36%	28%
% chicken population	24%	15%	32%	39%
Potential yield increase rate	22% to 180%	22% to 180%	22% to 180%	22% to 180%
% households adopting yield increasing technologies	3% to 5%	3% to 8%	3% to 10%	8% to 15%

Table 47: Key outcomes of level 2 model - Tanzania (goat)

Item	Seg 1	Seg 2	Seg 3	Seg 4
% households	18%	20%	38%	24%
% sheep population	23%	23%	36%	19%
Potential yield increase rate	25% to 140%	25% to 140%	32% to 167%	32% to 167%
% households adopting yield increasing technologies	2.5% to 8%	5% to 8%	5% to 8%	5% to 8%

Table 48: Key outcomes of level 2 model - Tanzania (cattle)

Item	Seg 1	Seg 2	Seg 3	Seg 4
% households	20%	19%	32%	29%
% cattle population	23%	28%	28%	21%
Potential yield increase rate	30% to 250%	30% to 250%	39% to 283%	39% to 283%

% households adopting yield increasing technologies	3% to 6%	3% to 13%	3% to 11%	5% to 20%

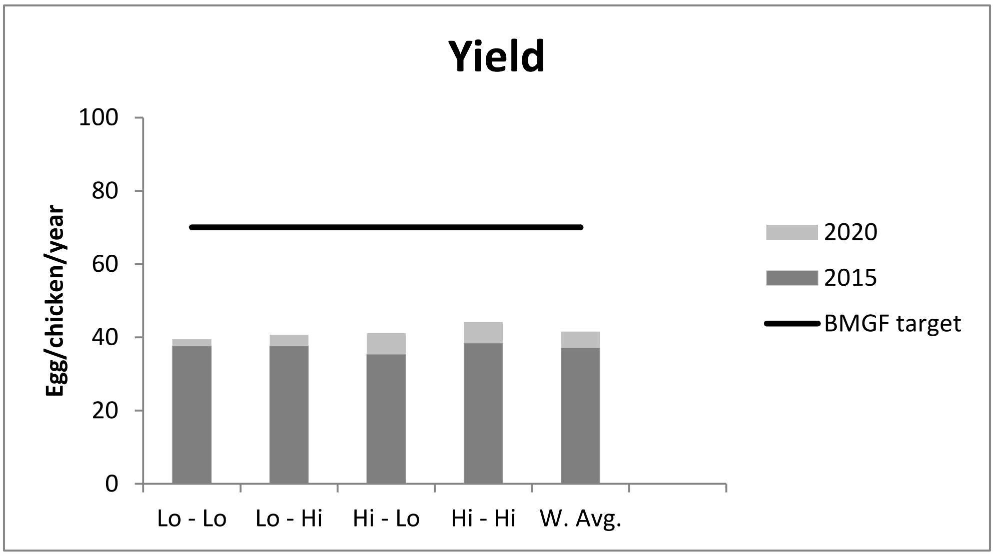
Table 49: Key outcomes of level 2 model - Tanzania (sheep)

Item	Seg 1	Seg 2	Seg 3	Seg 4
% households	25%	23%	36%	16%
% sheep population	24%	28%	33%	15%
Potential yield increase rate	25% to 140%	25% to 140%	32% to 167%	32% to 167%
% households adopting yield increasing technologies	2.5% to 8%	5% to 8%	5% to 8%	5% to 8%

- **Level 3 model:**

Figure 6 shows level 3 model results for chicken in Tanzania, followed by figures 7, 8, 9, and 10 for goat, cattle, sheep, and overall household income form livestock activities, respectively.

Figure 6: Level 3 model results – Tanzania (Chicken)



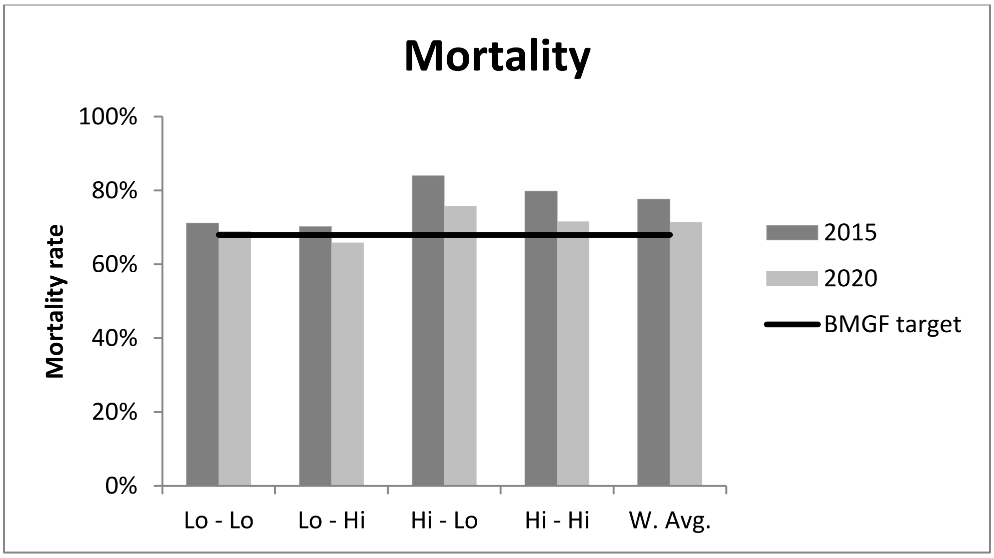


Figure 7: Level 3 model results – Tanzania (Goat)

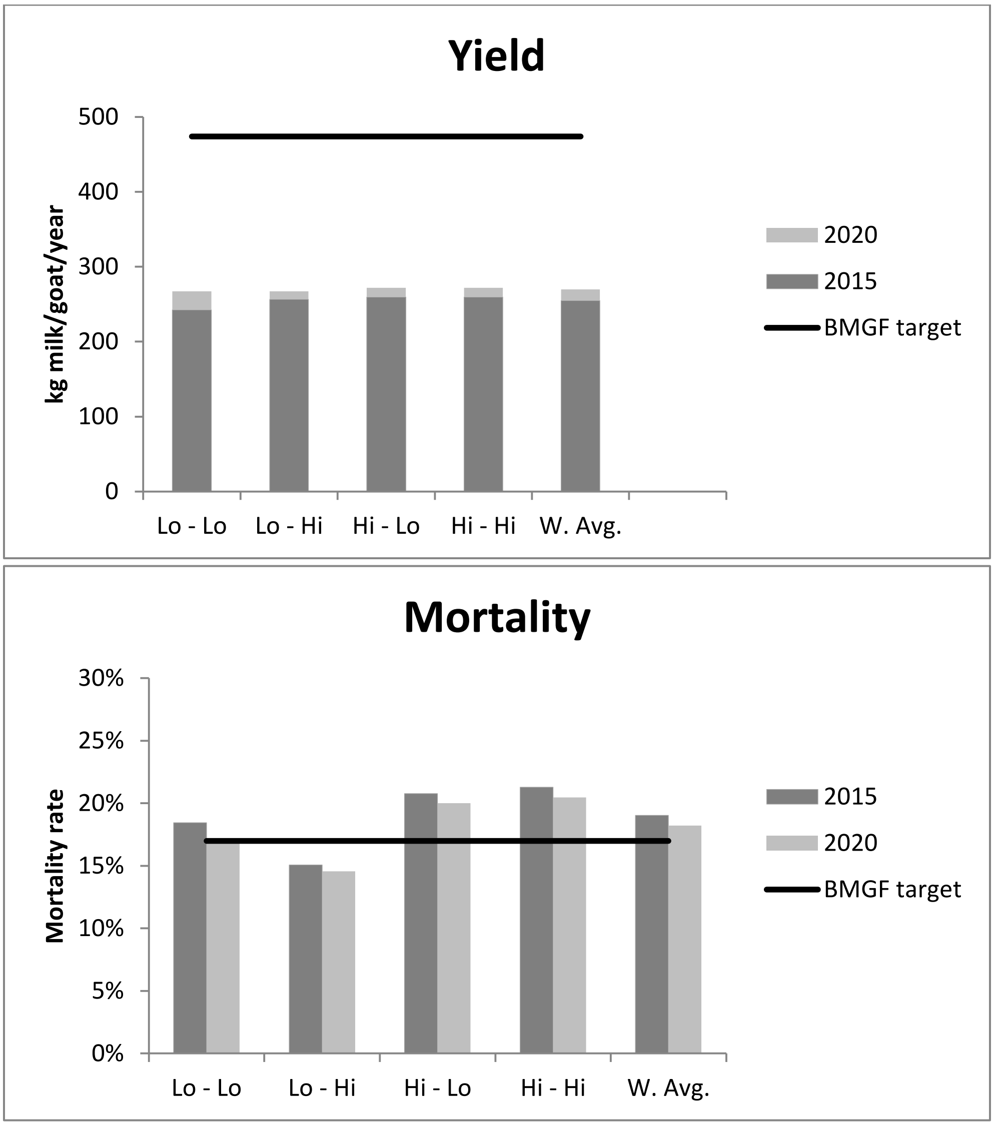


Figure 8: Level 3 model results – Tanzania (cattle)

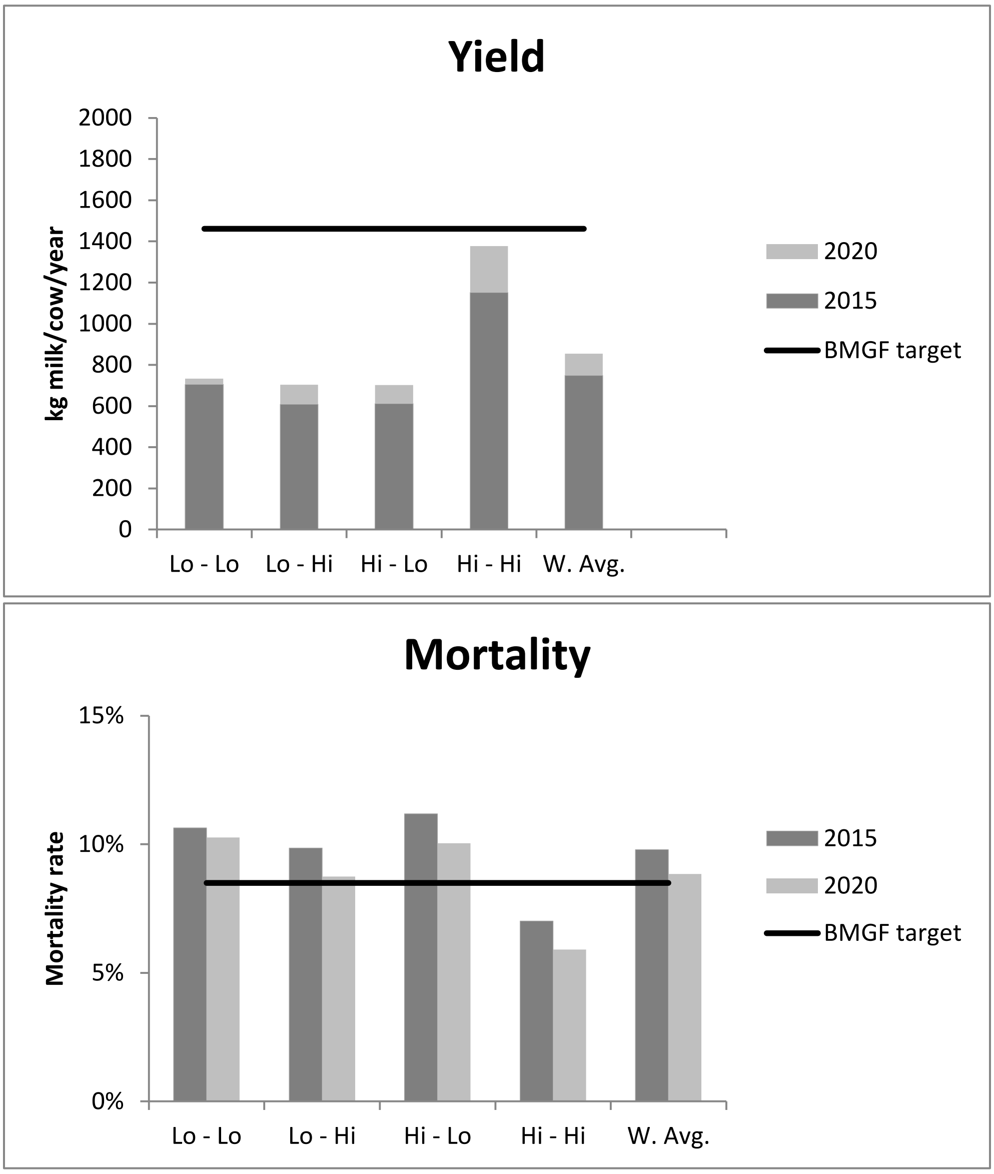
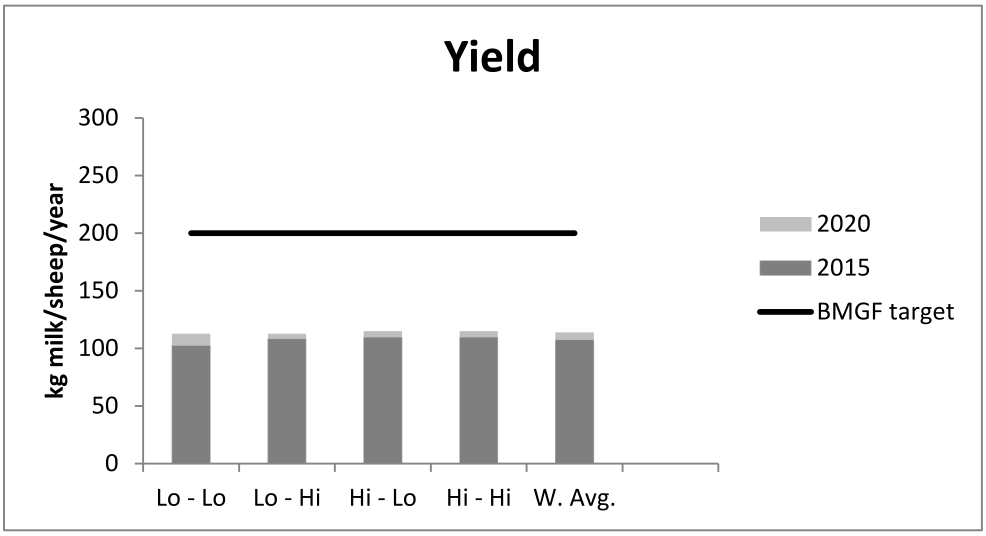


Figure 9: Level 3 model results – Tanzania (sheep)



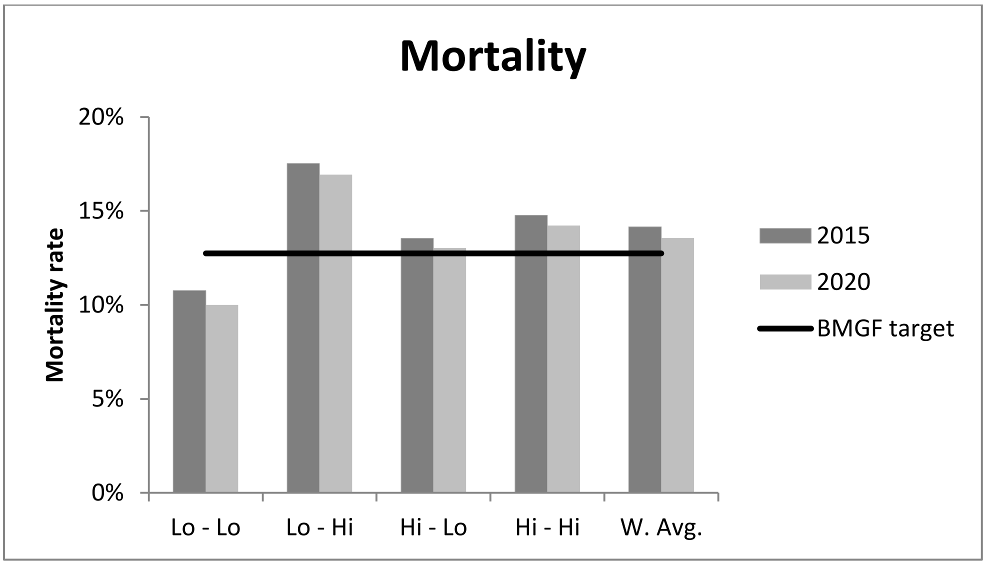
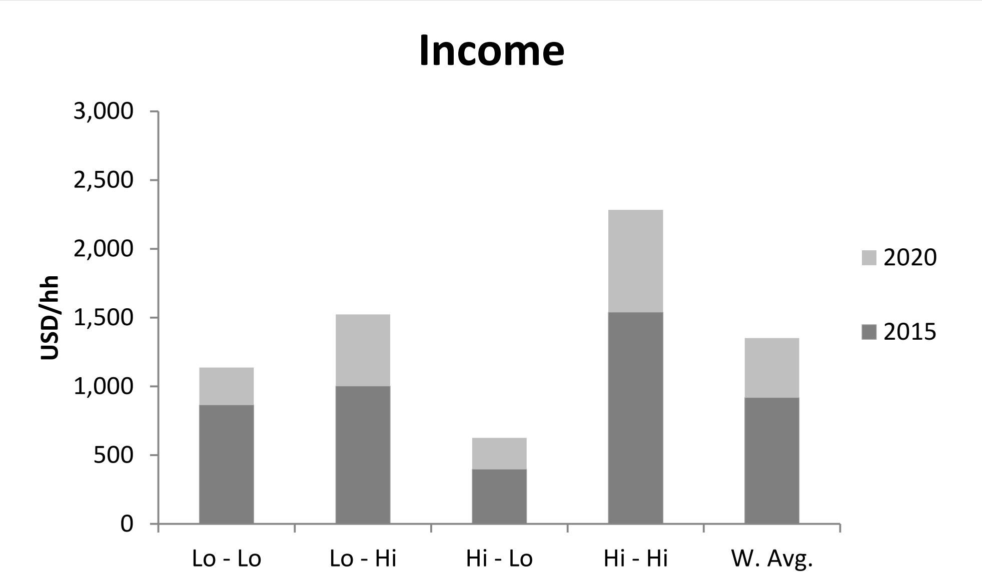


Figure 10: Level 3 model results – Tanzania (Total livestock income per household)



Nigeria

- **Level 1 model:**

Table 11 summarizes the main outcomes of level 1 model in Nigeria. The majority of smallholder households in Tanzania produce goat, followed by chicken, sheep, cattle, Guinea fowl, pigs, donkey, ducks, turkey, camel, horses, and Rabbits, respectively.

Table 50: Main livestock species in Nigeria

Item	Approximate number of households (millions)	Livestock/household
Goat	7.329	6.5
Chicken	7.118	17.4
Sheep	3.884	6.3
Cattle	2.934	10.5
Guinea fowl	0.618	13.7
Pigs	0.341	9
Donkey	0.33	1.6
Ducks	0.276	5.6
Turkey	0.126	10
Camel	0.062	4.2
Horses	0.059	8.6
Rabbit	0.029	18.1

- **Level 2 model:**

Table 12 summarizes key outcomes of level 2 model for goats in Tanzania, followed by tables 8, 9, and 10 that reports level 2 model results for chicken, sheep, and cattle, respectively.

Table 51: Key outcomes of level 2 model - Nigeria (goat)

Item	Seg 1	Seg 2	Seg 3	Seg 4
% households	9%	50%	6%	35%
% sheep population	10%	59%	5%	26%
Potential yield increase rate	25% to 140%	25% to 140%	32% to 167%	32% to 167%
% households adopting yield increasing technologies	2.5% to 8%	5% to 8%	5% to 8%	5% to 8%

Table 52: Key outcomes of level 2 model - Nigeria (chicken)

Item	Seg 1	Seg 2	Seg 3	Seg 4
% households	8%	38%	8%	46%
% chicken population	8%	39%	10%	43%
Potential yield increase rate	22% to 180%	22% to 180%	22% to 180%	22% to 180%
% households adopting yield increasing technologies	3% to 5%	3% to 8%	3% to 10%	8% to 15%

Table 53: Key outcomes of level 2 model - Nigeria (sheep)

Item	Seg 1	Seg 2	Seg 3	Seg 4
% households	10%	77%	2%	12%
% sheep population	10%	79%	1%	9%
Potential yield increase rate	25% to 140%	25% to 140%	32% to 167%	32% to 167%
% households adopting yield increasing technologies	2.5% to 8%	5% to 8%	5% to 8%	5% to 8%

Table 54: Key outcomes of level 2 model - Nigeria (Cattle)

Item	Seg 1	Seg 2	Seg 3	Seg 4
% households	15%	74%	3%	8%
% cattle population	12%	63%	2%	23%
Potential yield increase rate	30% to 250%	30% to 250%	39% to 283%	39% to 283%
% households adopting yield increasing technologies	3% to 6%	3% to 13%	3% to 11%	5% to 20%

- **Level 3 model:**

Figure 11 shows level 3 model results for goat in Nigeria, followed by figures 12, 13, 14, and 15 for chicken, sheep, cattle, and overall household income form livestock activities, respectively.

Figure 11: Level 3 model results – Nigeria (Goat)

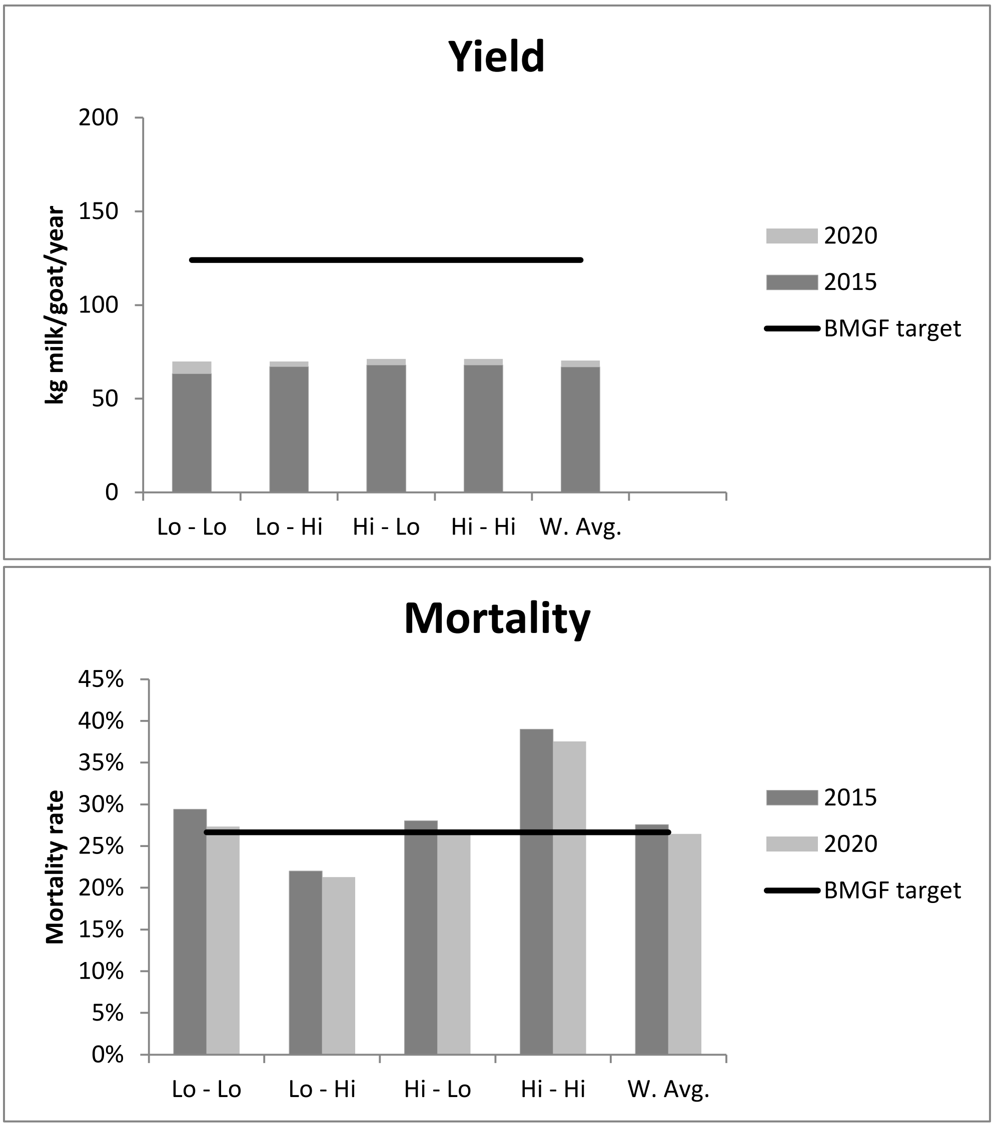


Figure 12: Level 3 model results – Nigeria (chicken)

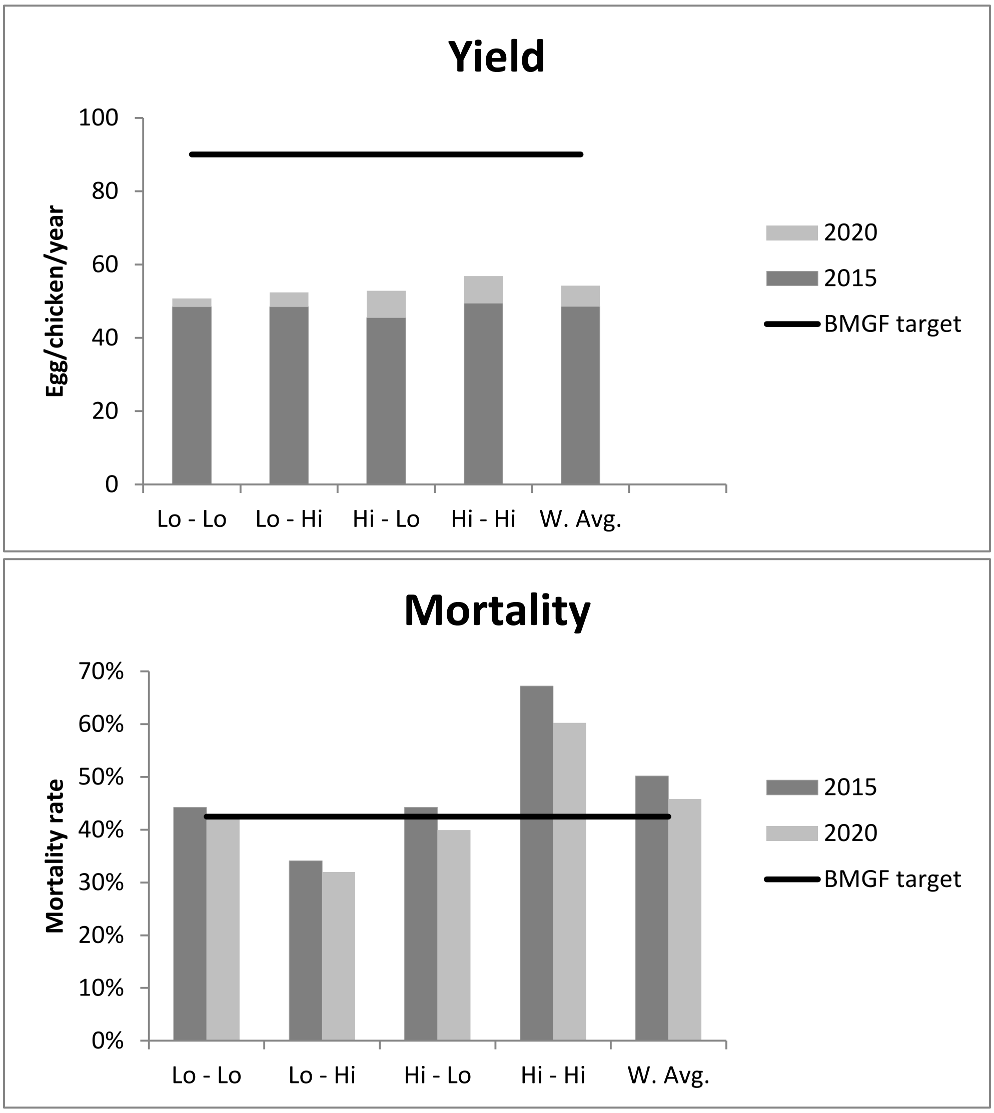
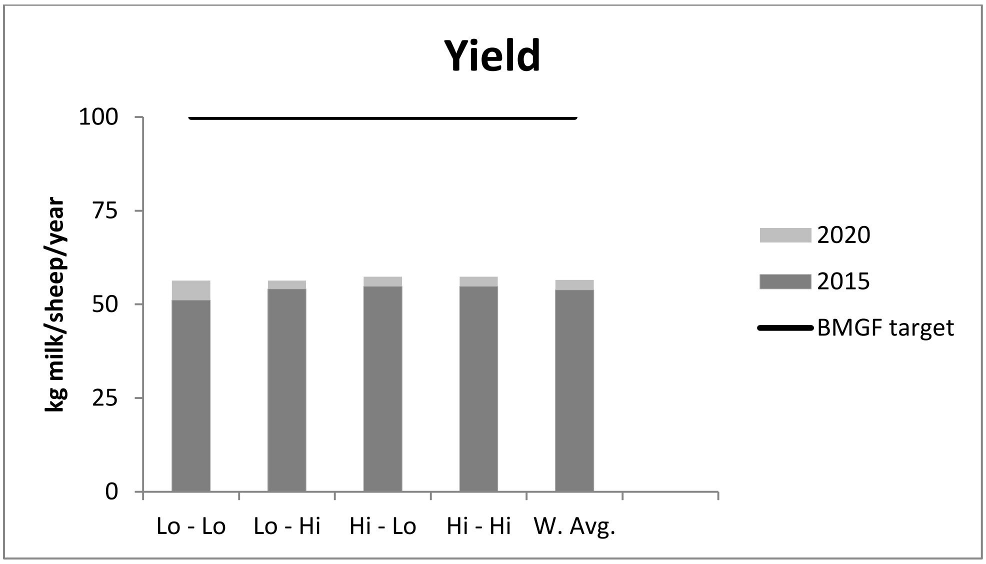


Figure 13: Level 3 model results – Nigeria (sheep)



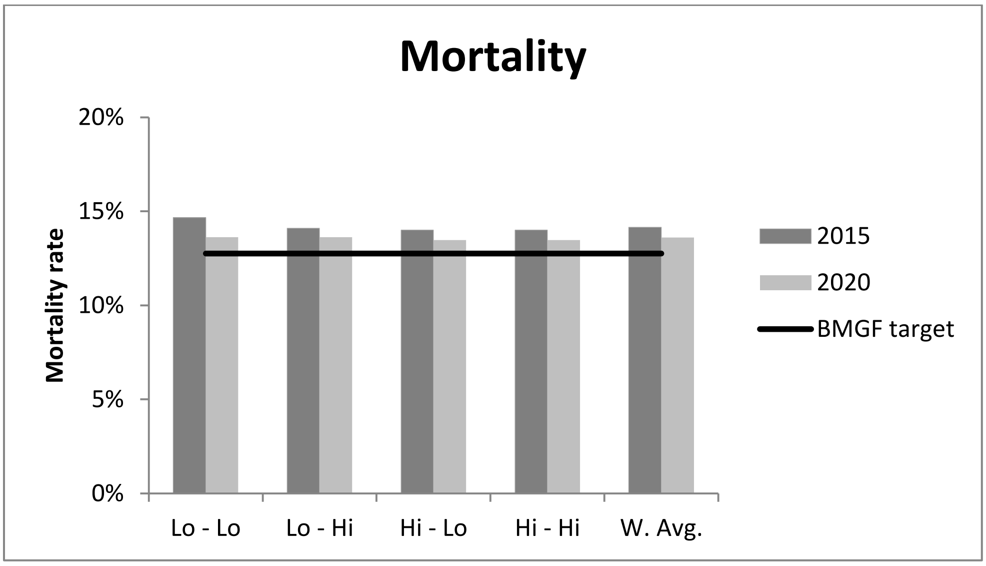
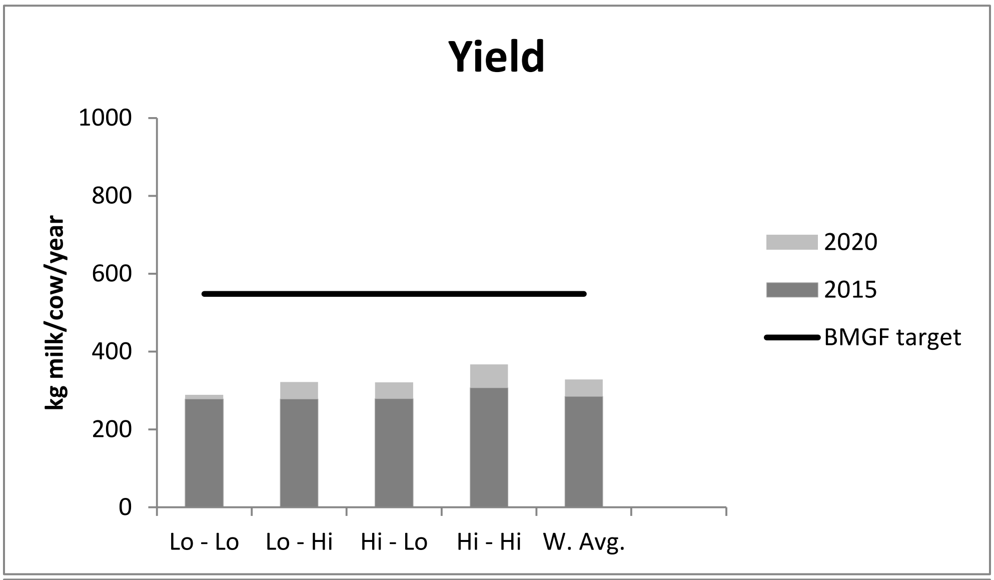


Figure 14: Level 3 model results – Nigeria (cattle)



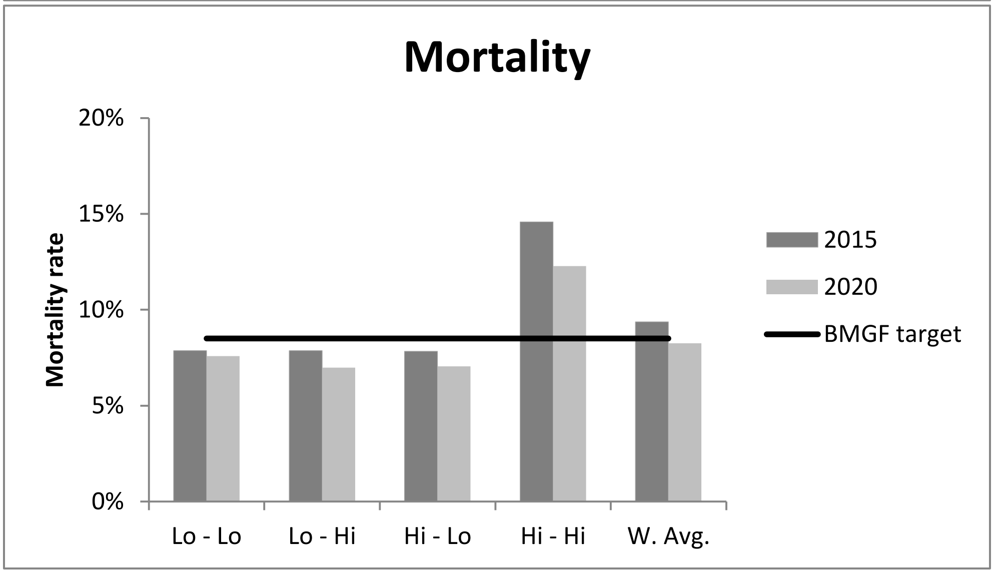
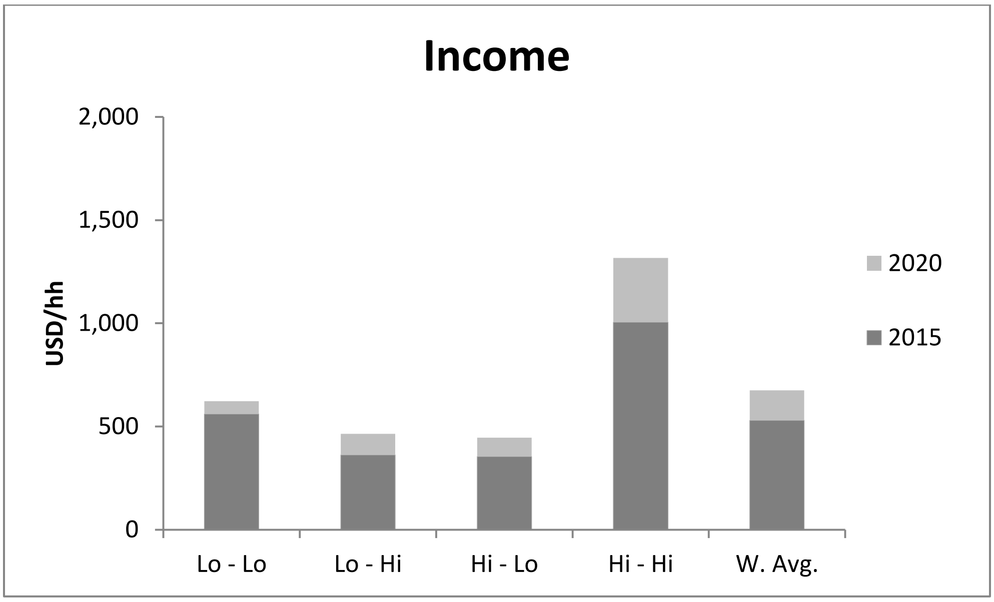


Figure 15: Level 3 model results – Nigeria (Total livestock income per household)



India

In this section, we report level 1, 2, and 3 model results for states of UP, Bihar, and Odisha in India. Level 1 model results follow the same procedure as level 1 model for SSA countries, which reports main livestock species, number of smallholder households, and average number of livestock per household. Level 2 and 3 models for India present similar results as in models for SSA countries. However, level 2 and 3 models for India differ from SSA countries models in two ways. First the segments defined as livestock producers that does not produce crops, livestock producers operate on unirrigated crop lands, and livestock producers operate on irrigated crop lands. Second, we only focus on cattle in level 2 and 3 models. Level 2 and three models allocated smallholder producers to three different segments:

India Segments:

1- No crops
2- Irrigated
3- Non-irrigated

India (UP)

- **Level 1 and 2 models:**

Table 16 summarizes the main outcomes of level 1 model in UP, India. The majority of smallholder households in UP produce buffalo, followed by cattle, goat, chicken, pig, and sheep, respectively. Similarly, Table 17 summarizes key outcomes of level 2 model for cattle in UP.

Table 55: Main livestock species in UP, India

Item	Approximate number of households (millions)	Livestock/household
Buffalo	11.956	2.6
Cattle	8.133	2.4
Goat	4.525	3.4
Chicken	2.292	4.5
Pig	0.2	6.7
Sheep	0.110	12.3

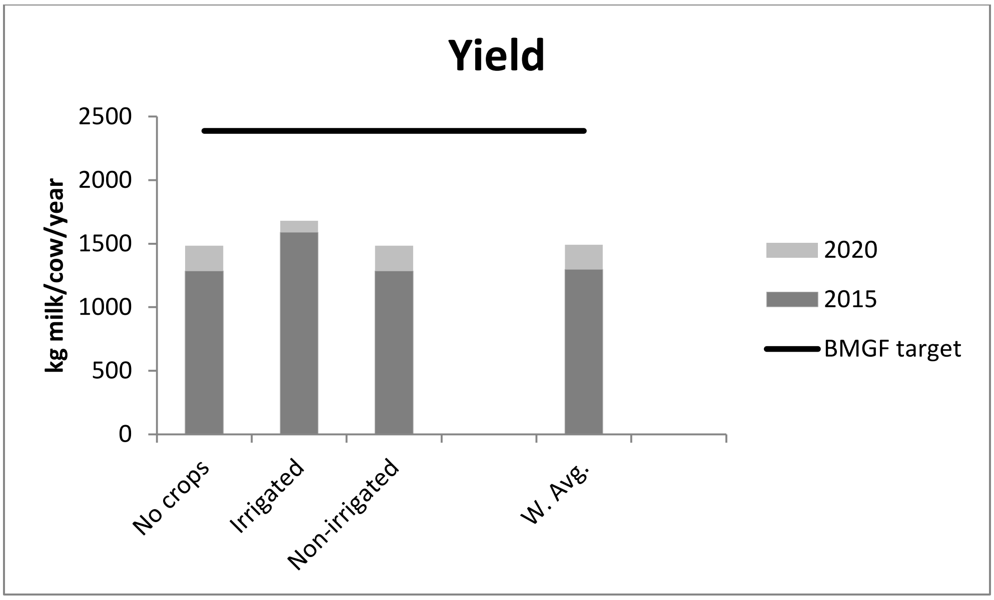
Table 56: Key outcomes of level 2 model - UP, India (Cattle)

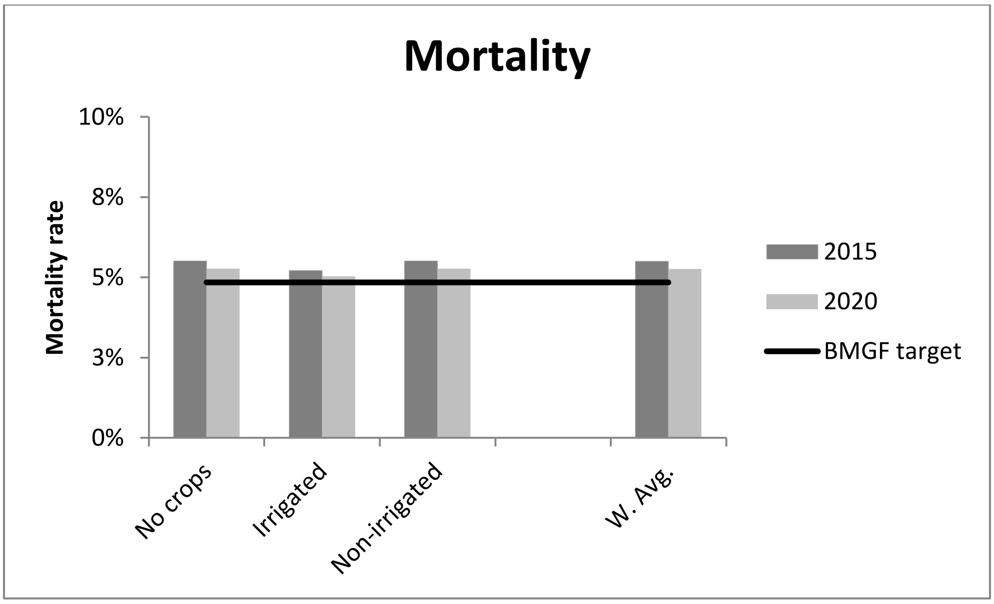
Item	No crops	Un-irrigated	Irrigated
% households	22%	3%	75%
% sheep population	19%	4%	77%
Potential yield increase rate	35% to 343%	35% to 343%	35% to 343%
% households adopting yield increasing technologies	5% to 10%	10% to 15%	5% to 10%

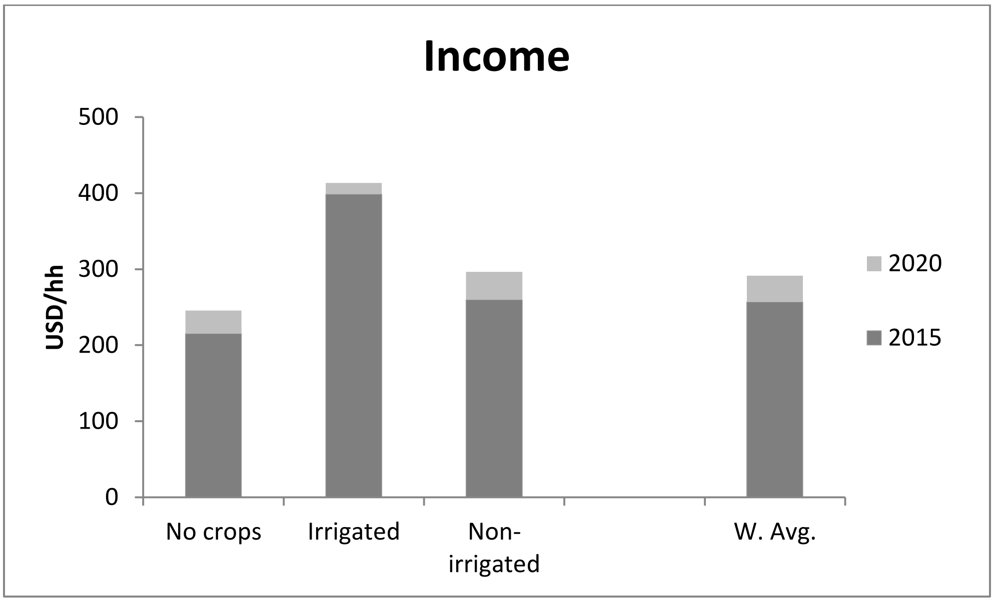
- **Level 3 model:**

We present similar figures for level 3 models for states in India as in level 3 models for SSA countries. A notable difference among level 3 model results in India and SSA countries is the differences in segments. The x-axis in figures presented in India section include no crop, unirrigated and irrigated segments instead of agricultural and market potentials as in SSA countries. Figure 16 shows yield, mortality and income figures for level 3 model in UP, India.

Figure 16: Level 3 model results – UP, India (Cattle)







India (Bihar)

- **Level 1, 2, and 3 models:**

Table 18 summarizes the main outcomes of level 1 model in Bihar, India. The majority of smallholder households in Bihar produce cattle, followed by goat, buffalo, chicken, pig, and sheep, respectively. Similarly, Table 19 summarizes key outcomes of level 2 model for cattle in Bihar. Figure 17 shows yield, mortality and income figures for level 3 model in Bihar, India.

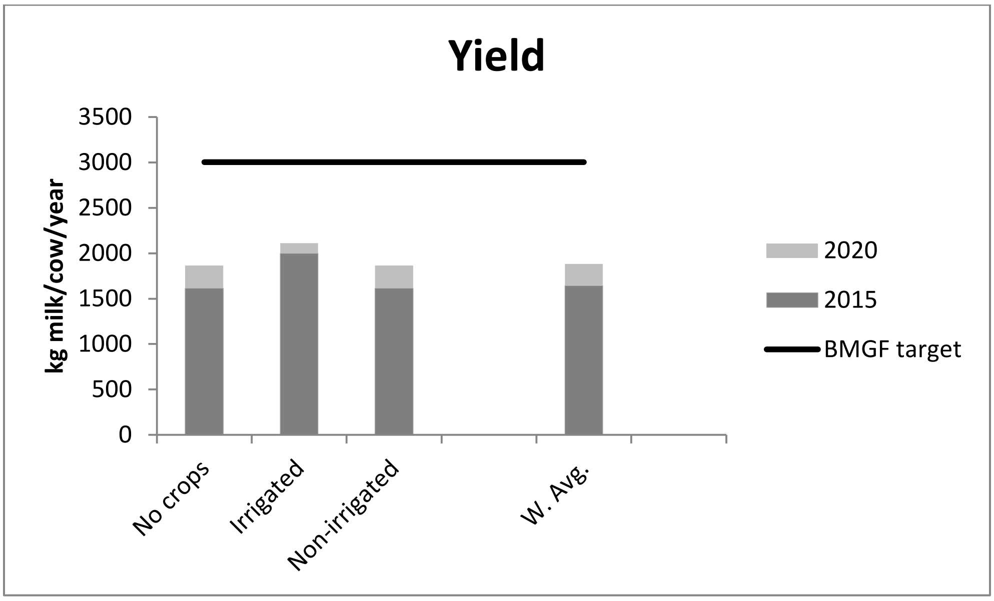
Table 57: Main livestock species in Bihar, India

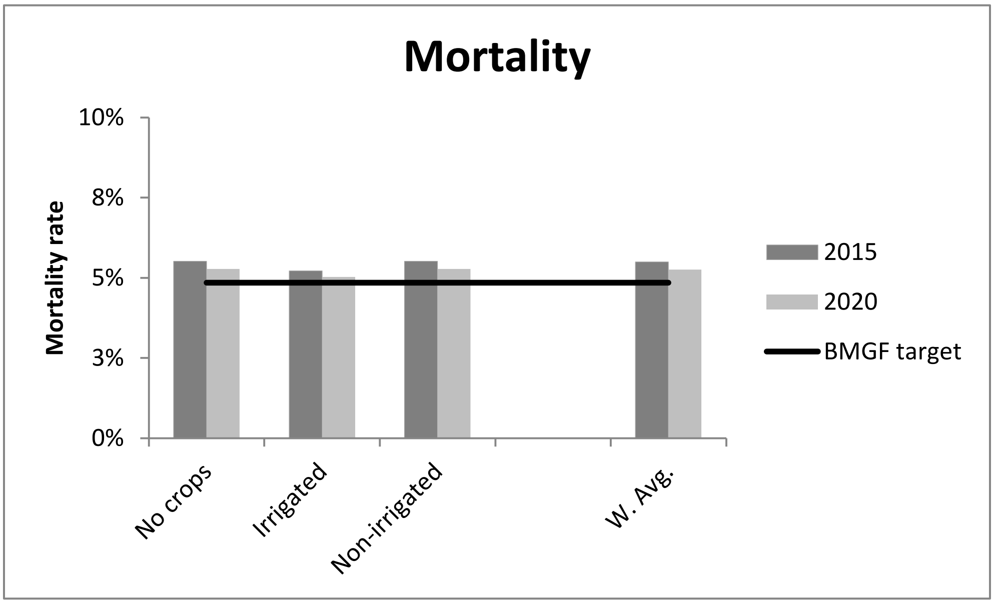
Item	**Approximate number of households (millions)**	**Livestock/household**
Cattle	5.568	2.2
Goat	4.128	2.9
Buffalo	3.554	2.1
Chicken	0.274	18.3
Pig	0.127	5.1
Sheep	0.022	10.4

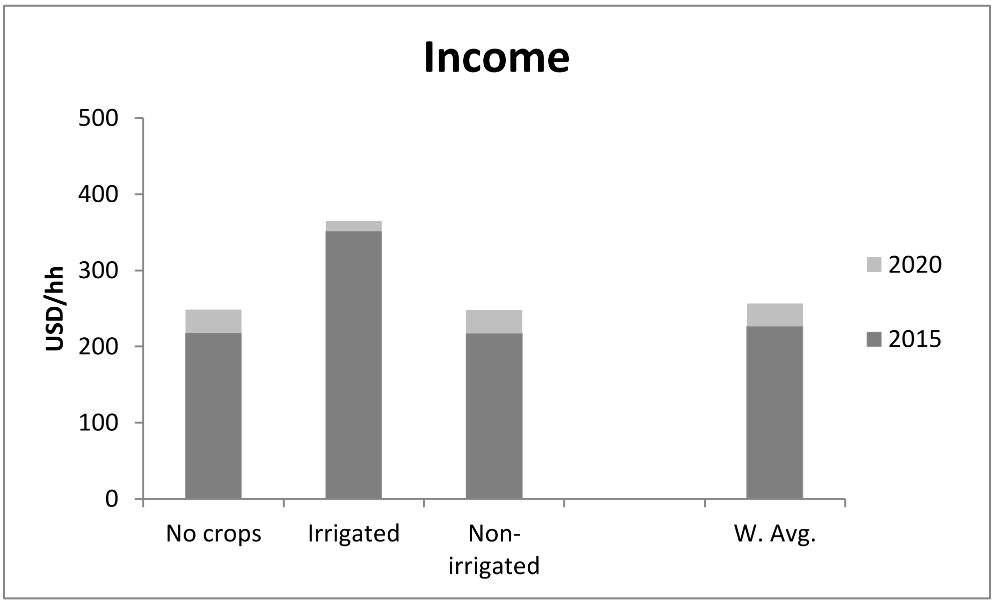
Table 58: Key outcomes of level 2 model - Bihar, India (Cattle)

Item	**No crops**	**Un-irrigated**	**Irrigated**
% households	45%	49.5%	5.5%
% sheep population	44%	49%	7%
Potential yield increase rate	35% to 343%	35% to 343%	35% to 343%
% households adopting yield increasing technologies	5% to 10%	10% to 15%	5% to 10%

Figure 17: Level 3 model results – Bihar, India (Cattle)







India (Odisha)

- **Level 1, 2, and 3 models:**

Table 20 summarizes the main outcomes of level 1 model in Odisha, India. The majority of smallholder households in Odisha produce cattle, followed by goat, chicken, sheep, buffalo, and pig, respectively. Similarly, Table 21 summarizes key outcomes of level 2 model for cattle in Odisha. Figure 18 shows yield, mortality and income figures for level 3 model in Odisha, India.

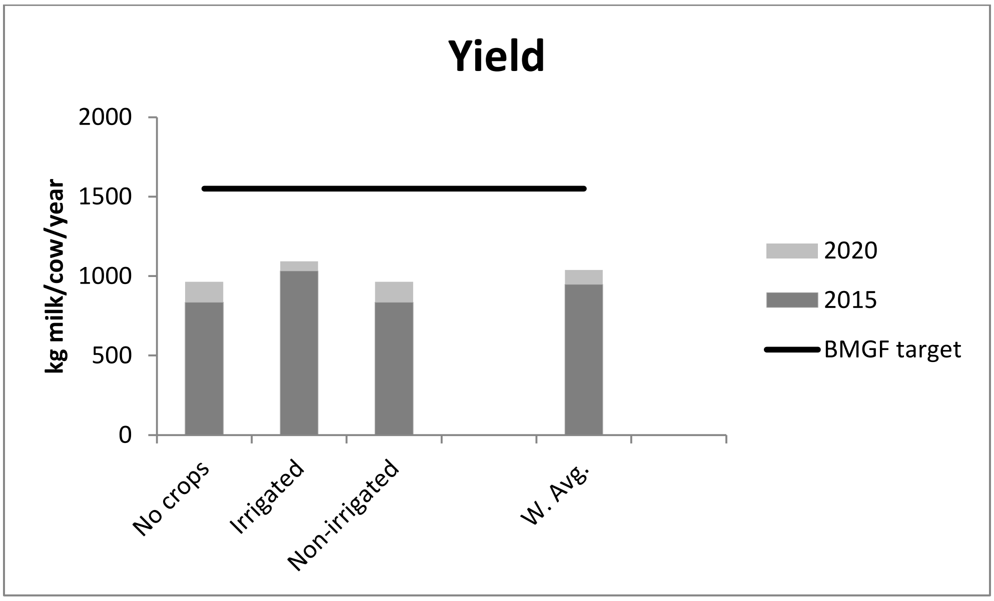
Table 59: Main livestock species - Odihsa, India

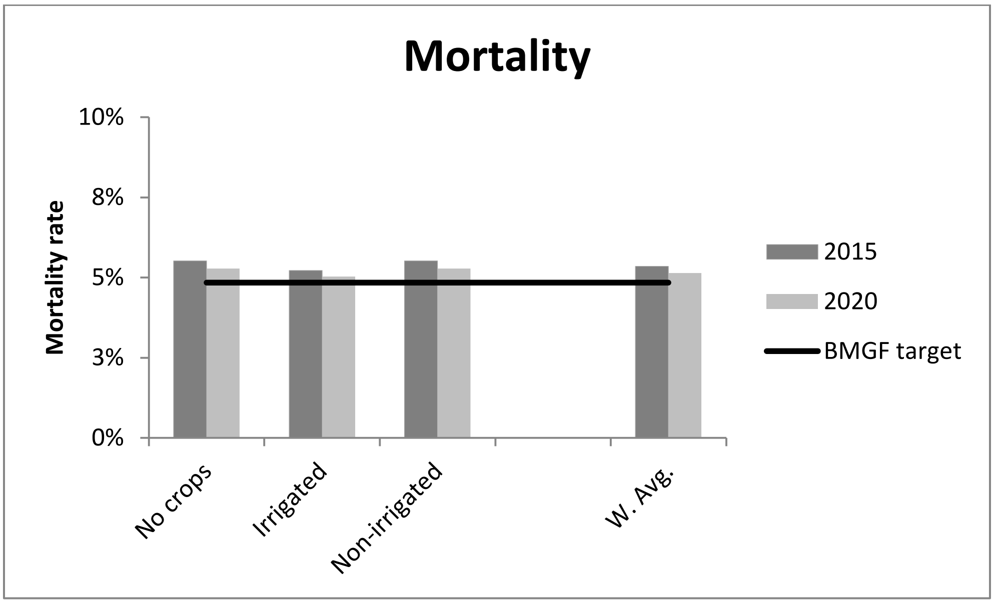
Item	Approximate number of households (millions)	Livestock/household
Cattle	3.772	3.1
Goat	1.271	5.1
Chicken	0.306	24.6
Sheep	0.240	6.6
Buffalo	0.726	4.1
Pig	0.059	4.7

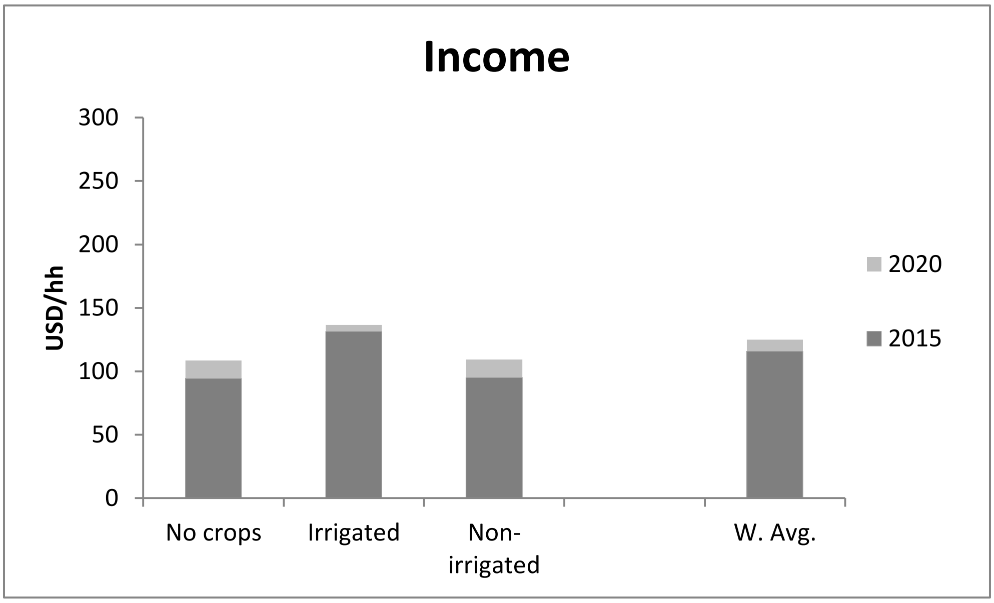
Table 60: Key outcomes of level 2 model - Odisha, India (Cattle)

Item	No crops	Un-irrigated	Irrigated
% households	20%	25%	55%
% sheep population	19%	24%	57%
Potential yield increase rate	35% to 343%	35% to 343%	35% to 343%
% households adopting yield increasing technologies	5% to 10%	10% to 15%	5% to 10%

Figure 18: Level 3 model results – Odisha, India (Cattle)




Mortality
10%
8%
5%
3%
0%
Mortality rate
2015
2020
BMGF target
No crops
Irrigated
Non-irrigated
W. Avg.


Income
300
250
200
150
100
50
0
USD/hh
2020
2015
No crops
Irrigated
Non-irrigated
W. Avg.

Dashboard Interpretive Guide: Livestock

Contents:

1 Introduction

The livestock sector is large. Twenty billion animals make use of 30% of the ice-free terrestrial land area for grazing, one-third of global cropland area is devoted to producing animal feed[1], and 32% of freshwater is used to provide direct livelihood and economic benefits to at least 1.3 billion producers and retailers[2,3]. As an economic activity, livestock contributes to 40-50% of agricultural GDP globally[4].

The livestock sector is also very dynamic and growing mostly in the developing world. Global per-capita consumption of livestock products has more than doubled in the last 40 years[4]. Increasing human population, incomes, and urbanization are projected to drive increases in the consumption of milk and meat over the next twenty years, at least at previously observed rates[1,5], with most of the growth projected to occur in the developing world. In response to these demand trends, the sector has managed to significantly increase production. Beef and milk production have more than doubled over the last 40 years and monogastric production (pigs and poultry) has grown in places by a factor of five or more[2]. Intensification of production, in terms of increased livestock and/or crop productivity, has played a pivotal role in raising output per unit of land and animal[1].

These two characteristics make livestock a key sector, especially in growing economies. A sector that due to its dynamism requires a robust set of indicators to monitor it progress in contributing towards the attainment of poverty, food security and environmental protection. This dashboard presents a simple set of indicators that demostrate the status of the livestock sector in a country. The indicators have been chosen to represent the economic and social roles of livestock while also providing productivity and health status indicators.

Section 2 provides overall background to the dashboard, Section 3 discusses the indicators in detail, and Section 4 highlights important information about the data.

last section to be done

2 Indicator Discussion

Table 1. Productivity dashboard indicators

#	Indicator	Numerator	Denominator	Notes
1	**Livestock contribution to agricultural GDP (% of ag GDP)**	Livestock GDP	Agricultural GDP	
2	**Consumption of animal source foods (kg per capita)**	Sum of livestock products consumed standardize to protein (kg)	Human population	Includes all edible livestock products (milk, meat, pork, poultry and eggs)
3	**Importance of local production vs imports (% of production produced locally)**	Local production of all livestock products (MT/yr)	Total availability of livestock products from local production and imports (MT/yr)	
4	**Importance of the smallholder sector (% of livestock production coming from smallholders)**	Production of all livestock products by smallholders (MT)	Total production of livestock products of a country (MT)	Excludes non-edible livestock products

#	Indicator	Numerator	Denominator	Notes
5	**Availability of improved breeds (Percentage of smallholder herds with improved livestock)**	Number of improved animals	Total number of animals	Estimated for dairy only
6	**Level of genetic improvements (rate of genetic gain per year, %)**	Change in productivity per animal over X years	X years * 100 (%)	• This indicator is very difficult to obtain. Most often we only estimate the changes in productivity of a country for each livestock product. Apportioning the genetic component of these changes is difficult
7	**OIE PVS score**	PVS Score	N/A	
8	**Importance of formal value chains (% of production traded in formal value chains)**	Livestock products traded in formal value chains (MT)	Total livestock production (MT)	Done across all livestock products, although the proportion traded can vary significantly by livestock product.
9	**Importance fo ruminants vs monogastrics (% of production from ruminants)**	Total production of meat and milk in MT protein from ruminants	Total livestock production from ruminants and monogastrics in MT protein	
10	**Livestock yield gaps (potential production as a % of baseline production)**	Potential production in kg per animal of livestock product	Baseline production	Done for dairy Can be done for different livestock species and weighted accordingly, although more useful by species.

Importance of the livestock sector

Share and contribution of livestock to Agricultural GDP (% of ag GDP per year)

Livestock production in the developing world is an important economic activity. Livestock products are high value products, especially when compared to crops. For example, the average global price of a tonne of red meat is more than 10 times higher than the price of soybean, while that of milk is 70 percent higher (data from FAOSTAT 2011). This makes milk and meat to rank as some of the agricultural commodities with the highest gross value of production (VOP) in the developing world (FAOSTAT 2011). In the last decade, livestock have represented between 17 and 47 percent of the total agricultural VOP in developing-country regions (range defined by South East Asia and Central America, respectively) (FAOSTAT, 2011). Over the last 40 years, the value of livestock production has seen an average 2.7 percent growth per year in sub-Saharan Africa (SSA), 3.4 percent in Central America, and 4.1 percent in South East Asia (SE). These indicators of growth compare favourably with, for example, a mean annual growth in VOP of 1.2 percent in North America over the same period (FAOSTAT 2011). These growth rates are largely a reflection of increased production in the developing world.

Level of domestic consumption

Animal source food consumption per capita (kg per capita)

In poor countries livestock and fish make significant contributions to diets. In East Africa, for example, livestock provide on average 11% of energy and 26% of protein in poor people's diets (FAOSTAT 2011). Fish, meanwhile, account for at least half the animal protein intake for the 400 million poorest people in Africa and South Asia (FAO 2009). For some vulnerable groups, such as the worlds 180 million pastoralists, the contribution of livestock products to diet is much higher; for example, among Nuer agro-pastoralists in Sudan half of the total energy intake of children aged less than 5 years comes from milk (Fielding et al. 2000).

While livestock and fish clearly make important contributions to overall food security, there is an even more important role of animal source foods in achieving nutrition, as opposed to food, security. Animal source foods are dense and palatable sources of energy and high-quality protein, important for vulnerable groups, such as infants, children, pregnant and nursing women, and people living with HIV with high nutritional needs. They also provide a variety of essential micronutrients, some of which, such as vitamin A, vitamin B12, riboflavin, calcium, iron, zinc and various essential fatty acids, are difficult to obtain in adequate amounts from plant-based foods alone (Murphy & Allen 2003). Animal source foods provide multiple micronutrients simultaneously, which can be important in diets that are lacking in more than one nutrient: for example, vitamin A and riboflavin are both needed for iron mobilization and haemoglobin synthesis, and supplementation with iron alone may not successfully treat anaemia if these other nutrients are deficient (Allen 2002). Micronutrients in animal source foods are also often more readily absorbed and bioavailable than those in plant-based foods (Murphy & Allen 2003).

Consumption of even small amounts of animal source foods has been shown to contribute substantially to ensuring dietary adequacy and preventing under-nutrition and nutritional deficiencies (Neumann et al 2003). Extensive longitudinal studies in Egypt, Kenya and Mexico (Neumann et al 2002) have shown strong associations between intake of animal source foods and better growth, cognitive function and physical activity of children, better pregnancy outcomes and reduced morbidity from illness. Consumption of adequate amounts of micronutrients, such as those that can be found in animal source foods, is associated with more competent immune systems and better immune responses (Keusch and Farthing 1986; Neumann et al 1975, 1991). Low levels of consumption of animal source foods by the poor are due to limited supply in some regions, such as sub-Saharan Africa, as well as income constraints. It has been estimated that to effectively combat under-nutrition, 20 g of animal protein per person per day is needed, which can be achieved by an annual consumption of 33 kg lean meat, 230 kg milk or 45 kg fish (FAO 2009).

Importance of local production vs imports

% of consumption met by local production

Trade is an important dimension in the economics of livestock. Local consumption dominates livestock product demand and international trade is relatively small. However, international trade has increased in recent years as a result of trade (FAO 2009). Dairy and eggs dominate trade, but meat exports are important for a handful of countries (i.e. Brazil, Thailand) (FAO 2009). Most trade of livestock products occurs within a country, with movements of animal products, inputs and services being very dynamic due to increased internal connectivity, transport networks, improved value chains and the increasing need to supply the growing urban populations.

Importance of smallholder production

Percentage of livestock production coming from smallholder systems

Cost of production is a key indicator of economic performance for agricultural systems. Proponents of net farm income emphasize that the highest-yielding strategy for smallholder farmers (maximizing quantity produced per hectare) may not align with the best income-generating strategy per crop (maximizing net quantity produced per dollar spent) or per farm (choice of crops to maximize net income earned per dollar spent) (Harris et al. 2016).

Measurement of costs of production requires calculation of both variable and fixed costs. Fixed costs are those that do not vary with changing volumes of production and remain constant even if nothing is produced (e.g. land), whereas variable costs, such as inputs costs of feed and fertilizer can fluctuate and can impact the volume of production. Valuation of fixed costs can be difficult to estimate and variable costs have a greater impact of the realized value for smallholder farmers. It is noted that household labor is a crucial variable cost, however this indicator only includes *purchased* inputs. This indicator represents the cash outlay required for each dollar of revenue generated.

Availability of improved breeds

Percentage of smallholder herds with improved livestock

The productivity of domestic livestock is centred around 3 axes: nutrition, genetic and health. Any attempt to sustainably intensify livestock production requires packages of interventions to maximize the chances of increasing productivity. Having animals of superior genetics allows changes in management to be translated more effectively into increased productivity. Therefore it is necessary to have improved livestock in target countries to ensure that productivity enhancing technologies can be implemented effective.

The availability of improved breeds in smallholder systems, is an indicator that allows R4D programmes and investors in the livestock sector gauge the adequacy of the geneteic material available for increasing productivity. It helps target AI and other programmes aiming at increasing the proportions of cross-bred or improved animals in target countries.

Level of genetic improvements

Rate of genetic gain per year

Together with the availability of improved breeds, trends in productivity improvements per animal over time are essential to monitor the status of the growth of the livestock sector. These often represent a mixture of changes in management, investment and health practices and a part of these increases are often due to genetic improvements. This is a common indicator used by geneticists to determine action and priorities for breeding programmes and for targeting investments.

Performance of veterinary services

OIE PVS score (description from the OIE website)

In this era of globalisation, the development and growth of many countries, as well as the prevention and control of major biological disasters, depend on the performance of their agricultural and food policies and economies, and this, in turn, directly relates to the quality of their Veterinary Services (VS). Important roles for VS include veterinary public health – including food-borne diseases – and regional and international market access for animals and animal products. To meet current and future opportunities and challenges, VS should be independent and objective in their activities and decisions should be based on sound science and immune from political pressure.

Strengthening of VS to help them comply with OIE international standards for quality and evaluation requires active participation and investment by both the public and the private sector. The World Organisation for Animal Health (OIE) has refined an Evaluation Tool developed initially in collaboration with the Inter-American Institute for Cooperation on Agriculture (IICA) to produce the OIE *Tool for the Evaluation of Performance of Veterinary Services* (OIE *PVS Tool*). The OIE *PVS Tool* is designed to assist VS to establish their current level of performance, to identify gaps and weaknesses in their ability to comply with OIE international standards, to form a shared vision with stakeholders (including the private sector) and to establish priorities and carry out strategic initiatives.

In the international trade of animals and animal products, the OIE promotes animal health and public health (as it relates to the prevention and control of zoonoses including food-borne diseases of animal origin) by issuing harmonised sanitary standards for international trade and disease control, by working to improve the resources and legal framework of VS / AAHS and by helping Members comply with the OIE standards, guidelines and recommendations, consistent with the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement) of the World Trade Organization (WTO).

The traditional mission of VS was to protect domestic agriculture and most resources were directed towards the control of diseases that threatened primary production. The services began at the national borders and were focused domestically. The prevention and control of major aquatic animal diseases is similarly the basis of AAHS in many countries. The credibility of these services, as viewed by domestic stakeholders and other countries, largely depended on the effectiveness of these domestic programmes, and the response of VS and AAHS to animal disease emergencies.

In light of the growing technical requirements, consumer expectations and opportunities for international trade, the VS / AAHS should adopt an appropriate mandate and vision and provide services that respond to the needs and expectations of stakeholders. This will entail stronger alliances and closer cooperation with stakeholders, trading partners and other countries, national governmental counterparts and relevant intergovernmental organisations (in particular the OIE, the Codex Alimentarius Commission and the WTO SPS Committee).

Under the WTO SPS Agreement each WTO Member has the right to impose SPS measures to protect plant, animal and human life or health but measures should be based on science and risk analysis and implemented transparently. For animal health and zoonoses, the OIE is recognised as the reference organisation for measures relating to international trade in animals and animal products. The implementation of the OIE standards, including on quality and evaluation of VS / AAHS, is the best way to facilitate safe and fair international trade.

Effective VS / AAHS have four fundamental components:

1. the human, physical and financial resources to attract resources and retain professionals with technical and leadership skills;
2. the technical authority and capability to address current and new issues including prevention and control of biological disasters based on scientific principles;
3. the sustained interaction with interested parties in order to stay on course and carry out relevant joint programmes and services; and
4. the ability to access markets through compliance with existing standards and the implementation

of new disciplines such as the harmonisation of standards, equivalence and zoning.

Importance of formal value chains

% of livestock products traded in formal value chains

The growth in demand for milk and meat, and mainly driven by urban consumers in developing countries, is projected to double (Delgado et al., 1999; Rosegrant et al. 2009). This rising demand for milk, meat, fish and eggs has generated jobs all along the livestock value chain, from input sales through animal production, trading and processing to retail sales.

Trading and processing jobs in the livestock sector are especially high in the so-called informal sectors of countries in Asia and Africa, where most meat, milk, eggs and fish are sold (Grace et al., 2008) and where most of the people selling and buying livestock foods are themselves poor (Omore et al., 2001; Kaitibie et al., 2008). Street food is a large part of the informal sector in most developing countries—the largest in South Africa (Perry and Grace 2009)—and therefore a major source of income and employment for the poor. Animal-source foods are among the most commonly sold street foods (Perry and Grace 2009), with an estimates 50-80% of all livestock products traded in informal value chains in developing countries. Importantly, it is poor women who do most of the work preparing and selling these foods. It is estimated that up to 1.3 billion people globally are employed in different livestock product value chains globally (Herrero et al 2009a).

Importance of ruminant products

% of livestock products coming from ruminants relative to monogastrics

Livestock production in the developing world occurs in a wide range of heterogeneous production systems. These can range from pastoral/grassland based systems, which occupy most of the land area and have low human population densities; through mixed crop-livestock systems, usually in areas suitable both for arable and livestock production and where the bulk of rural human population lives; and intensive systems usually in peri-urban/urban areas. Landless systems are also often found in urban areas. All these systems in developing countries produced about 50% of the beef, 41% of the milk, 72% of the lamb, 59% of the pork and 53% of the poultry, globally (Herrero et al 2009a). These shares are likely to increase, as most future growth in livestock production is projected to occur in the developing world (Bruinsma 2003, Rosegrant et al. 2005). Most meat and milk in the developing world comes from mixed systems (Sere and Steinfeld 1996, Steinfeld et al 2006, Herrero et al. 2009). These systems play a very important role in global food security, as they also produce close to 50% of the global cereal output (Herrero et al. 2009, 2010). However, the highest rates of increase in animal production observed in the last decades, and forecasted into the future, are in the intensive pig and poultry sectors of the developing world (Delgado et al. 1999, Bruinsma 2003, Steinfeld et al. 2006).

Livestock yield gaps

% increase in potential productivity relative to the baseline productivity (%)

The productivity of livestock in the developing world is low, relative to its potential (Herrero et al 2013b). There are significant opportunities to increase it via adequate mixtures of technologies, policies and investments in farms and product value chains. However, until recently, the baseline data needed to adequately characterize livestock productivity levels in different parts of the developing world was either not available, nor at the level of disaggregation necessary to make informed decisions on the upscaling potential of key interventions and their impacts on productivity and household nutrition and income. This is quickly changing due to new data sources (i.e. see Herrero et al 2013b) but there is a significant need to study and synthesize the potential for productivity increases in smallholders systems for improved programmatic decision making and for targeting poverty and food security strategies.

Productivity and yield gap analyses help define the most appropriate technology entry points for different livestock species: health, nutrition, genetics, policy levers, others. This information will contribute to making informed investment decisions and target technologies in the livestock sectors of developing countries.

4 Data Discussion

Many organizations and governments working to catalyze agricultural development are focused on improving productivity for smallholder farmers and they measure productivity at the macro and micro levels. Unfortunately, there has been no standardization across organizations to agree on common metrics and no common agreement about which data sources to use.

The source of nearly all statistical agricultural data is either national statistics offices (NSO) or Ministries of Agriculture and Livestock. The quality of data generated by NSOs is subject to several institutional constraints: understaffing, lack of qualified staff, short-term time horizon, insufficient funding, and problematic (or absent) intra-organizational collaboration (Carletto 2010). These resource problems are, of course, most pronounced in lower-income countries where the data has high value for supporting decision-making in international development. The widely-adopted, World Bank-supported Living Standard Measurement Survey (LSMS) is addressing this. BMGF has supported expansion of the scope of the LSMS to include an Integrated Survey on Agriculture (LSMS-ISA). This is now being conducted as a panel survey repeated typically every other year in our focus countries in Africa (see below for more details).

The FAO also collects cross-national comparative data through annual questionnaires completed by official national sources (often national statistics offices), or from field surveys. However, these sources are supplemented data obtained from other national sources, or sector-specific international sources, such as professional organizations (FAO 2014). The FAO attempts to maintain standard definitions and reporting methods, but complete consistency across countries and over time is not possible. Also, FAO's published statistical data reflect performance across all national production contexts and do not focus on smallholders.[1]

Living Standard Measurement Study - Integrated Surveys on Agriculture

The agricultural productivity dashboard draws exclusively on data from the Living Standard Measurement Study - Integrated Surveys on Agriculture (LSMS-ISA), a nationally representative multi-topic household panel survey. While we began the search for productivity measures broadly, and considered many different sources, the most accurate data for different measures of on-farm productivity for smallholder farmers were only found in the LSMS-ISA.

The LSMS-ISA includes modules covering household, community, agriculture, livestock, and fishery data. The LSMS-ISA makes a significant contribution to the quantity and quality of data available on agricultural practices, particularly for rural populations and smallholder farmers. The LSMS-ISA has made great strides in making available rigorously collected and relatively comparable data across the

[1] Many academic studies on agricultural productivity exist, but nearly all rely on data produced by NSOs and LSMS, and impute missing data.

eight countries where surveys are administered. The rapidly expanding body of evidence being generated using LSMS-ISA is advancing our understanding of productivity, income, land, nutrition, gender and poverty issues in rural households, and the survey teams deployed by NSOs, backstopped by the World Bank, continue to test and apply improved methods and data collection protocols.

As with other data sources, the LSMS-ISA is subject to measurement challenges for many aspects of agriculture, ranging from estimating plot size, through assessing crop yields in intercropped systems, to valuing agricultural output consumed at home. Some of the recognized limitations in LSMS-ISA data follow and should be noted when interpreting dashboard results:

- **Scope of coverage.** The LSMS-ISA is currently administered in eight countries in Sub-Saharan Africa (Tanzania, Ethiopia, Nigeria, Burkina Faso, Niger, Malawi, Mali, and Uganda). Extrapolation beyond these countries, particularly to agricultural practices in Asia, is not recommended.
- **Cross-country comparability.** The LSMS-ISA questionnaires vary somewhat across countries with respect to the content and depth of modules, discrepancies in question phrasing, and differences in administration techniques (e.g., interviews with women). They also employ different practices with respect to tracking households over time. With intentions to address country-relevant aspects of agricultural systems through customization, the nonstandard nature of the questionnaires may have some impact on comparability.
- **Sample characteristics.** The characteristics of the households sampled differs from country to country. For example, Ethiopia is the only country that restricts its sample to the rural population. Further, countries define rural and urban differently based on local density definition.
- **Reliability of data.** The data are collected at the household level and rely on self-reporting which may lead to inaccurate reporting of data. This is illustrated in the discrepancy in estimation of plot area when comparing GPS measurements to self-reported estimates of plot area. Further, most surveys are administered at one point in time, with lengthy recall periods, even though key agricultural decisions are made over a cropping cycle.
- **Measurement precision.** There are potential biases due to the timing of survey administration. In some countries, the questionnaires focus on production over the seven days prior to the administration of the interview, which may not be representative of the average yearly production of crops. Repetition of household level data collection in both post-planting and post-harvest time aims to reduce error, but this is not done consistently for all countries surveyed. In countries where data collection only occurs once a year, sub-samples of households visited may have different recall lags for specific events such as planting (e.g., input purchases) or planting) (e.g., crop sales).
- **Temporal frame.** The surveys are typically administered in two- or three-year intervals, which pose challenges in capturing fluctuations in production due to changing agro-climatic conditions. Some countries are adopting higher frequency data collection to address the temporal instability of agricultural production.
- **Measurement of production.** The valuation of agricultural production for home consumption is particularly subject to measurement problems. Survey techniques vary across countries from food diaries to household reported valuation to imputation methods, but each of method poses its challenges. Net income data are also deficient, particularly related to measuring costs.
- **Livestock metrics.** Quantification of livestock production and income is particularly difficult, particularly related to value of by-products. The net livestock income indicator does not consider livestock as assets, thus does not capture the phenomena of herd size as a wealth

indicator. Rather, higher values on this indicator reflect sales of livestock and by-products, thus this indicator is limited in describing the livelihoods of smallholders with livestock. Further, there are challenges related to difficulty of inclusion of pastoral populations in the dataset.

5 Data interpretation

#	Indicator	Low range	High range	Notes
1	**Livestock contribution to agricultural GDP (% of ag GDP)**	<25 to 30%	>30% up to high values above 45%	The contribution of livestock to agricultural GDP ranges from 5-55%. The higher the number the more important livestock is to the agricultural sector.
2	**Consumption of animal source foods (kg per capita)**	< 70 - 100	> 100	Average consumption of livestock products in the developing world is 28 kg of meat and 44 kg of milk per capita, while the developed world has far higher values of 78 kg per capita for meat and 202 kg/per capita for milk. An increasing trend in countries with low consumption is desirable.
3	**Importance of local production vs imports (% of production produced locally)**	> 10%	< 10%	Trade in livestock products is increasing as population grows and developing countries cannot keep production abreast to match the population growth. A decreasing trend is desirable. Also values lower than 10% suggest that most production is local, and demonstrate economically viable, and competitive industries. This indicator is often useful to disaggrete it by species.
4	**Importance of the smallholder sector (% of livestock production coming from smallholders)**	< 30% of production would imply a modest contribution from smallholder farmers	Countries where this indicator is higher than > 50%	Excludes non-edible livestock products.
5	**Availability of improved breeds (Percentage of smallholder herds with improved livestock)**	<20%	>50%	Higher % denotes the ability of a country to source and replace their own improved herd. This means that accessibility for other farmers can also be higher. Artificial insemination is also a key ethod for increasing this indicator.
6	**Level of genetic improvements (rate of genetic gain per year, %)**	Less than 1% per year	Anything over 3% per year	• This indicator is very difficult to obtain. Most often we only estimate the changes in productivity of a country for each livestock product. Apportioning the genetic component of these changes is difficult
7	**OIE PVS score**	< 3.5	>4	Higher numbers are better. Positive trends desired
8	**Importance of formal value chains (% of production traded in formal value chains)**	<20%	>50-60%	Higher numbers are better

#	Indicator	Low range	High range	Notes
9	**Importance of ruminants vs monogastrics (% of production from ruminants)**	< 30%	> 70%	
10	**Livestock yield gaps (potential production as a % of baseline production)**	<50%	➢ 150-500%.	A high yield gap denotes low productivity relative to the potential production that could be achieved A negative trend is good, as it means that yield gaps are reducing relative to the potential. Productivity is growing.

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Appendices

Appendix A Attributes of the various production systems used for ruminants in Ethiopia

Appendix A: Attributes of the various production systems used for ruminants in the Ethiopian study (LG: lowland grazing zone, MRD: highland mixed crop-livestock moisture deficient zone, MRS: highland mixed crop-livestock moisture sufficient zone)

Region	Animal type	Intervention	Herd size	Attributes
LG	Borana cattle	Baseline	25-40	Grazing natural pasture with small amounts of noug seed cake
	Borana cattle	Legume	25-40	Natural pasture oversown with legume + noug seed cake
	Local goats	Baseline - restricted	35-40	Grazing natural pasture + browse but restricted by area grazed
	Local goats	Baseline	35-40	Grazing of natural pasture + browse unrestricted
	Local goats	Low mortality	35-40	Grazing of natural pasture + browse unrestricted with reduced mortality
	Local goats	Legume	55-60	Natural pasture oversown with legume
	Local goats	Legume + low mortality	55-60	Natural pasture oversown with legume with reduced mortality
	Crossbred goats	Baseline	30-40	Grazing of natural pasture + browse unrestricted
	Crossbred goats	Low mortality	30-40	Grazing of natural pasture + browse unrestricted with reduced mortality
	Crossbred goats	Legume	40-50	Natural pasture oversown with legume
	Crossbred goats	Legume + low mortality	40-50	Natural pasture oversown with legume with reduced mortality
MRD	Local Zebu	Baseline	4-8	0.8 ha natural pasture + cereal straws + hay + some noug seed cake
	Local Zebu	Concentrates	4-8	0.8 ha natural pasture + cereal straws + hay + higher amounts of noug seed cake and wheat bran concentrate
	Local Zebu	Improved forage	4-8	0.3 ha pasture + 0.5 ha lablab + cereal straws + hay + noug seed cake
	Crossbred dairy cattle	Baseline	4-8	0.8 ha natural pasture + cereal straws + hay + some noug seed cake
	Crossbred dairy cattle	Concentrates	4-8	0.8 ha natural pasture + cereal straws + hay + higher amounts of noug seed cake and wheat bran concentrate
	Crossbred dairy cattle	Improved forage	4-8	0.1 ha pasture + 0.7 ha lablab + cereal straws + urea treated stover + hay + noug seed cake
	Local goats	Baseline	20-25	0.8 ha natural pasture + browse + low quality cereal straw
	Local goats	Low mortality	20-25	0.8 ha natural pasture + browse + cereal straw + reduced mortality
	Local goats	Improved forage + low mortality	20-25	0.5 ha natural pasture + 0.3 ha lablab + browse + urea treated stover + pulse straw + reduced mortality
	Crossbred goats	Baseline	15-20	0.8 ha natural pasture + browse + low quality cereal straw
	Crossbred goats	Low mortality	15-20	0.8 ha natural pasture + browse + cereal straw + reduced mortality
	Crossbred goats	Improved forage + low mortality	15-20	0.5 ha natural pasture + 0.3 ha lablab + browse + urea treated stover + pulse straw + reduced mortality
MRS	Local Zebu	Baseline	3-6	No cropping land. All purchased fodders – cereal straw + legume straw/hay + noug seed cake
	Local Zebu	Concentrates	3-6	All purchased fodders – cereal straw + legume straw/hay + noug seed cake + wheat bran concentrate
	Local Zebu	Improved forage	3-6	All purchased fodders – urea treated stover + legume straw/hay + noug seed cake

	Crossbred dairy cattle	Baseline	3-6	No cropping land. All purchased fodders – cereal straw + legume straw/hay + noug seed cake
	Crossbred dairy cattle	Concentrates	3-6	All purchased fodders – cereal straw + legume straw/hay + noug seed cake + wheat bran concentrate
	Crossbred dairy cattle	Improved forage	3-6	All purchased fodders – urea treated stover + legume straw/hay + noug seed cake
	Crossbred goats	Baseline	15-20	No cropping land. All purchased fodders – cereal straw + legume straw/hay
	Crossbred goats	Low mortality	15-20	All purchased fodders – cereal straw + legume straw/hay + reduced mortality
	Crossbred goats	Improved forage + low mortality	15-20	All purchased fodders – urea treated stover + legume straw/hay + noug seed cake + reduced mortality

Appendix B Attributes of the various production systems used for ruminants in India

Appendix B: Attributes of the various production systems used for ruminants in the Indian study

Region	Animal type	Intervention	Herd size	Attributes
Irrigated	Buffalo	Baseline	2-3	0.5 ha cropping land used to grow rice and wheat. She-buffalo fed cereal straw, grass + 1.5 kg bran/day. Additional feed purchased as required.
		Improved straw quality	2-3	Energy content of straw improved by 1 MJ/kg dry matter.
		Green feed	2-3	Additional good quality grass fed to all female animals
		Increased bran	2-3	Bran increased to 5 kg/head.day
		Green feed + bran	2-3	Additional grass and bran fed to female animals
Rainfed	Indigenous cattle	Baseline	1-3	1 ha cropping land used to grow maize, sorghum and wheat. Cattle fed crop residues + native grass. Additional feed purchased as required.
		Low concentrate	1-3	Baseline scenario + cows fed 1 kg bran/day.
	Buffalo	Baseline	1-3	Baseline scenario with buffalo replacing indigenous cattle.
		Low concentrate	1-3	Baseline scenario + she-buffalo fed 1 kg bran/day.
		High concentrate	1-3	Baseline scenario + she-buffalo fed 3 kg bran/day.
	Crossbred cattle	Baseline	1-3	Baseline scenario with crossbred cattle replacing indigenous cattle.
		Low concentrate	1-3	Baseline scenario + cows fed 1 kg bran/day.
		High concentrate	1-3	Baseline scenario + cows fed 3 kg bran/day.
Arid	Local goats	Baseline	8-10	Restricted grazing (80% daily feed intake from native pasture), no supplementation, baseline flock mortality of 20%, male offspring sold at 6 months.
		Free grazing	4-6	Unrestricted grazing with no supplementation, reduced flock size.
		Baseline + low mortality	8-10	Baseline scenario, flock mortality reduced to 10%.
		Supplement does (wheat bran)	8-10	Baseline scenario with wheat bran provided to does at 200 g/head.day.
		Supplement does (cereal straw)	8-10	Baseline scenario with cereal straw provided to does at 0.5kg/head.day.
		Supplement kids	8-10	Baseline scenario with wheat bran provided to weaned male offspring at 200 g/head.day and sold at 10 months.
		Improved pasture	8-10	Restricted grazing, quality of pasture improved through addition of legume/better management, no supplementation.
		Improved pasture + low mortality	8-10	Improved pasture scenario, no supplementation, flock mortality reduced to 10%.