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The position of cattle production in agricultural systems: A balance between food security and emission

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Abstract. The growth of the global population leads to an increase in demand for human edible food and cattle production plays an important role to realize this aim. Cattle or ruminants are capable to transfer fibre rich materials into human-edible products, such as meat and milk. This capability allows the exploitation of grassland, which is 50% of the land available for livestock, and the reuse of a large scale of by-products for the production of food. The use of non-human edible materials may make ruminants net producers of human-edible proteins. The disadvantages of this capability are the emission of methane, contribution to global warming, and the low milk N efficiency, leading to N emission to the environment contributing to water eutrophication, soil acidification, and global warming. Research work showed that the possibilities to reduce both types of emissions are relatively limited. The inclusion of more high-quality protein and starch into the diet reduces these emissions but this change also has a negative effect on the balance between the input of non-human edible material and the output of human-edible products. Balancing between both aspects is done by focusing on the ratio of emission units per animal product. This ratio should be minimized which can also be achieved by improvement of digestion of typical feed ingredients for ruminants, such as forage and fibre-rich by-products, leading to high animal production. Research work should focus on further improvement of the digestion of forages by technological, chemical, and biological treatments. The implementation of these improvements in practice, however, is a great challenge because it affects local agricultural systems and may lead to an increase in the price of animal products.

1. Introduction

Food production for the global population, or food security, is currently a major problem. The FAO estimated that in 2015 approximately 800 million people were undernourished which means insufficient access to macronutrients, i.e. proteins, fats, and carbohydrates, and micronutrients like vitamins [1]. Food from animal origin forms a significant part of the total food supply and globally contributes to 18% of the calorie and 25% of the protein consumption [2]. The contribution of products of animal origin to human food consumption is a subject of strongly emotional debates that affects the position of livestock production within agricultural systems. Gerber et al. [3] evaluated the role of livestock production on food security by focusing on additional positive effects such as the direct supply of macro- and micronutrients, the contribution of production animals to the agricultural system by production of manure, and the generation of income for people. This publication mentioned as negative effects on food security: animal feed that contains human-edible ingredients, agricultural land that is used for feed instead of food production, and the low efficiency of animals to convert feed into human-edible products. This low efficiency is a very important topic within the food security and focuses often on the production of cattle. The production of 1 kg beef is often criticized for its high consumption of grain [4] which has a very negative effect on food security. This negative effect will increase in the future because

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of the predicted global growth in demand for cattle products such as meat and milk with 57% and 48% respectively in the period 2005 to 2050 [5].

Animal production from cattle is not only criticized because of its negative impact on food security but also because of its negative impact on the environment. Global warming is regarded as a fundamental problem for the future of our planet and there is much pressure from society on politics to take measures to reduce the emission of Greenhouse gasses (GHG), such as methane, that are responsible for the increase in temperature. Livestock production contributes 13% to the total GHG emission which is for the main part related to cattle production (Gerber, 2013). The second emission is the N-outflow in the form of leaching of NO_3 and the volatilization of NH_3 and NO_2 into the environment (Dijkstra et al., 2013). These emissions have an impact on the direct environment and can affect the landscape and the water and air quality with a negative effect on human health especially in areas with a high population density like the Netherlands.

These emission problems had led to a political debate surrounding the reduction of dairy production by decreasing the number of cattle in the future in the Netherlands. The export of agricultural products, such as dairy products, is an important part of the national income of the Netherlands. Ruminants also play an important role within a sustainable agricultural system because of their capacity to transfer nonhuman-edible ingredients, such as forages and fibre-rich by-products, into food which has a positive effect on food security. This advantage makes this debate more complex and an increasing number of scientists are involved to find solutions regarding cattle production. This paper describes the contribution of scientists, especially in the field of animal nutrition, to face these challenges and solve the problems and challenges regarding cattle production.

1.1. Dairy production and digestion physiology

The Netherlands is one of the global leading countries regarding the production of dairy products and it has a very long tradition in the use and breeding of especially Holstein-Frisian cows with high productivity. The number of cattle in the Netherlands was around 3,720,000 in 2019, from which 1,590,000 can be regarded as dairy cattle. The total volume of milk produced was 13,787,769,000 kg with an average fat and protein content of 4.41% and 3.58% respectively. The average milk yield per dairy cow was 8,617 kg/year.

The digestion process of dairy cattle is much more complex because of the presence of an additional reticulorumen before the stomach and intestine compared to other production animals, such as pigs and poultry. The reticulorumen facilitates a pre-digestion of the diet before entering into the abomasum by two processes: rumination and fermentation. Rumination is a mechanical movement of the ingested diet between the mouth and rumen to reduce the feed particle size which is facilitated by saliva enzymes. Microorganisms in the rumen, such as bacteria and protozoa, are responsible for the anaerobic fermentation of the different dietary nutrients and this degradation contributes to the growth of bacteria. The advantages of this fermentation process are that ruminants can digest fibre and produce bacterial protein. In this fermentation process, short-chain fatty acids, i.e. acetate, propionate, and butyrate, are produced and absorbed in the bloodstream and use as an energy source by the cow. The microorganisms use the released energy and the available nitrogen, which can be in the form of ammonia, urea, amino acids, and small peptides, to synthesis the own proteins and the outflow of this microbial protein is the most important supplier for the absorption of amino acids in the small intestine. A part of the ingested feed, however, will not be fermented and these nutrients in this bypass fraction and a part of these may be (after hydrolysis) directly absorbed in the small intestine. The flow of protein into the gastrointestinal tract contains microbial protein and non-fermented bypass feed protein.

Numerous studies have been conducted to investigate this complex system of digestion and the utilization of nutrients during the last half of the previous century. This research work has resulted in the development of different feed evaluation systems [8-11]. The availability of these evaluation systems allowed farmers to achieve a more efficient utilization of diets leading to a more profitable production of milk.

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1.2. Cattle production in relation to food security and sustainability

The position of cattle production in relation to food security requires more information about feed use and feed use efficiency compared to the general statement, such as the use of grains for meat production [12]. This information should focus on the use of human-edible ingredients in the diet and the use of arable land to produce animal feed instead of producing food directly. The global livestock sector used 6.0 billion tonnes of feed (based on the dry matter) in 2010 [2]. The three major feed materials were grass and leaves (42%), crops residues such as straw (19%), and grains (13%). The contribution of human-edible feed materials was limited to 14% of the global livestock ration. The distribution of these materials in the ration strongly depended on the type of production animal. The diet of ruminants under grazing conditions was mainly roughage (approximately 90%) whereas the diet of industrial layers and pigs contains mainly grains (more than 50%) [2]. The largest fraction, i.e. grass and leaves, were exclusively used for ruminants that also produced most of the protein of animal origin (45%). These feed materials were divided into three groups by using the criteria human-edible and competes with food-crops for land [2]. The first group contained nonhuman-edible materials such as grass, fodder, silages, and several by-products from food production, such as rapeseed meal and corn gluten feed. The second group and the third group contained human-edible materials including soybean cakes. The feed conversion rate (FCR) for ruminants, expressed as kg protein feed/kg protein product, was 20 when all feed protein consumed is taken into account. This figure appears to be unfavourable, but these feed materials for ruminants contain mainly nonhuman-edible proteins. The FCR decreases to a favourable 0.6 if only human-edible proteins are taken into account, which means that the production of 1 kg protein product required 0.6 kg of human-edible proteins. The FCR based on human-edible protein can even be further decreased because ruminants do not need human-edible proteins in their diets [7]. Ruminants can, therefore, be regarded as net human-edible protein producers instead of consumers in contrast to other production animals such as pigs and poultry in most systems globally.

The second important issue is the use of arable land to produce animal feed instead of producing food directly. The total global area used to produce forage and feed is approximately 2500 million ha [2]. Grasslands make up 77% (i.e. 1700 million ha) of this total area and are used mainly for cattle production. Based on environmental conditions, such as soil, weather, and infrastructure, only around 33% of these grasslands are suitable for crop production, which leaves an area of 1260 million ha only suitable for cattle production. The exclusive use of 50% of the available area also emphasized the position of ruminants to fully exploit the agricultural resources to ensure food security in the future.

Cattle also play an important role in the valorisation of by-products and therefore contributes to realizing a sustainable agriculture system. By-products are mainly the remains of the food processing industry and they contribute to nearly 30% of global livestock feed intake [7]. The growing demand for food will likely increase the volume of these by-products. Production of sugar from sugar beets is a good example to illustrate the magnitude of the volume of by-products (beet pulp), which is for this process 84% of the original product. In 2018, a volume of 5.6 million tonnes of by-products was used for livestock in the Netherlands for which nearly 50% within cattle diets. The most important sources of these by-products were the grain processing industry (brewers grains and corn gluten feed), the potato processing industry (potato pulp and potato cuttings), the sugar processing industry (sugar beet pulp and chicory pulp), and the fermentation and yeast industry (wheat yeast concentrates). Some major characteristics of these by-products are their usually high fibre content and the low digestibility of the starch which makes them very suitable to use in cattle diets.

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1.3. Cattle production in relation to emission

The greatest challenge of cattle production is its emission of methane and nitrogen that both have a negative ecological effect on the environment. The emission of methane, which is an important greenhouse gas, is strongly connected with global warming or climate change which is one of the most urgent environmental topics in the future. The contribution of livestock production to the emission of GHG was 14.5% in 2013 which was mainly caused by ruminants [6]. The methane emission was estimated as 60 to 160 kg/yr for cattle but this value was strongly related to the feed intake and this value usually varies between 16 and 26 g/kg of dietary DMI (dry matter intake) [13]. An important approach to reduce methane emission was focusing on diet composition and management and the addition of additives to the feed. A lot of research capacity was spent on investigation of the relation of feed and methane emission and testing of strategies to reduce emission. A broad range of additives was tested and experiments showed that the addition of nitrate [14] ionophores [15], and tannins [16] had a positive effect on reducing methane emission. Additives, however, could also reduce the digestion of diets as was demonstrated for tannins [17]. A general problem with additives is the adaptation of microbes to these chemical compositions leading to a diminished effect after a certain time. The stoichiometry of ruminal fermentation predicts that more methane is produced with the fermentation of fibre compared to starch [18]. A higher inclusion of concentrates, such as grains, also reduced the methane emission but also increased the production leading which improved the ratio of both values [19]. Research work focusing on the diet composition that the emission of methane was positively correlated to the Gross Energy and fibre (i.e. NDF) intake and negatively correlated to the fat intake [20]. Improvement of nutritional quality and digestibility of forage also reduced methane emission [21] The positive effect of starch on reducing methane emission was also demonstrated by replacing grass silage by maize silage in the diet [22].

The second challenge for cattle production is the reduction of N-outflow into the environment. This N-outflow contains different forms such as leaching of NO_3, volatilization of NH_3, and the emission of N_2O. N_2O is a greenhouse gas and therefore contributes to the global warming problem that is associated with cattle production. Volatilization of NH_3 and leaching of NO_3 affects the local ecosystem and this emission has a negative effect on the air and water quality and landscape characteristics. The impact of these effects is especially large in the areas with a high population density such as the Netherlands. In this country, there is pressure from society to decrease cattle production and therefore to reduce its negative effect on the ecosystem and quality of life. The outflow of N is caused by the inefficient use of N by cattle, and to improve the utilization of N is regarded as an important challenge for dairy nutritionists in the Netherlands. The complexity of the digestive system of ruminants that enables the digestion of fibre and synthesis of microbial protein is the main reason for this low efficiency. The estimated theoretical maximum value for milk N efficiency of dairy cattle based on a standard diet and milk yield is 43% but in practice, this value varies from 20 to 25% [7]. This deviation from the theoretical maximum shows some room for improvement of the milk N efficiency. This may be obtained by balancing the supply of energy and protein to the microorganisms in the rumen, and by balancing the availability post-absorptively of energy-containing nutrients and amino acids.

Ammonia is the most important source of N for microbial protein synthesis and a concentration between 6 to 18 mM in the rumen is required to maximize microbial protein synthesis [23]. These concentrations will automatically lead to a net unavoidable loss of at least 30 g/d [7]. In vitro studies showed that supplementation of amino acids and peptides instead of only ammonia could improve this microbial efficiency to a certain point [24]. The diffusion of free ammonia through the rumen wall leads to an increase of urea in the blood that can be recycled to the rumen or be lost by the urine. Recycling of this urea followed by incorporation in microbial protein is important to increase the N efficiency which offers the opportunity to decrease the N content in diets [25]. Optimal microbial protein synthesis depends on a balance between available N and energy for the production and growth of microbes. The Dutch feed evaluation system (DVE/OEB 2007) expressed this balance as OEB value (rumen degradable protein balance) that can be estimated for the ingested diet based on table values [8]. The system recommends small positive values for OEB to be sure of the optimal utilization of N in the

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rumen to reduce its emission. Under optimal conditions the apparent efficiency of the use of dietary N to microbial N is 0.90, however, 20-25% of the microbial N is nucleic acid N that will be mainly lost in the urine [7]. The transformation of the absorbed amino acids to milk protein production is another important factor that affects milk N efficiency. Two efficiency factors were identified: the efficiency for an 'ideal' amino acid mixture and the efficiency for the difference between the absorbed amino acid mixture and the ideal one [26]. The total efficiency factor is set to 0.68 but based on animal trials this value seems to overestimate the efficiency of this process in practice leading to a much lower total efficiency, i.e. 0.38 [7].

A strategy to improve N milk efficiency is to only supply intestine digestible protein to avoid rumen fermentation, which leads to an increase in milk N efficiency from 0.43 to 0.65. This approach, however, has a very strong impact on the ratio between the output of human-edible protein in animal products and the input of human-edible in the feed. In practice, this value varied between 1.4 to infinite for dairy cattle and between 0.33 to infinite for beef cattle [7]. The inclusion of a great amount of high-quality protein would have a negative effect on this ratio.

2. Discussion

Ruminants play an important role within food security because of their capacity to convert fibre-rich material, such as forage and by-products, into human-edible products such as milk and meat. More than half of the global area used for livestock can only be used as grassland and the presence of ruminants enables society to use this area for the production of human-edible products. Ruminants are also important in the valorisation of fibre-rich by-products from food processing and therefore play a vital role in circular and sustainable agricultural systems. Their capacity to synthesis protein from non-protein N sources and nonhuman-edible proteins makes ruminant net human-edible protein producers. The price of these benefits is the impact of the production on the environment by the emission of greenhouse gasses, especially methane, and the outflow of nitrogen. Research work showed that the exchange of fibre by starch and the inclusion of more high-quality protein reduced these emissions but made the diet more comparable to that of a monogastric animal. These diets will contain more human-edible feed ingredients and have therefore a negative effect on the feed food discussion. To balance both aspects, research is starting to express the amount of emission related to the corresponding amount of animal products such as methane/kg milk. The next step could be to relate emission to net human-edible protein production. The challenge for nutritionists is to minimize this ratio for typical ruminant materials such as forages and fibre-rich by-products. The improvement can be realized by technological, chemical, or biological treatment of forages that focus on the degradation of cell wall components. The presence of lignin-cellulose complexes forms a rigid barrier that prevents the degradation of cell wall components [27]. Incubation of forages with white-rot fungi is an effective method to break down the lignin-cellulose complex in such a way that cell wall carbohydrates become available for ruminal microbes [28]. A recent in vitro study confirmed this positive effect of this treatment also for wheat straw which is an important by-product [29]. This research work shows that there are still scientific opportunities to further improve digestibility and therefore the balance between production and emission.

The greatest challenge, however, is to implement these kinds of improvements in practice [29]. This implementation has some serious consequences for the type of livestock system by changing from free grazing in pasture to more housing in a barn that offers the opportunity of pre-treatment of materials and precision feeding to achieve a better ratio between production and emission. This transition, however, needs the commitment of society before it can be successfully implemented. Society should be willing to pay the costs for this transition which will lead to an increase in the price for animal products.

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