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Assessing and Interpreting Food and Land Use Efficiency by Ruminants

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There are many indicators for assessing feed and land use efficiency in ruminants. In this article, we present the main ones and summarise the numerous studies that have used them to improve their interpretation.[1]

Introduction

After the Second World War, agricultural policies were put in place to increase food production. Together with developments in genetic selection, mechanisation and the use of inputs, they led to a significant increase (about over 300%) in crop yields, particularly in Europe (Mazoyer & Roudart, 2002; Lang & Haesman, 2015; FAO, 2024). The outcome has been a cereal surplus in Western countries and the introduction of nutritionally richer products in animal feed. In parallel with these changes, we have seen the intensification and territorial specialisation (Roguet *et al.*, 2015) of animal production systems, whose productivity has also risen by around 130% (FAO, 2024).

Foods of animal origin, such as meat, milk and eggs, provide 18% of the energy and 25% of the protein consumed by humans worldwide (Mottet *et al.*, 2017). Among other things, they are recognised for their high energy, protein and vitamin density, particularly vitamin B12 which is not present in plant-based foods and micronutrients such as iron, zinc and calcium. Their qualities, ranging from high digestibility and bioavailability to richness in limiting amino acids, correspond to human dietary requirements (Randolph *et al.*, 2007; Dror & Allen, 2011; Gorissen *et al.*, 2018; Day *et al.*, 2022; Beal & Ortenzi, 2022; Costa-Catala *et al.*, 2023).

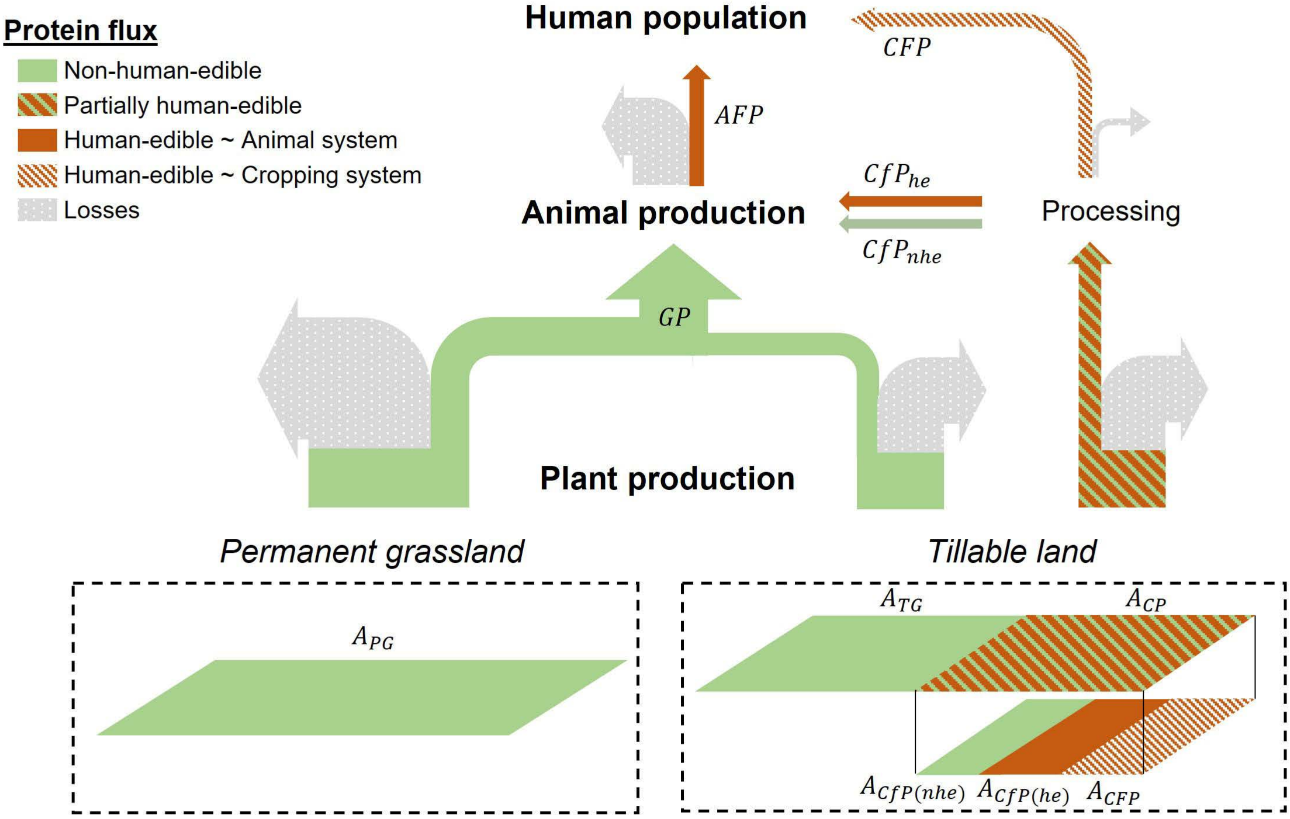
However, when livestock consume agricultural products that are edible for humans, they represent an additional trophic level in the agro-ecosystem between plants and humans, leading to unavoidable losses. On a global scale, 86% of the feed consumed by farm animals is fodder and industrial by-products inedible by humans (Mottet *et al.*, 2017) although it is currently suggested that more food could potentially be produced in certain agricultural areas presently used for livestock production if they were converted to alternative cropping systems giving priority to humans-edible crops (van Zanten *et al.*, 2016). As a result, animals are often directly viewed as one of the main causes of inefficiency in food systems (Garnett *et al.*, 2015; Poore & Nemecek, 2018).

Furthermore, the use of biomass for other purposes is expected to increase as fossil fuel usage decreases. In France, for example, while 36 Mt of dry matter (DM) are used each year for bioenergy (methanisation, biofuels, wood, wood waste), an additional 28 Mt DM/year will be needed by 2030 (SPGE, 2024). The European Biogas Association is also aiming to boost production by a factor of 30 by 2050 (de Groot *et al.*, 2022).

Nevertheless, much work is being carried out in France and Europe to prioritise the different uses of biomass. The General Secretariat for Ecological Planning is proposing a form of *merit-order*, in which food and feed are among the uses given priority while electricity production is classed as a development to be moderated. The *"Food Waste Hierarchy"* communicated by the European Union also favours animal feed over bioenergy (European Commission, 2020).

1 This article was presented at the 27th Rencontres autour des Recherches sur les Ruminants, 4-5 December 2024 in Paris (Mertens *et al.*, 2024).

Figure 1. ***Protein flows and associated surface areas in an agro-ecosystem, with losses between tropical levels due to metabolic losses and various losses (during harvesting, storage, etc.).***



Abbreviations: P: Protein, A: Area, AFP: Animal-food protein, CFP: Crop-food protein, CfP_{he}: Human-edible crop feed protein, CfP_{nhe}: Non-human-edible crop feed protein, GP: Grass-based protein, CP: Crop protein, PG: Permanent grassland, TG: Temporary grassland, CP: Crop protein area (Battheu-Noirfalise *et al.*, 2023).

The sharp uptick in the human population to 9.8 billion by 2050, the expected increase in demand for animal products of 20% (FAO, 2023) as well as the depletion and pollution of natural resources coupled with the effects of climate change (Foresight, 2011), are calling into question the ability of current agricultural systems to guarantee future food security. This situation is currently prompting renewed interest from the political and scientific communities in terms of the contribution of livestock production to food security. In the context of competition between food and feed, the main issues are food availability and quality. Tools need to be defined and mobilised to inform the debate and guide decisions.

The aim of this review article is *i)* to present indicators for characterising feed and land use efficiency on cattle farms, *ii)* to summarise the performance of these farms and *iii)* to analyse the relationship between these indicators and the characteristics of these farms.

1. Indicators for assessing the use of food resources and land by livestock production systems

The indicators presented in this study are based on the general concept of efficiency, namely the ratio between an output and the resources mobilised to achieve that output. They are taken from the literature and described in Figure 1 and Table 1.

These indicators consider two main resources that limit animal production (feed and farmland) while the products comprise the energy and protein contained in milk, eggs and meat. Inputs (e.g. farmland) used upstream of the farm, for the production of purchased feed to cite an example, are also taken into account.

Four types of indicator were identified and are described in Table 1: net efficiency, net productivity, *land use* and *land use* ratio. Databases were compiled in order to summarise the various results obtained for the recognised indicators. For each database obtained, the type of data (experimental farm, commercial farm, test case, etc.), the number of systems studied, the type of livestock, the region and the indicators used are summarised in Table 2.

2. Feed conversion efficiency

2.1. Gross efficiency

Gross feed conversion efficiency represents the quantity of Animal source food (ASF) produced in relation to the total quantity of feed used. This can be calculated per kg of product or by taking into account only the protein or energy components of the feed produced and consumed.

Improving gross feed conversion efficiency has been a major focus of

Table 1. ***Names, authors, equations and characteristics of the various indicators. The equations are written for protein-related indicators.***

Indicator	Author, Year	Equation	Features
Gross efficiency		$\frac{AFP}{GP + CfP_{he} + CfP_{nhe}}$	Processing efficiency expressed as dry matter (DM), energy or protein.
Net efficiency	Wilkinson *et al.* (2011)	$\frac{AFP}{CfP_{he}}$	If > 1: net protein producer. If = 1: transformer. If < 1: net consumer.
Net efficiency + Protein quality	Ertl *et al.* (2016a)	$\frac{AFP \times DIAAS}{CfP_{he} \times DIAAS}$	Like net protein efficiency but taking into account the quality of the protein for human consumption (DIAAS).
Land Use	De Vries *et al.* (2010)	$\frac{A_{PG} + A_{TG} + A_{CfP(nhe)} + A_{CfP(he)}}{AFP}$	Surface area used (m²) per unit of product (kg DM, Joule or kg protein).
Ploughable	Nijdam *et al.* (2012)	$\frac{A_{TG} + A_{CfP(nhe)} + A_{CfP(he)}}{AFP}$	Ploughed area (m²) used per unit of product (kg DM, Joule or kg protein).
Permanent meadows		$\frac{A_{PG}}{AFP}$	Area of permanent grassland used (m²) per unit of product (kg DM, Joule or kg protein).
Land Use Ratio (LUR)	van Zanten *et al.* (2016)	$\frac{\text{Potential } CFP}{AFP}$	The ratio between potential plant production and observed animal production from the same soil.
LUR + Edible portion of food and protein quality	Hennessy *et al.* (2021)	$\frac{\text{Potential } CFP \times DIAAS}{AFP \times DIAAS}$	Use of edible portions of potential plant production and DIAAS protein scores.
Net productivity	Battheu-Noirfalise *et al.* (2023)	$\frac{AFP - CfP_{he}}{A_{PG} + A_{TG} + A_{CfP(nhe)}}$	Productivity of surfaces not in competition with the Man of the breeding system.

Abbreviations: P: Protein, A: Area, AFP: Animal-food protein, CFP: Crop-food protein, CfP_{he}: Human-edible crop feed protein, CfP_{nhe}: Non-human-edible crop feed protein, GP: Grass-based protein, A_{CP}: Crop protein area, PG: Permanent grassland, TG: Temporary grassland, DIAAS: Digestible indispensable Amino Acids Score (Battheu-Noirfalise *et al.*, 2023).

research and development in animal production. Various levers such as husbandry, feeding, genetic selection, nutrition and animal health have been mobilised (Garnett *et al.*, 2015), leading to significant improvements, particularly for poultry.

Ruminants, and in particular suckler cattle systems, which are less standardised than monogastric systems (Gerber *et al.*, 2015), have highly variable gross efficiencies (GEs) by mass. For example, Wilkinson (2011) has shown that beef production systems in the UK consume between 7.5 (GE = 13%) and 27.5 kg (GE = 4%) of feed per kg of meat produced, depending on the type of animal and feed considered.

These differences are repeated when we look at gross energy efficiency. Laisse *et al.* (2018) calculated gross energy efficiencies of 25% for broilers, 26% for pork and only 4% for beef. The difference between broilers and other meat products increases when the protein fraction of feed is considered. In fact, gross protein efficiency reaches 54% for broilers versus 40-42% for pork and 8% for beef. This may cultivate the simplistic idea that replacing all beef with poultry would enable feeding for a greater number of people. In the United States, this would represent 116 million extra people being fed (Shepon *et al.*, 2016).

Gross protein feed conversion efficiency reaches 27% for laying hen systems and 19-24% for dairy cow systems (Laisse *et al.*, 2018).

■ 2.2. Net efficiency

Compared with monogastric animals, which use enzymatic digestion, ruminants are able to make better use of grass and other fibre-rich feedstuffs that are inedible by humans, thanks to the specific microbial predigestion that

Table 2. ***Data collected with evaluation of certain efficiency or land use indicators.***

Source	N	Type of Data	Type of Farm	Region	Indicators
Laisse *et al.* (2018)	10	Case types	Dairy and beef cattle, beef sheep, pigs, broilers, laying hens.	France	Gross and net efficiency.
Mosnier *et al.* (2021)	16		Dairy and beef cattle.	European Union	Net efficiency, land use.
DAEA, incl. Battheu-Noirfalise *et al.* (2023, 2024b)	262	Commercial farms	Dairy and beef cattle.	Wallonia (Belgium)	Gross and net efficiency, land use. Net productivity.
AUTOPROT project	213		Dairy cattle.	Belgium (Wallonia), France (Lorraine), Luxembourg, Germany (Rhineland-Palatinate and Saarland)	Gross and net efficiency, land use. Net productivity.
IDELE	142		Beef cattle.	France	Gross and net efficiency.
van Zanten *et al.* (2016)	123		Dairy cattle.	France	*Land use* ratio.
Hennessy *et al.* (2021)	3	Case types	Dairy cattle, pigs.	Ireland	*Land use* ratio.
Allix *et al.* (2024)	12		Dairy cattle.	France	*Land use* ratio.
Rouillé *et al.* (2023)	498	Commercial farms	Cattle, sheep, dairy goats.	France	Gross and net efficiency.

N: Number, DAEA: Department of Agricultural Economic Analysis.

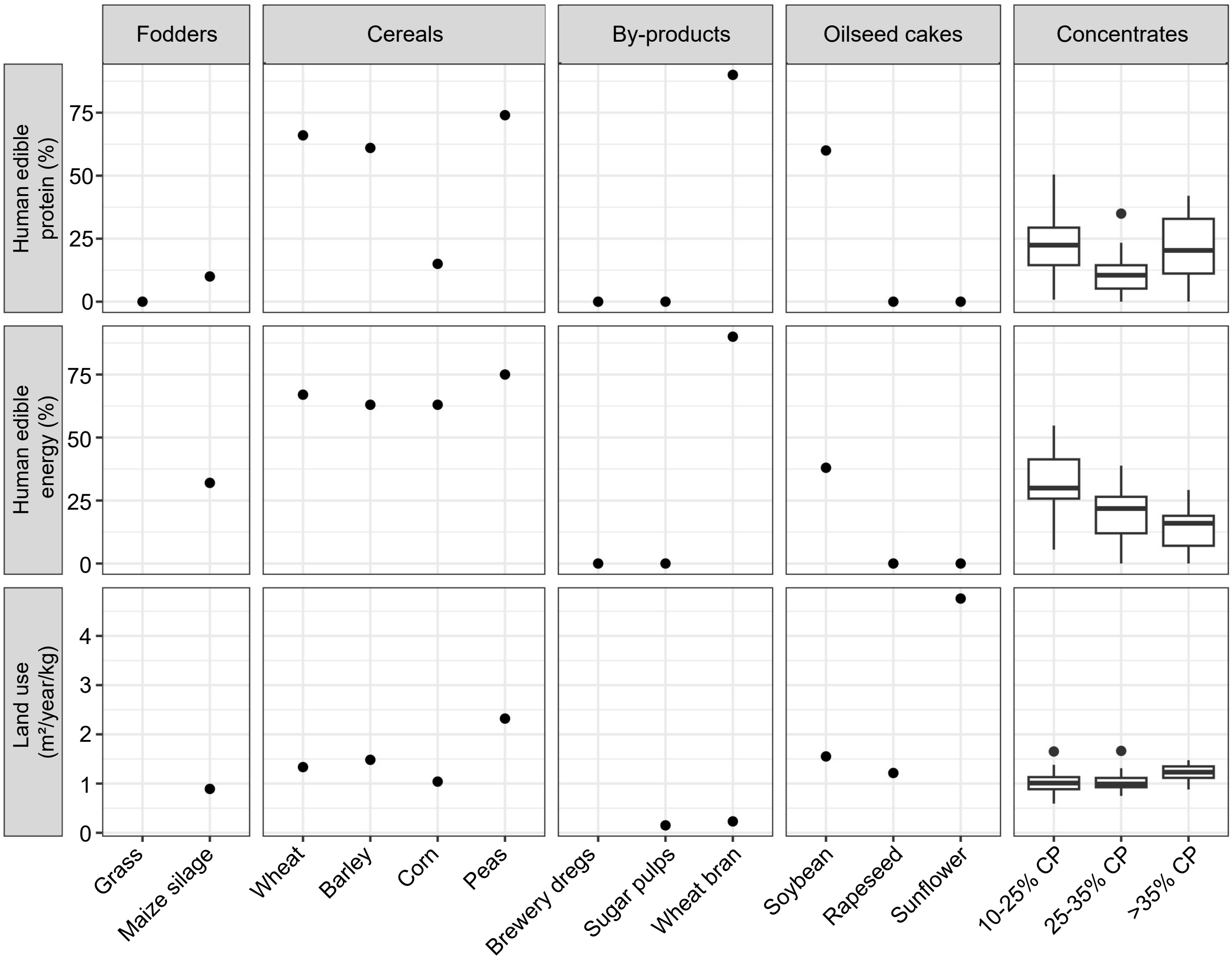
takes place in their rumen. Steinfeld *et al.* (1997) first proposed a "human-edible feed conversion efficiency", estimating that, worldwide, animals use 1.4 times more human-edible feed than they produce ASF. Wilkinson (2011) formalised the "edible feed conversion ratio" indicator and described the performance of a variety of livestock production systems in the UK. Net feed conversion efficiency was proposed later (Ertl *et al.*, 2015; Laisse *et al.*, 2018) and is referenced in this paper. It represents the inverse of the indicator presented by Wilkinson (2011); the amount of ASF produced is divided by the amount of human edible feed used.

To calculate this ratio, the human edible fraction of each food is estimated as the proportion of the product that can currently be valued as food for humans (Figure 2). Since food crops are split into different fractions (for example, milled wheat grains are separated into flour, wheat bran and gluten), the amounts of protein and energy directly edible by humans represent the weighted proportions of protein and energy found in each of the fractions edible to humans (Figure 2). For many animal feeds, the energy and protein fractions consumable by humans are very similar; however, some have more significant differences. For example, maize is largely valued for its starch while the protein-rich by-products (corn gluten feed and corn gluten meal) can currently not be eaten by humans (Laisse *et al.*, 2018).

On this basis, as part of the Interreg AUTOPROT project (037-4-09-092), 210 concentrate formulas marketed in Wallonia (Belgium), Lorraine (France), Luxembourg, Rhineland-Palatinate and Saarland (Germany) were studied. The proportion of protein competing with humans in concentrates with a protein content below 25% depended mainly on the proportion of cereals. For concentrates with a high protein content, the proportion of rapeseed meal (which was not considered to be in competition) and soya meal in the concentrated feed explain the variability observed (Figure 2).

For French-type livestock systems, the net protein efficiency estimate was greater than for dairy cattle (1.01-2.57), pig and laying hen (1.02) systems; they produce more human-consumable protein than they consume while it was less than one for beef cattle (0.67-0.71) and broiler (0.88) systems (Laisse *et al.*, 2018). Meat sheep performed better (1.28) or worse (0.34) depending on the production system. The net energy efficiency estimate was systematically lower and only extensive grass-fed dairy systems exhibited a value greater than one (Laisse *et al.*, 2018). In terms of dairy systems, cattle demonstrated better average performance than ewes and

Figure 2. ***Proportions of protein and energy and land use for different feeds based on Laisse* et al. *(2018) and the ECOALIM database for land use, for staple feeds and 203 concentrate recipes (AUTOPROT Project).***



CP: Crude protein.

goats (Rouillé *et al.*, 2023). When analysing European beef systems, Mosnier *et al.* (2021) also highlighted the importance of taking into account the different phases in the life of beef animals. In fact, cow-calf systems that use a lot of grass generally have high net efficiency while fatteners can have lower performances due to greater use of feed competing with humans such as cereals. Breeding systems therefore have to be combined with fattening systems, which makes them net consumers of plant proteins consumable by humans in most cases (Mosnier *et al.*, 2021).

Furthermore, the fraction of animal feed that is edible for humans is neither fixed nor generalisable given that it depends on the context and technologies available in the agri-food sector of the country in question (Laisse *et al.*, 2018). For example, Ertl *et al.* (2015) considered that 30% of the proteins present in rapeseed meal can be extracted and valorised in human food. However, Laisse *et al.* (2018) assumed that the protein fraction of rapeseed edible by humans was zero because this extraction process is not implemented in France. They described different scenarios in terms of the edible fraction of animal feed for humans. Indeed, in the future, higher extraction rates due to new technological processes and changes in consumption habits could lead to higher edible fractions (Ertl *et al.*, 2015). Adopting these scenarios, Laisse *et al.* (2018) found a reduction in net protein efficiency of 16-40% for ruminants and 36-51% for monogastrics.

■ 2.3. The role of protein quality

In order to represent the difference in protein quality and digestibility, the Digestibility of Indispensable Amino Acids Score (DIAAS) has been proposed by the FAO (2013) as a reference method. This score represents the content of the first limiting indispensable amino acid in the protein tested versus the content of the same amino acid in a reference protein corresponding to the needs of a child aged six months to three years and based on the actual ileal digestibility of indispensable amino acids (Rutherfurd *et al.*, 2015).

Initially, it was suggested that DIAAS values should be truncated at 100% because the higher values represent a surplus in relation to human nutritional requirements and are therefore not valued by the human body if the food is the only component of the plate (FAO & WHO, 1991). Later, it was argued that non-truncated values should be considered because, in mixed diets, a high-quality protein-based food can supplement another food that is deficient in essential amino acids (Rutherfurd *et al.*, 2015). The FAO (2013) suggests using the amino acid requirements for a child aged six months to three years as the reference protein. Taking DIAAS into account when calculating net efficiency multiplies net efficiency values by 1.7 to 2.4 for milk production, 1.6 for egg production and 1.4 to 1.9 for meat production (Ertl *et al.*, 2016a, 2016b; Laisse *et al.*, 2018).

The efficiencies obtained from the different sources, according to the different variants presented above, are summarised in Figure 3. Figure 3B depicts the net efficiency of systems with a double beef herd as a function of the proportion of suckler and dairy cows. The net protein efficiencies for the different types of beef herd (Figure 3C) and dairy herd (Figure 3D) are also illustrated.

3. Use of surfaces

The availability of agricultural land, and in particular arable land, is considered to be the most limiting factor for feeding the planet in 2050 (Bruinsma, 2009). Total land use represents all the agricultural land used (on and off the farm) per unit of animal product (e.g. per kg of protein produced).

In a review of 16 life cycle assessment (LCA) studies, De Vries and De Boer (2010) found that the land required to produce animal products ranged from 1.1 to 2.0 m^2/kg for milk, 4.5 to 6.2 m^2/kg for eggs, 8.1 to 9.9 m^2/kg for chicken, 8.9 to 12.1 m^2/kg for pork and 27 to 491 m^2/kg for beef. However, not all land has the same agricultural value. More specifically, there is a big difference between the potential value of permanent grassland and arable land (Wirsenius, 2003). In another study, Nijdam *et al.* (2012) calculated the share of grassland and showed that, although beef production from extensive pastoral systems has the highest land use, it can be entirely composed of permanent grassland.

Historically, permanent grassland corresponded to land that could not be ploughed, shallow soils and/or soils with a high stone content and plots that were inaccessible and/or very steep. However, with the specialisation of production systems and territories, some arable land has been transformed into grassland which has become permanent. It is now estimated, on the basis of soil and climate conditions, that some permanent grasslands could be cultivated (IIASA/FAO, 2012). More notably, Mottet *et al.* (2017) estimated that, on a global scale, 35% of the two billion hectares of grassland used by livestock could be converted to cropland. However, this change in land use could lead to GHG emissions due to the release of carbon stored in the soil, losses in biodiversity and other ecosystem services (Foley *et al.*, 2005).

3.1. *Land use* ratio

Indicators of land use, whether total, arable or permanent grassland, give an idea of the efficiency of land use for different types of livestock production. However, it is not certain that the arable land used by animals could produce more food on the basis of a rotation optimising the presence of crops for human consumption than current ASF production.

To answer this question, van Zanten *et al.* (2016) proposed the *land use* ratio (LUR) which compares the potential for plant protein production on land used by livestock with protein production by livestock. Grassland on sandy soil is considered arable with a production potential of 56 t/ha of potatoes or 7.3 t/ha of wheat. Two livestock systems in the Netherlands (one with laying hens and the other with dairy cows on sandy soil) had a LUR greater than one, indicating that a cropping system would produce more protein per unit area than the livestock systems currently in place. The dairy system on peaty soil, which is less suitable for crops, exhibited a LUR of less than one.

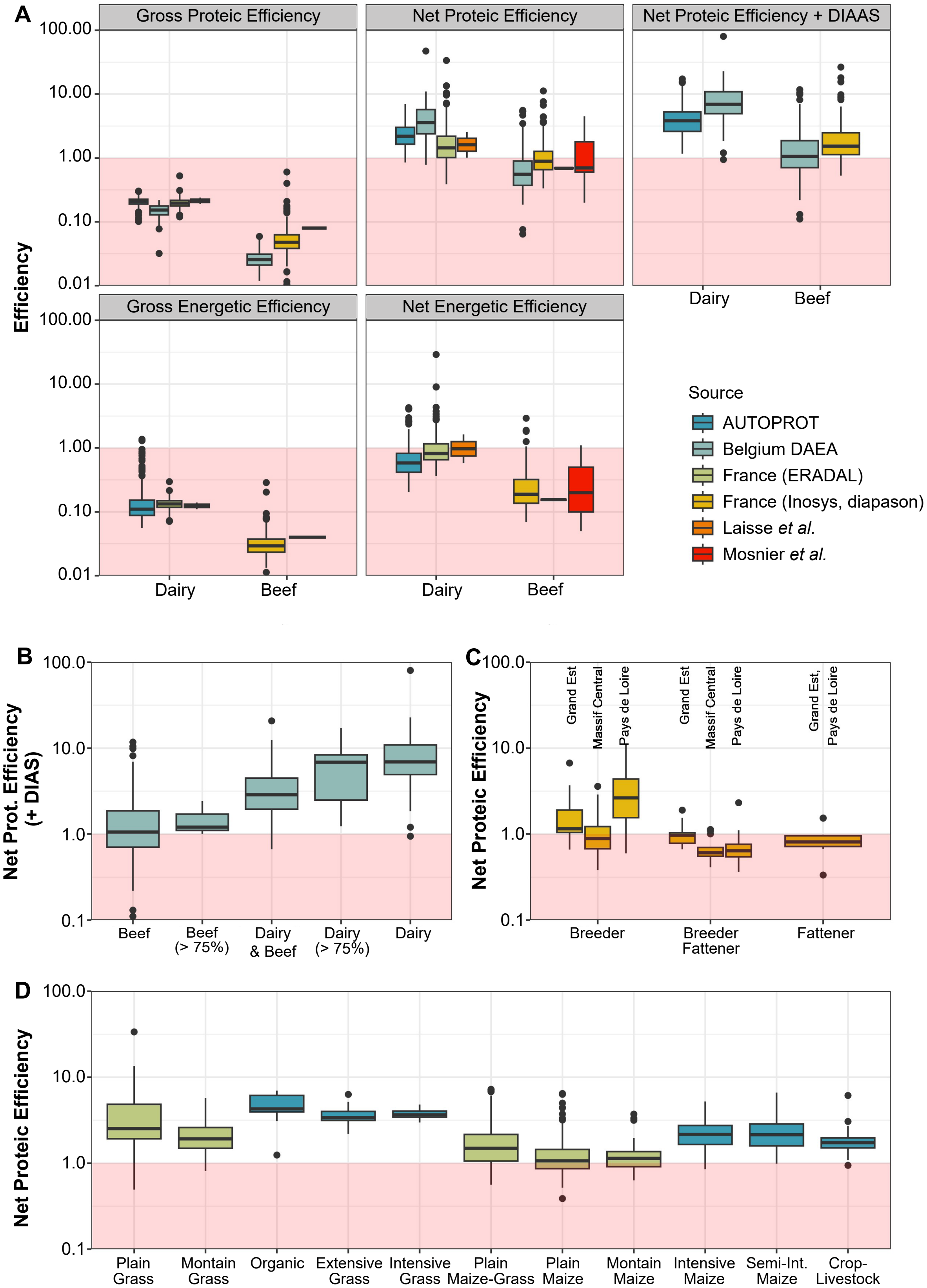
Hennessy *et al.* (2021) suggested a LUR based on edible protein multiplied by the DIAAS score for dairy, suckler and pig farming systems in Ireland. They modelled the influence of the share of arable permanent grassland on their result. On this basis, when the proportion of arable grassland increases from 0 to 100%, the LUR rises from 0.25 to 1.35 for dairy cattle systems and from 0.28 to 3.77 for suckler cattle systems. Pig systems would only be slightly affected due to their low use of grassland. They also illustrate the importance of the crop rotation used for the comparison. Using a high-protein crop rotation (cereals, protein crops), the LUR will be higher than using low-protein crops (potatoes, sugar beet). The potential offered by cropping systems is also associated with considerable uncertainty as to their long-term viability (e.g. maintenance of soil fertility, pest control) and the variability of expected yields depending on biophysical context and farm management systems.

Allix *et al.* (2024) calculated the LUR using both methods for 12 French dairy systems (four grassland, four mixed and four maize). As shown in Figure 4, the LUR obtained was lower for grassland systems and generally higher using the van Zanten *et al.* (2016) method. This study, which, unlike the two previous studies, assumes that permanent grassland cannot be cultivated, nevertheless evinces that the result depends heavily on the assumptions made specifically regarding the potential of the land used by ruminants in terms of crop production and whether or not differences in the nutritional quality of animal and plant products are taken into account.

3.2. Net productivity

Net productivity has been proposed as a more accurate representation for the contribution of livestock production systems to food availability

Figure 3. ***Gross and net feed protein and energy conversion efficiencies for different types of beef farms (Source: ERADAL and AUTOPROT projects).***



A: Protein (top), energy (bottom), gross (left), net (centre) and DIAAS (right, for protein) efficiencies of beef systems. The data comes from different sources (colours in the legend). The y-axis is on a logarithmic scale.
B: Net protein efficiency, with protein quality taken into account for Walloon beef farms (data source: DAEA) as a function of the number of dairy and suckler cows.
C: Net protein efficiency for different types and regions of suckler farms.
D: Net protein efficiency for different types of dairy farm.

Figure 4. *Results of the Land Use Ratio (LUR) as defined by van Zanten et al. (2016) on the left for French (FR) and Dutch (NL) systems and by Henessy et al. (2021) on the right for various dairy systems and an Irish beef system (IR).*

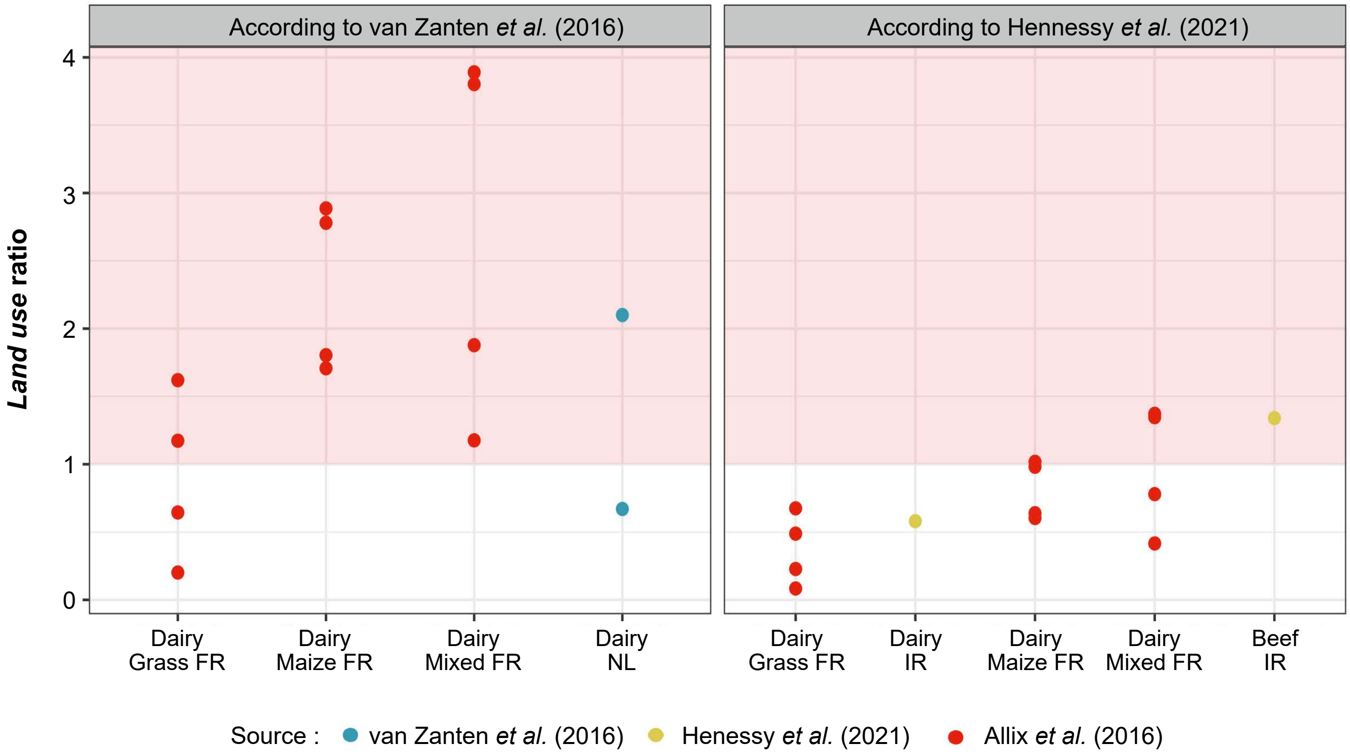
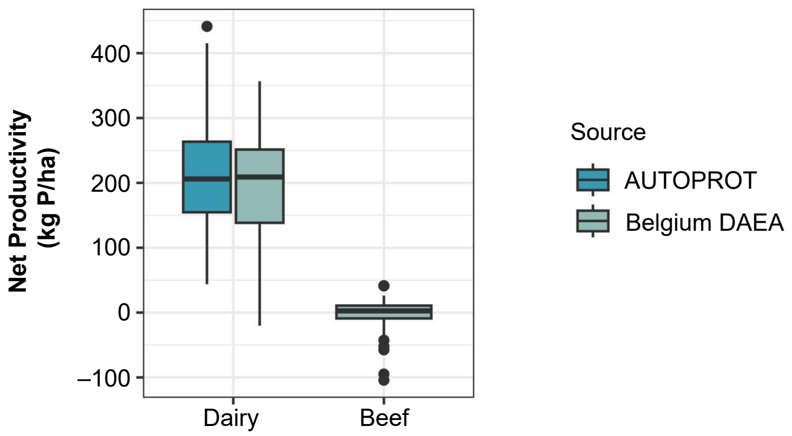


Figure 5. *Net protein productivity for dairy and beef systems.*



4. Farm performance and technical parameters

through integration of the use of food competing with human food and the use of agricultural land (Battheu-Noirfalise *et al.*, 2023). This indicator is equal to the difference between the quantity of ASF produced and food competing with human food used, divided by the surface area utilised by livestock farming that cannot be used to produce human-edible food. This "inedible" area corresponds to all permanent grassland and the share of arable land associated with the fractions (co-products) of crops that cannot be used by humans. The net productivity value is positive when the system produces proteins edible by humans and negative otherwise. Dairy systems achieve positive net productivity with around 200 kg of protein produced per hectare that cannot be consumed by humans. Beef systems have a productivity of around zero (Figure 5). Battheu-Noirfalise *et al.* (2024b) observed –8 kg protein/ha for maize and intraconsumption based systems at 22 kg protein/ha for grass-based systems.

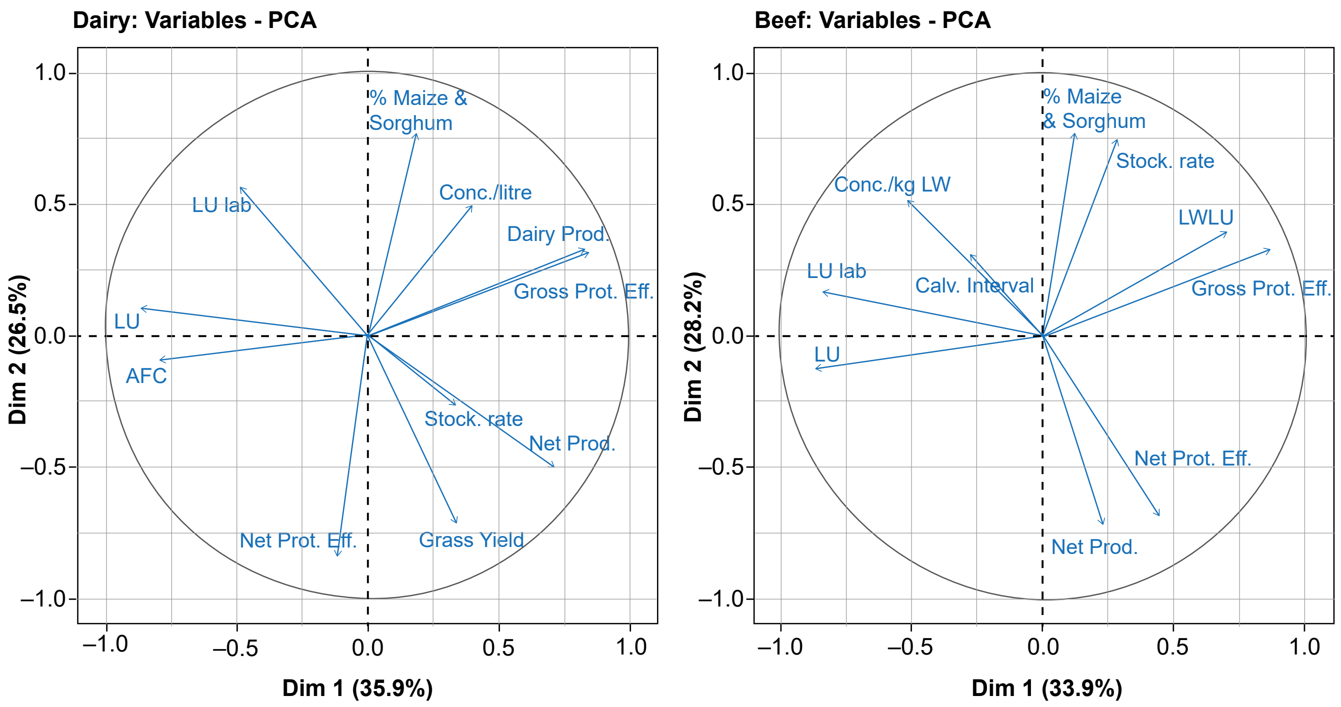
In order to gain better understanding of the variability of the performances observed, a summary of the correlations between management parameters and efficiency, land use and productivity indicators (calculated separately for the different databases used) is set out in Table 3. Graphs of the variables resulting from the principal component analysis are presented in Figure 6. Gross efficiencies (protein and energy) are strongly correlated with productivity per cow for dairy farms and weight gain per LU for meat farms, and therefore, in both cases, with the proportion of maize in the ration. Gross efficiency is also negatively correlated with age at first calving and calving-to-calving interval. In fact, the lower the age at first calving and the shorter the calving-to-calving interval, the lower the unproductive, and therefore inefficient periods for the animals. Net efficiencies (protein and energy) are negatively correlated with the use of concentrates (per litre or per kg of live

Table 3. ***Summary of correlations between efficiency, land use and net productivity indicators and different management parameters on dairy and beef farms.***

	Dairy Cattle							Beef Cattle				
	Concentrates (kg/litre of milk)	Milk production per cow per year	Age at first calving	Loading	% Maize in forage	Grazing	Grass production (kg/ha)	Calving-to-calving interval	Live weight produced per LU	Loading	Concentrates (kg/kg PV)	% Maize in forage
Gross protein efficiency	-	+ + +	- -	0	+ +	- -	0	- - -	+ + +	+	+	+ +
Gross energy efficiency	0	+ + +	- -	+	+ +	- -		- -	+ +	+	+	+ +
Net protein efficiency	- -	-	+	0	- -	+ +	+	-	0	-	- -	-
Net efficiency	-	- -	+	- -	- - -	+ + +		0	-	0	- - -	- -
Land use (kg protein/m²)	-	- -	+ +	-	0		-	0	-	-	+	-
Arable Land use	+	-	+	0	+ +		-	0	-	0	+ +	0
Net productivity	0	+ +	- -	+	-		+ +	-	0	-	- -	- -

0: correlation < 25% or not significant;
+/- corresponds to 25-50%;
+ +/- - to 50-75%;
+ + +/- - - to > 75%.

Figure 6. ***Principal component analysis carried out on the technical performance of dairy farms on the left (data sources: DAEA and AUTOPROT) and suckler farms on the right (data sources: DAEA).***



Abbreviations: Conc./litre: Concentrates (kg/litre of milk), Conc./kg LW: Concentrates (kg/kg LW), LWLU: Live weight produced per LU, Dairy Prod.: Milk production per cow per year, AFC: Age at first calving, Stock. rate: Stocking rate, Grass Yield: Grass production (kg/ha), LU: Land use (kg protein/m²), LU lab: Land use arable land (kg protein/m²), Gross Prot. Eff.: Gross protein conversion efficiency, Net Prot Eff.: Net protein conversion efficiency, Net Prod.: Net productivity, % Maize & Sorghum: Share of maize and sorghum in forage.

weight) and the proportion of maize in the ration but positively correlated with the proportion of pasture for dairy farms. These findings support the observations made by Laisse *et al.* (2018) regarding a less productive grass-fed dairy cattle system but with higher net efficiency than the maize-based dairy system.

Land use, where we are aiming for a low score and therefore correlations to be interpreted in the opposite way, is correlated with age at first calving and negatively correlated with milk and meat productivity. In contrast, the use of arable land is positively correlated with the use of maize and concentrates.

Net productivity is positively correlated with milk productivity and grass yield but negatively correlated with age at first calving and the use of maize and, in the case of beef farms, concentrates. Battheu-Noirfalise *et al.* (2023) also observed a correlation with the protein content of concentrates used in dairy systems.

For dairy farms, net productivity is negatively correlated with arable land use and correlated with net efficiency as observed by Battheu-Noirfalise *et al.* (2023). For suckler farms, net productivity is strongly correlated with net efficiency and both variables are negatively correlated with arable land use.

5. Indicators, interpretation and outlook

The interpretation of indicators such as net efficiency can be simple. In this case, a farming system is considered to be a net protein producer if it has an efficiency greater than one. However, this indicator provides only partial information on the system's performance. For example, having an efficiency level much higher than one does not always imply better contribution to food security than a lower value since this indicator does not take into account the level of livestock production per unit area, which can be very low. The net productivity indicator, which factors in production and surface area used, is not subject to this shortcoming. A net productivity of 300 kg of protein per hectare that does not compete with humans will, by definition, contribute more to protein production for humans than a farm producing 100 kg of protein per hectare. However, the levels achieved for this indicator also need to be put into perspective. The soil and climate context largely determines production potential, and depending on how it is implemented (as a basis for comparison), it does not necessarily supply information on how far systems can progress. By comparing it with optimal crop production, the LUR theoretically takes better account of the margins for progress than other indicators. However, the yield assumptions used to calculate the LUR remain theoretical. For the LUR, comparing systems to an optimum yield also raises questions. Is there not another optimum than the all-plant system? What about animal alternatives or even mixed crop-livestock systems that aim to optimise animal-plant synergies and maximise food production for humans on the same land?

The indicators described in this contribution aim to quantify the efficiency and production levels achieved on the basis of plant and soil resources. However, many other criteria currently need to be taken into account to meet current challenges, such as environmental impacts and/or services or economic and social performance. In particular, methane emissions are another major criticism of ruminant livestock farming. Solutions therefore need to be found to combine food production with a reduction in greenhouse gas (GHG) emissions. Ineichen *et al.* (2024) proposed combining net production and GHG emissions in a single indicator. For 87 Swiss farms, net protein production per kg CO_2 eq averaged 16.8 g crude protein/kg CO_2 eq and was strongly negatively correlated with the use of concentrates.

In addition, based on modelling, Mertens *et al.* (2023) and Kearney *et al.* (2022) evaluated sustainability indicators, including profitability, methane emissions and net efficiency of meat production from dairy calves, demonstrating the interest of these systems from an environmental point of view and the compromises to be found between profitability and use of arable land.

However, there is no guarantee that the various indicators will converge towards values that are favourable to the various sustainability criteria and adjustments will certainly have to be made in order to define the development paths to be implemented. Such an exercise has already been carried out with a multi-stakeholder panel using a decision support tool (Battheu-Noirfalise *et al.*, 2024a) for dairy systems.

Conclusion

This summary brings together the many indicators and large datasets used to characterise current ruminant farming systems and their capacity to act as net producers of food for human consumption. The performance of the systems is analysed as a function of the type of livestock, crop rotation and management parameters. The study shows that there is room for improvement, specifically by basing livestock farming on grass and reducing the use of maize and concentrates. This summary, which focuses on France and a number of neighbouring countries as well as other international articles, demonstrates the value of ruminant livestock systems for making the most of biomass that is inedible by humans. In the future, when demand for food is set to increase and plant resources are likely to be mobilised for other purposes (e.g. energy, fibre, etc.), the key issues affecting ruminants will focus on optimising the use of food that cannot be consumed by humans and land that cannot be farmed, without overlooking the other services provided by livestock farming. This means rethinking the place and optimal practices of livestock farming in agro-ecosystems.

Author contributions

Alexandre Mertens: conceptualisation, data curation, visualisation, editing – original version; Caroline Battheu-Noirfalise: conceptualisation, resources, validation, editing – original version; Pauline Madrange: editing – revision and correction; Michaël Mathot: conceptualisation, editing – revision and correction; Alice Berchoux: resources; René Baumont: conceptualisation, resources, editing – revision and correction.

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Abstract

While animal-based foods account for 25% of the protein consumed by humans worldwide, and are recognized for their nutritional quality, livestock farming is regularly criticized for its inefficiency. In particular, the use of edible human food and arable land to produce food for animals raises questions. Numerous indicators have been developed to objectivize the contribution of livestock farming to human food supply: net protein and energy conversion efficiency, arable land use, land use ratio and net productivity. These indicators, which exist in a number of variants, are described, analyzed and evaluated on the basis of a compilation of various dairy and beef farm databases. The analysis demonstrates the value of many ruminant systems and identifies areas for improvement, in particular by basing systems on grass and reducing the use of human edible feed.

Résumé

Évaluer et interpréter l'efficience d'utilisation des aliments et des terres par les ruminants

Alors que les aliments d'origine animale représentent 25 % des protéines consommées par l'Homme dans le monde et sont reconnus pour leur qualité nutritionnelle, l'élevage est régulièrement critiqué pour son inefficience. En particulier, l'utilisation d'aliments comestibles par l'Homme et de terres cultivables pour produire de l'alimentation à destination de l'animal pose question. De nombreux indicateurs ont été développés afin d'objectiver l'apport des élevages à la fourniture d'alimentation humaine : l'efficience nette de conversion des protéines et de l'énergie, l'utilisation des terres arables, le land use ratio et la productivité nette. Ces indicateurs, qui existent avec plusieurs variantes, sont décrits, analysés et évalués sur base d'une compilation de différentes bases de données d'élevages bovins lait et viande. L'analyse démontre l'intérêt de nombreux systèmes ruminants et permet d'identifier des marges d'améliorations, notamment en basant les systèmes sur l'herbe et en réduisant l'utilisation des matières premières directement utilisables en alimentation humaine.

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