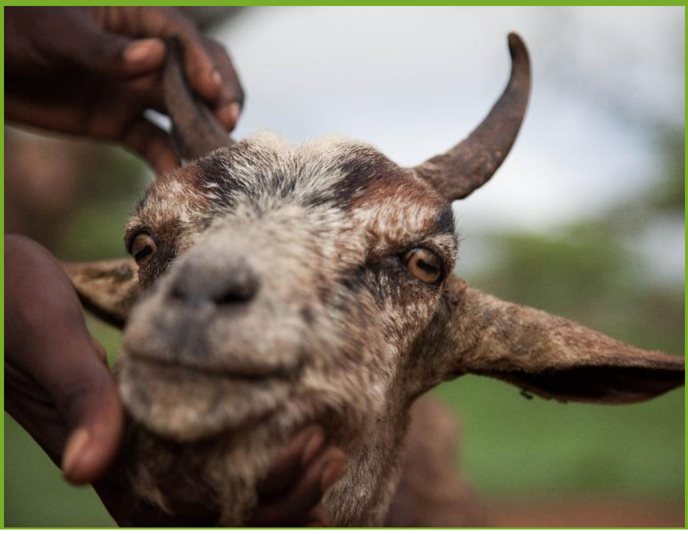
Improved ruminant genetics: Implementation guidance for policymakers and investors



Overview

Genetics makes use of natural variation among animals. Selecting preferred animals as parents can yield permanent and cumulative improvements in the population. More efficient animals can greatly reduce greenhouse gas emissions and feed costs. Breeding, including cross-breeding between indigenous and imported species, can also improve resilience to diseases and heat stress and increase reproductive performance.

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KEY MESSAGES

1. Improved genetics results in permanent and cumulative changes in livestock productivity
2. Breeding can increase the resilience of livestock to climate-related stress and diseases and increase reproductive performance
3. Methane emissions intensity (emissions per litre of milk or kg of meat) can be improved by breeding for productivity in many countries
4. In 10 years, an 11-26% reduction in methane emissions intensity can be achieved by targeted breeding
5. In some systems, breeding must integrate multiple purposes for livestock in addition to milk and meat production

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Improved livestock genetics

The global livestock sector, particularly ruminants, contributes approximately 14.5% of total anthropogenic greenhouse gases (GHG) emissions (Gerber et al. 2013). At the same time, the sector supports about 1.3 billion producers and retailers and contributes 40-50% of agricultural gross domestic product (GDP) (Herrero et al. 2016). The livestock sector is vulnerable to impacts of climate change through increased heat and reduced pasture productivity especially in drought-prone dryland areas. Animal breeding exploits natural variation between animals (both within and between breeds) to increase productivity, reduce emissions and to improve resilience to environmental stresses. This strategy is cost-effective, permanent, and cumulative. Improved livestock genetics can thus contribute to mitigation and adaptation strategies and support other development goals, but requires individual information on many animals.

Mitigation

In developing countries, increasing the productivity of livestock systems is a key way of reducing methane emissions intensity. Improved genetics is a strong tool to increase productivity, as has been shown in the last decades. However, improved genetics also needs improved herd management and feeding systems to optimise the benefit. Overall, herd and nutritional improvements can focus both on productivity per animal (milk yield, weight gain) and productivity across herds and flocks (reproductive performance, longevity and disease resistance, which reduce the number of non-productive animals in a herd in any year).

To give a sense of scale, improved dairy cow productivity (and associated feed conversion efficiency) in the USA over the past ~60 years has led to substantial (>40%) reduction in methane produced per unit of product (Gerber et al. 2011; Hristov 2016). This indicates the very large reductions in emissions intensity that can be achieved in countries that currently have lower levels of productivity (see Figure 1).

A rapid pathway for global genetic performance improvement with associated methane mitigation in these countries is through cross-breeding elite beef and dairy cattle from temperate regions with local (often indigenous sub-tropical) breeds to maintain heat tolerance as well as disease and parasite resistance (Renaudeau et al. 2012). Importing non-adapted breeds from other countries is a higher risk strategy (see adaptation discussion below).

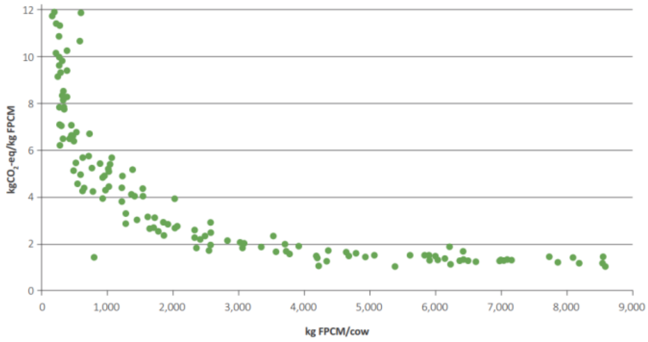


Figure 1. Correlation between emissions intensity (all gases) and milk yield (fat and protein corrected milk, FPCM) per cow. Data from the Global Livestock Environmental Assessment Model (GLEAM), FAO (Gerber et al. 2011).

In developed countries, where the production levels of livestock are already high and genetic recording schemes are in place, reductions in emissions intensity through increasing animal productivity are still possible but at a much slower pace. In these countries further reduction of GHG emission intensity can be achieved by directly selecting for animals that exhibit naturally lower emissions of methane for a given amount of feed intake.

Recording individual methane emission data on a large scale is practically impossible for single countries. Collation of international data on methane emission and associated information from research herds and nucleus breeding herds is one approach to increase the quantity of methane emission data available for the estimation of breeding values. However, if direct measures are not possible or very expensive to record, the indicators, like milk fatty acids, might be an option. If a relationship can be established between the trait of interest and an easy and cheap-to-measure indicator, this can be applied as the selection option.

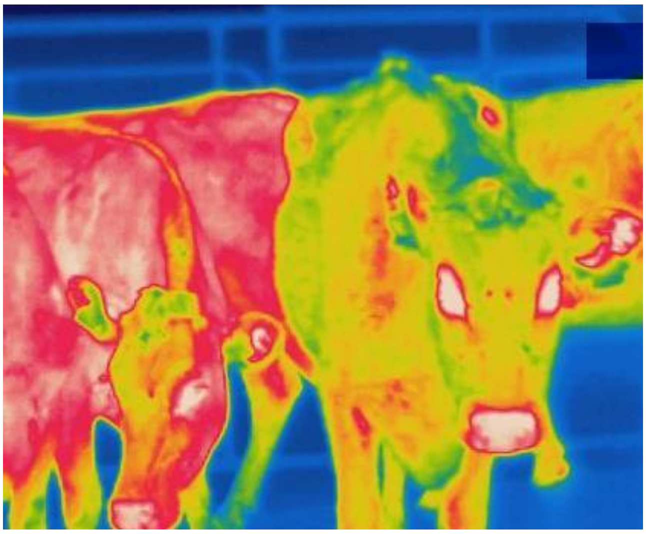
Adaptation

There are approximately 270 million dairy cattle on Earth with the majority in tropical countries. Genetically-improved temperate breeds are a relatively small proportion of the total dairy population, but their elite genetic status could be a major driver for global improvement in per animal productivity provided heat tolerance and parasite and disease resistance are improved.

Genetic improvement of dairy and beef cattle performance has been undertaken largely with breeds in temperate climates. Local cattle breeds in tropical climates have (mostly) not been selected for performance. However, they have adapted to the tropical heat by acquiring the essential traits of heat tolerance and tick resistance seen, for example in the zebu (*Bos indicus*) breeds.

Attempts to improve productivity of cattle in the tropics have employed direct transfer of "improved", temperate cattle into hot environments. After the common failure of that strategy through heat intolerance of the temperate breeds, crossbreeding with climate-adapted local breeds (usually *Bos indicus*) was attempted in order to capture performance and heat tolerance characteristics in the same animal. A recent example of this is the Girolando breed in Brazil which is a composite dairy breed based on the Gir (*indicus*) and Holstein breed types. Cross-breeding temperate and tropical breeds of small ruminants has been less successful, but cross-breeding diverse native small ruminant breeds has shown encouraging results (Kosgey et al. 2006).

Crossbreeding and traditional selection methods are a long-term strategy for cattle improvement and require recording systems and infrastructure to implement. A more rapid strategy is now feasible following discovery of a dominant, major genetic variation for heat tolerance (the "slick" gene) in *Bos taurus* breeds (Senepol and Romosinuano: Littlejohn et al. 2014). This discovery raises the prospect of breeding this specific heat tolerance variant (and other heat tolerance variants) into performance-improved, *Bos taurus* cattle, enabling their effective deployment into the tropics and accelerating genetic improvement in performance and fertility traits in such geographies.



Thermographic image of effect of coat type on surface temperatures of NZ dairy cattle. Short summer coat (left, red) is associated with greater surface temperature and heat loss than a hairy coat. Image: Livestock Improvement Corporation, New Zealand.

Rapidly breeding genetic variants such as "slick" into elite temperate breeds will enable substantial and rapid gains in cow performance in the tropics. This approach to breeding is also called 'introgression'. Given that the majority of beef and dairy cattle in the World are located in tropical countries and are of relatively poor genetic merit for production, the relatively simple introgression of the heat tolerance trait to enable productivity of temperate genetics in hot environments offers an attractive option to increase food production and security, resilience to climatic stress and reduce methane emissions intensity from a genetically-improved tropical cattle population.

Benefits of improved livestock genetics

Genetics works as an effective mitigation strategy and adaptation tool because selection is cumulative and permanent. This means that the effect is directly transferred from generation to generation and the effect is there every day in the life of an animal. Tailor-made breeding schemes are important, as the focus on how to achieve this is different in each country, in each production system, for each farmer.

In some regions in developing countries, livestock serve multiple purposes in addition to producing meat and milk, such as sources of draught power, manure, capital, insurance and social status (Rivera-Ferre et al 2016). The value placed on targeted breeding for productivity and reduced emissions intensity will depend on the extent to which improved productivity also serves such wider social and environmental objectives in specific contexts.

Increased productivity per animal

Breeding can increase the milk yield or weight gain of animals, thus increasing the amount of food that farmers can produce within available resources. Animals with greater productivity use a higher percentage of their energy intake to generate the product in question rather than simply maintain their bodies; this means that more productive animals almost invariably have lower emissions intensities.

Increased lifetime production and disease resistance

Every herd includes non-productive animals (e.g. cows that have failed to get pregnant but are kept with the goal of achieving pregnancy in the following year). Reducing the number of non-productive animals and extending the productive lifetime of animals can make an important contribution to increase productivity across farms, maximise utilisation of feed resources especially in times of scarcity, and reduce emissions intensity. Despite the low estimated heritability, breeding can influence reproductive performance and lifetime productivity including the age at first calving, longevity of animals, and their resistance to diseases, mainly because of the permanent and cumulative changes each year (Cassell 2009).

For example, lambing percentage in New Zealand increased from 95% (i.e. less than one healthy lamb born per ewe, on average) in 1990 to more than 130% in 2015 (Stats NZ 2016). While some of this improvement is due to improved management practices, a large fraction of this increase is due to improved genetics of the animals including the introduction of highly fecund sheep breeds.

Resilience to heat and drought

Thermoregulation is a vital process of animals to maintain normal body temperature to a combination of environmental parameters (e.g. temperature, humidity, radiation solar and wind speed). Species, breeds and individuals have their appropriate comfort zone where body heat is effectively dissipated and the physiological state is maintained. When those environmental parameters go beyond this thermo-neutral zone (threshold), animals will start to experience heat stress. There is genetic variation in tolerance to heat stress, both within and between breeds, so selection for improved heat tolerance could result in cumulative and permanent gains (Nguyen et al. 2016).

Woman tending goats in Nyando, Kenya, one of CCAFS' climate-smart villages with on-going goat breeding programs. Image: V. Atakos, CCAFS

For example, in semi-arid regions of Kenya, community breeding programmes have sought to improve the productivity and resilience of local goat breeds by crossing local East African goats with Galla goats. The East African breed survives heat, drought and disease well but is slow to regain weight following such stresses. It is also generally small, has a low growth rate, and produces very little milk. The Galla goat, indigenous to northern Kenya, is fast-maturing, has an adult weight nearly double that of East African, can be kept for milk as well as meat, and regains weight quickly after drought seasons. By crossing Galla and East African goats, breeding efforts have created animals with the resilience of East African goats and the productivity of Galla goats.

Lower absolute methane emissions

Enteric methane emission of dairy cattle and sheep is a heritable trait, with heritability varying between 0.16 and 0.21. Including methane emissions as a specific selection objective will therefore reduce greenhouse gas emissions over and above reductions that can be achieved by focusing on productivity per animal and across herds alone. Based on variability identified in current sheep and dairy herds (Pinares-Patiño et al. 2013; Lassen et al. 2016), directly selecting animals with naturally lower methane emissions intensities could reduce emissions by up to about 5%, possibly rising to 10 or 20% if this becomes a breeding objective over several decades. However, there remains a research need to establish if selection against methane emission might have a negative impact on other aspects of animal efficiency or productivity.

Challenges to adoption of improved livestock genetics

Slow process

One of the reasons why genetics is not adopted widely as agricultural development strategy is that it is a long-term process. Choices made today for a mating between a cow and a bull results in a lactating animals in 3 years from now (in cattle). Long-term development strategies, stable business and rural development environments, and in some cases support from governments are key for fostering an environment where breeding is seen as making a major contribution to improving productivity, increase resilience and reduce emissions.

Lots of records and coordination needed

Breeding invariably requires the selection of the best performing animal out of a large pool, so that those desired traits become more and more dominant in subsequent generations. This principle applies regardless of the specific trait that is selected for, and regardless of whether selection is done based on external traits (e.g. actual milk yield or reproductive performance) or on genetic data. This means that breeding programmes usually benefit from, and in some cases require, programmes to measure traits in standardised formats and pool information so that more rapid progress can be made. In many industrialised countries, dedicated breeding programmes exist with support from industry and occasionally governments. Coordination is often less effective and more challenging where the sector consists of many small-holder farmers and national industry bodies are lacking.

Nevertheless, development of heat tolerant, elite dairy cattle has the potential to provide a relatively immediate lift in animal performance in many developing countries. In this scenario, elite temperate dairy breeds would become the genetic engine for productivity gains in developing countries. However, introduction of such cattle needs to be done in parallel with improvement in feeding management.

Ankole cattle, Uganda. Image: Susan MacMillan, ILRI

Identifying reliable traits, managing trade-offs

If the main goal of breeding is to improve productivity, the trait that farmers want to breed for (such as milk yield, weight gain or reproductive performance) is readily identifiable and measurable. However, for the trait of methane emission, easy and cheap ways to measure emissions across large numbers of animals are limited, e.g. by using the portable accumulation chambers for small ruminants (sheep and goats). This reduces the available data for genetic analyses.

The situation becomes even more challenging when farmers want to simultaneously select for several traits. For example, cattle with higher milk yields often have reduced reproductive performance. Increasing net productivity therefore requires ways of quantifying the relative gains from selecting for individual traits to allow farmers to make decisions about priorities and trade-offs.

Limited incentives for farmers to breed for low methane emissions

There are obvious and immediate incentives for farmers to breed animals with increased productivity. Breeding to increase resilience to climatic stress is also in the self-interest of farmers, but given the slow pace of breeding this requires a degree of foresight and information. If breeding for lower emitting animals is to become adopted widely, farmers need incentives to give weight to this trait as part of their overall breeding goals. This could come in the form of carbon prices or support for breeding programmes. An indirect incentive is that methane is a lost in energy efficiency, and therefore, the high emitting animals in principle should be less efficient. However, these gains are likely to be small compared to the benefits from directly selecting for the most productive animals regardless of their methane emissions.

Where can improved livestock genetics be practiced?

Breeding strategies can be applied everywhere and indeed are the source of the diverse and highly adapted domesticated breeds currently in existence around the world.

Genetic improvement strategies can be optimised to suit the needs of very different production systems and geographic regions. In the case of small holder systems, very simple genetic selection or crossbreeding programmes aimed at increasing productivity, longevity or reproduction directly support food security and resilience to climate change but can also greatly improve the GHG to production output with relatively low financial input.

While the use of advanced genetic techniques and elite breeds can in principle allow very rapid progress, implementation of such programmes can be challenging in developing countries. There has been some evidence of success with community-based breeding programs among smallholders in the tropics, particularly with small ruminant livestock. Such programs have been most successful when they are based on the breeding goals of farmers (rather than researchers), there are strong market incentives for improved animal productivity and strong support services such as extension and veterinary services.

Directly breeding for lower emitting animals is currently in a pilot phase. Several countries have identified genetic markers for low emissions animals (sheep and cattle) and confirmed that lower emitting animals do not have lower productivity, and that the low-emissions trait is not strongly correlated with overall productivity. While some additional testing still needs to be done, this information is close to being ready for handing over to industry breeding programmes, but a key constraint for their adoption remains the lack of incentives for farmers to select for this trait. Another challenge for upscaling this approach consists of the small number of animals that have been identified as low emitting and that can be used for breeding purposes.

In the case of high input systems, it may be possible to select for improved feed efficiency and reduced methane emissions through the combining of methane and feed intake records from research herds (expensive and small scale) with methane and feed intake proxy traits recorded in commercial herds (cheaper and large scale). Another advantage is that improved genetics from high input systems can filter down to lower input systems.

Contribution to CSA pillars:

Improved livestock genetics increases productivity of livestock and can be used to improve their resilience to climate-related stresses, which supports farm livelihoods and food security. More productive livestock also generally reduce the emissions intensity of livestock production.

How does improved livestock genetics increase farm livelihoods and food security?

Traditionally, breeding goals for farm animals have focused on genetic improvement of economically important production traits. Consequently, productivity in farm animals rose dramatically during the second half of the twentieth century, especially in developed countries, and effective selective breeding programmes were a major factor. The milk yield per cow in dairy and growth rate and feed conversion efficiency of broiler chickens illustrate these changes vividly. In many countries, milk yield per cow has more than doubled in the last 40 years. This increased productivity allowed farmers to enlarge their income and reduce their costs.

However, the combination of selective breeding narrowly focused on production traits and the intensification of animal production systems have increased the risk for animals from behavioural, physiological and immunological disorders, i.e., poor welfare. Therefore, the breeding goals are now becoming more complex in order to meet challenges set by consumers and society. The breeding goals do not solely focus on increased productivity anymore, but also ensure the animals live long, stay healthy, and are fertile as well.

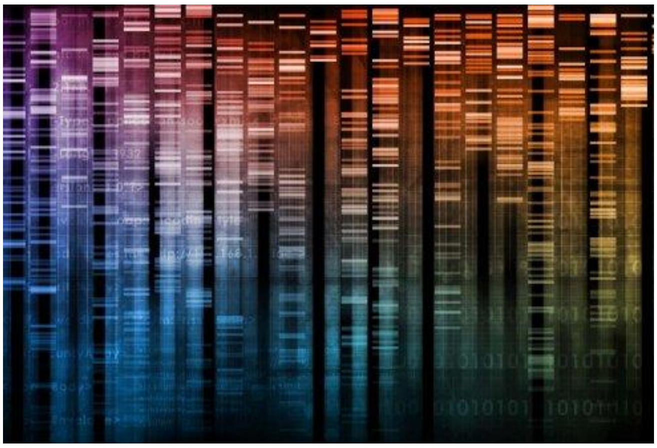
While the cost of breeding is not zero, in most cases it has been much lower than the economic benefits from more productive and resilient animals and farm systems. However, specifically selecting for additional traits (such as low methane emissions) does have an opportunity cost in that it reduces the rate of progress that can be made with regard to other breeding objectives.

How much can improved livestock genetics mitigate greenhouse gas emissions?

More productive animals use a greater fraction of their intake to produce the desired goods such as milk and meat, and less for simply maintaining their bodies. Increased longevity and reproductive success also means that a lower number of animals needs to be kept in a herd to maintain overall production.

Using improved livestock genetics to increase productivity thus directly reduces the emissions intensity of livestock systems. Over 10 years, an 11-26% reduction in methane emissions intensity can be achieved by targeted breeding (de Haas et al., 2011; Pickering et al. 2015).

Directly selecting for lower-emitting animals, in addition to general productivity traits, offers an additional reduction of initially around 5% but growing over time to potentially 10-20%. This targeted approach is still at the pilot phase but should become commercially available over the next few years where good genetic data exist.



'Bands' or 'ladder' of PCR (polymerase chain reaction) produced DNA, showing that some genes pop up in some individuals and not in others, and vice versa. Image: Wageningen UR.

What breeding practices and goals are effective?

Increased genetic merit

Genetic improvement programmes in cattle breeding largely focus on quantitative traits. The models devised to do this analysis have historically used pedigree information to devise an animal's genetic merit based on its ancestry and relationships with other animals in the dataset. Best linear unbiased prediction (BLUP) has been the cornerstone of genetic evaluation programmes almost universally. The ease of exchange of genetic material worldwide in dairy cattle breeding, principally using artificial insemination (AI) but also embryos, has further supported genetic improvement in many traits. By genetically improving a trait of interest, livestock genetics helps livestock to adapt to and increase resilience to climate change impact.

Crossbreeding

Often, genetic improvement programmes focus within a breed, but sometimes it might be beneficial to make crosses between breeds in order to capture favourable traits of two difference breeds into one crossbred animal. This way performance of animals can be improved and traits of interest in one breed (e.g. heat tolerance or resistance to ticks) transferred to another breed (e.g. one that has higher yields but would not perform well in high temperatures).

Precision breeding

The example of the slick gene has been mentioned earlier. Rapid introgression of such genetic variants of subtropical and tropical origin into elite animals from temperate climates could enable substantial and rapid gains in cow performance in the tropics with consequent advantages for methane intensity. While such introgression can be undertaken by standard breeding methods, introduction of the specific base deletion by gene editing technology could be a much faster and more flexible approach. Societal discussions are needed to explain the concept and why this is needed to feed the world in 2050 when a forecast 9 billion people will require feeding.

Metrics for CSA performance of improved livestock genetics

One way of validating genetic selection is through yearly evaluations of average performance for the traits undergoing selection. These can include traits that deliver on increasing food security, adaptation to climate change, and mitigation – noting that in many cases, a single trait may address all three CSA pillars. For example, breeding for increased resistance to diseases will increase food security by reducing the risk of major production losses; if the breeding is done in response to changing disease pressures in a changing climate, it helps farmers adapt to climate change; and reducing the disease incidence in herds increases the overall productivity of the farm system and reduces its emissions intensity.

Where livestock serve critical roles other than meat and milk production, e.g. as capital investment or insurance, productivity can still offer synergies with such other objectives. Other social and environmental functions, e.g. as draught power, manure/fertiliser source, or social status, may have a less direct correlation with productivity and this needs to be considered in specific breeding contexts.

Male Beetal goats at Eid festival markets near Lahore, Pakistan. Image: M. Sajjad Khan, ILRI

Evaluation of average performance is often done in developed countries where selection is done population-wide for many traits and breeds. In developing countries this is not always implemented but many developing countries are now also setting up registration systems and national inventories currently under guidance and knowledge exchange with developed countries. The monitoring can also be done on genetic trends but this will be a challenge as registration systems are necessary to do genetic evaluations.

Interaction with other CSA practices

Farmers face many challenges as they seek to increase food production, adaptation to climate change and reduce emissions. Emissions of livestock can be reduced by, for example, providing dietary additives, updating health management, or by changes in the manure management. However, in many situations, particularly in pasture based production systems, these interventions may not be feasible due to expense and or the extensive nature of the production systems.

Genetic improvement as a cumulative, permanent and cost-effective solution to future challenges goes beyond those limitations offering viable targets. In most instances, gains derived from breeding should be additional to gains that can be made by other mitigation options.

However, as mentioned before, genetic improvement is a slow process, so synergies with other livestock management practices have to be built in order to tackle the challenge both on the short term and in the long run. The most obvious synergies are between feeding and genetics, animal health and genetics, and productivity and genetics.

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PRACTICE BRIEFS ON CSA

The Practice Briefs intend to provide practical operational information on climate-smart agricultural practices. Please visit www.climatesmartagriculture.org for more information.

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