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The Role of Ruminants in Sustainable Agriculture 2020

Benefits and Impacts; Mitigation Strategies; Future Directions and Policies

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Executive Summary

Food security is a very important phrase which is defined as: access to sufficient, safe, nutritious food to maintain a healthy and active life. Fortunately, in the developed world, the modern levels of food supply are so high that food security is now taken for granted. However, the global food supply for the human population depends upon just five commodities: cereals, fruits, vegetables, oilseeds and forages. Amongst these five, forages, cannot be directly consumed by humans but can only be used by ruminants. This demonstrates the great value of ruminants in that they can convert forages, which are inedible for humans, into human food products with high nutritional value such as meat and milk.

There is wide acceptance of the concept of sustainability nowadays in many areas of human activity, not only in agriculture. By definition, sustainable development means meeting the needs of present generations without jeopardising the ability of future generations to meet their own needs.

Ruminants have served and will continue to serve a valuable role in sustainable agricultural systems. They are particularly useful in converting vast renewable resources from rangeland, pasture, and crop residues or other by-products into food edible for humans. Also, nutrients in the by-products that are utilized in ruminant feeds do not become a waste-disposal problem and this contributes to the Circular Economy.

There are five major pillars or sectors of sustainability which apply to animal agriculture and are also applicable to ruminants: Safety, Environment, Economy, Waste and Nutrition. Ruminant research is now addressing all of these issues to ensure that ruminants can be managed in a sustainable manner.

Analysis of sustainability can be conducted through Life Cycle Assessment (LCA). This is a standardized scientific method for systematic analysis of flows (*e.g.* mass and energy) associated with the life cycle of a specific product, technology, service or manufacturing process to assess its environmental impacts. The use of LCA across agri-food supply chains is now considered as one of the most informative tools to quantitatively compare environmental performances of multiple farming strategies at the systems level. A problem with much of the research on LCA from agriculture is that it does not incorporate the nutritional value of the foods but rather focuses on mass of product produced. However, it is important to be able to capture the actual nutritional value of food products of animal origin for humans in order to fully assess the efficiency of animal production. It is evident that LCA can be used to generate a wide range of values relating to global warming potential and greenhouse gas emissions. Nevertheless, it is clear that comparing environmental performances of products on a mass basis may not be appropriate but the nutrient composition of the product must also be considered. It is also very clear that foods from ruminants with a high nutritional value can be produced that do not contribute excessively to environmental problems.

Meat, especially beef, is a good source of protein and of micronutrients such as iron, selenium, vitamins A, B12 and folic acid. Iron has a high bioavailability when derived from meat. Milk and other dairy foods, particularly cheese, provide important nutrients such as calcium, magnesium, protein and fat.

A criticism that has been directed towards ruminant production is that they consume food edible for humans and graze on pastures that could be used for crop production. Furthermore, livestock, especially ruminants are often portrayed as poor converters of feed ingredients into human food products. In reality, ruminants yield more human food per unit of human-edible feed consumed because most of their feed is obtained from materials that cannot be consumed directly by humans. This fact has frequently been overlooked in assessments of the role of animals in food production. On a global basis, less than 3.0 kg of grain are required to produce 1.0 kg of meat from ruminants and less than 1.0 kg of grain per kg of milk. A very important aspect of ruminant nutrition is that a large proportion of most ruminant diets are various forages such as hay, silage or fresh grass. These materials are totally inedible for humans and they are produced in large volumes. Ruminants, both beef cattle and dairy cows, have historically also been the main consumers of by-products from the human food and biofuels industries.

Ruminants can make a significant contribution to a Circular Economy and reduce waste. By re-cycling biomass from forages and nutrients from various by-products into the human food system, ruminants play a crucial role in feeding humanity and in supporting a sustainable food system within the Circular Economy.

Ruminants have two major adverse impacts upon the environment. They produce various greenhouses gases and release nitrogen and phosphorus into the environment which can impact upon air quality, global warming, and soil and water pollution. These problems are recognised and are being addressed. Reducing crude protein levels to around 140 g/kg DM in dairy cow diets increases the efficiency of nitrogen capture and reduces nitrogen excretion to the environment. Similarly, reducing over-feeding of phosphorus is a powerful tool to decrease the phosphorus content of manure.

A fundamental improvement in sustainability can be achieved by improving ruminant production. Higher output of milk and meat from ruminants reduces the number of animals required. This in turn reduces feed requirements and the consequent environmental pollution. There is considerable scope to improve dairy cow efficiency in the EU which will help in sustainability.

A major strength in the argument for the sustainability of ruminant production is the fact that ruminants eat substantial quantities of forages. It must be continually emphasised that these forages are quite inedible for humans. Ruminants have the unique ability to convert inedible forages into high quality human food products. Increasing quality or digestibility of forages will increase production efficiency. There has been a large amount of research directed to processing various crop residues to improve their digestibility for ruminants. Various chemicals such as sodium hydroxide, potassium hydroxide, calcium hydroxide, ammonia and urea are the most important and effective in improving the digestibility and nutritive value of straws.

Methane is a major greenhouse gas emitted by ruminants and nowadays there is considerable research efforts devoted to reducing these methane emissions. Phytochemicals, vaccines, dietary lipids, electron acceptors such as nitrate and ionophores have all been studied as part of a methane reduction strategy. The compound. 3-nitrooxypropanol is of particular interest in methane reduction. Good manure management and anaerobic digestion also contribute to reducing the environmental impact of ruminant production.

Future directions are to improve the nutritional quality of meat and milk, to manage ruminant health without antibiotics and to develop the use of new and novel feed ingredients such as wood, microalgae, seaweeds and insects.

Ruminants have served and will continue to serve a valuable role in sustainable agricultural systems. They supply large volumes of high value food and utilize low value feed ingredients.

The efficiency of human food production was substantially higher on replacing cereal grains and soyabean meal with the human-inedible agricultural by-products. It is clearly possible to obtain good efficiency of food production from dairy cows when fed sustainable diets.

Table 1: HeFCR and FCR with different concentrates plus forage in dairy cows

Parameter	Concentrate			
	Cereal, Soyabean meal (Control)	Sugar beet, Distillers grains	Sugar beet pulp, Rapeseed meal	Sugar beet pulp, Rapeseed meal, Distillers grains
HeFCR				
Protein (kg/kg edible material in feed)	0.73	2.56	2.63	2.68
FCR (kg energy corrected milk/kg feed)	1.46	1.47	1.51	1.44
Proportion human edible material in concentrate (%)	72	20	20	20

A similar approach to that of the Human-edible Feed Conversion Ratio (HeFCR) is to consider the Human-edible Return (HER) (Broderick, 2018). The HER is calculated as the quantity of human edible products divided by the quantity of human edible inputs. As shown in Table 2 milk yields the highest HER. Beef from the USA and Argentina was also superior to other animal protein sources in terms of HER. The high HER for beef from Argentina is derived from the fact that beef cattle consume only pasture and by-products non-edible for humans. This is another very powerful illustration of the value and sustainability of ruminants in converting feed ingredients, non-edible for humans, into high value food products.

Table 2: Human-edible returns of protein from various animal production systems

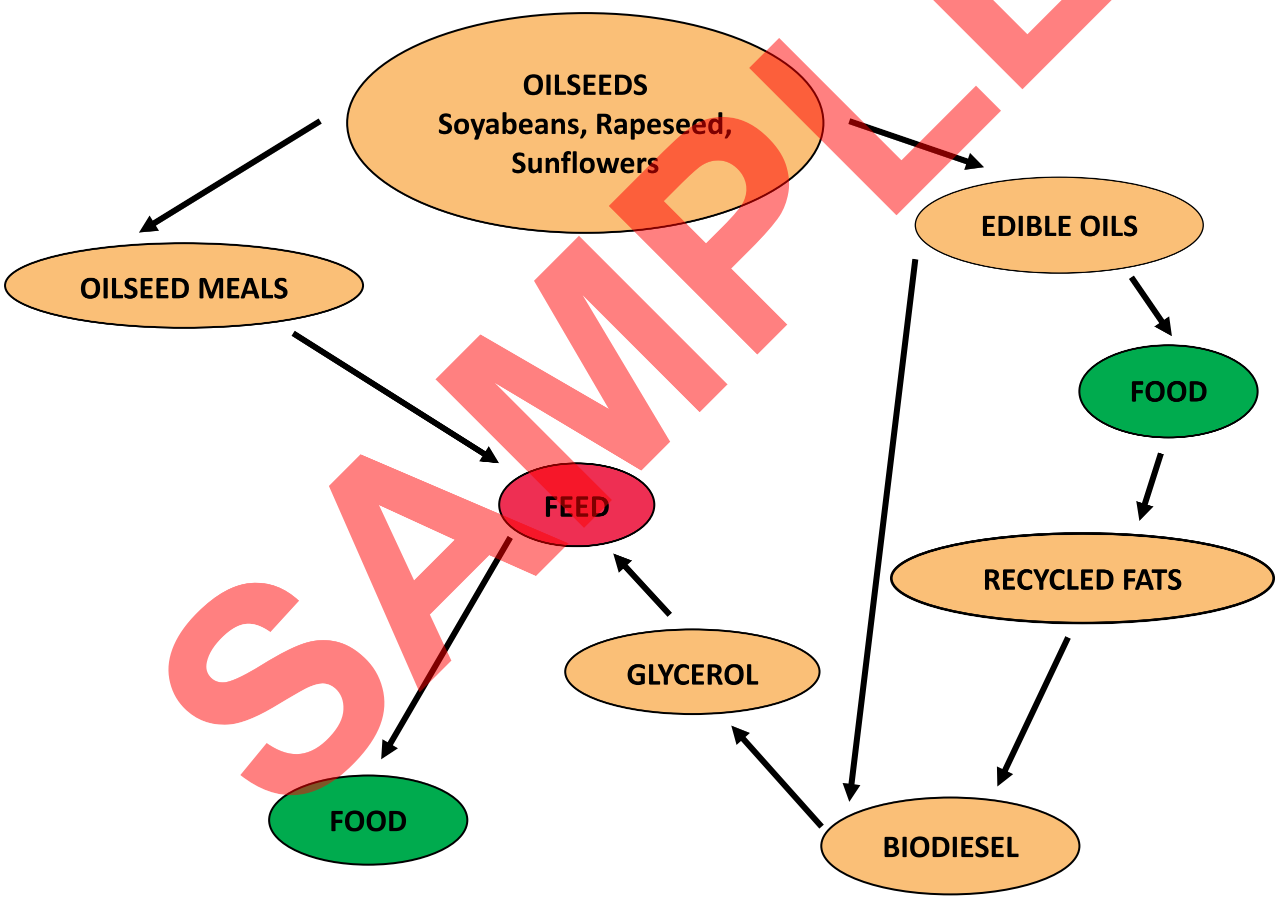
Food	Country		
Source	UK	USA	Argentina
Eggs	0.43	0.36	0.45
Poultry meat	0.48	0.62	0.69
Pork	0.38	0.29	0.11
Beef	0.49	1.19	6.12
Milk	1.41	2.08	1.64

The sustainable increase in ruminant productivity, which is key to meeting the large current and future demand for milk and meat cannot be achieved without the use of Sustainable Animal Diets. The concept of Sustainable Animal Diets integrates the importance of efficient use of natural resources, protection of the environment, socio-cultural benefits, ethical integrity and sensitivity. Sustainable Animal Diets are expected to be beneficial for the animal, the environment and society (FAO, 2014).

ruminant feeds. Also, some of the cereal harvest is utilized for bioethanol production and this generates DDGS as a by-product. The DDGS must be disposed of by the ethanol producers and it is widely used in ruminant feeds.

By recycling biomass from forages and nutrients from by-products into the food system, ruminants play a crucial role in feeding humanity and in supporting a sustainable food system within the Circular Economy. Initial estimates show that this route can provide up to one third (9–23 g) of the daily protein needs of an average global citizen (~50–60 g) (Van Zanten *et al.,* 2019). Ruminants contribute significantly to the human food supply, while at the same time reducing the environmental impact of the entire food system. Specifically, cattle act as upcyclers, meaning they eat forages such as grass or silage and by-products from human food or biofuels production and upgrade them into nutritional, high-quality protein. In fact, they produce 19 percent more edible protein than they consume (CAST, 1999)

Figure 2. Role of ruminants in the Circular Economy to maximise the value of oilseeds



somatic cell counts, reduction in the plasma concentrations of non-esterified fatty acids and beta-hydroxybutyric acid (Yang *et al.,* 2018).

The effects of essential oils from various plants have been studied in many species in recent years. In ruminants *in vitro* experiments suggest that essential oils may influence ruminal fermentation and also modulate the absorption of cations like sodium, calcium and ammonium across ruminal epithelia. Feeding a blend of essential oils elevated milk yield, milk fat and protein yield as well as feed efficiency, whereas urea levels in plasma decreased. In addition, plasma calcium levels increased significantly upon supplementation with essential oils. This supports the hypothesis that enhanced cation absorption might contribute to the beneficial effects of these essential oils (Table 6) (Braun *et al*, 2019).

Table 6: Effect of a blend of essential oils on dairy cow performance

Performance	**Treatment**	
Parameter	**Control**	**Essential Oils**
DMI (kg/day)	19.7	19.5
Milk (kg/day)	31.8	33.0
Fat (%)	3.25	3.79
Protein (%)	3.39	3.40
Feed Efficiency (kg milk/kg DMI)	1.62	1.70
Plasma		
Calcium (mmol/l)	2.46	2.53
Urea (mmol/l)	4.28	3.92

4.1.2. Organic Production

There clearly are many consumer concerns over modern food production. One manifestation of this concern is the significant and growing interest in "Organic Food" production where crops and animals are produced without the use of pesticides, chemical fertilisers or antibiotics. Detailed comparisons of the nutritional quality of foods produced under organic *versus* conventional systems are not easy to make. Foods of plant origin produced under organic systems may have a higher content of some components but there seems little difference in overall nutrient content (Brandt and Molgaard, 2001). A further extensive review of the nutritional value of organic food considered 98,727 articles (Dangour *et al*., 2010). After a systematic review of this published literature there was no evidence that organic food had any superior health benefits to conventional food.

The quantity of organic food production will inevitably be limited by the exigencies of the production system and organic food will always be significantly more expensive than the products from intensive agriculture. A comparison of the yields of organic and conventional framing systems in the USA indicated that organic farms produced one-third less wheat whilst soyabeans and potato production on organic farms was 62% lower (Kniss *et al.,* 2016). Furthermore, if all US wheat production were grown organically, an additional 12.4 million hectares (30.6 million acres) would be needed to match 2014 production levels.

mixture of garlic and citrus compounds without exhibiting negative side effects on rumen fermentation. Whilst these are promising results, they still need confirmation in animal trials.

A meta-analysis on the effect of plant essential oils in ruminants showed that they acted as a potential methane inhibitor similar to the ionophore monensin. These responses were more pronounced in beef cattle than in dairy cattle (Khiaosa-ard and Zebeli, 2013). There is an enormous and diverse range of phytochemicals so it is highly likely that some of them could be useful in mitigating methane production in ruminants.

A novel approach to methane reduction is the use of the red macroalgae *Asparagopsis taxiformis.* This was shown to be a highly efficient feed supplement for methane mitigation during fermentation studies with rumen fluid (Machado *et al.,* 2014). *A. taxiformis* addition to rumen fluid was able to reduce methane production by 98.9% after 72 hours.

More detailed *in vitro* studies with *A. taxiformis* in a semi-continuous *in-vitro* rumen system with rumen fluid from dairy cattle, showed a significant reduction in methane production at a 5% inclusion rate (Roque *et al.*, 2019). There was a decrease in total gas production by some 50% and in methane production by about 95% (Table 7). A significant reduction of methane was measured 12 hours after *A. taxiformis* addition while carbon dioxide production and VFAs profiles remained unchanged throughout the fermentation process. This suggests that supplementation with *A. taxiformis*, inhibits methanogenesis but not carbon dioxide production,

These *in vitro* results with rumen fluid strongly suggest that *A. taxiformis* is a promising candidate as a methane mitigation strategy for dairy cattle (Machado *et al.*, 2014; Roque *et al*., 2019). However, its effect *in vivo,* in dairy cattle, remains to be investigated in animal trials.

Table 7: Effects of *A. taxiformis* on gas production and volatile fatty acid production with rumen fluid

Gas production (ml/g Organic matter)	Control	*A. taxiformis*
Methane	12.08	0.59
Carbon dioxide	15.67	14.24
Total gas production	28.54	14.81
Volatile fatty acid production (ppm)		
Total VFA	2332.52	2105.11
Acetate	1056.99	856.77
Propionate	481.12	490.54
Butyrate	394.35	423.01
Valerate	212.79	168.72
Isovalerate	102.44	86.21

Further studies have shown that the active ingredient for methane reduction in *A. taxiformis* is bromoform (Figure 4) (Machado *et al*., 2016). Bromoform was the most abundant natural product in the biomass of *A. taxiformis* and was present in sufficient quantities to elicit a methane reduction effect. Another Important aspect was that the degradability of organic matter and synthesis of volatile fatty acids were not influenced at effective concentrations of bromoform to reduce methane production.

and insufficient crude protein for maintaining animal production. When nitrates are used, it is critical that the animals are properly adapted to avoid nitrite toxicity (Gerber *et al.,* 2013).

Another nutritional strategy is to feed linseed in combination with 1.8% nitrate as this has a long-term mitigating effect on methane production in dairy cow (Table 8), (Guyader *et al.*, 2016).

Table 8: Effect of linseed and nitrate on dairy cow performance and methane emissions

Treatment	Control		Linseed + Nitrate	
Week No.	**5**	**16**	**5**	**16**
Performance characteristic				
DM Intake (kg/day)	20.8	20.7	18.8	17.3
Milk yield (kg/day)	32.6	29.9	28.9	28.1
Fat (kg/day)	1.39	1.21	1.03	1.08
Lactose (kg/day)	1.65	1.50	1.49	1.37
Methane emission				
g/day	414	409	226	211
g/kg DM	12.1	13.2	8.9	8.1

Methane production was decreased by 30% (g/kg DM) when dairy cows were supplemented with 1.8% nitrate plus 3.5% added fat from extruded linseed. The methane-mitigating effect of linseed and nitrate was maintained throughout the 16 weeks of the experiment, indicating that this dietary strategy could be applied on farms.

However, the dry matter intake and milk production tended to be lower for dairy cows supplemented with linseed and nitrate, although the treatment diet had no effect on concentration and production of fat and lactose in milk. Linseed plus nitrate is an efficient feeding strategy to reduce methane emission in the long-term without altering animal health.

4.3.5. Ionophores

The antibiotic monensin is an ionophore that has been used in dairy cows to improve feed efficiency and to counteract ketosis. It is no longer authorised in the EU as a growth promoter but monensin is used in lactating dairy cattle for control of ketosis in an oral device (controlled release capsule) releasing monensin in the rumen.

Its mode of action has been attributed to its effects in the rumen on methane suppression and ammonia reduction. This is more likely to occur in ruminants fed high-grain or grain-forage diets and the effect is less consistent in ruminants fed pasture (Hristov *et al.,* 2013).

A methane reduction strategy based on antibiotic treatment is not a sustainable approach as a major consumer demand nowadays is to reduce the use of antibiotics in animals. Therefore, the use of monensin will not contribute to a sustainable system for ruminants.

5.2.2. Prebiotics

Prebiotics are carbohydrates which are non-digestible in the small intestine of monogastric animals. Consequently, prebiotics are only likely to be effective in young calves because the rumen is not fully developed. In mature cattle, on the other hand, prebiotics would be quickly digested in the fully formed rumen, and thus rendered ineffective.

Several different prebiotics have been used in calf nutrition such as, beta-glucans, inulin, lactulose and mannanoligosaccharides. They may be a viable option to increase the proliferation of commensal bacteria in the gastrointestinal tract, modulate feeding behaviour, and increase immune function to optimize calf health (Singh *et al.,* 2017).

The addition of mannanoligosaccharide to milk replacers has been shown to promote growth and prevent disease in young dairy calves (Heinrichs *et al*., 2003). Addition of either the prebiotic or antibiotics to milk replacer improved faecal scores in calves. The results suggest that antibiotics in milk replacers could be replaced with compounds such as mannanoligosaccharides to obtain similar calf performance.

The prebiotics inulin and lactulose showed effects on immune regulation and inflammation both systemically and locally in the gastrointestinal tract of calves. There were decreased signs of immune activation and increased anti-inflammatory signals and lowered pro-inflammatory signals. Presumably, these effects were generated by a decline in pathogen load in the intestine commonly attributed to prebiotic treatment (Masanetz *et al*., 2011).

Large quantities of antibiotics are used to treat calves and perhaps further development of prebiotics could help reduce this. Prebiotics are attractive because they are safe, being based on carbohydrates, and in the EU they are classified as feed ingredients, not feed additives, which substantially reduces the regulatory burden.

5.2.3. Egg Yolk Antibodies

The production of egg yolk antibodies, generally referred to as IgY, is another technique that appears to have considerable potential as an alternative to antibiotics. To produce the antibodies, laying hens are injected with micro-organisms that cause specific diseases in various animals. The injection of these antigens induces an immune response in the hen which results in the production of antibodies. These antibodies are typically deposited in the egg yolk and are then extracted and processed. Antibodies can be administered in the feed in several forms including whole egg powder, whole yolk powder, water-soluble fraction powder or even purified IgY.

A survey of seven studies on the effect of IgY against diarrhoea in calves showed beneficial results (Diraviyam *et al*., 2014). As indicated in Table 10, IgY treatment of calves was able to reduce both the incidence of diarrhoea and mortality caused by diarrhoea. These results strongly suggest that IgY could be useful, for prophylaxis and treatment of gastrointestinal disturbances by oral passive immunization as an alternative strategy to antibiotics.