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Climate Smart Livestock Feed Improvement Promising and Prioritized Technologies and Intervention Options: A review

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Abstract

The global livestock sector contributes a significant share to anthropogenic green-house gas (GHG) emissions. With emissions estimated at 7.1 gigatonnes CO2-eq per annum, representing 14.5 per- cent of human-induced GHG emissions, the livestock sector plays an important role in climate change. Recent analysis suggests that developing world regions contribute about two thirds of the global emissions from ruminants, with sub-Saharan Africa a global hotspot for emissions intensities, largely due to low animal productivity, poor animal health and low-quality feeds. Feed and nutrition directly affect an animal's productivity and health status and can strongly influence GHG emissions per unit of product. Low digestible feeds affect nutrient uptake and result in low animal productivity. For ruminants, a large fraction of GHG emissions is caused by enteric methane production in the rumen. While total enteric emissions might be lower with low digestible feed, so is overall production; as a result, emissions intensity tends to be much higher. There are multiple ways in which feed quality and digestibility can be improved in all production systems. Feed substitutes and supplements are highly effective ways to increase resource efficiency and change fermentation processes in the animal to decrease GHG emissions intensity. In conclusion, incorporating low greenhouse gas traits in to forage plants, identification and synthesis of compounds from plants that can reduce methane and nitrous oxide, low methane feeds, low nitrogen feeds, forage crops with improved energy values and lower nitrogen content, precision feeding, feeding management, nuclear and isotopic techniques and improved forage quality would improve livestock productivity and reduces green-house gas emission intensity..

Keywords: Livestock; Green-house gas; Feed improvement; Methane; Silage

Abbrevations: GHG: Green-House Gases; GDP: Gross Domestic Product; UMMB: Urea Molasses Multi-Nutrient Blocks: LWG: Live weight gain; IAEA: International Atomic Energy Agency

Introduction

Projections based on population growth and food consumption patterns indicate that by 2050 agricultural production will need to increase by at least 60-70 percent to meet demand [1,2]. The livestock sector supports over 1 billion people accounts for 40% of global agricultural gross domestic product (GDP) and provides over 33% of the world's protein intake [1]. Livestock's contribution goes beyond the production of meat, milk and eggs and a number of factors determine their overall impact on food security [3]. Livestock production must deal with the increased competition between human food and animal feed and the greater demand for animal products globally and the resulting environmental impacts as human populations increase, and their dietary preferences change [4].

Livestock production globally contributes about 9% of total anthropogenic carbon dioxide (CO_2), 37% of methane (CH_4) and 65% of nitrous oxide (N_2O) emissions [5]. Globally, enteric fermentation from all major ruminant species is responsible for 2.7 Gt CO_2 eq. (almost 40% of total greenhouse gas emissions from the livestock sector) in 2005 [4,6]. In aggregate, the large number of domestic ruminants, particularly beef cattle and dairy cattle - combined with the high level of methane emissions per head and the high global warming potential of methane - makes enteric fermentation a significant contributor to global greenhouse gases from agriculture, with around 30% of GHGs in the agriculture sector coming from enteric fermentation. Dietary factors are known to affect the community of microorganisms in the digestive tract and thus affect the quantity of methane produced. This has resulted in an increasingly large body of literature which suggests that we can manipulate CH_4 production using diet [4,7-9].

Crop residues can be used for feeding dairy cattle but cannot supply adequate nutrients without supplementation. Because of their low digestibility they remain in the rumen for a long time, limiting intake. The other major limitation is that they do not contain enough crude protein to support adequate microbial activity in the rumen. This often leads to feeding a nutritionally imbalanced ration which contains protein, energy, minerals and vitamins either in excess or in shortage relatively to the nutrient requirements of the animals. Consequently, the digestibility of average feed ration in all four systems is very low: 43% and 45% in pastoral system and rural mixed crop-livestock system, respectively and 49% in both market-oriented systems. These constraints explain the low milk yields and short lactations, high mortality of young stock, longer parturition intervals, low animal weights and high enteric methane emissions per unit of Metabolisable energy [8].

The feed and nutrition-related interventions (supplementation with leguminous shrubs, use of urea molasses multi-nutrient blocks (UMMB), use of urea treated crop residues, supplementation with high protein or energy concentrate) result in a reduction in emission intensities between 16-44% [8]. The treatment of crop residues with urea results in an emission intensity reduction of 44% relative to the baseline. Supplementation of lactating cows with UMMB results in a reduction of emission intensity between 20-27% [8]. These reductions are a consequence of the improved feed digestibility, increased animal feed intake and associated increases in milk production. All interventions returned a positive productivity outcome with increases in milk production ranging between 8-70% [8].

Objective

To review climate smart feed improvement technologies and intervention options

Literature Review

Fodder cultivation

The possible opportunity for livestock related mitigation through improved pasture management has been quite widely described [10]. The main species that were promoted were *Vigna unguculata*, *Dolichos lablab*, *Macroptilum atropurpureum*, *Panicum maximum*, *Cenchrus ciliaris*, *Chloris gayana*, *Cajanus cajan*, *Leucaena leucocephala*, *Stylosanthes* and *Brachiaria riziziensis*. However, most of the adoption was concentrated in the sub-humid zone, perhaps due to the adaptability of the species. Cowpea is a species expanding in the Sahelian zone as a multi-purpose crop, the grain being used for human consumption while fodder for animal feeding.

According to [11], an extensive cultivation of high biomass grass, *Brachiaria ruziziensis*, was introduced to farmers in Africa under some projects to promote the use of this grass as livestock feed. Furthermore, farmers were encouraged to collect crop residues of several leguminous plants including Mucuna, cowpea and soybean for incorporation into livestock feed rations during the dry season. Despite these efforts, the dry season availability of feeds for livestock continues to constrain sustainable livestock production in the region.

Brachiaria grass varieties better adapted to drought and low fertility soils. Increases in forage availability by up to three months in the dry season, milk production increases between 15 and 100% and live body weight gains of over 50% in heifers. Highly nutritious, palatable and easily digestible grass. Brachiaria grass alleviates livestock feed shortages, increases nitrogen use efficiency and minimizes GHG emission. Thriving all year round, it also provides a constant supply of animal feed and can easily be dried and conserved as hay [12].

Fodder conservation

Some projects in Africa introduced a silage production technology to farmers and further organized training for women farmer groups in silage production using locally available herbage, such as grasses, cereals and salt [13]. For silage making, naturally growing wild grasses, mainly *Andropogon gayanus*, *Brachiaria ruziziensis*, *Digitaria ciliaris* Echinocloa and *Pennisetum pedicullatun*, were harvested at the early flowering stage when the moisture content is about 30-40%. Green cereals residues of poorly developing maize, rice, sorghum or millet crops are also harvested for use in silage production. The herbage is then left to ferment and cure for about 3 weeks after which it is ready and collected for feeding to livestock. Through FAO/INERA collaboration, extensive studies in Western Burkina Faso showed that the opportunity cost of silage and salt lick production using this technology is low with a cost-benefit ratio of 527% and highly profitable and beneficial to small holder livestock farmers.

Feeding Azawak cows on silage supplements resulted in a dramatic tenfold increase in milk production, while ewes fed on silage supplement-maintained milk yields throughout the year [13]. Farmers quickly adopted this silage production technology not only to successfully feed livestock during the dry season but also as an income generating opportunity through the sale of silage and saltlick blocks. To widely disseminate this technology, group training courses on silage and saltlick production were organized in several villages not only to build farmer capacities to produce silage and salt licks, but also to facilitate promotion of farmer-to-farmer dissemination of the practice [13]. Thus, through the introduction of forage technology for the production of livestock feeds, farmers successfully increased the levels of animal production and enhanced their farm incomes.

Improving forage quality

Improvements in feed digestibility can be achieved through the processing of locally available crop residues (e.g. treatment of straw with urea) and by supplementation of diets with better quality green fodder such as multipurpose leguminous fodder trees, where available. Better feed digestibility leads to better animal and herd performance. One way is to manipulate the physical structure of feeds (to increase intake), for example, by making feed blocks or by chopping poor-quality crop residues to increase their intake [14]. Combining the feeds produced by the household or acquired from neighbours, from common property resources

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or from formal market channels is necessary to better match the animal's nutrient requirements thereby increasing the efficiency of conversion of the feeds to live weight gain or milk. Other method involves urea treatment of crop residues to improve its quality and digestibility and hence reduced enteric methane emission [8]. Many studies have been done on improving their use for ruminant feeding, including physical treatments by chopping and treatment with urea or ammonia [8,15,16].

Forages are feeds with a high variation in composition. In ruminant farming systems using poor quality feed (such as straw, crop residues or dry fodder), forage processing can effectively improve digestibility of the diet and improve animal productivity at the same time. Systems using coarse straws from millet, sorghum and corn/maize have better feeding quality than slender straws (rice, wheat, barley). Grazing management and improving forage quality by changing forage species can equally contribute to a proper diet formulation in extensive systems, which can substantially increase feed efficiency and production, reductions in GHG emissions intensity of 30% are considered possible in systems that currently use low quality feed [7,17,18].

Dietary improvements and substitutes

Feed substitutes can change fermentation processes in the rumen and influence methane production. Feeding corn or legume silages, starch or soya decreases methane production compared to grass silages. Brassicas (e.g. forage rape) have also shown to reduce methane emissions in sheep and cattle, although with varying implications for productivity. Combining maize and legume silage also reduces nitrogen (N) excretion in urine which can have both GHG and water quality benefits in some systems. Corn/maize and legume silages often increase feed intake and production in dairy cows as compared to grass silages. However, the GHG mitigation effects of replacing grass by other forages need to be considered over the whole supply chain, taking into account changes in land use, emissions from crop production, resilience to climate and market variability, fertilizer inputs and net impacts on regional food security via land-use and food prices [7,17,18].

Feed supplements

Concentrate feeds and starch generally provide more digestible nutrients than roughages, which increases the digestibility of feed and generally lifts animal productivity. The suitability of this approach for GHG mitigation depends on the access to and availability of feed and potential competition with direct human consumption. Feeds for effective mitigation practices include lipids (from vegetable oil or animal fat) and concentrate feed supplementation in mixed and intensive systems. By-product feeds with high oil contents, such as distiller grains and meals from the biodiesel industry, can be cost-effective lipid sources. Lipids seem to increase feed efficiency, but their effect depends on feed composition and the effect is limited on pastures; the (long-term) effects on productivity and product quality need further research. Similarly, adding nitrate to the diet results in lower methane emissions since it is converted to ammonium (NH_4+) which leaves less hydrogen available for methane production. This approach may have applicability in places such as Australia and Brazil where nitrate could replace the urea which is added to low-quality diets to improve nutritive value. Toxicity issues are however a concern and more information is needed on the practicalities of this approach [7,17,18].

Precision feeding

Precision feeding is about getting the right nutrient to the right animal at the right time. The animal's need changes during their lifetime and cycles of reproduction. Understanding an animal's need on a daily basis can result in major resource efficiency gains. Although direct mitigation effects are uncertain and hard to predict, precision feeding will increase feed efficiency and productivity and consequently can improve farm profitability. Customized balanced feeding programme in grazing dairy cattle systems have shown to increase productivity and reduce enteric methane emissions intensity (15-20%) and also N excretion (20-30%), which results in reduced emissions from manure. Precision feeding, which combines genetics of the animal with feeding and grazing management, requires advanced technological facilities to precisely monitor the animal's needs and manage pastures and forage production appropriately and can be rolled out in high-value farm systems that use highly technological systems [7,17,18].

Integration of forage legumes into arable crops

Intercropping forage legumes with cereals offers a potential for increasing forage and consequently, livestock production. This intercropping has been shown to improve both the quantity and quality of fodder and crop residues leading to better system efficiency [19]. In such a system, the yield depression of the cereal grain should minimal, possibly not more than 15%, for it to be acceptable to the farmer. The time of sowing of cereal and legume is critical for the yield of each crop. The indication from the few studies on time-of-planting is that sowing a forage legume simultaneously with a fast-growing cereal has no effect on cereal yield [20].

Legumes have a potentially significant role to play in enhancing soil carbon sequestration. The role of legumes in supplying nitrogen (N) through fixation is increasingly seen as important as and more beneficial in terms of overall GHG balance than had once been thought [21]. Reported increases in soil carbon stock when forest or savanna was converted to pastures (5-12% and 10-22%, respectively). Legumes are likely to have a role to play in reducing GHG emissions from ruminant systems. An approach to reducing methane emissions of current interest and supported by some initial evidence is the use of tannin containing forages and breeding of forage species with enhanced tannin content. In the context of maintaining N fertility, [22] have called for greater efforts to improve annual tropical legumes to complement species such as lablab (*Lablab purpureus* L.) and cowpea (*Vigna unguiculata* L.). The use of forage legumes in many parts of the tropics is limited because they do not contribute directly to the human food supply.

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Grazing management

Grazing land management practices have potential to contribute towards food security and agricultural productivity via increased livestock yield and reducing land degradation. Pasture land can be improved by improving vegetation community through planting high productivity, drought tolerant and deeper-rooted fodder grasses and/or legumes [23] such as Superior Brachiaria bred cultivars (Mulato and Mulato II) and *Canavalia brasiliensis* [24]. Controlled grazing through stocking rate management, rotational grazing, fallowing grazing to allow rejuvenation of grasses have been reported to improve grazing land, ensure surface cover and reduced erosion while increasing fodder productivity [23].

One of the main strategies for increasing the efficiency of grazing management is through rotational grazing, which can be adjusted to the frequency and timing of the livestock's grazing needs and better matches these needs with the availability of pasture resources. Rotational grazing allows for the maintenance of forages at a relatively earlier growth stage. This enhances the quality and digestibility of the forage, improves the productivity of the system and reduces CH_4 emissions per unit of LWG [25]. Rotational grazing is more suited to manage pasture systems, where investment costs for fencing and watering points, additional labor and more intensive management are more likely to be recouped.

Other grazing management intervention includes adjustment of stocking densities to feed availability. Most of the areas with high livestock densities experience land degradation and deforestation as a result of overgrazing the pasture land which encourages poor fodder production and increased GHG emissions. There is thus need, to reduce the incidences of overgrazing and deforestation. This can be achieved by increasing livestock productivity so that fewer animals are raised to produce the required milk and meat leading to a reduction in the amount of GHG emissions. The interventions mainly involve keeping fewer but more productive animals in order to reduce the overall methane, nitrous and carbon dioxide gases produced and emitted from the livestock.

Grazing can be optimized by balancing and adapting grazing pressures on the land. This optimization can increase pasture land productivity and deliver mitigation and adaptation benefits.

However, the net influence of optimal grazing is variable and highly dependent on baseline grazing practices, plant species, soils and climatic conditions [26]. Perhaps the most clear-cut mitigation benefits arise from soil carbon sequestration that results when grazing pressure is reduced as a means of stopping land degradation or rehabilitating degraded lands [27]. In these cases, enteric emission intensities can also be lowered, because with less grazing pressure animals have a wider choice of forage and tend to select more nutritious forage, which is associated with more rapid rates of live weight gain (LWG) [28]. By restoring degraded grassland, these measures can also enhance soil health and water retention, which increases the resilience of the grazing system to climate variability. However, if grazing pressure is reduced by simply reducing the number of animals, then total output per hectare may be lower, except in areas where baseline stocking rates are excessively high [28].

Pasture management and nutrition

Pasture management measures involve the sowing of improved varieties of pasture, typically the replacement of native grasses with higher yielding and more digestible forages, including perennial fodders, pastures and legumes [29]. For example, in tropical grazing systems of Latin America, substantial improvements in soil carbon storage and farm productivity, as well as reductions in enteric emission intensities, are possible by replacing natural cerrado vegetation with deep-rooted pastures such as Brachiaria [30]. However, there are far fewer opportunities for sowing improved pastures in arid and semi-arid grazing systems.

The intensification of pasture production though fertilization, cutting regimes and irrigation practices may also enhance productivity, soil carbon, pasture quality and animal performance. These approaches, however, may not always reduce GHG emissions. Improved pasture quality through nitrogen fertilization may involve tradeoffs between lower CH_4 emissions and higher N_2O emissions [31]. Also, after accounting for energy-related emissions and N_2O emissions associated with irrigation, the net GHG emissions of this practice may be negative on grazing lands [25]. Grass quality can also be improved by chemical and/or mechanical treatments and ensiling.

Crop-livestock-tree

Combination of leguminous fodder shrubs and herbaceous legumes can be grown together with food crops with the aim of improving crop productivity and providing fodder for livestock. Trees and shrubs are planted on farms as live fences, boundary markers, windbreaks, soil conservation hedges, fodder banks and woodlots. Leguminous fodder shrubs have high nutritive value and can help to improve the diets of ruminants while they can also sequester carbon. Forages from the fodder shrubs can effectively replace some of the concentrates and part of the basal diet of dairy livestock leading to increased milk production per cow. Ultimately, this can result in the reduction of the number of cattle on the farm and thus reduce the amount of methane emission from individual farms [30]. Wider use of the right fodder trees in substitution for other feed options also provides mitigation opportunities through dietary intensification, tree carbon sequestration and savings through foregone concentrate and annual crop production and use. Trees also provide other functions important for climate adaptation, including shade for animals and, possibly, the provision of ethno-veterinary treatments to counter increased disease threats (such treatments are often relied on in areas with poor state veterinary services, especially in pastoral systems with poor infrastructure [32].

In most documented cases of successful agro forestry establishment, tree-based systems are more productive, more sustainable and more attuned to people's cultural or material needs than

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treeless alternatives. In addressing the challenge of adoption of improved agro forestry practices, better insights are needed into the productive and environmental performance of agro forestry systems, socio-cultural and political prerequisites for their establishment and the trade-offs farmers face in choosing between land use practices. These site factors are likely to vary at fine spatial and possibly temporal scales, making the development of robust targeting tools for agro forestry intervention a key priority in livestock-agro forestry research [33].

The major limitation of agro forestry systems is land tenure systems which tends to encourage over grazing beyond their carrying capacity [34]. Other obstacles to the adoption of agro forestry strategies are the lack of support for such systems through public policies [35], which often take little notice of tree-based farming systems. Consequently, agro forestry is often absent from recommendations for ensuring food security under climate change [36] even though many practices have been shown to deliver benefits for rural development, buffer against climate variability, help rural populations adapt to climate change and contribute to climate change mitigation [37,38].

In addition, many authors have reported the impact of browse tree in increasing livestock production in terms in meat and milk yield and reducing mortality as ethno-veterinary options. However, most of the studies only assumed reduction on GHG production as a result of improved nutrition. These studies have failed to assess the amount of GHG reduction as to basically identify best-fit species [15]. Mentioned that the evaluation of browse production is a complex task, especially for indigenous species in natural rangelands, marked by the diversity of species and the great heterogeneity in plant size. The constraints in browse biomass evaluation related to the time cost and tediousness of methods used has led to the development of allometric relations for indirect estimation of the production.

Whole system GHG analysis of the smallholder calliandra-feeding dairy approach to assess the fodder tree contribution to mitigation strategies is essential [39]. The adoption of the calliandra technology has led to an increased demand for fodder-tree seed, which has resulted in the evolution of networks of small-scale seed dealers to support supply. Seed dealers not only improve their livelihoods through seed sales, but as they are themselves frequently dairy farmers, they can benefit twice [40].

Improving silage quality

Farmers quickly adopted this production technology to successfully feed livestock during the dry season. Improving grass silage quality by cutting grass at an earlier stage considerably reduces enteric CH_4 emissions from dairy cows. Methane production of dairy cattle fed early-cut grass silage was up to 30% lower per kg milk. Thus, the CH_4 emissions depend on nutritive value and chemical composition of grass silage [41]. The quality of grass herbage and grass silage significantly affects enteric methane production. A considerable reduction in methane emission can be realized by shortening the grass regrowth interval. High fertilized and less mature grass herbage reduced enteric CH_4 production per kg milk. Generally, improving quality of grass, fed either fresh or ensiled, has large potential for dairy farmers aiming to mitigate methane emissions [41].

Livestock feed optimization

A substantial potential to improve animal production performance and to reduce methane emissions. The use of feed technology is reduced methane emissions per unit of livestock products [42,43]. The daily milk production increases from 25kg to 30kg, then the methane emissions per unit milk product decreases by 10% [44]. Moreover, according to the [43], when milk yield of dairy cow increases from 11kg to 13kg, the methane emission per unit of milk product decreases by around 39%.

Nuclear and isotopic techniques

Incorporation in rumen microorganisms of nitrogen-14, phosphorus-32, phosphorus-33 or sulphur-35 is used to study the uptake and utilization of rumen microbial protein. This also is used to identify better fodder crops. This can help improve feed conversion rates and energy utilization. Thus, reduce greenhouse gases [9].

Conclusion

Low-quality and low-digestibility feeds result in relatively high enteric emissions per unit of meat or milk, particularly in systems with low productivity. Improving feed digestibility and energy content and better matching protein supply to animal requirements can be achieved through better grazing land management, improved pasture species, changing forage mix and greater use of feed supplements to achieve a balanced diet, including crop by-products and processing of crop residues. These measures can improve nutrient uptake, increase animal productivity and fertility and thus lower emissions per unit of product, but care needs to be taken that emissions from off-farm production of supplementary feeds and/or processing do not outweigh any on-farm reductions.

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