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Indicators for animal health on agro-ecological dairy farms

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Abstract

Due to the increasing world population, conventional agriculture is facing increasing challenges, mainly concerning criticism from civil society regarding its sustainability. In this context, they focus especially on the use of non-renewable resources, environmental pollution and animal health.

Over the years, the agri-food sector has started to shift towards some and various innovative and more sustainable production methods; among these, especially regarding animal husbandry, agroecology is probably one of the most effective ways to achieve a higher level of sustainability of the production. Indeed, this discipline constitutes an innovative approach to agri-food production because it considers the farm as a fundamental part of the ecosystem in which it is embedded. The health of the system is also perceived as the result of the interactions between all its components: environmental, human and production. Making the most of these interactions is the key to achieving the highest possible level of sustainability. In addition, because of the local input-based production, agroecological livestock farming systems place great attention on grasslands. Here, they can represent both a direct source of feed through grazing, and a source of preserved forage for periods of the year during which the animals are kept in stables, e.g., in winter.

Consequently, assessing the health of the system is therefore fundamental in agroecology and, within the various models of analysis, the *Global Health* approach is perhaps the best to achieve it.

Talking about this thesis work, it is based on a Global Health approach to define a set of indicators to assess animal health on agroecological farms. Eighteen agroecological dairy farms, rearing cows, goats and sheep, were monitored over a two-year period, during which four rounds of on-site visits were conducted to carry out measurements and observations on the reared animals, covering behaviour, health status, milk parameters, blood sampling, parasite analysis on droppings, pasture and feed sampling.

Subsequently, the collected data were processed by using Microsoft Excel software, and then statistically analysed using Principal Component Analysis (PCA - R Software). The statistical results were combined with expert knowledge to extract a list of indicators,

including as many aspects as possible, to analyse and define animal health within agroecological farms. Two lists of indicators were therefore produced: one for dairy cows, and the other for small ruminants, sheep and goats. Then these indicators were used to conduct an evaluation of the 18 farms followed during the study and to test their appropriateness.

With regard to future perspectives of the work, it could be interesting to adopt the two tables of indicators for the evaluation of farms located in other geographical contexts and to implement them with supplementary specific indicators, to further deepen the analysis on animal health within these productive systems.

Riassunto

A causa dell'aumento della popolazione mondiale, l'agricoltura convenzionale sta affrontando sfide sempre crescenti, relative soprattutto alle critiche della società civile in merito alla sua sostenibilità. In questo contesto, l'attenzione è rivolta soprattutto all'uso di risorse non rinnovabili, all'inquinamento ambientale e alla scarsa attenzione verso la salute animale.

Nel corso degli anni, il settore agroalimentare si è orientato verso diversi metodi di produzione più sostenibili. Fra questi, l'agroecologia rappresenta probabilmente una fra le vie più efficaci per raggiungere un più elevato livello di sostenibilità delle produzioni. Questa disciplina, infatti, costituisce un approccio innovativo alla produzione agroalimentare, poiché considera l'azienda agricola come parte integrante dell'ecosistema in cui è inserita. La salute del sistema viene intesa, inoltre, come il risultato dell'interazione fra tutte le sue componenti, sia ambientali che umane e produttive. Sfruttare queste interazioni in modo ottimale, rappresenta la chiave per il raggiungimento di un livello di sostenibilità più elevato possibile. Inoltre, poiché l'agroecologia prevede una produzione basata su fattori locali, le aziende zootecniche agro-ecologiche rivolgono grande attenzione verso lo sfruttamento sostenibile dei prati-pascolo. Essi, infatti, possono sia fornire direttamente l'alimento attraverso il pascolamento, che produrre foraggio per i periodi dell'anno in cui gli animali sono tenuti in stalla, ad esempio in inverno.

Ciò detto, la valutazione della salute del sistema è quindi fondamentale in agroecologia e, fra le varie modalità di analisi, l'approccio Global Health è forse il migliore per realizzarlo.

Riguardo al presente lavoro di tesi, questo si basa appunto su un approccio Global Health per definire un insieme di indicatori ai fini della valutazione della salute animale in aziende agro-ecologiche. Diciotto aziende agricole agro-ecologiche da latte, con bovini, caprini e ovini, sono state seguite per un periodo di due anni, durante i quali sono state condotte quattro sessioni di visite in loco. Qui, sono state effettuate misurazioni ed osservazioni sugli animali allevati riguardanti comportamento, stato di salute, parametri del latte, prelievi di sangue, analisi parassitarie sugli escrementi, campionamento dei pascoli e dei foraggi.

Successivamente, i dati raccolti sono stati elaborati tramite il Software Microsoft Excel e poi analizzati statisticamente tramite Analisi per Componenti Principali (PCA – Software R).

I risultati statistici sono stati poi combinati con le conoscenze di expertise del gruppo di lavoro per estrarre una lista di indicatori, comprensiva di più aspetti possibili, per analizzare e definire la salute animale. Due liste di indicatori sono state quindi realizzate: una per le aziende con vacche da latte, e l'altra per quelle con piccoli ruminanti, ovini e caprini. Al termine, i suddetti indicatori sono stati utilizzati per condurre una valutazione sulle 18 aziende seguite durante lo studio e per testare la loro appropriatezza.

In futuro, lo studio potrebbe proseguire con l'adozione degli indicatori selezionati per la valutazione di aziende situate in contesti territoriali diversi, in modo da valutarne adeguatezza e adattabilità. Inoltre, potrebbe essere interessante implementare le due tabelle con altri indicatori, per approfondire maggiormente l'analisi della salute animale in questi sistemi produttivi.

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List of abbreviations

GHG: Greenhouse Gases.

UAA: Utilised Agricultural Area.

UFA: Utilised Forage Area.

LU: Livestock Units.

WQ: Welfare Quality®.

AWIN: Animal Welfare Indicators.

PCA: Principal Component Analysis.

NEFA: Non-Esterified Fatty Acids.

BHB: Beta-Hydroxybutyrate.

GLDH: Glutamate Dehydrogenase.

BCS: Body Condition Score.

ECM: Energy Corrected Milk.

QBA: Qualitative Behaviour Assessment.

SCC: Somatic Cell Count, number of somatic cells per ml of milk.

SARA: Sub-Acute Ruminal Acidosis.

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Introduction

By the end of this century, the world population is expected to grow further, and the global area for cropland will do likewise (Lanz et al., 2018).

However, due to the impacts related to the agri-food sector (chemical products, monocultures, overuse of water and GHG emission) and the related biodiversity loss (Lanz et al., 2018), this sector can both contribute food for human alimentation and valuable nutrients for crops, being responsible at the same time for ecosystem pollution and land degradation (FAO, 2021).

Within the agri-food sector, animal production is the largest land-use system on Earth (Herrero et al., 2013). Here, cattle breeding is capable of providing production (mainly dairy and meat) from the conversion of feed sources not directly suitable for human consumption, such as forage and grass (Hayes, et al., 2013).

However, the cattle sector is facing unprecedented challenges, mainly related to animal health and welfare, origin and authenticity of the products, nutritional benefits and quality (Smith et al., 2018). Indeed, intensive systems can contribute to addressing food security issues, in order to meet the growing needs of the world population (Akash et al., 2022). On the other hand, they are characterised by excessive land conversion and overexploitation of forage resources, the risk of disease spread due to the intensity of the production and the related high use of antibiotics, manure management and biodiversity loss (Michalk et al., 2019; Akash et al., 2022). Achieving greater sustainability, e.g. through agroecological breeding systems, could help in solving these controversies, at the same time achieving higher production with fewer environmental impacts (Michalk et al., 2019).

Nevertheless, by focusing on dairy production, a more sustainable way to realise it could be by exploiting grazing systems (Herrero et al., 2013), which are characterised by lower input use. As a result, a higher efficiency of the system could be achieved, at the same time maintaining and improving animal health and their well-being (Hayes, et al., 2013).

Context

1 – General considerations about this work

1.1 – Current status of agriculture and livestock breeding around the world

In this century, the world population is expected to increase by 50%, reaching an estimate of 11.2 billion people (Lanz et al., 2018). At the same time, the global area for cropland will be between 10 and 25% times larger in 2050, with a parallel rise in food production of between 43 and 99% compared to today (Lanz et al., 2018). This agricultural enlargement has been already put in practice, as the total production of primary crops increased by 53% between 2000 and 2019, to the record of 9.4 billion tonnes (FAO, 2021). One third of these was represented by cereals, then sugar crops (24%), vegetables (12%) and oil crops (12%) (FAO, 2021). Nevertheless, global agricultural land area had slightly decreased (-3%) in the same period, to the total of 4.8 billion hectares: 2/3 of these are represented by permanent meadows and pastures (3.2 billion ha; -6%), while the other 1/3 is represented by cropland (1.6 billion ha; +4%) (FAO,2021). The efficiency of the system has been improved, as cropland area per capita decreased around 17% (FAO, 2021). This has been made possible thanks to many factors, such as irrigation (+18% of irrigated area), use of pesticides and fertilisers, larger cultivated area, better farming practices, high yield crops combined with monoculture (Altieri, 1989; Gliessman, 1997; Lanz et al., 2018; FAO, 2021).

Within the agri-food sector, animal production is the largest land-use system on Earth. It occupies 30% of the world's ice-free surface, it contributes to 40% of global agricultural gross domestic product, providing income for more than 1.3 billion people and nourishment for at least 800 million food-insecure people (Herrero et al., 2013). It accounts on vast areas of rangelands, one-third of the freshwater, and one-third of global cropland as feed (Herrero et al., 2013). For these reasons, it can both contribute food for human alimentation and valuable nutrients for crops, being responsible at the same time for ecosystem pollution and land degradation. Its productions mainly belong to two categories: meat and milk. About the first one, it reached 337 million tonnes in 2019, with an increase of 44% compared with 2000 (FAO, 2021). Here, three species accounted for nearly 90% of the global production: chicken, pig and cattle; the largest producers were China (40% of world pig meat) and USA (17% of chicken and 18% of cattle meat) (FAO, 2021). In the same period, milk production has risen by 52% (883 million t), with an increase of 304 million tonnes; the main producer was Asia (42%), followed by Europe (26%) and the Americas (23%) (FAO, 2021).

With regard to cattle breeding, it contributes to the economy, rural development, social life, culture and gastronomy of the European countries. Moreover, ruminants represent an important ecological niche, thanks to their symbiotic relationship with fibre-fermenting ruminal microbes (Smith et al., 2018), which allow them to convert feed sources not directly suitable for human consumption, like forage and grass, into meat and milk, sources of high-quality nutrients for human alimentation (Hayes, et al., 2013). For these reasons, and following the trend of crop production, the demand for high-value outputs from livestock is likely to increase over the coming decades, due to the global population growth and advances in its wealth (Hayes, et al., 2013).

Ruminants are also responsible for much of the worldwide dairy production, which is dominated by the American Holstein-Friesian breed, originated in the US from animals imported from Northern Europe in the late 1800s (Rodríguez-Bermúdez, et al., 2019). This breed shows its best productive potential within highly specialised and technologically intensive conventional farms (Rodríguez-Bermúdez, et al., 2019). However, a more sustainable way to carry on dairy production is within grazing systems, which rely on grass and small occasional feed supplementations (Herrero et al., 2013). Generally, pasture-based systems rely more on rustic breeds, such as pasture-adapted Holstein-Friesian, local strains or crosses between them. Moreover, these breeds are more adaptable to the harder environmental and management conditions of these sites, thanks to their robustness, resistance to health problems (mastitis, parasites and lameness), higher longevity, fertility and roughage intake, low SCC rate (Rodríguez-Bermúdez, et al., 2019). Even so, this happens at the expense of milk production, with less yields than pure Holstein-Friesian, although fat and protein contents are generally higher (Rodríguez-Bermúdez, et al., 2019). Despite their high dependence on environmental factors, grass-based breeding could be part of multifunctional systems, involving on-farm sells of dairy products (milk, cheese, yogurt), additional incomes from better meat yields and public subsidies for genetic diversity conservation and cultural heritage of the breeds (Rodríguez-Bermúdez, et al., 2019). Globally, this type of production is prevalent in developing countries where, however, their income is modest, mostly due to low productivity and feed availability, which is also usually of poor quality (Herrero et al., 2013).

1.2 – Environmental impacts related to conventional agriculture

Modern agriculture contributes to feeding the world population and to facing its food insecurity issues, but it also involves severe consequences for the environment and its ecosystems. According to the "*World Food and Agriculture Report*", presented by FAO in 2021, the agricultural sector is both affected by climate change, representing at the same time an important contributor to greenhouse gas (GHG) emissions. Total emissions released in the atmosphere from agricultural land in 2019 amounted to 10.7 billion tonnes of carbon dioxide equivalent (Gt CO_2eq) of GHGs, showing a decrease of 2% compared with 2000. Asia was the top agricultural emitter (38%), followed by Americas (29%), Africa (22%) and Europe (9%). About the different contributors, CO_2 represented 42% of the total emissions, CH_4 accounted for 38% and N_2O for 20%.

The agricultural part was characterised by lower impacts compared to the livestock one, with 0.9 kg CO_2eq/kg for rice and 0.2 kg CO_2eq/kg for the other cereals (FAO, 2021). Its related impacts mainly derived from the use of chemical products (pesticides and fertilisers), adoption of monocultures, overuse of water and greenhouse gas (GHG) emission. Concerning pesticides, their worldwide use between 2000 and 2019 has increased by 36%, up to 4.2 million tonnes, reaching the highest rate in 2012, with Europe as the only continent in which it has decreased (FAO, 2021). Although they represent a vital tool for plant protection, their excessive utilisation may lead to bioaccumulation in the ecosystems, posing threat to human health and to the soil, where they hinder both the absorption of nutrients by plants and the natural symbiotic nitrogen fixation (Sharma et al., 2019). About chemical fertilisers, their utilisation, expressed as the sum of nitrogen (N), phosphorus (P_2O_5) and potassium (K_2O), reached 189 million tonnes in 2019 (+40%), with a slight decrease in Europe (-5%) (FAO, 2021). As mentioned by Lanz et al (2018), they are sources of threat to agricultural outputs, as their effects on the environment lead to a generalised loss of biodiversity, which is negatively correlated with crop productivity.

Biodiversity corresponds to the variability among living organisms from all sources, and the ecological complexes of which they are part, taking into account diversity within species, between species and of ecosystems (United Nations, 1992). In order to maximise their profit, most of farmers cultivate a small group of high yielding crops, which accounts for nearly a half of the global production: sugar cane (21%), maize (12%), rice (8%) and wheat (8%) (FAO, 2021). Nevertheless, biologically diverse farming systems can be less vulnerable to pests and pathogens, leading to a smaller dependence on pesticides and chemical inputs (Lanz et al., 2018).

Another main category of impacts concerns the overuse of water, for which both agriculture and animal production chains are responsible. Water stress is defined as the share of freshwater withdrawal in available freshwater resources, after taking into account environmental water requirements (FAO, 2021). It represents a global issue, which affects Northern Africa, Northern America, Central and Southern Asia and the West Coast of Latin America (FAO, 2021).

What has been said for crop systems is also true for the livestock sector that, due to the impacts of its intensive systems, especially in Europe is facing unprecedented challenges, which belong to animal health and welfare, origin and authenticity of the productions, nutritional benefits and quality (Smith et al., 2018). Here, the public pressure can jeopardise the consumers' acceptability for these types of products; in order to meet the preferences of the society and to reduce the related consequences on the environment, husbandry systems need to be re-evaluated and adjusted in the long-run. Anyway, it can also represent an opportunity to increase the appeal to consumers, to maintain the competitiveness of meat and dairy products on global markets (Hayes, et al., 2013), but also to improve the outcomes for farmers (Busch & Spiller, 2018).

Focusing on the activities within the farm gate, i.e. those related to crops and livestock, on the total of 7.2 Gt CO_2eq in 2019 (67%; +11% from 2000), animal production accounted for 55%, with only 40% from enteric fermentation of ruminants. Then, about 20% derived from manure and synthetic sources of soil fertilisation, 12% from drained organic soils and 10% from methane released by the cultivation of rice (FAO, 2021). The contribution of monogastrics to GHG emissions was only 10% of total livestock emissions, and most of this constitutes methane from manure, 56% (Herrero et al., 2013). Concerning meat sector, the most CO_2-intensive commodities were the ones from ruminants, mainly cattle (26 kg CO_2eq/kg) and sheep (22 kg CO_2eq/kg), as pig and chicken had lower values (1.5 kg CO_2eq/kg and 0.6 kg CO_2eq/kg respectively) (FAO, 2021). About processed products, cow milk accounted for 0.9 kg CO_2eq/kg and hen eggs for 0.6 kg CO_2eq/kg (FAO, 2021). Mixed crop–livestock systems produced the bulk of emissions from ruminants (61%), while grazing systems accounted for 12% (Herrero et al., 2013).

Therefore, a higher efficiency of the livestock sector is required in this framework, especially in terms of land use and water resources (Hayes et al., 2013), that represent the principal sources of competition with human alimentation. The possible actions to achieve this goal are mainly linked to animal potential and their diet composition (Herrero et al., 2013), as livestock consumed globally about 4.7 billion tons of feed biomass in 2000, with ruminants as the principal actors (3.7 billion tons vs 1 billion tons of pigs and poultry) (Herrero et al., 2013). Within these requirements, grass accounted for 48%, followed by grains (28%) and occasional feeds and stovers (Herrero et al., 2013). About grains, they were mainly used for pigs and poultry in industrial-intensive systems and for dairy production in crop-livestock systems to increase the yields (Herrero et al., 2013). However, in the coming years the impact of climate change on their production is likely to drive their prices higher (Hayes et al., 2013), exacerbating the competition with human alimentation. On the other hand, the majority of feed is used for large numbers of animals with low productivity, especially in developing countries within grass-based systems and diets with low digestibility levels (Herrero et al., 2013). Consequently, the levels of intensity change significantly across regions, due to the different productive efficiency: cattle meat is characterised by almost twice the world average levels in Africa (48 kg CO_2eq/kg) and nearly half in Europe (14 kg CO_2eq/kg) (FAO, 2021). For this reason, developing countries are likely to contribute 75% of global GHG emissions from ruminants and 56% of those from monogastrics (Herrero et al., 2013).

A future shift to low feed inputs such as grazing systems, would also require work on genetic selection, to obtain better performances with lower feed supply and different nutritional levels (Hayes, et al., 2013). Moreover, according to what has been said about public concern, an emphasis must be put on the maintenance and improving of animal health and their well-being (Hayes, et al., 2013). Lastly, according to the increasing challenges that modern agriculture has to face, an overview would be needed on more sustainable ways of production, which are characterised by fewer consequences on the environment.

2 – Emergence of new sustainable ways of breeding and agriculture systems

2.1 – Agriculture sector in a more sustainable way

Today's food and agricultural systems have succeeded in supplying large volumes of food to global markets. However, this high-external input and resource-intensive agriculture is responsible for plenty of consequences for the environment, such as massive deforestation, water scarcities, biodiversity loss, soil depletion and high GHGs emissions (FAO, 2018). Hence, due to other issues such as population growth and social marginalisation, an interest in sustainable agriculture has started to grow since the last decades of the XX century (Altieri, 1989; FAO, 2021). Consequently, there has been more effort lately to continue to ensure enough food to the world population, but in a more sustainable way in the long term.

Sustainable development was therefore defined by the United Nations (1987) as "*the development that meets the needs of the present generations without compromising the ability of the future ones to meet their own*". Hence, sustainable productions can be obtained in a way and at a rate that does not lead to the long-term decline of biological diversity (United Nations, 1992) of the ecosystems. Accordingly, this needs to be achieved in a balanced and integrated way through three dimensions: economic, social and environmental, to minimise their adverse impacts on human health and on the environment (United Nations, 2015). To reach this goal, some agricultural practices have already been implemented worldwide; according to FAO (2021), the most known one is organic agriculture, which has emerged as a reaction to the industrialisation of agriculture and its associated above-mentioned environmental and social problems (Rodríguez-Bermúdez, et al., 2019). In 2019, the area under certified organic status or in conversion to organic was 72.2 million ha (FAO, 2021). The most representative countries were Australia (50%), Argentina (5%) and Spain (3%), while the ones with the highest share of area under organic agriculture on the total agricultural area were Austria (25%), Sweden (20%) and Czechia (15%) (FAO, 2021). Moreover, fifteen of the top 20 countries were in Europe, highlighting the importance attached by the EU to this way of production (FAO, 2021).

Anyway, in this context of environmental deterioration, other production techniques have been established to try to produce food in a more sustainable way. One of these can certainly be agroecology, which offers a unique approach to meet the significant increases in our food needs, while ensuring no one is left behind (FAO, 2018).

2.2 – Agroecology, what is about and its status of development

Agroecology takes its origin from the evolution of two related-disciplines: agronomy and ecology, to face agricultural and environmental issues of conventional food production (Wezel et al., 2009). It has been defined as "*the application of ecology in agriculture*", or even "*a scientific discipline, movement and set of practices*" (Wezel et al., 2009) (Figure 1). Agroecology is therefore an integrated approach that simultaneously applies ecological and social concepts and principles to optimise the interactions between plants, animals, humans and the environment, while taking into consideration the social aspects that need to be addressed for a sustainable and fair food system (FAO, 2018). Consequently, it represents a methodology to assess the "health" of the agroecosystems, focusing on the ecological principles at the bottom of sustainable productions (Altieri, 1989). This discipline also constitutes a way to protect natural resources, and to redesign and manage sustainable food systems from the farm to the table, to achieve ecological and socio-economic sustainability (Altieri, 1989; Wezel et al., 2009; Gliessman, 2016). Last but not least, it improves the capabilities of farmers, conserving their resources and taking into account social, economic and political constraints, encouraging them to contribute to social movements (Altieri, 1989). Over the time, the focus of agroecology has shifted from on field scale, to farm and landscape agroecosystems (Wezel et al., 2009).

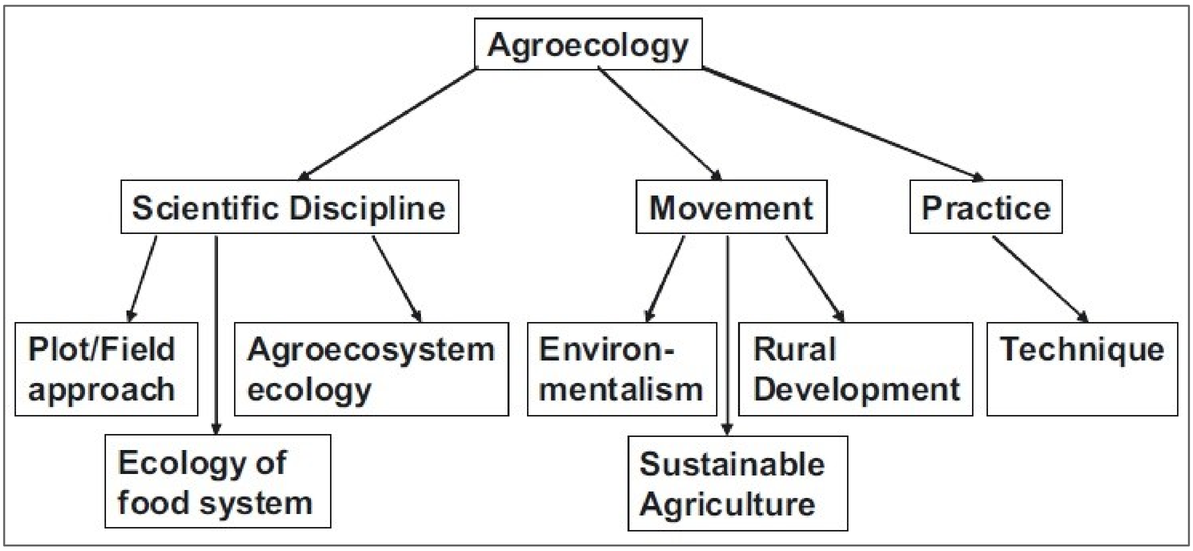

Figure 1 - Different meanings of agroecology (Wezel et al., 2009)

However, it is still difficult to identify a unique definition that can be used to put it in practice, due to the different levels in which it could be considered and applied (Wezel et al., 2009). Following what has been illustrated so far, it could be said that agroecology is a way to reach a better sustainability of food production, but in a way that is fundamentally different from other approaches to sustainable development. In fact, it is based on the co-creation of knowledge, combining science with the traditional, practical and local knowledge of producers (FAO, 2018). Rather than tweaking the practices of unsustainable agricultural systems, agroecology seeks to transform food and agricultural systems, addressing the root causes of problems in an integrated way and providing holistic and long-term solutions (FAO, 2018).

In guiding countries to transform their food and agricultural systems from an agroecological point of view, and to reach the FAO's SDGs, FAO (2018) has emanated the following 10 elements on agroecology (Figure 2):

1. *Diversity*: optimization of the diversity of species and genetic resources, increase of biodiversity. This can result in an increase of productivity, resource-use efficiency and ecological and socio-economic resilience;
2. *Co-creation and sharing of knowledge*: educate the actors involved, for a better response to local challenges;

3. *Synergies*: they enhance key functions across food systems, supporting production and multiple ecosystem services, greater resource-use efficiency and resilience;
4. *Efficiency*: produce more using less external resources, favour the natural ones and enhance biological processes;
5. *Recycling*: produce with lower economic and environmental costs, through the recycling of nutrients, biomass and water, to increase the efficiency and minimise waste and pollution. Some examples are the re-use of manure on the fields, crop residues and by-products as livestock feed, to close the nutrient cycles and reduce the dependency on external resources;
6. *Resilience*: greater capacity of the system to recover from disturbances, less economic losses, resistance against pests and diseases;
7. *Human and social values*: protect and improve rural livelihoods, equity and social well-being;
8. *Culture and food traditions*: promotion of healthy, diversified and culturally appropriate diets, food security and nutrition. Re-balancing tradition and modern food habits, to achieve a healthier food production and consumption;
9. *Responsible governance*: support producers in transforming their systems through subsidies and incentives for ecosystem services;
10. *Circular and solidarity economy*: reconnect producers and consumers by favouring local equitable markets and creating virtuous cycles. Shorter food value chains.

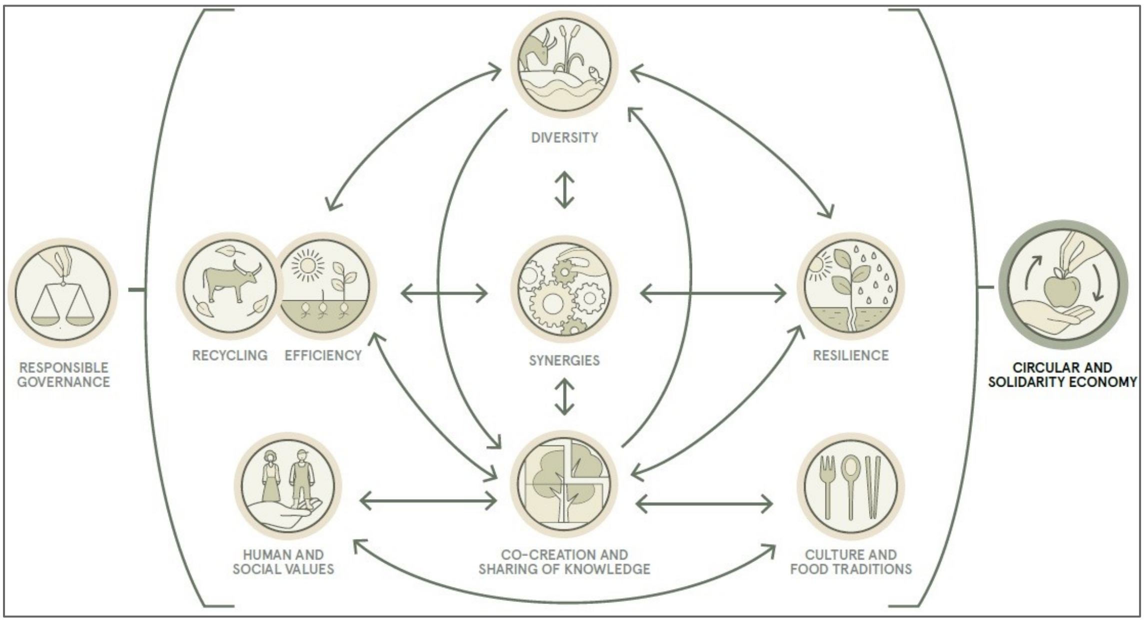

Figure 2 - The "Ten Elements of Agroecology" (FAO, 2018)

Referring to the different kind of production systems, the ones that can be considered the most effective in applying the agroecological principles are probably the "*integrated crop–livestock*" ones, thanks to the complementarities that are established between crops and livestock and the connectedness of livestock to the land (Bonaudo et al., 2013). They are based on the animal's abilities to convert non-food biomass, with the maintenance at the same time of soil fertility and crop production through the spread of manure and the use of non-farming areas (Bonaudo et al., 2013). Here, the diversification of the production is likely to minimise the need for external inputs, increasing the self-sufficiency (Bonaudo et al., 2013).

2.3 – Agroecology applied to livestock systems

Focusing therefore on livestock production, even though this represents a crucial contribution in the supply of food, and not least one of the largest land use sector on Earth, the majority of publications on agroecology are related to crop systems, whereas only rare of them refer to animal production (Dumont et al., 2013; Wezel et al., 2014). The increase in the level of intensity of this sector over time, measured as the quantity of inputs per hectare of utilised agricultural area (UAA) (Bonaudo et al., 2013), and the advent of larger and more specialised farms, is weakening the sustainability of animal production, also jeopardising its adaptation to global change (Brocard et al., 2016). Here, the often found disconnectedness of the animals from the land, probably represents the main threat to the sustainability of the system (Dumont et al., 2013). Hence, from 1961 to 2001, more than 60% of the world's maize and barley was utilised as livestock feed (Dumont et al., 2013). Together with the high demands of water, environmental pollution and biodiversity loss, these aspects have contributed to put the animal breeding sector in a bad light (Dumont et al., 2013).

Here, agroecology can help to address these challenges, by establishing systems that would be economically viable and liveable for farmers, inheritable and locally-culturally adaptable (Wezel et al., 2014). Thus, these systems rely on the interactions between livestock and the agroecosystem components, exploiting the capacity of ruminants to provide protein-rich food from the diversity of natural resources not directly utilisable by humans (Dumont et al., 2013). In this context, the better obtainable environmental performances could result in higher payments for environmental services (i.e. carbon sequestration, biodiversity, recycle of nutrients), and in preserving vast areas with high biodiversity potential (Dumont et al., 2013).

As a result, the overall self-sufficiency is increased, both via local feed resources use and the development of networks among producers (Brocard et al., 2016). Also according to the *Ten Elements of Agroecology* illustrated in the previous section, agroecological farming systems aim to ensure optimal quantities of production of good quality but at a lower cost, being at the same time economically beneficial for farmers, socially fair, conserve biodiversity, and not harmful for the environment (Altieri, 1989; Wezel et al., 2014). Contrarily to the conventional input-based agriculture, they pursue the restoration of the ecosystems, to benefit from the services they can offer thanks to the different levels of biodiversity that is hosted within them (Wezel et al., 2014).

An effective way to pursue these goals is represented by grasslands management. These surfaces can ensure a high rate of self-sufficiency for feed, which is defined as the balance between the herd requirements and the resources of on farm origin (Brocard et al., 2016). The production can be therefore carried out at a lower cost, both within the production process and through the less dependence on off-farm feeds (concentrates, silage), with less environmental impacts, such as nitrogen leaching or GHGs emissions (Wezel et al., 2014; Brocard et al., 2016). Grasslands can provide forages of good quality, sustain animal health and welfare, preserve the fertility by increasing organic and nitrogen contents of the soils and, last but not least, close the nutrient cycle through the re-use of manure (Wezel et al., 2014), respecting the FAO's (2018) *Ten Elements of Agroecology*. Pastures with a variety of grass–legume mixtures of long duration, including nitrogen-fixing legumes, represent an alternative to mineral fertilisation and can contribute to a high level of carbon sequestration in the soil, providing both high outcome without mineral fertilisation and higher yields for the grain crops planted after, thanks to less soil disturbance, high organic matter and weed control (Bonaudo et al., 2013; Dumont et al., 2013). In the end, additional advantages can be achieved in terms of weed control and reduction of mechanical interventions if grazing activity is conducted on them (Bonaudo et al., 2013). On a pasture-based livestock system, the animal production cycle can be also organised according to forage diversity and herbage seasonal dynamics, i.e. concentrating the calvings in spring to link the higher nutritional requirements of the animals with the large grass availability (Bonaudo et al., 2013; Dumont et al., 2013). On the contrary, this marked seasonality of production results in a workload concentration in specific periods and could be out of line with market requests (Dumont et al., 2013).

Properties, principles, and practices on which agroecology is based are illustrated in Figure 3.

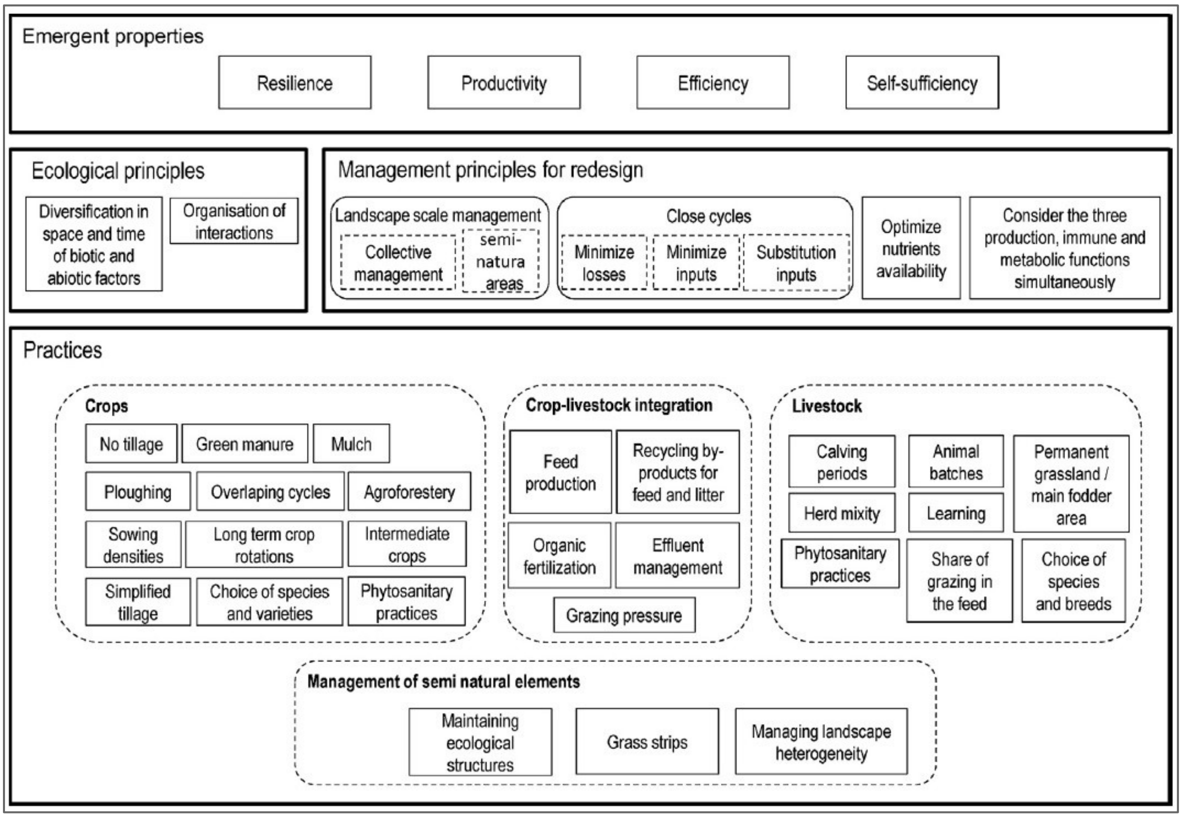

Figure 3 - Properties, principles, and practices to design agroecological production systems (Bonaudo et al., 2013)

On the other hand, due to the lower level of concentration of the feed provided to the animals and the lower input utilisation, the production level of agroecological farms could be lower. This can, however, be compensated by the lower incidence of health problems and longer lifetime production of the animals, higher added value and less input costs (Bonaudo et al., 2013; Dumont et al., 2013). Basing on the higher diversity within agroecological farms, the resistance against droughts, disease outbreaks and market price fluctuation is increased (Dumont et al., 2013). Thus, a diversity of forage resources also helps to face seasonal and long-term climatic variability (Dumont et al., 2013). Thanks to these advantages, good economic results could be obtained while limiting pollution risks, decreasing nitrogen fluxes and the dependence on nonrenewable energy (Dumont et al., 2013).

In order to try to put the agroecological transition of ruminant farming systems into practice and take what has been said above into account, besides the FAO's (2018) *Ten Elements of Agroecology* and basing on the studies of Dumont et al (2013), Wezel et al. (2014) and Gliessman (2016), specific principles can be proposed here:

1. **Adopting management practices aiming to improve animal and production health**
   Higher focus on animal health and on the causes of their diseases, to reduce their occurrence, the related use of chemical drugs and the resistance to antibiotics, which represent public health and environmental issues. Enhance the natural resistance of the animals, by choosing breeds adaptable to harsh environments (local and double-goal ones) and management practices that make the best possible use of livestock adaptations, to obtain better income while maximising the use of grasslands. Diversification of production and combinations between different factors, such as grasslands and crop rotation, or pasture alternance, to increase the natural resistance to adversities (parasites, weeds, diseases).
   Improve the health of the productions, thanks to the effect of the grass on the nutritional profile of food. An example is the general higher level of PUFAs, omega3/omega6 fatty acids ratio and conjugated linoleic acids (CLA), and less saturated fatty acids in bovine milk (Kalač et al., 2010; Wezel et al., 2014) compared to the one from conventional systems.
2. **Decreasing the inputs needed for production**
   Ecosystem-based production systems, to reduce the high proportion of arable land devoted to the production of animal feeds, and the related high requirements in chemical fertilisers and water. Reduce the commercial inputs utilisation to increase the sustainability of the system. This can be achieved both through a higher efficiency of feed utilisation by animals, and the use of resources that do not

compete with human food supply. Among the latter, permanent pastures and rangelands are the most representative ones.

3. **Decreasing pollution by optimising the metabolic functioning of farming systems**
   Resource management: optimisation of nutrient cycles, water and energy use, organic fertilisation from manure, nitrogen-fixing legumes and permanent soil cover. Diet manipulation to reduce nitrogen and phosphorus excretion and GHGs emission. Establishment of integrations between animals and farm operations, to capture their positive synergies.
4. **Enhancing diversity within animal production systems to strengthen their resilience**
   Agricultural intensification has drastically reduced diversity, and so the related resilience of animal production. On agroecological farms, biodiversity is considered as the driver of the agroecosystem, through the setup of multi-breeds systems to preserve genetic diversity and the enhancement of semi-natural elements such as grasslands. The diversity within grasslands, and the derived complementarities, are fundamental to secure animal performance in crucial periods, such as lactation, while rangelands could be mostly grazed when the animals have low nutrient requirements.
5. **Preserving biological diversity in agroecosystems and exploit their benefits**
   Contrast the local breeds replacement due to the higher performance of commercial breeds, to rely on their abilities to survive and produce in harsh environments. Moreover, the production that can be obtained from traditional breeds with strong local identity can achieve higher prices, as consumers perceive them of superior quality and their link with the territory. Establishment of synergies between farmers and consumers, for locally-produced food, quality labels and short and medium market chains.

According to these principles, agroecology considers the agroecosystems as a whole, in their biological, technical and social dimensions (Dumont et al., 2013), assessing their overall health status (Altieri, 1989; Wezel et al., 2014). To monitor these aspects, two approaches can be adopted: ① put in practice new technologies for the collection and processing of information on the system, and ② propose indicators and evaluation tools to help farmers in acquiring specific knowledge and skills for the management of the system and higher efficiency (Dumont et al., 2013). Consequently, and to evaluate the agroecological livestock systems, a global health approach at farm level can be adopted, in order to investigate farmers' practices from a sociological, pragmatic and biotechnical point of view. Therefore, the health status of all farm components and parts can be assessed, through sampling sessions, data collection, observations and measurements. This thesis will thus adopt a pragmatic approach according to this methodology, based on the investigation of the actions and experiences of farmers involved in alternative production methods than the conventional ones.

3 – Animal health and global health: how they can be defined and what are they about?

3.1 – Concept of health and the ways in which it can be assessed

The lack of information and studies about agroecology applied to livestock systems could be addressed by putting in practice a methodology that works in the same way as agroecology, taking into account the relationships between all the different components of the agroecosystem. This goal can be pursued through an approach based on the assessment of the health of the system, which is, according to Wezel et al. (2014), one of the key principles at the bottom of this discipline and one of the highest goals of humanity. Normally, this concept focuses on different levels: the animals, their productions and the environment in which the farms are located (Vieweger et al., 2015). In fact, according to Vieweger et al, citing "*The Living Soil*" by Eve Balfour "*the health of soil, plant, animal and human is one and indivisible*", as they all concur to the establishment and promotion of human and ecosystem health. Likewise, the health of the whole system needs to be analysed through the adoption of a *non-separation approach*, which links together all the components within the agricultural sector, as there will be no overall health if there is no health in each one of them (Vieweger at al., 2015).

Accordingly, FAO (2011) cytes the concept of *One Health*, reporting the definition of "*an unifying force to safeguard human and animal health, to reduce disease threats and to ensure a safe food supply through effective and responsible management of natural resources*". It is a vision based on a holistic approach, which puts together human and veterinary medicine and biology into an interdisciplinary approach, to address complex challenges that threaten human and animal health, food security, poverty and the environments where diseases flourish (FAO, 2011; Lerner & Berg, 2015). In fact, over 60% of the pathogens that affect humans originate in animals, and the unregulated expansion of livestock farming encroaches on pristine habitats, pushes domestic animals, humans and wildlife closer (FAO, 2011).

The global level of health could also be cited to assess the proper functioning of an ecosystem, as it derives from the health of all of its components (Lerner & Berg, 2015). On the other hand, these different constituents are also somewhat independent from each other, due to their different reference fields (Vieweger et al., 2015). For instance, the concept of welfare in animal health cannot be transferred to other domains, such as soils or ecosystems (Vieweger et al., 2015). As a result, the promotion and improvement of health in agriculture critically depends on the way in which it is considered, which citing Vieweger et al, can happens following two broad approaches:

1. *Anthropocentric perspective*: the values of soils, plants and animals are seen through the beneficial services they provide to humankind, which constitutes the only reason to promote their health;
2. *Biocentric perspective*: animals, plants, soils and ecosystems are considered of interest, beyond the functions that may or may not be useful for humanity.

Focusing on the different levels of health, this concept can be considered among *International Health*, *Public Health* and *Global Health* (Koplan et al., 2009; Beaglehole et al., 2010). International Health focuses on the general health practices, policies and systems; it is mostly related to the developing world, where it applies the principles of public health to face local problems, challenges and the drivers that influence them (Koplan et al., 2009; Beaglehole et al., 2010). Public Health, instead, focuses on the health of a population that lives in a specific country or community, rather than individuals, and it is based on a prevention approach (Koplan et al., 2009, Beaglehole et al., 2010). It is the result of the combination of sciences, skills and beliefs to maintain and improve health, social justice and equity for all through collective or social actions (Koplan et al., 2009). Lastly, Global Health can be defined as "*collaborative trans-national research and action to globally improve health and equity for all*" (Koplan et al., 2009, Beaglehole et al., 2010). It acts upon domestic and cross-border issues, by adopting collaborative efforts in order to face health issues with multiplicity of determinants (Beaglehole et al., 2010). Hence, it relies on an interdisciplinary approach, as it encompasses prevention, treatment, and care (Koplan et al., 2009).

Apart from them, the level of health within agri-food systems is likely to influence the production levels (Vieweger et al., 2015). This is because the concepts of animal health and welfare are closely linked to the One Health approach, with the second one that is included within the first one. Animal welfare was therefore defined as "*a state of complete mental and physical health, where the animal is in harmony with its environment*" (Nicks &

Vandenheede, 2014). The approach to animal welfare embraces different categories, with a biological (behavioural aspects), zootechnical (productivity), physiological (focus on stress) and veterinary (absence of disease) points of view (Nicks & Vandenheede, 2014). However, lately, a hedonistic approach to animal welfare has been adopted, considering it related to animal health, which in turn can be considered as the absence of physical infirmity (Nicks & Vandenheede, 2014). Animal welfare reflects therefore a dynamic equilibrium between the animal and the environment; any eventual attempts to maintain or recover from its variations may cause physical and mental suffering, with a detriment of health (Nicks & Vandenheede, 2014). Hence, animal health and welfare are also linked with human health, as stress conditions of the animal significantly affect sensory and quality traits of its production (Nicks & Vandenheede, 2014).

Consequently, following the above-mentioned contributions, the agricultural sector needs to be designed and redesigned adopting an approach based on the principles of agroecological transition mentioned in the previous chapter, which should be put into practice through a Global Health approach. Moreover, based on the multidisciplinary field of agroecology, a dialogue could be established that embraces various fields, such as soil science, plant pathology, veterinary science and human medicine (Vieweger et al., 2015). Farm health can thus be considered through the health of its components, such as soil, the animals reared, the grown crops and the farmer.

4 – Aim of the Thesis Work – A project about farm health

With regard to this thesis work, it is embedded within a project called "***ReferAE; Caractérisation de la santé globale des fermes en agroécologie***", which spans three years, from 2020 to 2023.

The aim of this project is to characterise the overall health of an agro-ecological farm, through a global health approach at farm level, which will allow investigating farmers' practices from a sociological, pragmatic, anthropological, and biotechnical point of view. To realise it, a pragmatic approach will be adopted, based on the investigation of the actions and experiences of farmers involved in alternative production methods than conventional ones. The project is carried out by a partnership of five actors, which have contributed each to co-construct it:

1. The association "*Eleveurs Autrements*". Established in 2015, it brings together around 140 dairy cattle/sheep/goat farmers, which are under "agro-ecological transition", mainly located in the "*Massif Central*" region (administrative region Auvergne-Rhône-Alpes, France). The role of the association is to propose the farms that will be monitored by the project, and to contribute to the development of the protocol that will be used for the sampling on the farms.
2. The school of agronomic engineering "*VetAgroSup*". It is a teaching and research institute in France for the training of veterinary doctors, agricultural engineers and health inspectors. The project is led by the school's agronomic campus located in Lempdes (Clermont-Ferrand), in collaboration with the veterinary campus situated in Marcy L'Etoile (Lyon). This institute is involved in the project due to its research in the accompaniment of the transition of agricultural production systems.
3. The INRAE's (Institut National de Recherche pour l'Agriculture, l'Alimentation et l'Environnement) joint research units (UMR, Unité Mixte de Recherche) "*Herbivores*" (PHASE Department), which is involved in the field of biotechnical sciences, and "*Territoires*", in the field of the research for action and development ("SAD" Department).
4. *"Origens Medialab*". Interdisciplinary research lab within the humanities and social sciences. It investigates the ecological crisis that is currently going on, understood

as a true anthropological mutation, from different scales: farmers and breeders, local communities, and companies.

5. *"La MYNE"*. It is a citizen's lab whose purpose is to offer to its members an infrastructure to support cooperative and innovative projects with a social, cultural, humanitarian, scientific, artistic, or technical component, to promote the transmission of know-how and knowledge and to engage in civic research activities, experimenting with sustainable systems and lifestyles.

The project is also divided in three distinct phases:

1. Framework of the project, literature and expert work in order to define the analysis that will be conducted to assess the overall health of a farm;
2. Application of the analysis framework to agroecological farms, monitoring of farms over two years to collect data on their functioning;
3. Experimental focus on a management practice that can contribute to overall farm health, and validation of the analysis framework (how the change in cows' feeding can affect the stability of the milk).

To put it in practice, 18 agroecological dairy farms have been followed across the two-years duration of the project. Here, the work with research institutes (VetAgro Sup – INRAE) has been initiated to provide a scientific perspective on the management practices adopted by the breeders.

At the end, the results will contribute to enrich the zootechnical knowledge in agroecology and to promote the divulgation of the results.

Talking about the aim of this work, as mentioned in the context, agroecology can represent a valid opportunity to achieve a better level of sustainability for the whole livestock sector, based on its holistic approach at farm level. In order to try to address the lack in scientific publications and studies about animal production, this thesis work and the project to which it refers will deepen the overall health of the system. A Global Health approach at farm level will be therefore adopted, to take into account all of its components together and to evaluate the main topic on which agroecology is based: the health of the system. Specifically, this thesis work will focus on the animals reared, which represent one of the components of the farm, and their health. Here, they are mainly dairy cows and small ruminants, such as dairy sheep and goats.

Consequently, the main question at the heart of this work is: "***How the health of dairy cows, goats and sheep could be defined within agro-ecological farming systems and what might be the best categories of indicators to evaluate it?***"

Following this, it would be possible that the indicators considered to evaluate animal health within conventional livestock breeding systems may not be entirely suitable to answer this question, due to the different production context. Here, as the animals mainly rely on local inputs and generally spend long times grazing, it could be interesting to verify whether the specific indicators to assess their health significantly differ from conventional dairy production, which mainly focus on the production levels and its quality traits. For example, the activity at pasture might lead to a lower incidence of health issues (i.e. lameness and cleanliness) and a more positive behaviour but, on the contrary, to higher levels of parasitism. Moreover, the replacement rate of the animals could be lower and lead to their higher average age, thanks to the better health status and the better capability of the breeds to adapt to harsh environments. Lastly, as their feeding is mainly based on local sources like grass and hay, milk yields may be lower if compared to conventional production. However, their quality traits could be positively influenced by an alimentation composed of grass. For these reasons, this thesis work will be conducted directly on a sample of farms, in order to be able to directly analyse these aspects being able to rely on feedback on the spot.

The case study

1 – Materials and Methods - Network

1.1 – Sampling

The thesis work has been conducted on 18 agroecological dairy farms situated in the Massif Central area, in the administrative region of Auvergne-Rhône-Alpes, Centre France (Figure 4). A specific anonymous name has been assigned to each of them, progressively from E1 to E18. Generally, they are characterised by mid-mountainous pasture systems, in which strong environmental constraints make livestock farmers a vanguard in the face of climate change. Hence, these farms were chosen as adherents of agroecology and according to their diversity, so as to constitute a miscellaneous sample according to farm characteristics. In fact, the selected farmers put in practice a large number of innovative or alternative management practices on both the animals and on the pastures.

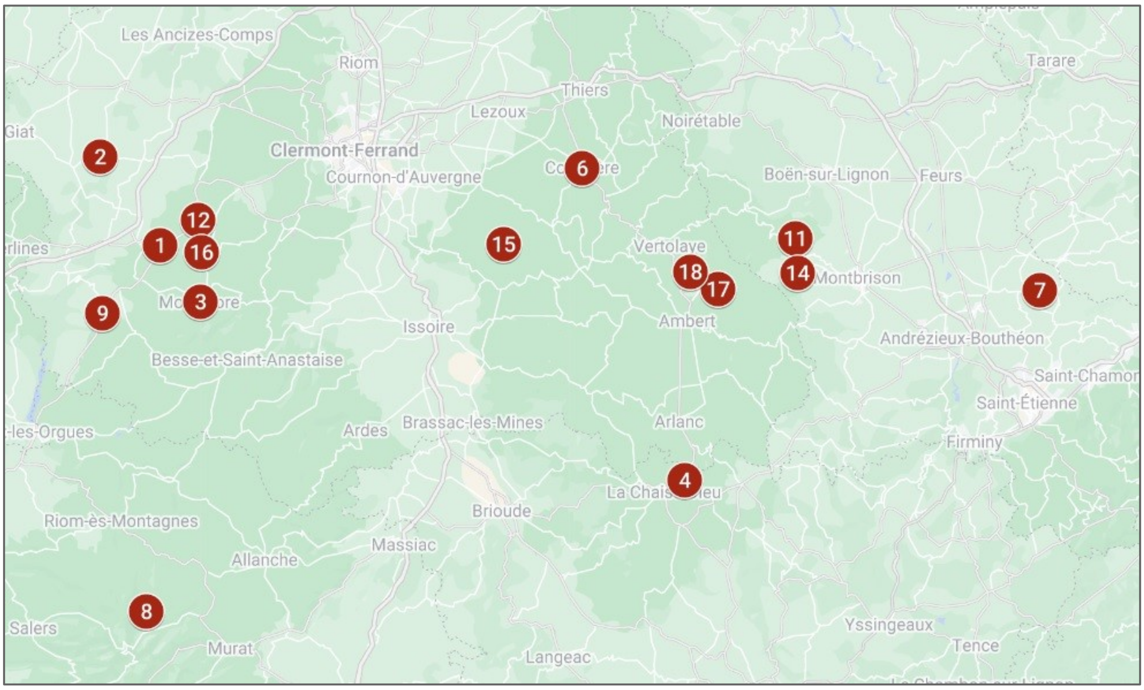

Figure 4 - Localisation of the farms involved in the analysis

1.2 – Description of the farms

Among the farms involved in the survey, 13 of them hosted dairy cows only, from E1 to E13; two of these, E12 and E13, were didactic farms, where students are used to conduct practical activities to put theory into practice. The E14 farm hosted both dairy cows and dairy goats. In general, the cows belong both to commercial breeds, such as Prim'Holstein (especially for didactic farms), Montbéliarde, Simmenthal and Brune, and to more local ones, like Tarine, Salers, Abondance, Normande and Ferrandaise.

The farms E15 and E17 bred only dairy goats, also present in the farms E14 (that also hosted dairy cows) and E18 (together with dairy sheep). These animals belong to the "Alpine" and "Massif Central" breeds.

Lastly, dairy sheep were present in the E16 farm, and in E18 together with dairy goats. Here, they refer to "Thône et Marthod" and "Manech à Tête Rousse" breeds.

Moreover, some farms only hosted purebred animals, while in other ones they were crossbreds. About herd size, dairy cows' farms ranged from 13 to 80 lactating cows, dairy goats' ones from 10 to 60 lactating goats, and dairy sheep's ones from 48 to 80 lactating sheep.

Regarding the general characteristics, the majority of the farms were located in mountainous areas, from 420 m asl to 1180 m asl. Among them, 9 were classified as "GAEC" (Groupement Agricole d'Exploitation en Commun), 6 were individual farms, 2 were "LEGTA" (Lycée d'Enseignement Général et Technologique Agricole), and for one no information had been provided. Moreover, 14 of them were certificated under organic agriculture.

Concerning the production, on average, the animals were milked two times per day, and only once in four out of the 18 farms. The milk was sometimes sold to dairy companies, but was mainly processed directly on the farm, for twelve of them, to obtain cheese, yogurt and other dairy products. Moreover, three farms were under a PDO certification: "Cantal", "Saint Nectaire", and "Salers".

Concerning the characteristics of the analysed farms, they are reported in Table 1 for dairy cows and Table 2 for dairy sheep and goats.

Related to the Utilised Agricultural Area (UAA), for dairy cows' farms it ranged from 30 ha to 192 ha and from 20 to 50 ha for dairy goats' and sheep's farms. At least half of the UAA were dedicated to grasslands in both the types of farms, with permanent and temporary grasslands, used for hay production or directly for grazing. The hay was mainly dried on the ground, but two farms dried it in the barns. Information about pasture management was only available for dairy cows' farms. Among them, grazing activity was conducted as "wire grazing", "free grazing", and "rotational grazing". The return time on the plot ranged from a minimum of 15 days to a maximum of 45 days. The grazing days per year ranged from a minimum of 188 days, for the farm located at the highest altitude, to 330 days.

Focusing on the animals, Livestock Units (LU) ranged from 0.55 to 1.60 (cows' data only).

Concerning the production, expressed as litres of Energy Corrected Milk (ECM) per animal, for dairy cows' farms it ranged from 6.8 to 23 l/d. For the small ruminants, these data were only available for two farms: 0.51 and 0.64 l/d.

Lastly, the use of concentrates was generally low. In particular, the data were only available for dairy cows' farms: two of them didn't use them at all, whereas for the other they ranged from 0.5 to 4 kg/cow/day.

Variables	Minimum	Average	Maximum
Altitude (m asl)	420	871	1180
UAA (ha)	30	95	192
UFA (ha)	30	90	189
LU / ha	0.55	0.91	1.60
Days at pasture	188	235	330
Return time on plot (days)	15	31	45
Lactating animals	8	38.29	80
ECM / cow (l/d)	6.8	15.1	23
Concentrates / cow (kg/d)	0.5	1.82	4

Table 1 - Principal characteristics for the analysed farms for dairy cows

Variables	Minimum	Average	Maximum
Altitude (m asl)	640	792	920
UAA (ha)	20	38	50
UFA (ha)	20	28	40
Lactating animals	10	48.83	80
ECM / animal (l/d)	0.51	0.6	0.64

Table 2 - Principal characteristics for the analysed farms for dairy sheep and goats

2 – Measurements of health analysis

2.1 – Measurement and Sampling on the farm network

This thesis work has been included within the second phase of the "***ReferAE***"s project, which involved the on-farm measurements, divided in four sessions. These phases, called P1 – P2 – P3 – P4, were carried out during wintertime (P1 and P3), and in late springtime (P2 and P4) (Figure 5). They focused on different components of the farm: the animals reared, the milk, the stable and the grasslands.

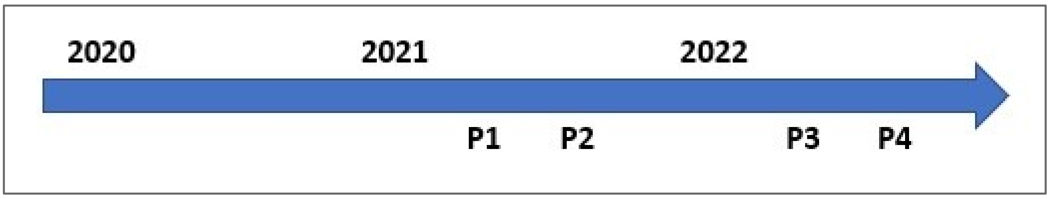

Figure 5 - Duration of the project and on-farm surveys

The measurements of the animals were conducted according to specific protocols: "*Carnet Clinique – Médecine de troupeau en élevage laitier"* (Alves de Oliveira et al., 2016), *"Welfare Quality® assessment protocol for cattle"* (Welfare Quality®, 2009) concerning the cows; "AWIN welfare assessment protocol for goats" (AWIN Goats, 2015) concerning the goats; "AWIN welfare assessment protocol for sheep" (AWIN Sheep, 2015) concerning the sheep.

2.1.1 – Types of measurements conducted during the on-farm visits

The examinations carried out during each of the on-farm surveys were classified around:

1. *Milk samplings*. Withdrawals of five samples from the tank of the farm, to focus on: vitamins, formagraph, fatty acids, germs and the evolution of the curds.
   Laboratory analysis of the collected samples to analyse, through milk infrared spectrometry: fat content, protein content, lactose, urea, somatic cells, casein content and germs.

These withdrawals were taken across six phases, P1 – P2 – P3 – P4 – P5 – P6, as they were also conducted in two additional sessions, during the summer and autumn of 2021 (P2 and P4).

Figure 6 - Collection on milk samples during an on-farm survey

2. *Behaviour analysis*.
    - *Qualitative behaviour assessment*: Observation of the herd, indoor during winter and at grazing during spring, for a total time of 20 minutes. At the end, the herd was classified according to 20 qualitative behavioural indicators, from the lowest to the highest level. The categories of behaviour taken into account are reported in Table 2; they were 15 for the cows, 13 for the goats and 21 for the sheep (Welfare Quality®, 2009; AWIN Goats, 2015; AWIN Sheep, 2015).
    - *General behavioural assessment*: additional assessment conducted during winter sessions (P1 and P3). The herd was firstly visually divided into small groups, which were then observed twice each, for a total of two hours. Depending on the number of groups, the observation lasted from a minimum of 15 minutes to a maximum of 30 minutes for each. At the

beginning and at the end of the assessment, the following categories were analysed, by noting the number of animals concerned: *lying*, *lying outside the resting areas*, *standing at rest*, *standing at the feeding trough*. During the observations, social behaviour was assessed according to different categories of social interactions, by noting the numbers of animals concerned: *head-butt*, *striking – hitting – pushing while moving*, *fighting*, *making another animal stand up*, *collisions with the stable*. Other categories concerned by this phase were: *cough* (number of animals), *lying down time* (in seconds), *chewing rhythm per minute* (number of ruminations), *chewing rhythm on the duration of a food bolus* (number of ruminations), *duration of a food bolus* (seconds).

The evaluation grids used during the on-farm surveys are reported in the "*Annexes*" part: Figure 11 for dairy cows and goats, Figure 12 for dairy sheep.

3. Blood samplings on a restricted group of animals, to analyse their health and metabolic status. Blood samples were taken from a veterinarian, from the tail vein for the cows, and from the neck vein for small ruminants (sheep and goats).

   The analysis focused on the definition of the following parameters: *Non-Esterified Fatty Acids (NEFA)*, *Beta-HydroxyButyrate (BHB)*, *Glucose*, *Urea*, *Acetic Acid*, *Glutamate Dehydrogenase (GLDH)*, *Lactic Acid*, *Methanephrine*, *Normethanephrine*, *Cortisol*, *Copper*, *Zinc*, *Calcium*, *Phosphorus*, *Magnesium*, *Sodium*, *Total Protein*, *Albumin*, *Aluminium* and *Selenium*.

4. Health measurements.
   - Herd health assessment: observation of as many animals as possible, to evaluate specific aspects, according to the species. The evaluation was conducted using a grid, where for each registered animal the scores it achieved for each of the following indicators were reported. They are reported in the "*Annexes*" part; Figure 13 for dairy cows, Figure 14 for dairy sheep, Figure 15 for dairy goats.

Considering the **cows**, the categories were selected based on two protocols; from the one of Alves de Oliveira et al: *lactation stage*, *rumen filling*, *BCS*, *cleanliness*, *ease of movement*, *uprights*, and *stool consistency*. From the protocol Welfare Quality® the following indicators were selected: *BCS*, *cleanliness of back – legs – udder*, *lameness*, *nasal discharge*, *ocular discharge*, *difficult breathing*, *vulvar discharge*, *distance of approach*. They are all reported in Table 3.

Regarding the **goats**, herd health was evaluated by considering the categories of indicators reported in Table 4, mainly from the AWIN protocol (AWIN goats, 2015): *lactation stage*, *sternal BCS*, *lumbar BCS*, *cleanliness*, *tail cleanliness*, *ease of movements*, *uprights*, *lameness*, *presence of abscess*, *nasal discharge*, *ocular discharge*, *udder asymmetries*, *overgrown claws*, *stool consistency*.

Concerning the **sheep**, herd health was evaluated by considering the categories of indicators reported in Table 4, mainly from the AWIN protocol (AWIN sheep, 2015): *lactation stage*, *BCS*, *faecal soiling*, *tail – udder – hocks cleanliness*, *wool quality*, *tail cleanliness*, *tail length*, *nasal discharge*, *ocular discharge*, *mucosa colour*, *ease of movements*, *uprights*.

- *Intestinal parasites analysis*. Sampling session conducted in late springtime (P2 and P4), for the collection of freshly excreted faeces using a special container, from multiple animals. The samples were then stored at cool temperatures and analysed to detect the presence of intestinal parasitism, through "*Flotation method in eggs/g – ZnSO4 saturation*".

5. *Technical and management aspects*. For all the species (dairy cows, goats, sheep), the following information was collected each year, during direct interviews with the farmer:
    - *Reproduction* → duration of *Calving Interval* in days.
    - *Production* → *milk yield* of the herd, in litres.
    - *Health parameters* → as a number/year of *vaccinations*, *veterinary interventions*, *antibiotic treatments*, *preventive treatments*, *curative*

treatments, *total treatments* (as a sum of antibiotics + preventive + curative), *mastitis*, *deworming treatments*, *difficult calving*. Additional notation of *dead rate of calves*, *mortality rate of cows*, *number of cows lying* (ketonemia),

Concerning the measurements carried out on the field, the results about nutritional value of forages, intestinal parasitism, milk analysis, blood analysis were put on a specific database, created with "Microsoft Excel" Software, together with the information about the farm and the technical – management practices adopted by the farmers.

2.2 – Data analysis

After the on-farm surveys, the data concerning herd health and QBA were transferred in a "*Microsoft Excel 2016*"'s database. Subsequently, the percentages of animals for each indicator and each score achieved for them were calculated, for each of the four periods (P1 – P2 – P3 – P4), in order to transform qualitative data into quantitative ones. Then, the percentages for each indicator were aggregated into an average, according to the period of the survey, to obtain two data for each farm and for each indicator: one for winter (P1 and P3), and one for late spring (P2 and P4).

To select relevant indicators, a multivariate analysis approach was adopted, by putting in practice two Principal Component Analysis (PCA), using "*R*" Software (version 4.1.3; 2022-03-10 and 4.1.2; 2022-06-23). Here, PCA was conducted to reduce the number of indicators collected on the field, according to the correlations and the contributions of the variables that were considered. However, because of the small sample size of farms (11 for cows and 6 for sheep and goats) and thus for the lower reliability of the statistical analysis, the PCA was managed more as a guideline, in combination with expert knowledge of the working group, to interpret and to integrate the results. At the end, two lists of indicators to assess animal health on agroecological farms were identified, one for dairy cows and the other for small ruminants, both for winter and summer periods, which were then tested on the surveyed farms.

Dairy cows' and small ruminants' farms were analysed separately. For each of them, one PCA was conducted using the data from winter and another one using the data from spring. Regarding the cows, only 11 out 14 farms were considered, as the two "didactic farms" (E12 and E13, because of the presence of the students who could alter the data collection) and E14 (too few animals reared, also kept outdoors during wintertime) were excluded from the analysis. Concerning the small ruminants, all farms were included in the assessment.

Both for dairy cows and small ruminants, indicators about blood parameters were not considered, because the results from the lab analyses were not available on time.

Lastly, the indicators to be selected at the end of statistical and expert work, have been classified around six categories, according to their characteristics:

1. "**Animal Health**"; it refers to the general health status of the herd and individuals.
2. "**Housing**"; it refers to the appropriateness of the stable and building in which the animals are housed.
3. "**Behaviour**"; it refers to the behavioural traits expressed by the animals, measured at herd level. This category was only considered for dairy cows, as for small ruminants, according to what has been said above, the protocols that have been adopted do not provide a methodology to calculate it as a score.
4. "**Feeding**"; it refers to the adequacy of the ration given to the animals, measured as the animals' state of body fatness (BCS).
5. "**Production**"; it refers to the production level of the herd and its health traits.
6. "**Reproduction**"; it refers to the reproductive aspects of the herd. As with "Behaviour", this category was only considered for dairy cows, because the data about "Calving Interval" were not available for all the small ruminants' farms involved in the surveys.

2.2.1 – Dairy cows' data analysis

Considering dairy cows, the list of variables taken into account for wintertime and late springtime (P1 – P3 and P2 – P4) is reported in Table 3.

Here, not all the variables measured during the on-farm surveys were integrated into the PCA. Specifically, *rumen filling*, *stool consistency*, *vulvar discharge*, *difficult breathing*, *distance of approach*, *nasal discharge* and *ocular discharge* were excluded due to discrepancies or lack in data. Moreover, some data were not considered as they related to the same area: *ease of movements* and *uprights* were considered as referring to the *lameness*-like scope, and *cleanliness of legs – back – udder* were considered as referring to the *cleanliness*-like scope.

Additionally, the majority of the indicators were directly integrated in the PCAs, whereas the variable about parasitism (Paramphistomum spp) was evaluated separately, by human expertise, as no sampling was expected for that during wintertime (periods P1 and P3). The selection of this specific indicator within all the others about parasitism was due to its recurrence among all the farms.

Dairy cows – Indicators considered to evaluate animal health
“***Teg_0***”. Percentage of animals with no tegument alterations.
“***Teg_lesion***”. Percentage of animals with presence of tegument lesions.
“***Nasal_discharge_WQ_0***”. Percentage of animals without nasal discharge.
“***Cleanliness_medpop_1***”. Percentage of clean animals.
“***Lameness_WQ_0***”. Percentage of animals without lameness problems.
“***BCS_lact_medpop_0***”. Percentage of animals with a good score of BCS according to the lactation stage, calculated as described in the annexes (par 4.1).
“***QBA_WQ_score***”. Score of QBA for each farm, calculated as described in the annexes (par 4.1).
“***Prevention_cow_year***”. Number of preventive treatments carried out on each cow/year.
“***Curative_cow_year***”. Number of curative treatments carried out on each cow/year.
“***Antibiotics_cow_year***”. Number of antibiotic treatments carried on for each cow/year.
“***Vaccins_cow_year***”. Number of vaccinations carried out on each cow/year.
“***Vermifuges_cow_year***”. Number of deworming treatments carried out on each cow/year.
“***Mastitis_cow_year***”. Incidence of mastitis per cow per year.
“***Percentage_difficult_calving***”. Percentage of difficult calving on each farm.
“***Percentage_mother_lying***”. Percentage of mothers which were lying on the ground (ketonemia).
“***Vet_intervention_year***”. Number of veterinary interventions on each farm, divided by the numbers of lactating cows
“***Cow_age_reform***”. Average cows’ age at reform.
“***Reform_rate***”. Percentage of cows reformed per year.
“***Renewal_rate***”. Percentage of cows which were renovated per year.
“***Rate_dead_mother_cows***”. Percentage of cows which were dead after calving.
“***Calves_dead_less_one_months***”. Number of calves <1 months age dead.
“***Weaning_age_months***”. Average weaning age of the calves.
“***ECM***”. Energy Corrected Milk, calculated as described in the annexes (par 4.1).
“***Calving_Interval***”. Average number of days within two calving of the same cow.
“***Cells_ml***”. Number of somatic cells / ml of milk.
“***Paramphistome***”. Concentration of parasitism infestation by Paramphistomum spp in the faeces.

Table 3 - Categories of indicators chosen for the PCA about dairy cows' herd health

Then, this list of indicators was used to evaluate the situation and the performance of the farms in the sample followed by the project, to test its accuracy. Here, all the farms were included in the assessment, also involving the ones that had been excluded from the data processing for the PCA: E12 – E13 – E14. Moreover, the surveyed farms were evaluated by using those indicators for which reference thresholds were defined by the protocols, reported in Table 5 of the Results' chapter.

To obtain the data of each farm referring to the specific indicators, the collected data have been processed to calculate the percentages of animals belonging to each threshold for all the indicators. The data referring to the indicators for which there are no reference benchmarks have been reported only to give an overview of the situation of the farms (Table 7 of the Result's chapter). All the results refer to the average of the four periods of observation (P1 – P2 – P3 – P4).

2.2.2 – Small ruminants' data analysis

Concerning small ruminants, the list of variables used for the two PCAs (P1 – P3 and P2 – P4) is reported in Table 4.

Following what has been said above about dairy cows, not all the variables measured during the on-farm surveys were integrated into the PCA. Indeed, some of them were excluded before carrying on the analysis.

About dairy goats, this happened because of:

- Lack of data, discrepancies or low importance within the surveyed farms. *Overgrown claws*, *stool consistency*, *presence of abscess*, *nasal discharge* and *ocular discharge*.
- Similarity to other indicators. *Tail cleanliness* was considered as referring to the same area of general *cleanliness*; *ease of movements* and *uprights* were considered as referring to the same area of *lameness*.

Talking about dairy sheep, the variables that have been excluded were:

- Due to discrepancies, lack of data and low importance. *Tail length*, *nasal discharge*, *ocular discharge*, *mucosa colour*.
- Similarity to other variables. *Faecal soiling*, *wool quality* and *tail cleanliness* were considered as referring to the *cleanliness*-like scope. *Uprights* was considered as referring to *ease of movements* (lameness).

The indicators for parasitism, *Eimeria* and *Strongles*, were added to the assessment after the PCA, by human expertise, as during wintertime (periods P1 and P3) no sampling was expected for that. They were selected from all the indicators about parasitism as they were the most common ones among all the farms.

Moreover, the data about QBA were not taken into account due to the fact that the AWIN's protocols do not provide a methodology to calculate it as a score, like the Welfare Quality® one. Lastly, the ECM's variable was not considered either, due to a lack of data about production for some farms.

Small ruminants – data considered for the PCA about herd health
"***Nasal_discharge_0***". Percentage of animals without nasal discharge.
"***Cleanliness_1***". Percentage of clean animals.
"***Lameness_0***". Percentage of animals without lameness problems.
"***BCS_lact_0***". Percentage of animals with a good score of BCS according to the lactation stage, calculated as described in the annexes (par 4.2).
"***Prevention_ind_year***". Number of preventive treatments per animal across the year.
"***Curative_ind_year***". Number of curative treatments per animal across the year.
"***Antibiotics_ind_year***". Number of antibiotic treatments per animal across the year.
"***Vermifuges_ind_year***". Number of deworming treatments per animal across the year.
"***Mastitis_ind_year***". Incidence of mastitis per animal per year.
"***Percentage_difficult_calving***". Percentage of difficult calving for each farm.
"***Vet_intervention_year***". Number of veterinary interventions on each farm, divided by the total number of animals reared in each.
"***Average_age_reform***". Average age of the individuals at reform.
"***Reform_rate***". Percentage of animals reformed each year.
"***Rate_dead_mothers***". Percentage of mothers which were dead after calving.
"***Offspring_dead_less_one_month***". Number of individuals <1 months age dead.
"***Cells_ml***". Number of somatic cells / ml of milk.
"***Eimeria spp***". Level of parasitism infestation by "Eimeria spp" in the faeces.
"***Strongles***". Level of parasitism infestation by "Strongles Gastro-Intestinal" in the faeces.

Table 4 - Categories of indicators considered to assess small ruminants' health

Following the work conducted on dairy cows' farms, this list of indicators has been applied to the surveyed farms, by putting together goats' and sheep's ones. Here, the goats' farms were classified as "C" (Caprine) and the sheep's ones as "O" (Ovine).

According to what has been said above, the protocols AWIN Goats and AWIN Sheep do not provide specific reference thresholds for the indicators, so the data are presented to give an overview on the farms, without a specific evaluation.

3 – Results

3.1 – Indicators retained for dairy cows

Talking about dairy cows, the results from the PCA are divided by the two periods of on-farms visits: wintertime and late springtime.

The results for the indicators measured during wintertime (periods P1 and P3) are reported in Figure 7.

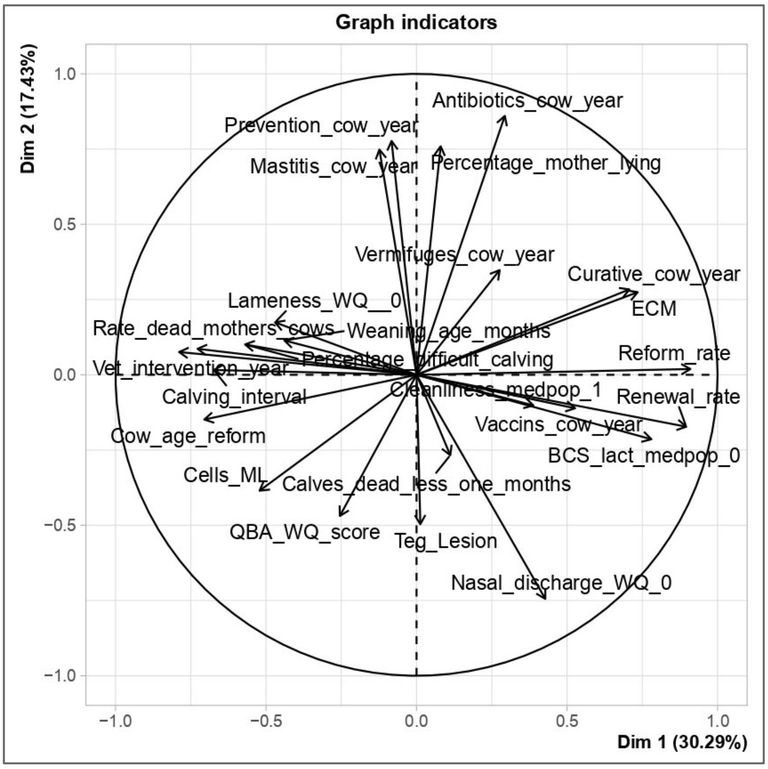

Figure 7 - Graph of variables for wintertime (periods P1 and P3)

The results for the indicators measured in late springtime (periods P2 and P4) are reported in Figure 8.

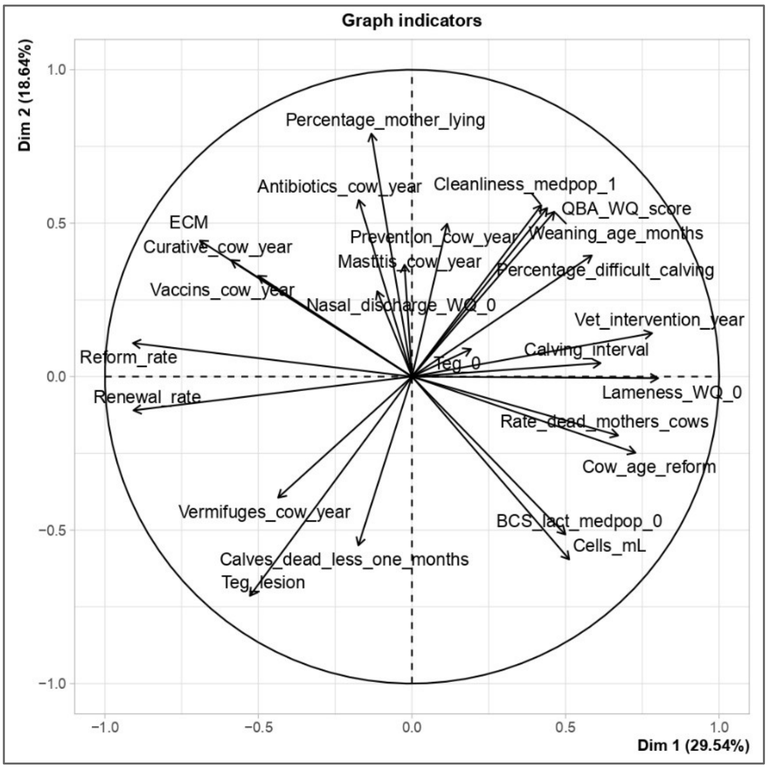

Figure 8 - Graph of variables for late springtime (Periods P2 and P4)

The two analyses of the indicators to assess animal health, carried out during wintertime and late springtime data of the 11 agroecological dairy cattle farms, allow some observations to be made.

Firstly, the percentage of inertia is quite high, both for wintertime (47.72%) and late springtime (48.18%). Then, some interesting correlations can be seen in the graphs reported above:

1. For both periods, ECM is negatively correlated with the number of cells per ml of milk, and in late springtime, also with the BCS.
2. Both in wintertime and late springtime, Reform Rate is negatively correlated with "*Rate Dead Mother Cows*", "*Cow Age Reform*" and "*Lameness_0*".

3. For wintertime and late springtime, Antibiotics Treatments are positively correlated with Mastitis.

In a second step, the outcomes of the statistical work have been combined with the expert knowledge of the working group, to analyse the indicators included in the PCA and to extract a representative amount of them, which should include the best ones to assess animal health on agroecological dairy farms. To do this, only the most representative and specific indicators have been extracted, trying at the same time to maintain as high a representativeness as possible of all fields of interest and to possibly exclude some of them that refer to the same topic.

The indicators that have been selected are reported in Table 5. Here, when possible, the reference thresholds for each of them are also shown, which have been taken from the protocols of Alves de Oliveira et al (2016) and Welfare Quality (2009).

	Indicators to evaluate dairy cows' health
Animal Health	*Curative_cow_year* *Antibiotics_cow_year* *Prevention_cow_year* *Lameness_WQ_0* *Teg_lesion:* Normal situation with <15 % of the cows with hock lesions (Alves de Oliveira et al., 2016) *Cow_age_reform* *Renewal_rate* *Rate_dead_mothers*: warning threshold at 2.25% and alarm at 4.5% (Welfare Quality®) *Vet_intervention_year* *Paramphistome*
Housing	*Cleanliness_medpop_1*: normal situation with an average score of 2 – 2.5. In particular, at least 60% of cows with score 1 – 2, <15% score 4 and <10% score 5.
Behaviour	*QBA_WQ_score*
Feeding	*BCS_lact_medpop_0*: normal situation with an average score of 3 (2.5 at lactation peak and 3.5 at the start of dry period. In particular, normal score at calving 3 – 3.5; normal score above 2 – 2.5 at lactation peak (maximum drop of 1 point from calving).
Production	*ECM*: warning signals: ≤10% of the cows with abnormal drop in production (if <15% compared to the previous month) and/or drop at the second month (inversion of the lactation peak, possible ketosis). *Cells_ml*: normal situation with >85% of the cows with individual SCC < 300000/ml and < 5% of the cows with individual SCC > 800000/ml (Alves de Oliveira et al., 2016)
Reproduction	*Calving_interval*: on average 365 – 390 days (Alves de Oliveira et al., 2016)

Table 5 - Indicators to assess dairy cows' health within agroecological farms and reference thresholds when available

3.2 – Application of the retained indicators to dairy cows' farms

As described in the Method section, the list of indicators that has been created at the end of the data analysis has been applied to the farms belonging to the sample followed by the project, to evaluate their situation and to test the accuracy of the chosen indicators.

The results are reported in the following tables: Table 6 for the indicators with specific threshold, and Table 7 for the ones for which no specific reference thresholds could be found in the bibliography. The data referring to the indicators for which there were no reference benchmarks have been reported here to give an overview of the situation of the farms.

However, some data were not available for the farms that have not been included in the selection of indicators: E12 – E13 – E14.

Evaluation of dairy cows' farms with indicators and thresholds

Farm	Health (%)		Housing (%)	Feeding (%)	Production		Reproduction
	Dead Mothers	*Tegument lesion*	*Cleanliness 1+2*	*2,5<BCS>3,5*	ECM l/d	Cells/ml	*Calving Interval d*
E1	2	19.24	88.12	88.60	17.9	307500	400
E2	15	0	65.14	84.58	6.8	496600	420
E3	3	1.56	100	87.32	9.5	117000	380
E4	6	21.67	92.50	47.20	15.1	161200	370
E5	4	0	100	84.89	15.7	172500	440
E6		7.26	89.26	66.90	17.6	183000	380
E7	2	0.43	95.80	59.09	23	75333	382
E8	3	6.30	85.37	80.28	15.2	257200	389
E9	0	1.43	96.76	87.36	16.5	224833	320
E10	1	9.79	76.75	77.33	11.6	186333	380
E11	2	7.14	97.62	65.35	17	174800	380
E12		8.33	96.21	75.92		91250	412
E13		11.19	88.75	80.94		185000	401
E14		16.34	100	70.24		847000	360
Average	3.8	7.91	90.88	75.43	15.08	248539	387

Table 6 - Evaluation of the surveyed farms through the selected indicators with reference thresholds.

Situation of dairy cows' farms through indicators without thresholds									
Farm	Health								Behaviour
	Lameness0 (%)	*Prevention (n/ind)*	*Curative (n/ind)*	*Antibiotics (n/ind)*	*Vet interv/ind*	Age reform	Reform (%)	*Paramphistome (paras)*	*QBA score*
E1	94.59	0	0	0.05	0.10	10	20	150	63.59
E2	98.33	0	0	0	0.23	11	15	326	64.88
E3	100	0	0	0	0.09	10	20	38	73.83
E4	100	1	0.33	0.67	0.11	10	17	40	65.46
E5	100	0	0	0	0.28	9	18	42	76.07
E6	95.24	0	0.5	0.5	0.11	7	30	40	31.20
E7	88.99	0	0.5	0.3	0.09	6	28	176	70.01
E8	86.26	0	0.2	0.1	0.06	7	30	0	63.98
E9	98.57	0	0.5	0	0.06	9	30	5	70.96
E10	97.78	0	0.46	0.1	0.13	11	25	48	79.17
E11	100	0.5	0.5	0.5	0.16	10	22	208	70.64
E12	90.97	0.03	1.06	0.75	0.34	4.5		46	
E13	81.28	2	2.5	0.2	0.42	6		170	
E14	100	0	2	1	0.38	7		102	
Average	95.14	0.25	0.61	0.30	0.18	8.39	23.18	99.36	66.34

Table 7 - Situation of the surveyed farms through the selected indicators without reference thresholds.

Referring to the data reported in Table 6 and Table 7 above, it can be said that the majority of the farms appeared to be in a decent situation for all the indicators. Specifically, sanitary treatments are generally low, due to the agroecological and, in many cases, organic farming. Also, the incidence of tegument lesion, lameness and dirty animals is quite low.

Concerning the indicators with specific thresholds, almost all the farms generally comply with the limits for all of them. Some exceptions are present for the following farms:

- E1: high incidence of tegument lesions (19.24%) and long calving interval (400 days). Relatively high SCC (307500/ml), but only slightly above the reference threshold.
- E2: highest rate of dead mothers (15%), high SCC (496600/ml) and long calving interval (420 days). Lowest amount of milk production.

- E4: high incidence of tegument lesions (21.67%) and over the limits for the rate of dead mothers (6%). In addition, relatively low percentage of animals with normal BCS (47.20%).
- E14: high incidence of tegument lesions (16.34%) and highest SCC (847000/ml).

However, concerning the SCC, E2 and E14 used the milk for direct cheese production on the farm. Moreover, calving interval is sometimes long due to specific management strategies put in practice by the farmer, for instance to extend the lactation over a longer period.

Talking about the indicators without reference thresholds, all the farms showed a very low incidence of lameness (highest in E13, with 19.72% of lameness) and a very similar situation for the other health indicators. In particular, the use of preventive treatments on the animals was very low and adopted only in four farms: E4 – E11 – E12 – E13. Antibiotics and Curative ones were more used.

The age at reform of the cows was around 10 years; E12 achieved the lowest value (4.5 years) and E2 – E10 the highest one (11 years). About the reform rate, it was around 20% for all the farms: E2 had the lowest one (15%) and E6 – E8 – E9 the highest one (30%).

Concerning parasitism, the incidence of infestation from Paramphistomum was present in all farms except for E8. Lastly, all the farms showed high QBA scores, except for E6.

3.3 – Indicators retained for small ruminants

As for dairy cows, the results from the PCA are divided by the two different periods of on-farm surveys: wintertime and late-springtime.

The results for the indicators measured during wintertime (periods P1 and P3) are reported in Figure 9.

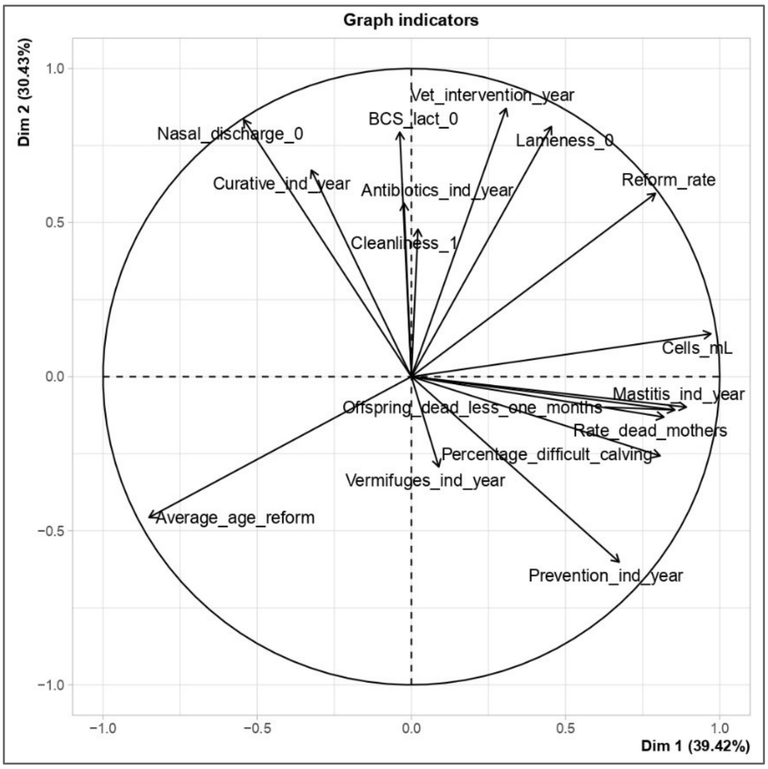

Figure 9 - Graph of variables about small ruminants for wintertime (periods P1 and P3)

The results for the indicators measured in late springtime (periods P2 and P4) are reported in Figure 10.

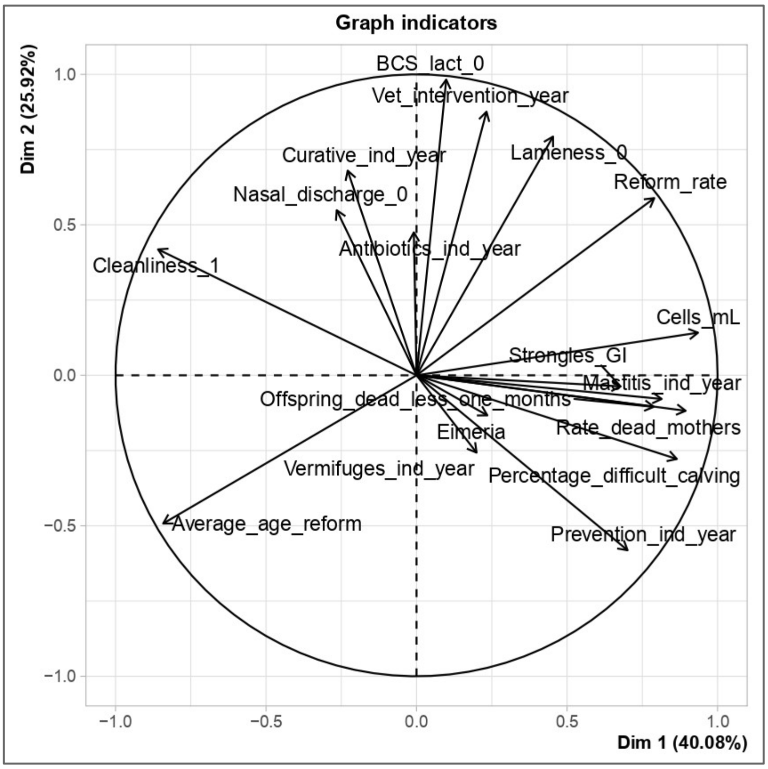

Figure 10 - Graph of variables about small ruminants for late springtime (periods P1 and P3)

Here, the numerosity of the sample is even smaller if compared with dairy cows. Despite that, the percentage of inertia of the PCA is higher than before, with 69.85% for wintertime and 66% for late springtime.

Looking at the graphs reported in the previous chapter, some considerations can be made:

1. "*Nasal Discharge_0*" is positively correlated with "*Curative Treatments*", both during wintertime and late springtime. Moreover, during wintertime, "*Curative Treatments*" are negatively correlated with "*Prevention Treatments*". Hence, it would be reasonable to keep the variables referring to the treatments from the PCA.
2. "*Age Reform*" is negatively correlated with "*Veterinary Interventions*", "*Lameness_0*", "*Reform Rate*" and number of somatic cells per ml of milk, for both

the two periods. Additionally, during late springtime also "*Mastitis*" is negatively correlated with "*Age Reform*".

3. During late springtime, "*Cleanliness_0*" is negatively correlated with "*Strongles*".

Based on these results, following the work carried out for dairy cows, the outcomes from the PCA have been combined with expert knowledge of the working group. According to this, some consideration can be made:

- Referring to the indicators about **animal health**. Despite the variable "*Vermifuges_ind_year*" has not been selected for dairy cows, for small ruminants could be more interesting, because of the higher incidence of worm infestations within the surveyed farms.

  Subsequently, also the indicator "*Offspring dead less than one month*" could have more importance here, also because of the higher mortality within the surveyed farms.
- Concerning the indicators about **production**. "*ECM*" has been added to the indicators to be maintained by expertise, as for the majority of the surveyed farms there was a lack of data for that.

Therefore, the indicators selected from the PCA and expert knowledge that can be used to assess the health of dairy goats and sheep within agroecological farms could be listed in Table 8. Unfortunately, here it was not possible to find specific information about thresholds for the indicators on the reference protocols, as it has been done for dairy cows.

Indicators to evaluate dairy sheep’s and goats’ health	
	Curative_ind_year
	Antibiotics_ind_year
	Prevention_ind_year
	Vermifuges_ind_year
	Vet_intervention_year
	Average_age_reform
Animal Health	Reform_rate
	Offspring dead less than one month
	Rate_dead_mothers
	Lameness_1
	Eimeria
	Strongles
Housing	Cleanliness_1
Feeding	BCS_lact_0
	ECM
Production	Cells_ml

Table 8 - Indicators to assess dairy sheep's and goats' health within agroecological farms

3.4 – Application of the retained indicators to small ruminants’ farms

Following the work conducted on dairy cows’ farms, the list of indicators has been applied to the farms belonging to the sample of the project, to test its accuracy and appropriateness. The results of the health indicators are reported in Table 9, and the ones for health – feeding and housing ones are shown in Table 10.

Consequently, an evaluation was not conducted on the data reported in the following tables, which are presented to give an overview about the situation of the surveyed farms.

Situation of dairy goats' and sheep's farms through indicators without thresholds

Farms	Health								
	Lameness0 (%)	Prevention (n/ind)	Curative (n/ind)	Antibiotics (n/ind)	Vermifuges (n/ind)	Vet interv/ind	Age reform	Reform rate (%)	Dead Mothers (%)
E14 C	97.70	2	0.08	0.05	1	0.1	5	33	23
E15 C	100	0	1	1	0.5	0.1		30	
E16 O	74.93	1	0.07	0	1	0.01	11	13	5
E17 C	100	0	1	0	1	0.09		22	9
E18 C	100	1	1	0	2	0.1	7.5		5
E18 O	99.38	2	1	0	3	0.02	7.5		25
Average	95.34	1	0.69	0.18	1.42	0.07	7.75	24.5	13.4

Table 9 - Situation of small ruminants' surveyed dairy farms through the health indicators.

Situation of dairy goats' and sheep's farms through indicators without thresholds

Farms	Health			Production		Housing	Feeding
	Offspring dead (%)	Eimeria (paras)	Strongles (paras)	ECM l/d	Cells / ml	Cleanliness1 (%)	BCS_Lact_0 (%)
E14 C	18.9	12	1365	0.51	891200	84.24	71.05
E15 C		130	800		434250	98.81	95.90
E16 O	4.2	31	82	0.64	141750	94.94	42.22
E17 C	3.3	14	812		203333	98.77	92.12
E18 C		23	766			100	88.89
E18 O	3.3	240	2552		213600	86.95	78.19
Average	7.43	75	1063	0.58	376827	93.95	78.06

Table 10 - Situation of small ruminants' surveyed dairy farms through the health – production – housing – feeding indicators

Concerning the tables above, some considerations can be made. Firstly, there is a higher lack of data if compared with dairy cows' farms, especially for production (ECM). Then, as for dairy cows, the recurrence of sanitary treatments and veterinary interventions is low, due to the agroecological and organic farming systems. Indeed, here only one farm did not belong to organic agriculture. In addition, the incidence of lameness and dirty animals is low. Lastly, Vermifuge treatments were conducted more often on all the farms, probably due to the fact that the animals are allowed to spend longer periods outdoors on these systems, with a higher incidence of parasitism.

More specifically, all the farms looked quite similar around the various indicators, especially concerning the ones referring to the health category. In particular, the incidence of lameness is low, with the higher one at 25.07%. A similar trend is shown by cleanliness, with at least 84.24% of clean animals.

Among the sample, the following farms differed from the others:

- E16 (dairy sheep), concerning the highest presence of lame animals (25.04%), the highest age at reform (11 years) and low percentage of animals with appropriate BCS (42.22%). However, this farm shows a discrete situation concerning parasitism and SCC.
- E14 (dairy goats), concerning the lowest age at reform (5 years) and thus highest reform rate (33%) and the high rate of dead mothers (23%) and offspring (19%). This farm also shows the highest SCC value (891200/ml), but it directly used the milk for the on-farm cheesemaking.

4 – Discussion

4.1 – General considerations about the utilised methodology

In the first phase of the project, four sessions of measurements have been conducted on the farms, to collect as much data as possible for statistical analysis by PCA, which have been then combined with expert knowledge. Here, the farms have been divided into two groups: dairy cows and small ruminants, to select two lists of indicators to assess the health of the animals hosted by them.

Accordingly, thanks to the considerable availability of data collected, once the two lists of indicators were defined, they were applied to the two samples of farms, to evaluate them in terms of animal health and to test the accuracy of these new variables. As for the statistical work, also this assessment has been conducted separately for dairy cows' farms and small ruminants' ones.

The main concern in the work is about the low numerosity of the sample. Indeed, it was only based on 18 farms, also divided in two groups. Consequently, the PCAs that have been carried out on the two samples were characterised by a low reliability, which is why the results were managed in combination with expert knowledge. However, the statistical analyses were a discrete tool to detect a general tendency within the data and therefore to select the indicators to be kept for the assessment of animal health within the surveyed farms.

4.2 – A first step of indicators for animal health within agroecological farms

First of all, it can be said that, compared to conventional livestock systems, these farms resorted very little to sanitary treatments, either veterinary interventions or use of antibiotics. This stems from the fact that most of them not only adhered to agroecology but were also certified as organic agriculture.

Subsequently, among the specific indicators to assess animal health retained at the end of the study, there are both variables that can be adapted to conventional farms, as well as those specific to agroecological ones.

In particular, for dairy cows' farms, the first ones refer to the protocols of Alves de Oliveira et al (2016) and Welfare Quality, which have been adopted for the present work: *Lameness*, *Tegument Lesion*, *Cleanliness*, *Behaviour* (QBA), *Appropriate Feeding* (BCS) and production (*ECM* and *SCC*). Besides these ones, the other chosen indicators could be more specific to agroecological farms: *Treatments* (*Curative – Antibiotics – Prevention*), *Age at Reform* and *Renewal Rate*, *Rate of Dead Mothers*, *Veterinary Interventions* and *Parasitism Infestation* (Paramphistomum for this geographical context).

On the other hand, concerning dairy goats' and sheep's farms, the indicators common for the two types of breeding are similar to dairy cows: *Lameness*, *Cleanliness*, *Appropriate Feeding* (BCS), *Production* (ECM – Cells). However, the most characteristic variables for agroecological farms here are: *Treatments* (*Curative – Antibiotics – Prevention – Vermifuges*), *Veterinary Interventions*, *Age at Reform* and *Reform Rate*, *Offspring Dead less than one month*, *Rate of Dead Mothers*, *Parasitism Infestation* (*Eimeria* and *Strongles* for this geographical area).

Consequently, it can be said that the evaluation of animal health could rely on indicators also adaptable to conventional farm concerning, above all, the visible health status of the animals (*Lameness*, *Cleanliness* etc). Furthermore, for a complete assessment conducted within agroecological farms, the adoption of other and more specific indicators is needed, to better investigate the link with the territory (such as the results about parasitism) and on the management practices of the herd (such as *Reform Rate*, *Treatments* and *Veterinary Interventions*).

In the same way, when the blood samples will be analysed, they will certainly help to conduct an even more thorough analysis on animal health. In fact, here it was not possible to conduct an evaluation on specific metabolic disorders, such as Sub-Acute Ruminal Acidosis (SARA) and ketonemia.

On the other hand, agroecology also takes into account the health of all the components of the ecosystem in which the farm is located. Accordingly, in the framework of future research, it could be useful to enlarge the present study by including data from the analysis of other domains, such as grasslands, feed and, maybe, qualitative traits of the productions and the certification of organic agriculture. Furthermore, it would be appropriate that the sample of farms would also be larger, so as to include more data and rely on better reliability of statistical analysis.

Moreover, an investigation of ways to improve the score of each indicator could be effective for the general enhancement of animal health within all farms in the same situation.

Lastly, it would be good to adopt the present indicators for the assessment of animal health to farms located outside the study area and in different geographical contexts, in order to check whether they were still reliable and functional.

5 – Conclusions

The objective of the study, to reveal a list of indicators to be used to evaluate cows', sheep's and goats' health within agroecological dairy farms, can be deemed to have been achieved.

The evaluation of the surveyed farms though the selected indicators showed a similar situation for all of them, with only few exceptions. In particular, the age at reform was quite high for all and there was a very low incidence of lameness and dirty animals. The analysed parasites (Paramphistome for dairy cows and Eimeria – Strongles for small ruminants) were present in all the farms except one, probably due to the fact that the animals were allowed to spend more time outdoors.

Future perspectives for the study could concern the enlargement of the present work, basing it on a larger sample of farms, and the focus on the improvement of specific indicators, especially those that exceeded the reference benchmarks. Besides this, other indicators referring to animal health and their production might be taken into account, such as the certification of organic farming, which has not been considered in this work.

Moreover, the aforementioned lists of indicators could also be applied to agroecological farms located in different geographical contexts than the present study area, to test how and if its accuracy and appropriateness change in a different territory.

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Annexes

1 – Categories of behaviour considered for each of the herds

Dairy cows' QBA	Dairy Sheep's QBA	Dairy Goats' QBA
Active	Alert	Aggressive
Relaxed	Active	Agitated
Fearful	Relaxed	Alert
Agitated	Fearful	Bored
Calm	Content	Content
Frustrated	Agitated	Curious
Friendly	Sociable	Fearful
Bored	Aggressive	Frustrated
Playful	Vigorous	Irritated
Positively Occupied	Subdued	Lively
Irritable	Physically Uncomfortable	Relaxed
Uneasy	Defensive	Sociable
Sociable	Calm	Suffering
Apathetic	Frustrated	
Happy	Apathetic	
	Wary	
	Tense	
	Bright	
	Inquisitive	
	Assertive	
	Listless	

Table 11 - Categories of behaviour taken into account for the QBA

2 – Evaluation grids for data-collection during the on-farm surveys

2.1 – General behaviour assessment

Nom Eleveur : ………………………………………… Date : …………………… Nom observateur : ………………………………

Noter le nombre d'animaux concerné par observation. Le temps total d'observation est de 120 minutes

<20 animaux : diviser en 2 zone (jusqu'à 10 animaux observés en même temps). 2 répétitions pour chaque zone. 4 segments de 30 minutes.
20 – 40 animaux : diviser en 3 zones (7 à 13 animaux à observés en même temps). 2 répétitions pour chaque zone. 6 segments de 20 minutes.
40-60 animaux : diviser en 4 zones (10 à 15 animaux observés en même temps).). 2 répétitions pour chaque zone. 8 segments de 15 minutes
60-80 animaux : diviser en 4 zone (15 à 20 animaux observés en même temp). 2 répétitions pour chaque zone. 8 segments de 15 minutes

Observat° Heure début Heure fin	debout	Mange ou bois	couchée	Couchée en dehors zone	Coup de tête, corne sans déplacement	Coup de tête efficace = entraine un déplacement	Combat (>10 sec : nouvelle séquence)	Poursuite	Poursuite et Fait lever un autre animal	Nb animaux entrant en collision avec élément bâtiment	Animal qui tousse (nb de toux en 15 mins)	Temps de couchage en seconde (30% du troupeau)	Rythme de masticat° Par minutes	Rythme de masticat sur la durée d'un bol	Durée du bol
Segment 1 :	Début : Fin :	Début : Fin :	Début : Fin :	Début : Fin :											
Segment 2 :	Début : Fin :	Début : Fin :	Début : Fin :	Début : Fin :											
Segment 3 :	Début : Fin :	Début : Fin :	Début : Fin :	Début : Fin :											
Segment 4 :	Début : Fin :	Début : Fin :	Début : Fin :	Début : Fin :											
Segment 5 :	Début : Fin :	Début : Fin :	Début : Fin :	Début : Fin :											
Segment 6 :	Début : Fin :	Début : Fin :	Début : Fin :	Début : Fin :											

Figure 11 - Evaluation grid for dairy cows' and goats' behaviour assessment

Nom Eleveur : …………………………………… Date : …………………… Nom observateur : ……………………………

Noter le nombre d'animaux concerné par observation. Le temps total d'observation est de 120 minutes

<20 animaux : diviser en 2 zone (jusqu'à 10 animaux observés en même temps). 2 répétitions pour chaque zone. 4 segments de 30 minutes.
20 – 40 animaux : diviser en 3 zones (7 à 13 animaux à observés en même temps). 2 répétitions pour chaque zone. 6 segments de 20 minutes.
40-60 animaux : diviser en 4 zones (10 à 15 animaux observés en même temps).). 2 répétitions pour chaque zone. 8 segments de 15 minutes
60-80 animaux : diviser en 4 zone (15 à 20 animaux observés en même temp). 2 répétitions pour chaque zone. 8 segments de 15 minutes

Observat Heure début Heure fin	debout	Mange ou bois	couché	Couché en dehors zone	Retrait social (nb)	Stéréoty p (nb)	Démangeais. excessives	Coup de tête, corne sans déplacemt	Coup de tête efficace = entraine un déplacemt	Combat (>10 sec : nouvelle séquence)	Poursuite	Poursuite et Fait lever un autre animal	Nb animaux entrant en collision avec élément bâtiment	Animal qui tousse (nb de toux en 15 mins)	Temps de couchage en seconde (30% du troupeau	Rythme de masticat° Par minute	Rythme de masticat sur la durée d'un bol	Durée du bol
Segment 1 :	Début : Fin :	Début : Fin :	Début : Fin :	Début : Fin :														
Segment 2 :	Début : Fin :	Début : Fin :	Début : Fin :	Début : Fin :														
Segment 3 :	Début : Fin :	Début : Fin :	Début : Fin :	Début : Fin :														
Segment 4 :	Début : Fin :	Début : Fin :	Début : Fin :	Début : Fin :														
Segment 5 :	Début : Fin :	Début : Fin :	Début : Fin :	Début : Fin :														

Figure 12 - Evaluation grid for dairy sheep's behaviour assessment

2.2 – Animal health assessment

Nom Eleveur : Date :

Suivi santé du troupeau

Nom de l'éleveur : .... Nom de l'observateur : .... Date d'observation : ....

Italiques :

<30 VL : toutes les vaches 30-40 VL : 33 VL 40-50VL : 37 (32) 60-70 VL : 41 (35) 70 à 80 VL : 44 (37) 80-90VL : 47 (39)

		1 2 3 4 5		0 : normal 1 : très maigre 2 : très grasse	1ere note med. Pop. 0 : pas saleté 2 : plaques de saleté Zones : bas des pattes/arrière/mamelle	1 : sain 2 : léger boit 3 : modér boit 4 : boiteuse 5 : grave boit	1 : parallèles 2 : rotation légère 3 : rot >24° jarrets	0 : pas boiterie 1 : boite 2 : grave boite	1 : diarrhée 2 : bouses étalées 3 : bouse type crème 4 : type ourée 5 : type crottin	*Pas d'altération Alteration faible Alteration forte*	*0 : absence 1 : présence*	*0 : absence 1 : présence*	*0 : absence 1 : présence*	*0 : absence 1 : présence*	*T : touche <50 cm 50-100 cm >100 cm*
N° Vache	Stade de lactation	Remplissage rumen	NEC 0 à 5	NEC 0-1-2	Propreté 4 notes	Motricité	Aplombs	Boiterie	Bouses	*Altération tégument*	*Ecoulement nasal*	*Ecoulement oculaire*	*Respiration difficile*	*Perte vulvaire*	*Distance évitement*

Figure 13 - Evaluation grid for dairy cows' health

Nom Eleveur : ……………………………………… Date : …………………… Nom observateur : ………………………………

Suivi santé du troupeau brebis laitière

<30 : tous les animaux 30-40 brebis : 33 40-50 : 37 (32) 60-70 : 41 (35) 70 à 80 V: 44 (37) 80-90 : 47 (39)) 100 : 49 (40

			0 = sec et propre 1 = leger humide, leger boue 2 = très humide, sale 3 = très humide, très sale 4 = crasseux (recouvert ventre…)	Cuisse, mamelle, jarrets 1 = pas saliss. visible 2 = saliss. <50% zone 3 = saliss. > 50% zone 4 = plaque <50%a zone 5 = plaque > 50% zone	0 : bonne 1 : perte légère 2 : perte sévère	0 : propre sous la queue 1 : sale sous la queue	0 : queue présente 1 : queue coupée 2 : queue coupée trop court	0 : absence 1 : présence	0 : absence 1 : présence		1= sain 2= léger boiterie 3 = modér. boiteuse 4 = boiteuse 5 = grave boiteuse	1 = membres parallèles 2= rotation légère des jarrets 3 =rotation importante des jarrets > 24°	Note de 0 = Pas de boiterie. Note de 1 = boiterie mineure. Note de 2 =Boiterie. Note de 3 = Boiterie grave	0 : ok 1 : trop long	0 : absence 1 : mammite légère 2 : mammite grave	0 : absence 1 : présence
N° animal	Stade lactat	Nec	Propreté welfare	Propreté med pop	Qualité laine	Souillure queue	Longueur queue	Ecoulem nasal	Ecoulem oculaire	Couleur muqueuse	Note motricité	Note aplombs	Note boiterie	Ongle	Mammite + blessure mamelle	Respi difficil.

Figure 14 - Evaluation grid for dairy sheep's health

Nom Eleveur : ……………………………………… Date : …………………… Nom observateur : ………………………………

Suivi santé du troupeau chèvre laitière

<30 : tous les animaux 30-40 VL : 33 40-50 : 37 (32) 60-70 : 41 (35) 70 à 80 V: 44 (37) 80-90 : 47 (39)

				0 = normal, -1=très maigre, 1= très grasse	Cuisse, mamelle, jarrets 1 = pas saliss. visible 2 = salissure <50% zone 3 = salissure > 50% zone 4 = plaque <50%a zone 5 = plaque > 50% zone	0 : propre sous la queue 1 : sale sous la queue	1= sain 2= léger boiterie 3 = modér. boiteuse 4 = boiteuse 5 = grave boiteuse	1 = membres parallèles 2= rotation légère des jarrets 3 =rotation importante des jarrets > 24°	0 : pas boiterie 1 : boite	0 : absence 1 : présence	0 : absence 1 : présence	0 : absence 1 : présence	0 : symétrique 1 : asymétriq.	0 : ok 1 : trop long
N°animal	Stade lactat	Nec lombair	NEC sternale	Nec 0 ; -1 ; 1	Propreté	Souillure queue	Note motricité	Note aplombs	Note boiterie	Abcès	Ecoulemt nasal	Ecoulemt oculaire	Symétrie mamelle	Ongle

Figure 15 - Evaluation grid for dairy goats' health

3 – Categories of indicators for cows' herd health analysed during the on-farm surveys

Cows' herd health
Lactation Stage (month)
Rumen Filling. Score 1 (empty) to 5 (full)
Body Condition Score (BCS). Score 0 (very lean) to (5 very fat)
BCS; score 0 (good); 1 (lean); 2 (fat)
Cleanliness of the back part: Score 1 (clean) to 5 (very dirty)
Legs' – Back's – Udder's Cleanliness: Score 0 (clean); 2 (dirty)
Ease of Movements. Score 1 (good) to 5 (lameness)
Uprights. Score 1 (good); 2 (slight rotation); 3 (rotation >24°)
Lameness. Score 0 (good); 1 (slight lameness); 2 (lameness)
Faeces. Score 1 (diarrhoea) to 5 (solid)
Tegument Alterations. Score 0 (absence); lesions; depilation
Nasal Discharge. Score 0 (absence); 1 (presence)
Ocular Discharge. Score 0 (absence); 1 (presence)
Difficult Breathing. Score 0 (absence); 1 (presence)
Vulvar Discharge. Score 0 (absence); 1 (presence)
Distance of Approach. Score T (possible to touch); <50cm; 50-100cm; >100cm

Table 12 - Categories of indicators taken into account for cows' herd health

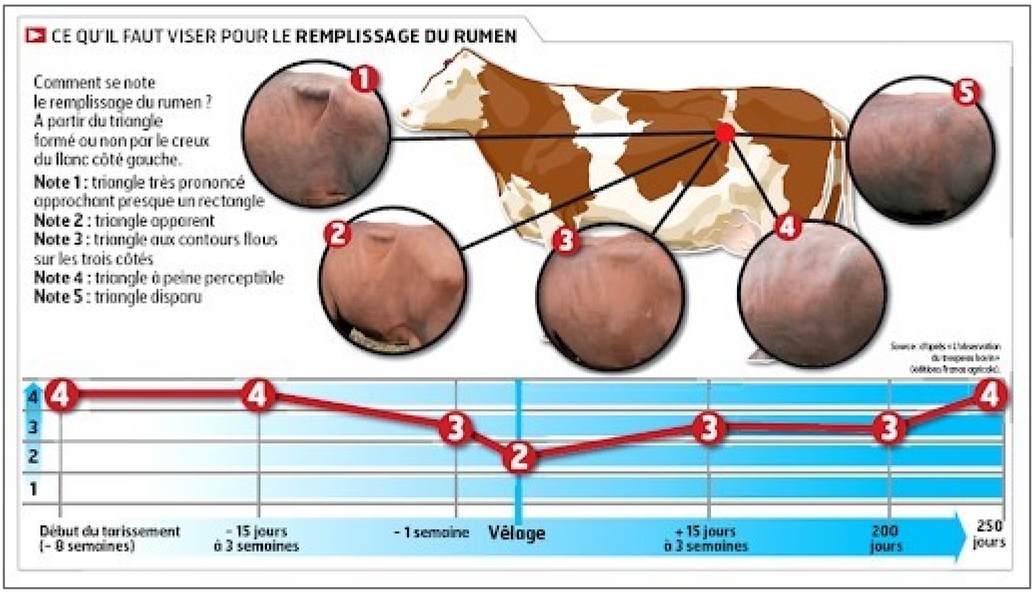

Figure 16 – Guide used as a reference to evaluate the cows' rumen filling (source fidocl.fr)

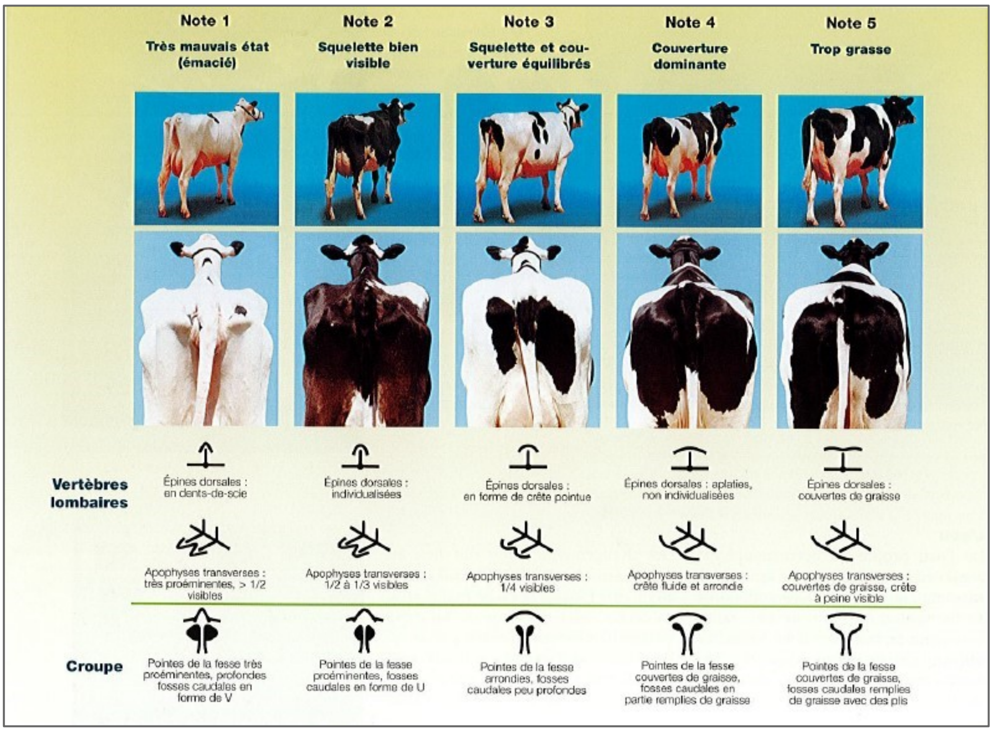

Figure 17 - Guide used as a reference to evaluate the cows' BCS

	Note : 1	2	3	4	5
					
Description	Fèces très aqueuses ; consistance d'une soupe de pois	Fèces crémeuses mais bouse reconnaissable. Eclaboussure à l'émission	Fèces épaisses. Bouse bien définie, de 2 cm d'épaisseur, s'étalant	Fèces dures. Bouse bien définie, en anneaux, s'étalant peu.	Fèces en balle (crotin). Surface sombre et luisante.
Test de la botte 			Pas de sensation de succion, pas d'empreinte	Succion au retrait, Empreinte de la semelle visible	Empreinte de la semelle visible

Figure 18 - Guideline used as a reference for the evaluation of the cows' faeces consistency

4 – Categories of indicators for goats' herd health analysed during the on-farm surveys

Goats' herd health categories	
Lactation stage (month)	
Body Condition Score	Sternal. Score 0 (very lean) to 5 (very fat)
	Lumbar. Score 0 (very lean) to 5 (very fat)
Cleanliness. Score 1 (clean) to 5 (very dirty)	
Tail cleanliness. Score 0 (clean); 1 (dirty)	
Ease of Movement. Score 1 (good) to 5 (severe lameness)	
Uprights. Score 1 (good); 2 (slight rotation); 3 (rotation >24°)	
Lameness. Score 0 (absence) – 1 (presence)	
Abscess. Score 0 (absence) – 1 (presence)	
Nasal Discharge. Score 0 (absence) – 1 (presence)	
Ocular Discharge. Score 0 (absence) – 1 (presence)	
Udder asymmetry. Score 0 (normal) – 1 (length >25% between the two nipples)	
Overgrown claws. Score 0 (good) – 1 (excessive length)	
Faeces consistency. Score 1 (normal); 2 (too solid); 3 (too liquid)	

Table 13 - Categories of indicators taken into account for goats' herd health

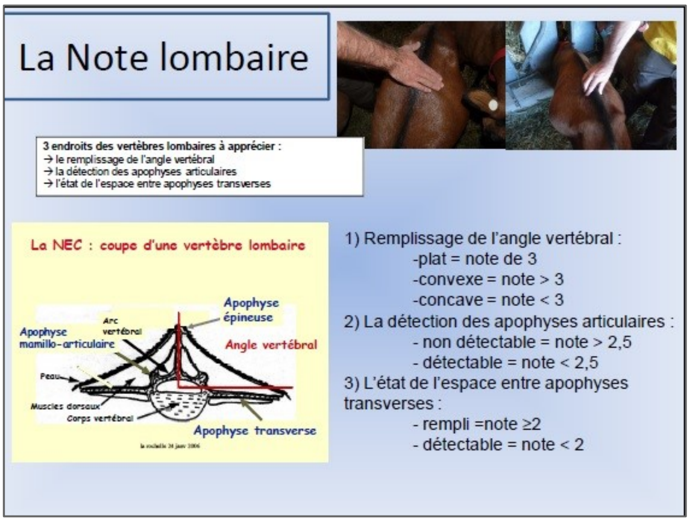

Figure 19 - Guide used as a reference to evaluate the lumbar BCS of goats

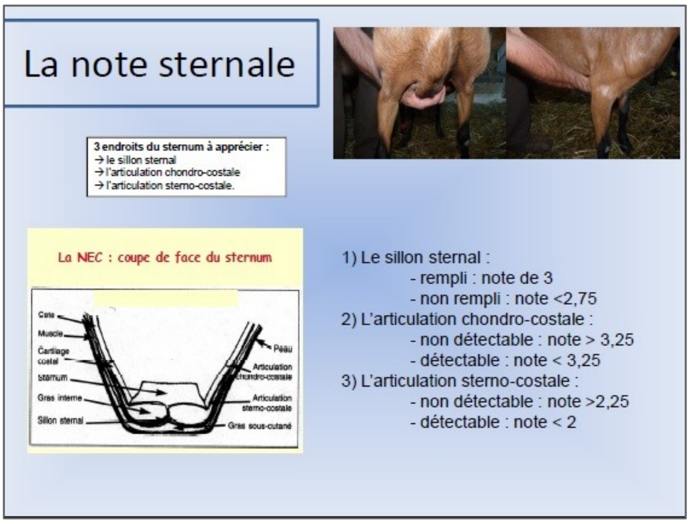

Figure 20 - Guide used as a reference to evaluate the sternal BCS of goats

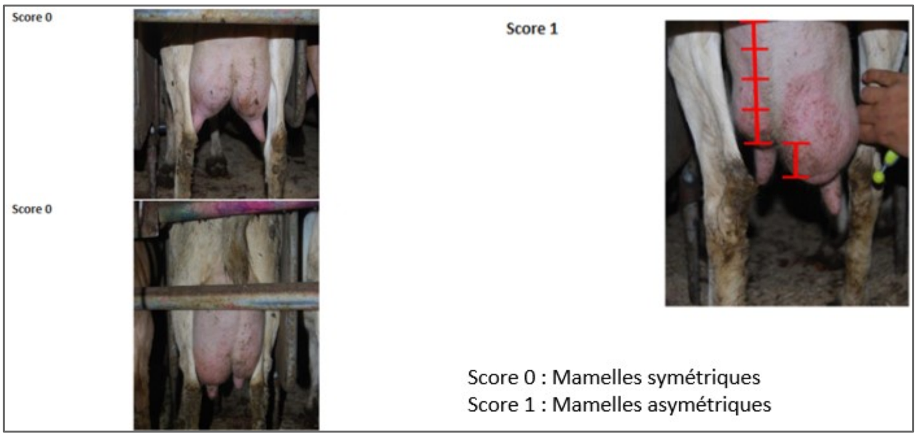

Figure 21 - Guide used as a reference to evaluate the udder asymmetry for goats (AWIN goats, 2015)

Figure 22 - Reference to evaluate the faeces consistencies for goats

Score 0	
Score 0	
Score 1	

Figure 23 - Reference to evaluate the claws length for goats (AWIN goats, 2015)

5 – Categories of indicators for sheep's herd health analysed during the on-farm surveys

Sheep' herd health categories
Lactation stage (month)
Body Condition Score (BCS). Score 0 (very lean) to 5 (very fat)
Faecal soiling. Score 0 (dry and clean) to 4 (severe dirty)
Tail – Udder – Hocks Cleanliness. Score 1 (clean) to 5 (very dirty)
Wool Quality. Score 0 (good); 1 (slight wool loss); 2 (severe wool loss)
Tail Cleanliness. Score 0 (clean) – 1 (slight dirty) – 2 (very dirty)
Tail length. Score 0 (presence) – 1 (docked tail) – 2 (short, docked tail)
Nasal Discharge. Score 0 (absence) – 1 (presence)
Ocular Discharge. Score 0 (absence) – 1 (presence)
Mucosa Colour. Score 0 (normal intense red) to 4 (yellowish)
Ease of movements. Score 1 (healthy) to 5 (severe lameness)
Uprights. Score 1 (parallel) – 2 (slight rotation) – 3 (rotation >24°)
Lameness. Score 0 (good) to 3 (severe lameness)
Hoof Overgrowth. Score 0 (good) – 1 (excessive length)
Mastitis and Udder Injuries. Score 0 (normal) – 1 (mild mastitis) – 2 (severe mastitis)
Respiration quality. Score 0 (normal); 1 (altered breathing)

Table 14 - Categories of indicators taken into account for sheep's herd health

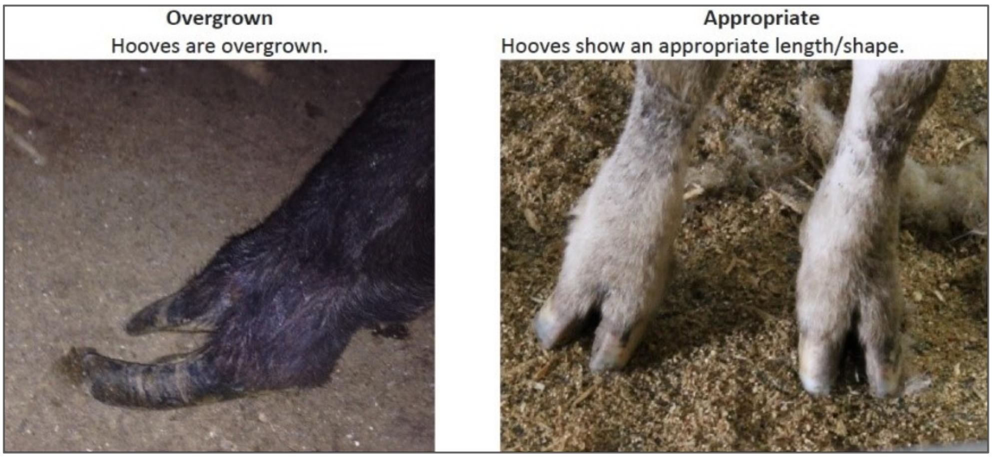

Figure 24 - Reference to evaluate the hoof length for sheep (AWIN sheep, 2015)

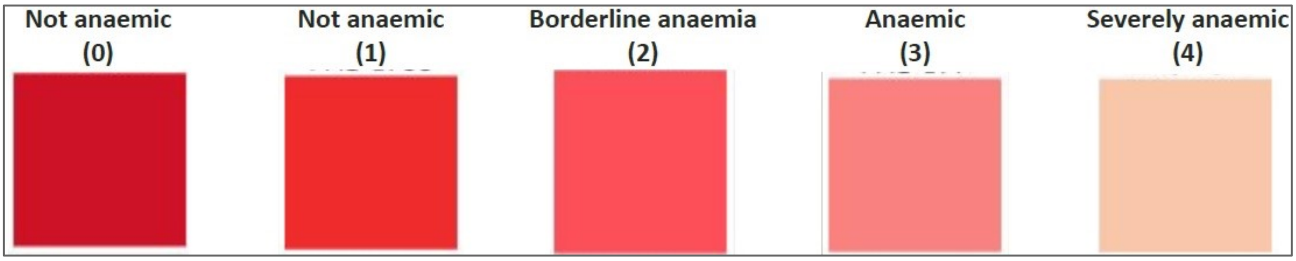

Figure 25 - Reference to evaluate the mucosa colour for sheep (AWIN sheep, 2015)

6 – Data processing and specific calculations

6.1 – Calculations of specific values about cows' herd health indicators

- *"**BCS_lact_medpop_0**"* → Percentage of animals with a good score of BCS according to the lactation stage. In detail, for each animal, the on-farm measured BCS was linked with its phase of lactation, by considering a reference value according to them, and to the protocol of Alves de Oliveira et al., 2016:
    - Start of lactation, BCS score 3
    - Mid-lactation, BCS score 2.5
    - Third lactation phase, BCS score 2.75
    - End of lactation, BCS score 3.25
    - Dry period, BCS score 3.5

  The above-described BCS scores have been slightly increased, due to the fact that the farms often bred cows belonging to breeds with a higher body mass than Holstein Friesian, i.e., Normande or Abundance.

  Then, the BCS of the animal, combined with the lactation stage, was subtracted from the reference values, considering a tolerance value of 0.5. Therefore, if the difference was < -0.51, the BCS was marked as "1" (too lean), on the contrary if it was > +0.51, as "2" (too fat), and "0" if -0.50 < BCS > +0.50.

- "***QBA_WQ_score***" → Score of QBA for each farm, calculated according to the formula proposed by the protocol Welfare Quality®, which brings the 20 categories together. To calculate the score for each farm, a specific index was firstly calculated according to each of the categories, by using the following formula:

$$Index = -3.40496 + \sum_{k=1}^{20} Wk\ Nk$$

  With: *Nk, the value obtained by a farm for a given term k*

  Wk, the weight attributed to a given term k

  Then, the index was split into a score using the following formula:

$$Score = a + b \times I + c \times I^2 + d \times I^3$$

  With *a, b, c, d* differing when *I* is lower or equal to a specific value (called *knot*). The values for *a, b, c, d,* and the knot were:

knot	***0***
a when *I* < *knot*	*50*
a when *I* > *knot*	*50*
b when *I* < *knot*	*8.75*
b when *I* > *knot*	*11.6667*
c when *I* < *knot*	*0.3125*
c when *I* > *knot*	*-0.55556*
d when *I* < *knot*	*0*
d when *I* > *knot*	*0*

- "***ECM***" → Energy Corrected Milk, calculated from the data collected during the on-farm visits, according to the following formula:

  $$(MY * (0{,}42 + 0{,}0053 * (FC - 40) + 0{,}0033 * (PC - 31))/0{,}42)$$

  Where: *MY (Milk Yield), FC (Fat Content), PC (Protein Content)*

6.2 – Calculations of specific values about small ruminants' herd health indicators

- "***BCS_lact_0***" → percentage of animals with a good score of BCS according to the lactation stage. In detail, for each animal, the on-farm measured BCS was linked with the phase of lactation, by considering a reference value according to this. In particular:
  - Sheep. Definition of three phases: *start of lactation* (BCS score 2.75), *end of lactation* (BCS score 2.5), *dry period* (BCS score 3.25) (Dudouet, 2012; Dudouet, 2016).
  - Goats. Definition of three phases: *start of lactation* (sternal BCS score 2.75 – lumbar BCS score 2.5), *end of lactation* (sternal BCS score 3 – lumbar BCS score 2.5), *dry period* (sternal BCS score 3.25 – lumbar BCS score 2.75) (Institute de l'Elevage, 2012).

  Then, the BCS of the animal, combined with the lactation stage, were subtracted from the reference values, considering a tolerance value of 0.5. About the goats, the values of sternal and lumbar BCS were aggregated into an average, to obtain a unique value.

Subsequently, if the difference was < -0.51, the BCS was marked as "1" (too lean), on the contrary if it was > +0.51, as "2" (too fat), and "0" if -0.50 < BCS > +0.50.

- "***ECM***" → Energy Corrected Milk, calculated from the data collected during the on-farm visits. In particular:
    - Goats (Institute de l'Elevage, 2012).

$$(MY * (0{,}0035 * FC) + (0{,}0031 * PC) + 0{,}2224)$$

Where: *MY (Milk Yield)*, *FC (Fat Content)*, *PC (Protein Content)*

- Sheep (Dudouet, 2012; Dudouet; 2016).

$$(MY * (0{,}0071 * FC) + (0{,}0043 * PC) + 0{,}2224)$$

Where: *MY (Milk Yield)*, *FC (Fat Content)*, *PC (Protein Content)*