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"MOUNTAIN PRODUCTS AND ECOSYSTEM SERVICES: ASSESSMENT METHODS AND ENHANCEMENTS STRATEGIES"

Dottoranda
dott.ssa Chiara Spigarelli

Supervisore
prof. Stefano Bovolenta

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Abstract

The gradual abandonment of traditional activities and the difficulties faced in promoting local productions, are challenging mountain cultural and natural heritage. The research aims to support mountain dairy food chains by adding value and traceability to local mountain products. The innovative approach consists in empowering the "mountain products" by identifying and quantifying external attributes as animal welfare, environmental sustainability and plant biodiversity linked to the natural and cultural assets of the area but which are currently hidden into a broader food quality concept.

Animal welfare, if properly performed, is a valid enhancing tool for the livestock production system and mountain products. The assessment protocol used refers to the Scientific Opinion of the European Food Safety Authority (EFSA) concerning the welfare evaluation on small-scale farms dairy cows. Protocol based on direct measures looking at the animals (animal-based measures - ABM), divided into observed (ABMo) and recorded (ABMr) from farm records and quartiles were identified for ABMo and ABMr in order to suggest critical/achievable levels. Data were discussed using a comparative analysis as an effective on-farm welfare management strategy and a stepping-stone toward continuous welfare improvement. The overall results displayed that good animal welfare can be obtained also in mountain farming system. Clinical indicators displayed a very low prevalence in fact the median prevalence of discharges and severe lameness were 0%. On the other hands, integument alterations exceeded the warning thresholds defined in previous studies. Median values were 31% of animals with hairless legs, 14 % with hairless body and 9 % of lesions and swellings with maximum values that also reached 94%, 71% and 58% of affected animals.

Environmental sustainability was carried out by analyzing the environmental footprint (Life Cycle Assessment -LCA- method) and production efficiency (gross energy and potentially human-edible conversion ratios, ECR and HeECR respectively). Impact categories assessed were Climate Change (GWP, kg CO2-eq), Eutrophication potential (EP, g PO4-eq) per 1 kg FPCM (1.2±0.2 kg CO2-eq e 6.0±1.7 g PO4-eq) and per 1 m2 of agricultural area (0.5±0.2 kg CO2-eq e 2.7±1.0 g PO4-eq), and the potentially human- edible gross energy conversion ratio (HeECR, MJ feed/MJ milk). Farms using pasture and/or summer farms for lactating cows showed similar values of impact (GWP, EP) per 1 kg FPCM, significant lower ($P<0.01$) for impact per 1 m2 and for HeECR (-41%) than farms with confined cows. The results evidenced that the traditional managing options in the mountain dairy farming system (small-scale farms using pasture and summer transhumance) generally do not worsen the environmental footprint indicators but enhance the decoupling of milk production from crop production intended for direct human consumption. The analysis of botanical composition together with an interview to farm owners has been used to evaluate plant richness of the areas and the farmer perception of biodiversity. The total plant species identified were 339 belonging to 44 families and 29 phytosociological classes. The results confirm a negative relationship between floristic richness and utilization intensity. However, the negative aspects deriving from an intensive management are balanced by the floristic diversity of surfaces that, for their conformation, can only be managed extensively. The results of this study show that farmers are able to recognize the areas with greater floristic diversity but, at the same time, are not very aware of the great importance that their work plays in its protection.

The identification and quantification of these attributes allow not only to support high-quality products also in terms of social and environmental sustainability, but also to meet the expectations of tourists and consumers by adopting effective communication strategies on traditional mountain products that contribute to a lively and attractive transboundary area.

Riassunto

Da alcuni decenni i territori alpini sono caratterizzati da un progressivo abbandono delle attività agricole tradizionali e dalla difficoltà nel valorizzare i prodotti locali, fattori che mettono a repentaglio l'importante patrimonio naturale e culturale dell'area. Questo studio mira a qualificare le filiere lattiero-casearie di montagna garantendo un valore aggiunto e una informazione trasparente per i prodotti agroalimentari ottenuti in queste zone. L'approccio utilizzato, con carattere di innovatività, consiste nell'affiancare ai prodotti di montagna una serie di servizi forniti dalle stesse filiere all'intera comunità, come benessere animale, sostenibilità ambientale-contenimento delle emissioni e biodiversità-paesaggio. Il benessere animale, quando opportunamente misurato, rappresenta un valido strumento per la valorizzazione dei prodotti di montagna e dell'annesso sistema di produzione. Il protocollo di valutazione utilizzato fa riferimento alla Scientific Opinion dell'Autorità Europea per la Sicurezza Alimentare (EFSA) riguardante la valutazione del benessere delle bovine da latte nelle aziende di piccola scala. Il protocollo si basa essenzialmente su misure effettuate direttamente sugli animali (animal-based measures-ABM), le quali vengono suddivise in osservate (ABMo) e registrate (ABMr). La distribuzione delle prevalenze dei diversi indicatori di benessere è stata definita mediante raggruppamento dei dati in quartili e in soglie critiche, oltre le quali il benessere animale può considerarsi compromesso. I dati sono stati poi interpretati e discussi tramite analisi comparativa per evidenziare gli indicatori che necessitano di una maggiore attenzione in azienda e dove un intervento degli operatori è ritenuto auspicabile. I risultati generali hanno dimostrato un buon livello di benessere animale nelle aziende di montagna. Nello specifico, gli indicatori di benessere clinico hanno evidenziato una bassa prevalenza, con una mediana di scoli e zoppie gravi pari allo 0%. D'altra parte, le alterazioni del tegumento hanno superato le soglie di allarme riscontrate in precedenti studi. Le mediane erano rappresentate da 31% di animali con zone alopeciche negli arti posteriori, 14 % con zone alopeciche nel resto del corpo e 9% con lesioni e gonfiori, con valori che raggiungevano il 94%, 71% e 58% di animali.

La sostenibilità ambientale è stata invece analizzata mediante l'impronta ambientale (metodo LCA, Life Cycle Assessment) valutando sinergie e trade-offs tra indicatori e testando l'effetto della dimensionale aziendale e dell'uso del pascolo sull'impronta ambientale e l'efficienza produttiva. Gli indicatori di sostenibilità sono stati i seguenti: impronta del carbonio (CC, kg CO_2-eq), del potenziale eutrofizzante (EP, g PO_4-eq), per 1 kg di latte (1.2±0.2 kg CO_2-eq e 6.0±1.7 g PO_4-eq) e per 1 m^2di superficie agraria (0.5±0.2 kg CO_2-eq e 2.7±1.0 g PO_4-eq), e l'efficienza di conversione dell'energia grezza degli alimenti potenzialmente edibili da parte dell'uomo (HeECR, MJ alimenti/MJ latte). Le aziende con vacche in produzione al pascolo presentano valori simili di impatto (CC e EP) per 1 kg di latte, significativamente inferiori ($P<0.01$) per 1 m^2e circa HeECR (-41%), rispetto alle aziende con vacche in stalla tutto l'anno. I risultati mostrano come le aziende a gestione più tradizionale (aziende di piccola scala che utilizzano il pascolo) riescano a sfruttare in modo ottimale le risorse foraggere locali senza penalizzazioni circa la loro impronta ambientale.

In ultimo, la valutazione della biodiversità vegetale è stata valutata mediante la ricchezza vegetale delle aree e la percezione che gli allevatori hanno di essa. Sono state identificate 339 specie appartenenti a 44 famiglie e 29 classi fitologiche. I risultati confermano una relazione inversa tra ricchezza floristica e intensità di utilizzo. Tuttavia, gli aspetti negativi derivanti da una gestione intensiva, dettata dalla necessità di ottenere alimenti di qualità in quantità sufficiente ad assicurare i fabbisogni degli animali, sono bilanciati dalla diversità floristica di quegli appezzamenti che per loro conformazione non possono che essere gestiti in modo estensivo. I risultati di questo studio evidenziano che gli allevatori sono in grado di riconoscere gli appezzamenti con maggiore diversità floristica ma, al tempo stesso, siano poco consapevoli della grande importanza che il loro lavoro svolge nella sua tutela.

L'individuazione e la misura di tali servizi, unitamente ad una efficace approccio comunicativo, permette non solo di valorizzare le produzioni di qualità, ma anche di soddisfare le aspettative dei consumatori e dei turisti.

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1.Introduction

1.1 The evolution of livestock farming systems in mountain area

During the last decades, livestock farming systems in the Alpine regions have experienced a progressive intensification. According to Vliet et al. (2015) intensification usually occurs on productive agricultural land through an increase in management intensity, thus becoming scarcely sustainable as regards ecological and social attitudes, therefore also in economic terms. Conversely, extensification or abandonment is characterized by a decrease in arable land and this can usually be found in marginal areas. As a consequence, the agricultural use of more productive lowland sites has been intensified and many less-favorable agricultural abandoned, both leading to a loss of biodiversity and a decrease in the quality and attractiveness (Tappeiner et al., 2008; Zimmermann et al., 2010). In fact, this evolutionary process has led to the overcoming of traditional extensive farming systems in terms of management, level of intensification, use of grasslands and dependence on external inputs, threatening the ecological functions of the mountain agroecosystems.

Mountain livestock farming appears as a complex mosaic of food resources, animal species and native breeds as an effect of the local socio-cultural traditions. The practices carried out in these areas are often considered environmentally-friendly and landscape-preservative, and farmlands evaluated are of High Nature Value (Opperman et al., 2012). Most farms are located in less favored areas (LFAs), where low-intensity and site-specific agricultural practices – mainly based on grassland resources – have been developed to limit the risks associated with inter- and intra-annual climatic fluctuations and ensure a more regular production (Caballero et al., 2009). These geographic and climatic traits represent a limit for feedstuff production – traditionally based on forages and pastures – due to difficulties in rural mobility, scope or land fragmentation (Porqueddu, 2007). For centuries, cattle and small ruminants – able to optimize these resources – have been reared through extensive or semi-extensive systems in a typical grassland-based system, with low use of pesticides, fertilizers, concentrates and irrigation. These traditional systems are largely based on the use of meadows and pastures in order not only to produce food but to provide other important services (MEA, 2005), without the need of any external input.

As an example, mountains agroecosystems can provide food and raw materials (crops, fodder, water, fuels, wood) (Cooper et al., 2009; Briner et al., 2013b), protection and support for human health (prevention of soil erosion, climate regulation, medical plants) (Ruiz-Mirazo et al., 2011; Bernstein, 2014) or recreational and cultural experiences (Schirpke et al., 2016). Therefore, mountain areas own a social, economic and environmental importance, which is recognized through national legislation since the late 19th century (EEA, 2010). In the context of human activities, the mountain landscape has been characterized by the coexistence of livestock practices and the whole economy of this area has been driven by this coexistence (MacDonald et al., 2000), where the multidimensional aspect of "pluriactivity" has played a crucial role. However, over the last few decades, the Alps have been subjected to the contrasting threats of intensification and abandonment, with different regional trends. As a consequence of the decreasing public sector support of this marginal area, a new model has emerged, characterized by specialization and standardization in production without any added value, mechanization of work and loss of the multifunctional vocation of activities, leading to a disruption of the traditional link between livestock and grassland (Cocca et al., 2012; Battaglini et al., 2014). Local climate issues – e.g., low temperature and limited length of the crop-growing season – combined with the harsh landscape – e.g., steep slopes and less fertile soils – entail the need for complex machinery and extra labour. These results, on one hand, in a lower total production with a higher labour time than lowland farms and, on the other hand, in several limitations to agriculture, discouraging new investments. The abandoning of grasslands is not homogeneous and is concentrated in the areas characterized by lower productivity and more difficult harvesting (Tasser et al., 2007). In 2010, meadows and pastures represented approximately 800,000 ha, with a reduction of 27% over the period 1990-2010, the AA (Agricultural Area) decreased by 8%

and the UAA (Utilised Agricultural Area) by 2.3% (ISTAT, 2010). Between 2015 and 2030 this trend is expected to continue and the UAA is estimated to shrink, mainly due to conversion into artificial areas, forest and natural vegetated areas (Perpiña Castillo et al., 2018). Farms have moved from decentralized areas to more intensive ones, such as flat lands, and small and unprofitable farms have been abandoned (Giupponi et al., 2006).

According to Streifeneder et al. (2007), in the period between 1980 and 2000, the number of farms has decreased by 40%, and between 2000 and 2010, the reduction value has been of 32.2%. In some regions, as Südtiroler Berggebiet and Innsbruck Land in Austria, 37% of the lands has been abandoned. Similarly, in Carnia (northeast Italy), nearly 67% of formerly agricultural areas has been left (Tasser et al., 2007). In Austria and Germany, these changes have been rather modest, whereas in Italy, France and Slovenia they have been major. In general, the abandonment of land affected all of these countries, particularly in the peripheral regions, mountain areas and less favored areas (Lasanta et al., 2017).

Traditional farming husbandry is historical based on small herds of dual-purpose breeds for milk and calves or meat production, housed in close barns during the winter and moved to the highland pasture during the summer. This regular practice of vertical transhumance allows the optimal exploitation of natural resources matching the grazing pressure to seasonal peaks in pasture productivity, now often replaced with permanent and more specialized farms.

The increasing prevalence of high-productivity breeds and the loss of meadows have concentrated the pressure in the most favourable areas (Gusmeroli et al., 2010). Despite the reduction of animals and farms, the herd size has increased (Battaglini et al., 2014), and this transition from small-scale to larger and more specialized non-seasonal or non-pasture dairy systems has resulted in a significant decrease of high-nature-value farmlands. These new farms rear cows specialized in milk production, leading to a detriment of local breeds more adapted to the mountainous areas (Bovolenta et al., 2008). Among the several consequences for dairy farms, we must highlight the high production costs and the trivialization of products with low ability to provide an added value. The loss of the multifunctional vocation of activities does not allow diversification between common products, and the propensity of the supply chain to provide useful services to the whole community is diminished (Dumont et al., 2019). This evidence appears in stark contrast with the indications coming from a market that is increasingly attentive to the typicality and identity of products, their origin, the conditions of well-being and health of farmed animals and environmental issues in general (in particular, global warming and biodiversity).

1.2 Mountain dairy products

Products of animal origin are considered noble foods, with the primary purpose of satisfying the nutritional needs of human beings from a quantitative point of view. For many years, the agricultural sector has been focused on the objective of fulfilling quantitative demands, up to the saturation of the general food market and the consequently increasing demand for high-quality products. Therefore, at the moment, the major issues regard how to define food quality and how to satisfy the consumer requirements on improved practices and additional features. Quality is an ambiguous term and the understanding of it depends on individual preferences. The International Organization of Standardization (ISO) provides the only definition of food quality supported from different backgrounds (politics, industries, science): “the totality of features and characteristics of a product or services that bear on its ability to satisfy stated or implied needs”. This concept is directly linked to intrinsic and extrinsic factors: food consumers demand both organoleptic and extrinsic quality attributes.

Intrinsic quality has been widely developed, in particular as regards mountain dairy products, where a pasture-based system is preserved. Many studies have shown that the forage component is able to modify milk with, for example, antioxidant substances (vitamin E, polyphenols and carotenoids) (Lucas et al., 2006) or polyunsaturated fatty acids (PUFA) and conjugated linoleic acid (CLA), which are able to decrease the risk of cardio-vascular and diabetic problems (Dewhurst et al., 2006). The same applies to cheese composition, where a lower level of total saturated fatty acids (SFA) and a higher level of PUFA have been found (Romanzin et al., 2013). These characteristics can also change the sensory proprieties of products, such as color, smell, aroma and texture (Coulon et al., 2004), and this reflects at best the originality and biodiversity of the area where they are produced. Some studies have emphasized the mountain product potential as rewarding and successful in the food market chain (Schjøll et al., 2010; Baritaux et al., 2011). For this reason, European consumers are willing to give a higher value to these products than to conventional food, because they link the mountain environment to the provisioning of natural feed and raw materials; therefore, the processing takes place in an area that is not contaminated (Santini et al., 2013). To avoid the risk of selling these products as mountain-related, without a real connection to this area, the European Union has regulated the conditions for a voluntary labelling scheme of mountain food products – Regulation EU n. 1151/2012 – in order to guarantee the authenticity and contribute to the economic sustainability of the mountain area (Tosato, 2013; Sidali et al., 2015). In fact, traditional products are able to integrate the long historic culture of those communities with new opportunities for touristic facilities, thus further reinforcing the local economy (Santini et al., 2013). This quality scheme regarding agricultural and food products – EU Regulation 665/2014 – has defined the conditions of use for the previous one and has also confirmed the importance of rural areas in this context (Belladonna et al., 2015).

In this sense, the European Parliament has drawn attention to the need to enhance the mountain area by establishing the optional quality term "Mountain Product". This term aims at promoting the labelling of all animal or food products from mountain areas and offers specific indications about all the activities involved in the production and transformation process. Specific breeding conditions must also be met, e.g., how long the animals are kept in the mountain area and the origin of the fodder, as well as how the products are transformed for the market, i.e., the origin/percentage of the raw materials and the place of transformation. At the beginning of this PhD, we have tested the feasibility of this quality standard at a local/regional level.

1.3 External quality attributes of mountain dairy products

The ISO 8402 standard defined quality as “the totality of features and characteristics of a product or service”. A majority of EU consumers (65%) find benefits in buying mountain products (Eurobarometer, 2011) which are mainly associated with environmental and economic sustainability (small scale, contribution to rural economy, short circuits), although not necessarily to wholesomeness or superior quality (Schjøll et al., 2010; Tebby et al., 2010). The most surveys on consumer perceptions in this regard highlight a willingness to recognize these "external" values, particularly in the mountain product, in parallel with the value generated by nutritional, organoleptic or dietary characteristics (Leroy et al., 2018; Bernues et al., 2019; Pochaud et al., 2020).

Traditional mountain farming and livestock activities are able to generate “values” and “services” of public utility and to respond to various pressing demands of the community.

Animal welfare assessment is an ongoing challenge and several methods have been identified to assess it at herd level. The importance of animal welfare is underlined by an increasing body of science which confirms that good animal welfare is an added value opening up new trade opportunities for farmers and other actors along the value chain. Animal welfare it is an important ethical issue, and a societal value which is strongly supported by citizens and consumers across the world. It has an international policy stream with agreed international standards, under the aegis of the World Organization for Animal Health (OIE), and regional strategies for the development of animal welfare covering all continents. Animal welfare is also inextricably linked with animal health, and human health and welfare. Protecting the welfare of farm animals has various links to food safety, humane treatment of animals and it can therefore be an important factor in decreasing the spread of disease (Zuliani et al., 2016). For these values and benefits, the “One Health” approach has become a well-entrenched collaborative effort of multiple disciplines to attain optimal health for people, animals and the environment (AVMA, 2008). Increasing awareness of the importance of animal welfare across the board has now led to moves to advance a “One Welfare” approach, which emphasizes these links, and brings forth a harmonized, interdisciplinary way of working (Garcia R., 2016).

Livestock play an important role also on non-productive functions that include grassland maintenance, protection of natural and domestic biodiversity, maintenance of landscape attractiveness and custody of cultural heritage, which can be classified as “ecosystem services” (MEA, 2005). Conceptual definition of "Ecosystem Services" is relatively recent, having been formalized for the first time in 2005 with the publication of the results of the work of a large group of international experts involved in the Millennium Ecosystem Assessment (MEA, 2005). In this definition, Ecosystem Services include the "direct and indirect benefits that people obtain from ecosystems", in perspective of reconciling ecology (ecosystems and the conservation of their functions) and economy (benefits for humanity, understood in a comprehensive and not just monetary). In the original classification, these services are divided into four categories:

1. Supporting: or “support” services, include the various processes that allow ecosystems to function and thus provide other services. Examples include nutrient cycles, soil formation, photosynthesis, pollination, etc.

2. Provisioning: or "supply" services, include the "production" of materials, water and energy, including therefore those of food, water, timber, fibers, medicinal resources, minerals, etc.

3. Regulating: or "regulation" services, include benefits in terms of regulation of various processes that have positive effects, for example, on climate and carbon sequestration, on hydrogeological instability and other catastrophic events, on purification of pollutants (in waters, soils, in the air), on the control of invasive (plant and animal) species and diseases, etc.

4. Cultural: or "cultural" services, group the benefits of a scientific (research and scientific discoveries), cultural (landscapes and cultural heritage, inspiration for art, folklore, etc.), recreational (sports, hiking, observation of flora and fauna, etc.) and spiritual (sense of belonging, religious meanings) that are perceived by man in relation to the different ecosystems.

Ecosystem services in the supporting, regulating and cultural categories are often grouped as "non-provisioning" services and are "public", unlike provisioning services where all individuals can use them, and their use by an individual does not reduce their availability for others (Cooper, 2009).

This original classification was complex to make operational when trying to quantify and evaluate the various Ecosystem Services (especially the supporting ones) also economically. For this, the project of The Economics of Ecosystems and Biodiversity (TEEB, 2010) subsequently incorporated supporting services into a new category, called Habitat and supporting, which includes the services of Habitat for species and Maintenance of genetic diversity. Finally, the Common International Classification of Ecosystem Services (CICES; Haines-Young, et al., 2018), an initiative promoted by the European Environment Agency in order to standardize and hierarchically classify Ecosystem Services for their quantification and economic evaluation, considers three types of services: provisioning, regulating and maintenance, within which there is the class "maintaining nursery populations and habitats” that we can match to the Habitat and biodiversity services of TEEB, and " cultural ". In this development from the original definition of the MEA to the CICES, the effort to produce an increasingly operational classification of Ecosystem Services for the purposes of their quantification and mapping is evident. Action 5 of the EU Biodiversity Strategy to 2020 requires member states to map and assess the state of ecosystems and their services in national territories and the Mapping and Assessment of Ecosystems and their Services (MAES) initiative has produced various reports, in 2018 was published the fifth (Maes et al., 2018), containing guidelines and indicators to identify the types of ecosystems and assess their status.

Ecosystem services of supply, those of habitat and biodiversity and many of those of regulation are linked to biophysical variables, which can therefore be measured to quantify the level of service (or disservice) because the variables and scientific fields of competence (agronomy, animal sciences, ecology, botany, entomology, zoology, engineering, social sciences, etc.) are very different. Furthermore, the choice of which variables to measure to quantify a specific service is not always unique. These interactions are relevant when we intend to identify the optimal levels of compromise between synergies and conflicts between several Ecosystem Services on a territorial scale (Rodríguez et al., 2006). The quantification of the various Ecosystem Services is understandably still inhomogeneous, probably also in relation to the greater or lesser ease of measurement, and has mainly concerned extensive agro-zootechnical systems, due to the multiplicity of services they can offer. A review by Rodríguez-Ortega et al. (2014) on livestock systems based on grazing showed that, until a few years ago, by far the most studied services were biodiversity, aesthetic quality, and climate regulation, while the others were little or very little considered. In addition to the need to quantify Ecosystem Services, it is necessary to understand their perception by the various components of society and the consequent social value attributed to them, which are highly variable depending on the environmental and socio-economic contexts and the category of stakeholders considered.

Only in this way is it possible to understand the knowledge, needs, and preferences of individuals, institutions and organizations, which is necessary to guide management and enhancement policies and initiatives (Quétier et al., 2010). For this reason, the evaluation of the social value of Ecosystem Services must however be completed with the estimate of their economic value. This is complicated by the fact that many procurement services are private and have a market that determines their economic value, while non-provisioned services are public and have no direct economic value (Small et al., 2017). There are socio-economic analysis approaches that allow us to estimate the social and monetary value of market-less services, and then to compare them with each other and with those that enjoy a market (TEEB, 2010; Alfnes and Rickertsen, 2011; Liekens and De Nocker, 2013). These methodologies can easily be associated with the analysis of agrozootechnical systems and different evolution scenarios (Bernués et al., 2014; Martín-López et al., 2014; Oteros-Rozas et al., 2014; Bernués et al., 2015).

Faccioni et al. (2019) examined the socio-economic value of some Ecosystem Services associated with dairy systems in the province of Trento. The total economic value (TEV) attributed to the various services in the selected scenarios, as indicated by the willingness to pay, was equal to 159 euros per year, of which 79 (50%) for the quality of the water, 40 (25%) for the biodiversity, 35 (22%) for the landscape, and only 5 (3%) for typical products, of which probably, given the already wide offer, the population did not feel the need for a further increase. This shows how it is possible to identify the services considered most socially important, and above all to attribute an economic value to them, which is not negligible and demonstrates how, up to now, the non-provisioned Ecosystem Services have been underestimated. The concept of multifunctionality refers to agriculture as an activity that produces not only private goods (food), but also a series of public goods.

The meaning with which the multifunctionality of farms in Europe is most frequently understood is in their role of conserving the landscape and supporting the development of rural areas, including recreational and tourist activities, and of ensuring quality products linked to specific territories (Renting et al., 2009). A reduced ability to provide a wide range of the ecosystem services (ES) and cultural resources traditionally delivered by mountain dairy farms, such as biodiversity and landscape conservation, soil protection, water quality and supply, carbon sequestration, avalanche and fire protection, agro-ecotourism, outdoor recreation, rural communities' and cultural heritage (Bernués et al., 2015; EEA 2010a,b; Giupponi et al., 2006; Mirazo-Ruiz, 2011; Renting et al., 2009; Schirpke et al., 2016; Sturaro et al., 2013). The agro-eco-systems, which they have helped to create and use, make it possible to obtain food for humans and animals and, in parallel, to provide important environmental services, guarantee biological diversity, ensure an acceptable level of welfare and health of farmed animals. Identifying and measuring these benefits is important in gaining recognition from citizens in their dual capacity as taxpayers and consumers. Despite the difficulties described above, progress towards the quantification of Ecosystem Services is rapid, also thanks to the progressive evolution of innovative approaches to make the consumer more fully aware of food products and clear up their doubts (McMorran et al., 2015). Livestock play a special role in the provision of ecosystem services and are an essential part of many agro-ecosystems. Many values and services if properly performed, is a valid enhancing tool for the livestock production system and mountain products. The roles of livestock species and breeds in providing external attributes depend strongly on how people manage them and the production systems of which they form a part. Depending on how they are managed, their impacts can be positive or negative. In well-managed production systems, services outweigh disservices. The social and economic value of livestock contribution to these external attributes and good practices needs to be assessed and quantified where possible. Mapping and assessment of values and services, by development of sustainability indicators, is seen as a key action for the advancement of animal welfare, environmental and biodiversity objectives, and also to inform the development and implementation of related policies and regional planning.

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2. Aims

The PhD thesis aims to support local mountain product, especially dairy supply chain by identifying and quantifying external quality attributes provided. The study was conducted in dairy farms in Eastern Alps conferring milk to dairy companies. Animal welfare, environmental sustainability and plant biodiversity were assessed using a scientific approach specifically adapted to mountain conditions. Scientific papers were carried out within the TOP Value project "The added value of the mountain product" (Interreg VA Italy/Austria 2014-2020) together with research partners of University of Padova and Umweltbüro of Klagenfurt. The results could be used by mountain dairies as part of a communication campaign to promote the improvement of the global quality of mountain dairy products.

First paper "Welfare Assessment on Pasture: A Review on Animal-Based Measures for Ruminants" aims to compiling a list of animal-based measures of welfare for domestic ruminants raised on outdoor/extensive. The development of these tools is a very promising opportunity to record welfare measures in this mountain context, where pasture-based system is widespread.

Second paper "Animal welfare and farmers' satisfaction in small-scale dairy farms in the Eastern Alps: a "One Welfare" approach" combined the evaluation of animal welfare and farmers' satisfaction following a One Welfare approach to highlight the interconnection between animal welfare, human well-being and environment in mountain area.

Third paper "Environmental impacts of milk production and processing in the Eastern Alps: a "cradle-to-dairy gate" LCA approach" focused on the evaluation of the environmental footprint and milk energy efficiency of dairy chains, taking into account both the milk production and dairy processing phases.

Fourth paper "Biodiversity patterns of mountain grasslands as influenced by farm management" aims to monitoring the biodiversity of mountain grasslands in dairy farms, in order to find the effect of farm management on grasslands species composition.

3. Animal welfare

3.1 Welfare Assessment on Pasture: A Review on Animal-Based Measures for Ruminants

Original paper: Spigarelli, C., Zuliani, A., Battini, M., Mattiello, M., Bovolenta, S. Welfare Assessment on Pasture: A Review on Animal-Based Measures for Ruminant. 2020. Animals. 10, 609. (ISSN: 20762615, DOI: 10.3390/ani10040609)

3.1.1 Introduction

In the past half-century, animal production systems underwent a radical transformation that led to the concentration of large herds in fewer specialized intensive farms, where animals are usually kept indoors. This transformation and ultimately intensification of animal production (Fraser, 2005) fueled a public debate on farm animal welfare and humane animal treatment. In response to the consumers' growing concerns, several indicators and assessment methods were developed to allow a scientific measurement of welfare targeting indoor farming systems. Since animal welfare is a multidimensional concept (Webster, 1994), its proper assessment relies on the identification of complementary measures covering all dimensions (Broom, 1991). The quality of the environment (e.g., bedding practices) or resources (e.g., water troughs) made available to the animal assessed with resource- and management-based (RBMs and MBMs) measures are considered as indirect indicators of animal welfare. Instead, direct indicators, or animal-based measures (ABMs), assess the response of an animal to the available resources and management practices. Recently, the importance of performing dairy cattle welfare assessment using ABM and acknowledging context-based variability in welfare outcomes was emphasized by the World Animal Health Organization (OIE, 2015) and the International Organization for Standardization (ISO, 2016). The adoption of ABMs over non-ABMs is also encouraged by the European Food Safety Authority (EFSA, 2012).

In Europe, the Welfare Quality® (WQ) project (Blokhuis, 2008) was one of the most important efforts towards the development of on-farm welfare assessment protocols compiling both ABMs and non-ABMs. The scores obtained are then collated to assess unit compliance with four main welfare principles (good feeding, good housing, good health and appropriate behavior). Finally, these principle scores are used to conclude on an overall evaluation.

Results on welfare assessment carried out with the above-mentioned methodologies highlighted that intensive housing systems could be associated with many behavioral and welfare problems (Boyle et al., 2008), in contrast to pasture-based systems, which seem to be advantageous for animal welfare (Ketelaar-De Lauwere et al., 1999). For example, many studies have suggested that pasture is beneficial for cows' welfare because it leads to the reduction of hock damage, lameness and claw disorders (Leaver et al., 1988; Loberg et al., 2004; Hernandez-Mendo et al., 2007). Furthermore, grazing implies more moving activity, that can induce positive modifications of the animal's metabolism, such as a more efficient clearance of plasma triacylglycerol's, and this may have a positive effect on animals' health and longevity (Ruhland et al., 1999). In addition, outdoor and extensive farming systems allow animals to behave in a more natural way and due to all these reasons, they are often perceived as welfare friendly. Nonetheless, the natural environment poses multiple challenges to the welfare of animals (e.g., parasites, variable climate or predation), sometimes hampering their capacity to cope. Therefore, extensive farming systems may also cause poor welfare conditions if not properly managed (Bertoni et al., 2001; Mattiello, 2008). In spite of this, welfare assessment in these systems has been investigated less frequently than in intensive rearing systems, and no official assessment method has been identified for these systems, despite the growing demand for pasture-based products (Conner et al., 2008).

This study aims at carrying out a review on animal-based measures of ruminants' welfare in outdoor/extensive systems, in order to map the current available knowledge on the topic and compile an exhaustive list of established indicators for ruminants in outdoor/extensive systems that can be applied for welfare evaluation on pasture.

3.1.2 Materials and Methods

A pre-defined protocol was established using the EFSA Guidance document on the application of systematic review methodology (EFSA, 2010), which was developed considering the Cochrane Handbook (Higgins et al., 2011) and according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statement (Moher et al., 2009). A search of electronic databases (Scopus, Web of Science and PubMed) was carried out regarding ruminants' welfare assessments in extensive and pasture-based systems and focused on scientific literature published from 1980 to 2019 using the following string: cattle OR cow* OR sheep OR goat* OR ruminant* AND assess* OR indicator* AND pasture OR outdoor OR extensive OR graz* AND evaluation OR measure* OR animal-based. The search strategy of the review was defined according to the population (P) and outcome (O) format: Population: domestic ruminants (adult cattle (no calves), sheep and goats (no lambs, no kids), excluding buffalos); Outcome: animal-based measures of welfare assessed in pasture-based/extensive systems. The articles retrieved from the above-mentioned electronic databases had to meet the following criteria: (i) written in English; (ii) including only primary research; and (iii) including animal-based welfare indicators measured on pasture-based/extensive systems. All direct indicators of welfare that can be recorded either by assessors looking at the animal, or by using sensors, were considered as animal-based measures, whereas indicators deriving from laboratory analysis of biological samples (e.g., blood, milk, etc.) collected from the animals were excluded.

The software Distiller SR (Distiller (Ottawa, Ontario), an online system for systematic reviews, was used to manage study selection and data extraction by two independent reviewers. At first, results from different databases were merged, and duplicates were removed. Study selection followed two steps: initial screening of titles and abstracts answering the question "Is the paper describing animal-based indicators of welfare for ruminants on extensive/pasture-based systems?”. Discrepancies were resolved by discussion and papers in full agreement or for which content was unclear were considered for screening of full text, while excluded studies were removed from the analysis. The second screening involved the full text examination and the description of each indicator considered in the study under review. Selected data were extracted and summarized in structured tables containing all assessments, the animal-based measures, their evaluation approach (by direct assessment (DA), video and/or audio recording (R), and/or sensor (S)), and the geographic location of the study. Divergences between reviewers were resolved by consensus or by a third reviewer, if necessary. The authors of the selected articles were not contacted for clarifications on missing or ambiguous data.

3.1.3 Results and Discussion

A total of 810 articles were recovered from the search of electronic databases following the above-mentioned inclusion criteria. Following the removal of duplicates, 699 articles were retained for first screening. In the next step, 169 articles were considered for full-text reading and 52 papers (i.e., 38 on cattle and 14 on small ruminants) matched all the inclusion criteria (Figure 1).

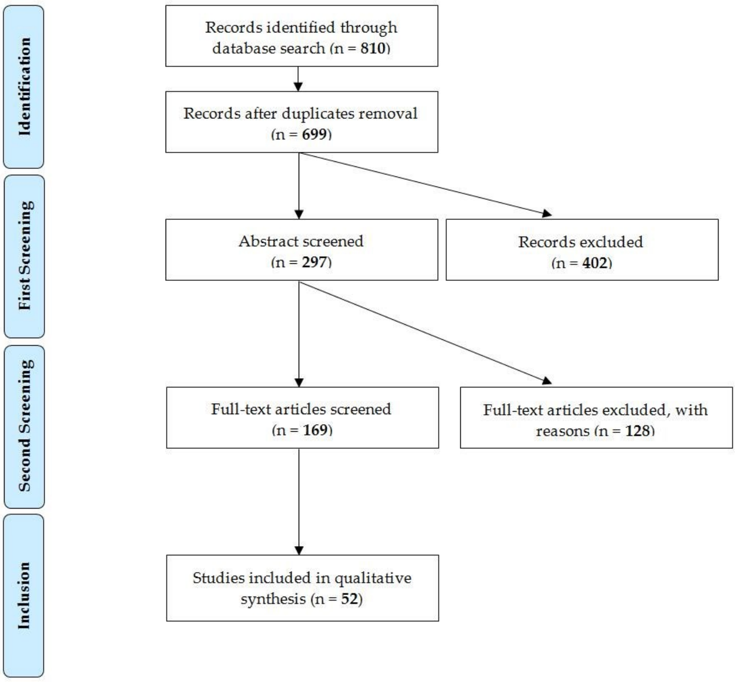

Figure 1. Flow chart of the systematic literature review process displaying exclusion and inclusion steps.

Despite the large number of papers retrieved at first screening, several were excluded from the analysis because they were assessing welfare before and/or after outdoor access (Burow et al., 2013; Magrin et al., 2016), or because they were based on the collection of biological samples such as hair (Peric et al., 2017), blood (Lima et al., 2018), milk (Veissier et al., 2018) and feces (Bovolenta et al., 2002) and thus required the use of analytical methods to define the welfare status of animals on pasture. While such ABMs also allow the collection of relevant information on animal welfare on pasture, they were not strictly speaking measured on pasture. This point was considered as a way to check the actual feasibility of each measure on pasture and to ensure the relevance of the results produced through the systematic review. For what concerns the timeframe, in spite of the fact that the search period spanned almost 40 years (i.e., 1980-2019), papers meeting the inclusion criteria were published only between 2000 and 2019, with a remarkable increase in number after 2015 (Figure 2). This may be due to the fact that outdoor/extensive farming systems were of limited interest for animal welfare scientists until recent years. In this regard, even if ABMs such as body condition were collected in early years by animal scientists, they would be described as production performance parameters using terminology that did not match our search string. It is interesting that only 25% of the studies reported in the selected papers involved the use of sensors, with a trend to increase this use in the last years, starting from 2015 (Figure 2).

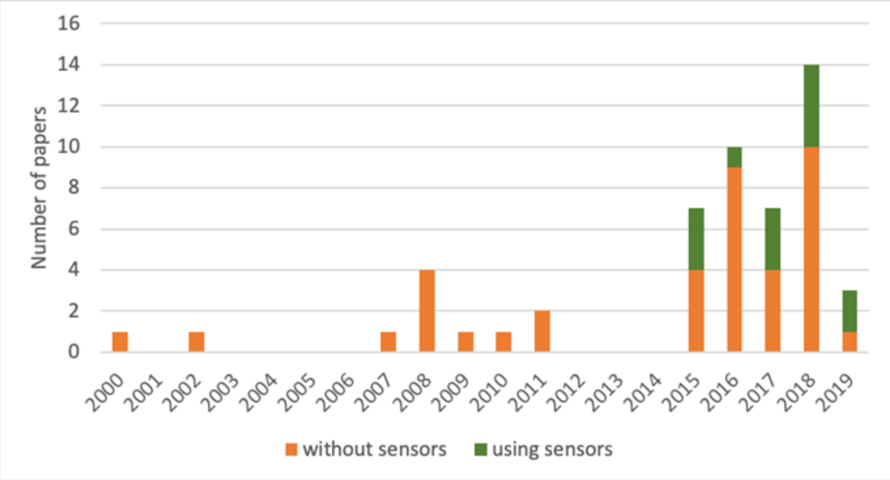

Figure 2. Total number of papers (involving or not involving the use of sensors) that met the inclusion criteria from 2000 to 2019 (no paper was retrieved from 1980 to 1999).

The indicators extracted were assigned to four principles, inspired by WQ® classification: comfort, behavior, feeding and health. The results are presented separately for cattle (including both dairy and beef cattle), and for small ruminants (sheep and goats) and separate tables were compiled for each criterion. For cattle, the production type was also specified (dairy or beef), while for small ruminants only the species (sheep or goats) was described, considering that small ruminants at pasture are mostly viewed as dual purpose animals, and therefore it was difficult to assign them to a specific production type.

3.1.3.1 Animal-Based Measures for Cattle on Extensive/Pasture-Based Systems

We identified 33 animal-based measures for cattle (Tables 1–4).

Table 1. Animal-based measures (ABMs) evaluated on cattle concerning the comfort principle.

ABMs	*Assessment*	*Unit*	*Production Type*	*Evaluation Approach 1*	*Country*	*Ref.*
Cleanliness	plaques of dirt on legs and udder	score 1–5	beef	DA	IRL	[26]
		score 1–4	dairy	DA	IND	[27]
		yes/no	dairy, beef	DA	ITA, MEX	[28,29]
	hind legs score and ventral part score	yes/no	beef	DA	COL	[30]
	degree of dirt on the body parts	yes/no	dairy	DA	MEX	[31]
Lying	duration of lying	seconds	dairy	DA	MEX, DEU	[31,32]
		min/bout	dairy	S	BRA	[33]
		min/day	dairy	S	USA, IRL	[34–36]
	number of lying bouts	bouts/day	dairy	S	BRA, USA, IRL	[33–36]
			beef	R	IRL	[26]
				S	AUS	[37]
		frequency of events	beef	DA	MEX	[38]
	lying still	min/day	dairy	S	USA, IRL	[34–36]
		hours/day	dairy	S	BRA	[33]
				DA	NZL	[39]
			beef	R	IRL	[26]
		% of time	dairy	DA	BRA	[40]
			beef	DA	FIN	[41]
				S	AUS	[37]
		% animals	dairy	DA	DEU	[32]
			beef	DA	URY, MEX	[42,43]
	hampered lying down movements	% events	dairy	DA	ITA	[44]
Resting	maintained standing or lying position	% of time	beef	DA	JPN	[45]
			dairy	DA + S	GBR	[46]
Sitting	abnormal posture with forelimbs extended	% of time	beef	DA	FIN	[41]
Standing	standing still	% of time	beef	S	AUS	[37]
				DA	FIN	[41]
			dairy	DA	BRA	[40]
		min/day	dairy	S	ITA	[47]
		hours/day	beef	R	IRL	[26]
			dairy	DA	NZL	[39]
		% of animals	beef	DA	URY	[42]
Rising	incorrect rising events, duration	% events, seconds	dairy	DA	ITA	[44]
Use of shade/shelter	time spent in shade	hours/day	dairy	DA	NZL	[39]
		% of time	dairy	S	BRA	[48]
				R	BEL	[24]
	time spent in natural and artificial shelter	% of time	beef	S	BEL	[49]

1 direct assessment: DA; recording (audio and/or video): R; sensor: S.

Table 1 displays seven ABMs concerning the comfort principle, reported in 25 papers deriving from studies carried out in all continents, and the evaluations were mainly carried out on dairy cows and by direct assessment. Most of authors evaluated cleanliness as yes–no binary rating, while only two (Hickey et al., 2002; Sharma et al., 2019) preferred to consider the animal score on a four- or five-point rating scale from clean to dirty. Hernandez et al. (2017) were the only authors evaluating animals at the milking parlor during milking all the others did it at pasture. Animal position on pasture (lying, resting, sitting or standing) was frequently assessed. Direct assessments mainly considered the time spent resting on the ground (Tucker et al., 2008) or standing still (Cruz et al., 2017), while authors who used sensors such as pedometers, mostly monitored the number of lying bouts and their duration (O'Driscoll et al., 2019). The use of sensors may be related to the difficulty of individually measuring these indicators. Time spent lying can be an indicator of welfare issues, for example lying was identified by Thompson et al. (Thompson et al., 2019) as an effective indicator of lameness in grazing systems, but the effect differs depending on both the severity of lameness and the type of lying surface. On the other hand, several authors (Wagner et al., 2018; O'Driscoll et al., 2019) found a positive influence of grazing and comfortable surfaces on lying movements and duration. Standing (O'Driscoll et al., 2019) and standing still with the head raised (Kohari et al., 2007; Williams et al., 2016) were identified as a potential warning signal for inadequate feed allocation. Concerning rising movement (Corazzin et al., 2010), the indicator is of limited importance on pasture condition as it aims at assessing the adequacy of available farm structures, even if longer rising times may be linked to feet injuries and locomotion issues similar to what was found for lying movements and duration. However, unless recorded with sensors, such indicators are extremely time consuming to collect and may be prone to observers' bias, reducing the feasibility of such indicators for welfare assessment on the pasture. Concerning sitting behavior (Tuomisto et al., 2008), it seems a rare finding on pasture and may describe a prolonged response to poor availability of on-farm resources. It is thus not considered a relevant ABM, at least for year-long grazing animals.

The use of shade or shelter was assessed as the passage of the animals to and from the water source or sun protection. Despite the great importance of shade at pasture for ensuring thermal comfort, few authors (Tucker et al., 2008; Van Laer et al., 2015; Lopes et al., 2016; Veissier et al., 2018) considered this indicator, probably because the number of trees is usually considered as a resource-based and not as an animal-based measure. Nonetheless, when access to shade was provided, cows spent less time at the water trough and laying down, and chose to perform behavioral activities, including grazing, in the shade emphasizing the benefits of silvo-pastoral systems for animal welfare.

Table 2. Animal-based measures (ABMs) evaluated on cattle concerning the behavior principle.

ABMs	***Assessment***	***Unit***	***Production Type***	***Evaluation Approach*** [1]	***Country***	***Ref.***
Vocalization	animals vocalizing	number of animals	beef	R	MEX	[43]
Qualitative behavior assessment	descriptors on a VAS scale	0–125 mm	dairy	DA	DEU, MEX	[31,32]
			beef	DA	COL	[30]
Avoidance distance test	flight distance	0–200 cm	dairy	DA	ITA, MEX	[31,44]
			beef	DA	COL, MEX	[29,30]
		0–300 cm	dairy	DA	ITA	[50]
Behavior during restraint	behavior (very calm- struggling)	score 1–5	beef	DA	BRA	[23]
Entry and exit speed	speed(walk-run)	score 1–3	beef	DA	BRA	[23]
Stereotypy	tongue-rolling	% of time	beef	DA	FIN	[41]
		% of events	dairy	DA	ITA	[44]
	bar-biting	% of time	beef	DA	FIN	[41]
	water lapping	% of events	dairy	DA	ITA	[44]
	licking objects	% of animals	beef	DA	URY	[42]
Comfort behavior	self-grooming	% of animals	beef	DA	URY	[42]
		% of time	beef	DA	FIN	[41]
		frequency, seconds	beef	DA	JPN	[45]
	grooming with trees	frequency, seconds	beef	DA	JPN	[45]
Cohesive behavior	allo-grooming	frequency, seconds	beef	DA	JPN	[45]
		frequency of events	dairy	DA + R	MEX	[51]
				R	MEX	[31]
				DA	CAN	[52]
			beef	DA	COL	[30]
		% of	beef	DA	FIN	[41]

		observations				
		animals involved	dairy	DA	CAN	[52]
		duration (min/animal)				
	playful horning	frequency of events	beef	DA	COL	[30]
		number of events	dairy	R	MEX	[31]
Explorative behavior	chewing objects (licking, gnawing, masticating)	% of time	beef	DA	FIN	[41]
Agonistic behavior	head-butts	frequency of events	dairy	R	MEX	[31]
				DA + R	MEX	[51]
			beef	DA	FIN	[41]
			beef	DA	COL	[30]
			dairy	DA	DEU	[32]
			beef	R	MEX	[29]
	feints	frequency of events	beef	DA	FIN	[41]
	displacements	frequency of events	dairy	DA	DEU	[32]
			beef	DA	COL	[30]
				R	MEX	[29]
			dairy	R	MEX	[31]
		% of time	dairy	R	BRA	[48]
	chases	frequency of events	beef	DA	COL	[30]
			dairy	R	MEX	[31]
	fights	frequency of events	beef	DA	COL	[30]
			dairy	R	MEX	[31]
	standing animals towards a standing counterpart	frequency of events	beef	R	IRL	[26]
Other activities	standing idleness	% of time	dairy	R	BRA	[48]
	lying idleness		beef	DA	MEX	[38]
			dairy	DA	BRA	[40]
	walking without grazing	% of time	dairy	DA	BRA	[40]
			beef	DA	MEX, FIN	[38,41]
		min/day	dairy	S	ITA	[47]
		number of steps	beef	S	AUS	[37]
			dairy	S	USA, ITA	[34,47]
		number of animals	beef	DA	JPN	[45]
		% of animals	beef	DA	URY	[42]
		% of time	dairy	DA + S	GBR	[46]
	cow-calf proximity	distance (m)	beef	DA	MEX	[43]

1 direct assessment: DA; recording (audio and/or video): R; sensor: S.

Table 2 summarizes the ABMs found in 21 papers related to the behavior principle to be collected in extensive conditions. From these papers, we identified 11 ABMs. Behavior principle is, indeed, characterized by a wide diversity of application, including daily activities, social interactions, human–

animal relationships, and the assessment of emotional state. Most ABMs (68.85%) are recorded by direct assessment, followed by video-recording (22.95%, that also include vocalizations collected by sound recording), and sensors (in only 8.20% of cases). The use of sensors was only limited to those papers that investigated activities such as walking (e.g., Rice et al., 2017; Campbell et al., 2017; Romanzin et al., 2018) and consists of data loggers attached to the hind legs or neck of the animals. Pedometers are not expensive and are already commonly used in many farms to record heat or to allow animals to be milked by automatic systems. Their use in extensive husbandry systems can provide information on the spatial behavior of cattle. However, more expensive sensors may be of use to investigate behaviors other than walking: spatial proximity loggers collect data on associations between cows and allow us to gather information on social networks and affiliative behaviors (Boyland et al., 2016). Cost may be a limit on the use of these sensors, but they can provide detailed information on the relationships and changes in behavior of the herd during the year.

Most behaviors are collected by direct assessment. Direct assessment can be adopted for behavioral observations and for indicators that require a test performed by humans, as in the case of the evaluation of human–animal relationships using an avoidance distance test (Mancera et al., 2018; Morales et al., 2017; Battini et al., 2011). These authors did not report any feasibility constraint; however, according to Hernandez et al. (2017), approaching animals in extensive systems may be difficult and sometimes not very informative as cattle bred in large groups in extensive systems may avoid the human touch, even if not necessarily afraid of it. The feasibility of direct assessment for behavioral observations is often low, especially in extensive/pasture-based systems: observations are usually time consuming (e.g., Tuomisto et al., 2008 up to 24 h/day), many assessors need to be trained (e.g., Blumetto et al., 2016 trained six observers), and, furthermore, information provided about inter-observer reliability is not always sufficient (Wagner et al., 2018) tested the inter-observer reliability of three trained assessors before applying the welfare protocol). The method most frequently used to record behaviors is the instantaneous and scan sampling method (Solano et al., 2018; Tuomisto et al., 2008; Blumetto et al., 2016).

Direct assessment was also used to assess animal emotions and the only indicator identified to this aim is Qualitative Behavior Assessment (QBA). Some authors (Morales et al., 2017; Wagner et al., 2018) reported more positive emotional states of cattle at pasture compared to animals kept indoors. Although QBA received some criticisms, mainly due to possible bias in judgment (Tuyttens et al., 2014) or subjectivity (Hernandez et al., 2017), it is important to notice that, when performing direct observations, observers are always unavoidably aware of the type of husbandry systems they are assessing, and this may concern both quantitative and qualitative indicators (Tuyttens et al., 2014), thus affecting their perception. However, a study conducted on dairy goats kept in indoor and pasture-based systems reported that if assessors receive an effective QBA training, this can help in overcoming the influence of an environment perceived as more “welfare friendly” (Grosso et al., 2016). The feasibility of QBA in extensive systems is high as observations last at most 20 minutes, followed by few minutes where the assessor scores the descriptors. Some situations may require the use of binoculars in order to observe the animals at a distance and avoid disturbing their activities. Video-recording for behavioral observations were mainly used to record social behaviors as cohesive and agonistic behaviors. The time of recording, when provided, is relatively limited (Hernandez et al., 2017 recorded the animals at pasture for only two hours) and sometimes influenced by factors, e.g., weather, temperature, routine changes, and animal behavior. Although the use of video-recording may increase the feasibility of an indicator, further research is needed in order to gather information on the right time for recording, including the best moment of the day to register a specific behavior and the sufficient length of the recording. Some papers included indicators already tested for indoor husbandry systems and the authors stated that they selected the most feasible indicators for extensive systems. However, valid and feasible indicators for indoor systems need to be tested again and sometimes adapted to be used in extensive systems. In most cases, insufficient information is provided about selection criteria or other useful information that can be extrapolated to suggest the use of a specific indicator for pasture-based systems.

Table 3. Animal-based measures (ABMs) evaluated on cattle concerning the feeding principle.

ABMs	***Assessment***	***Unit***	***Production Type***	***Evaluation Approach*** [1]	***Country***	***Ref.***
Body condition	BCS [2]	score 0–2	beef	DA	MEX	[29]
		score 0–2	dairy	DA	ITA, MEX	[28, 31, 44, 56]
		score 1–5	dairy	DA	IRL, BRA, IND	[27, 33, 35, 36, 57, 58]
		score 1–9	beef	DA	COL	[30]
		score 1–10	dairy	DA	NZL	[59]
Drinking	animals drinking and moving to water	% of animals	beef	DA	URY	[42]
	access to water source	number of animals	dairy	DA	MEX	[31]
		% of time	dairy	DA	BRA	[57]
	time spent drinking	% of time	beef	DA	FIN, JPN	[41, 45]
			dairy	S	BRA	[48]
Sign of dehydration	skin elasticity and enophthalmia	yes/no	beef	DA	COL	[30]
Urinating [3]	action	% of time	beef	DA	JPN	[45]
Eating	grazing and browsing	% of time	beef	DA	JPN, FIN, MEX	[38, 41, 45]
			dairy	DA + S	GBR	[46]
				S	BRA	[48]
				DA	BRA	[40]
		minutes and % of time	beef	DA + S	CAN	[60]
		hours/day	dairy	DA	NZL	[39]
				R	MEX	[51]
			beef	R	IRL	[26]
		frequency of events	dairy	DA	CAN	[52]
		% of animals	beef	DA	URY	[42]
	grazing time, grazing bites	min/day, number/day, number	dairy	S	ITA	[47]
	grazing intensity	bites/day	beef	R	IRL	[26]
			dairy	S	ITA	[47]

Rumination	ruminating (performing regurgitation and movements with the jaw)	% of time	beef	DA + S	CAN	[60]
				DA	JPN, FIN, MEX	[38, 41, 45]
			dairy	S	BRA	[48]
				DA	BRA	[40]
		min/day	dairy	S	ITA	[47]
			beef	DA + S	CAN	[60]
		% of animals	beef	DA	URY	[42]
	rumination bite, *boli*, rumination intensity	number/day, number/day, number bites/day or *bolus*	dairy	S	ITA	[47]

1 Direct assessment: DA; recording (audio and/or video): R; sensor: S. 2 BCS: subcutaneous fat stores based on visual evaluation of several body region. 3 Urinating, drinking, walking and grooming are recorded jointly as a single indicator.

Table 3 shows a total of six ABMs concerning the feeding principle, and 26 scientific papers investigating a link between these measures and animal welfare. The measurements were mainly carried out by direct assessment, while in only a few cases were sensors used. Sixty-nine per cent of the measures concerned dairy cows and the remaining 31% concerned beef cows. Latin America is the geographic area where most of the experiments were carried out.
A measure widely used to evaluate the nutritional status of animals, in particular dairy cows, refers to the amount of stored body fat. The body condition score (BCS) method (Roche et al., 2009) allows us to estimate the general body fat by means of a visual (or, less frequently, tactile) evaluation of the quantity of subcutaneous fat in certain body regions of the animal (essentially the tail head cavity, pin bones, rump, short ribs, backbone). In contrast to the measure of body weight, BCS is not affected by body size, by intestinal filling or by pregnancy status. The lowest value of the BCS indicates a very lean condition (linked to a serious underfeeding and/or a disease state), while the highest value indicates a very fat condition (linked to an overfeeding and consequent risk of metabolic diseases). Monitoring the BCS of grazing dairy cows is extremely useful and allows us to evaluate the energy balance in the various phases of the lactation cycle. Long periods on pasture with low energy intake cause an energy deficiency responsible for alterations in milk composition, milk yield and lactation persistency (Frey et al., 2018), and may be also related to reproductive performance (Pryce et al., 2001). During the grazing period, it is not always

easy to fulfill dairy cows' nutritional requirements only through grazing. The BCS therefore allows the breeder to understand if there is a need for food supplements in order to avoid hunger and nutritional imbalances. In the selected papers, several types of scores were chosen to assess the BCS as a welfare indicator of grazing animals. For dairy cows, in experiments conducted in Italy and Mexico, a score of 0–2 was used, in line with the WQ assessment protocol for cattle (Zuliani et al., 2018; Mancera et al., 2018; Hernandez et al., 2017; Corazzin et al., 2010; Comin et al., 2011), while in other countries and situations a score of 1–5 (Sharma et al., 2019; Thompson et al., 2019; O'Driscoll et al., 2015; Daros et al., 2017; Bran et al., 2018) or 1–10 (Roche et al., 2015) was used. Other authors (Morales et al., 2017) used a score of 1–9 for grazing beef cows. The review did not identify experiments that used 3D cameras to monitor the BCS of cattle in extensive situations, which may represent a promising and time-saving assessment option in the future (Mullins et al., 2019), considering the importance of body condition assessment on pasture.

In extensive systems, particular attention must be paid to water provision. Authors evaluated water utilization by using different methods: the time spent drinking (Tuomisto et al., 2008; Kohari et al., 2007; Lopes et al., 2016), the percentage and number of animals moving to water sources (Hernandez et al., 2017; Blumetto et al., 2016) rather than the access (free or limited) to the source (Daros et al., 2017). Some authors analyzed the consumption of water, through the presence of signs of dehydration on the animal (Morales et al., 2017) or by indicating the urinating actions (Kohari et al., 2007). Water provision and cow's welfare are closely connected, and climate change might further compromise animal well-being especially during the second phase of the grass vegetative stage or in geographical areas affected by droughts. Lardner et al. (2005) and Coimbra et al. (2010) underline the link between drinking behavior and body size, dry matter intake, production stage, air and water temperature, quality or type of water access. Thus, if not contextualized, the estimated daily average intake per animal at the troughs provides limited information on water requirement. On the other hand, a sign of dehydration seems a rather demanding measure to be taken in pasture-based and extensive systems, limiting the potential role of ABMs in the assessment of adequate water provision.

The evaluation of the feeding behavior of grazing cattle, in place of or in addition to the BCS, allows us to respond adequately to the feed requirements in terms of animal welfare. The availability of data regarding the feeding behavior of grazing cows allows the breeder to identify specific individual problems and act to restore the best conditions for animal welfare. In the past, these measurements were mainly carried out using visual methods (e.g., Tucker et al. (Tucker et al., 2008) with instantaneous scan sampling) and still today many authors, such as those identified in this review, adopt these rather than analytical methods which are more time consuming (e.g., Bovolenta and colleagues (Bovolenta et al., 2002; Bovolenta et al., 1998), estimating herbage intake using the n-alkane method). Grazing and rumination is positively related to feeding time and dry matter intake. Following periods of high feed intake, cows spend more time ruminating, usually after a 4-h lag. In recent years, the tools of "precision livestock farming" (Banhazi et al., 2012), adopted and developed indoors in order to optimize the use of resources and improve the productive and reproductive performance of animals, have also been proposed for the pasture environment (Andriamandroso et al., 2016), and could represent a radical change in terms of the feasibility and effectiveness of animal welfare monitoring in extensive systems. Some selected papers (Hickey et al., 2002; Williams et al., 2016; Romanzin et al., 2018; Lopes et al., 2016; Wolfger et al., 2015) have proposed electronic equipment (in particular behavior-monitoring collars, GPS devices, pedometers) for the continuous monitoring of feeding and locomotion behavior, which has proven to be efficient and reliable.

Table 4. Animal-based measures (ABMs) evaluated on cattle concerning the health principle.

ABMs	*Assessment*	*Unit*	*Production Type*	*Evaluation Approach* [1]	*Country*	*Ref.*
Lameness	lameness	yes/no	dairy	DA	MEX, ITA	[31,44]
			beef	DA	MEX	[29]
	severe lameness	yes/no	dairy	DA	ITA	[28]
	locomotion score	score 1–5	dairy	DA	IRL, USA, BRA, IND	[27,33, 40, 58, 70 ,71]
		score 1–4	dairy	DA	AUS	[72]
		score 0–3	dairy	DA	NZL	[73]
	limping of any type	yes/no	beef	DA	COL	[30]
	spine curvature, tracking, adduction/abduction, speed and head bob	score 1–5	dairy	DA	IRL	[35]
Claw alterations	heel erosion and dermatitis	score 0–5	dairy	DA	IRL	[35]
	sole thickness	millimeters	dairy	S	USA	[71]
	claw overgrowth	yes/no	dairy	DA	ITA	[28,44]
		score 1–4	dairy	DA	IND	[27]
	hoof abnormalities	yes/no	dairy	DA	BRA	[58]
Integument alterations	hairless patches, lesions, swellings/ inflammation	yes/no	beef	DA	COL	[30]
			dairy	DA	MEX, ITA	[28,31]
		number of cases	dairy	DA	ITA	[28,44]
			beef	DA	MEX	[29]
		score 1–4	dairy	DA	IND	[27]
Body alterations	open shoulder	yes/no	dairy	DA	ITA	[44]
Respiration	panting score (respiratory rate, deepness of panting, degree of drooling)	score 0–4.5	dairy	DA	BEL	[24]
	respiration rate (flank movements)	breaths/min	dairy	DA	BEL	[24]
	hampered respiration	yes/no	beef	DA	MEX, COL	[29,30]
			dairy	DA	MEX, ITA	[28,31]
Coughing and sneezing	coughs episodes	yes/no	dairy	DA	MEX, ITA	[28,31, 44]
			beef	DA	COL	[30]
		number of episods/animal/15min	beef	DA	MEX	[29]
	sneezes episodes	number of episods/animal/15min	beef	DA	MEX	[29]
Discharges	vulvar discharge	score 1–4	dairy	DA	BRA	[57]
		yes/no	beef	DA	MEX	[29]
			dairy	DA	ITA	[28,44]
	ocular and nasal discharge	yes/no	beef	DA	MEX, COL	[29,30]

			dairy	DA	ITA, MEX	[29,31, 44]
Diarrhea	diarrhea	yes/no	beef	DA	COL, MEX	[29,30]
			dairy	DA	MEX, ITA, IND	[27,28, 31]
	soft feaces	yes/no	dairy	DA	ITA	[44]
Bloat rumen	Presence bloated rumen	yes/no	dairy	DA	MEX	[31]
Parasites	ectoparasites	yes/no	beef	DA	MEX,COL	[29,30]
Body temperature	skin temperature	C°	beef	S	COL	[30]
	vaginal temperature	C°	dairy	S	NZL	[39]
	rectal temperature	C°	dairy	S	BEL	[24]
			beef	S	IRL	[26]

[1] Direct assessment: DA; recording (audio and/or video): R; sensor: S.

Table 4 displays 12 animal-based measures related to the health principle of large ruminants on pasture. Most indicators were measured by assessors through the direct observation of dairy cattle. While some measures were well-established indicators of health in indoor intensive systems and followed the WQ assessment methodology (Welfare Quality, 2009), others were specifically developed for grazing animals. For example, hoof and leg injuries, as well as integument and body alterations, represent major welfare issues for housed cattle and are among the most important reasons for culling. In particular, an open shoulder is an indicator of reduced tonicity, mostly found in pluriparous cows housed in permanent tie-stall systems and it may be an indicator of limited importance in year-round pasture-based systems. The pasture is also considered to be a protective factor against claw disorders and lameness (Hernandez-Mendo et al., 2007; Burow wt al., 2013) according to several studies that compared the occurrence of such conditions between indoor and pasture-based systems (Zuliani et al., 2018; Morales et al., 2017). Nonetheless, claw disorders and lameness do also represent a significant welfare issue in pasture-based systems, and thus should be constantly monitored. Despite no studies identified through this systematic review reporting the use of sensors, smart technologies could also play a role in the early detection of claw and locomotion disorders in grazing animals. Natural environments could also represent a risk for health and pose challenges for grazing animals. For example, diet composition cannot always be controlled in extensive systems and improper forage intake may result in gastrointestinal disorders. Signs of diarrhea, softer feces and bloated rumen were the indicators of gastrointestinal disorders assessed in dairy (Corazzin et al., 2010) and beef (Morales et al., 2017) cattle. Pasture access may also increase the risk of both endo- and ectoparasite infestation. While signs of endoparasite infestation may be assessed through body condition measurement or the observation of gastrointestinal disorders, the presence of ectoparasites was assessed through direct observation of parasites on hides or through the effects of their infestation such as skin lesions or ocular discharges (Mancera et al., 2018; Morales et al., 2017). Exposure to climate variability and extreme weather (e.g., heat waves) are a further challenge for grazing animals. Assessment of thermal stress was performed by observing respiration patterns or through temperature measurement. Unless recorded with laser thermometers as described by Morales and colleagues (2017), the measurement of body temperature appeared not suitable for beef cattle systems in which chances for animal restrain are little compared to dairy systems. In this regard, the direct observation of respiration patterns and rates may represent a better choice for all systems and production types, until new technologies will allow the remote monitoring and recording of body temperature, effectively combining the early detection of heat imbalances and disease occurrence.

3.1.3.2 Animal-Based Measures for Small Ruminants on Extensive/Pasture-Based Systems

Table 5. Animal-based measures (ABMs) evaluated on small ruminants concerning the comfort principle.

ABMs	*Assessment*	*Unit*	*Species*	*Evaluation Approach* [1]	*Country*	*Ref.*
Cleanliness	plaques of dirt on tail and perineal wool	score 0–3	sheep	DA	GBR	[76,77]
	soiling on breech and abdominal region	% of animals affected	sheep	DA	GBR	[78]
	fleece cleanliness	score 0–3	sheep	DA	AUS	[79]
Lying (excluding rumination while lying)	lying on ground with no jaw movement	% of time (total counts/min)	sheep	DA + S	GBR	[80]

[1] direct assessment: DA; recording (audio and/or video): R; sensor: S.

Table 6. Animal-based measures (ABMs) evaluated on small ruminants concerning the behavior principle.

ABMs	*Assessment*	*Unit*	*Species*	*Evaluation Approach* [1]	*Country*	*Ref.*
Qualitative behavior assessment	descriptors on a VAS scale	0–125 mm	goats	DA	ITA	[55]
			sheep	DA	GBR	[78]
Alert	vigilance episods	% of time	sheep	S	ARG	[81]
Human–animal relationship	flight distance	meters	sheep	DA	AUS	[82]
	behavior score (from calm to escape)	score 0–3	sheep	DA	AUS	[82]
Apathy (dull demeanour)	animal with lowered head carriage, showing behavioral separation from the rest	% of animals affected	sheep	DA	GBR	[78]
Walking	walking fast	% of time	sheep	S	ARG	[81]
	moving forward with the head up	% of time	sheep	DA + S	GBR	[80]
Circadian rhythms	% of harmonic/synchronized cyclic behavior	Degree of Functional Coupling	sheep	S	GBR	[83]

[1] direct assessment: DA; recording (audio and/or video): R; sensor: S.

Table 7. Animal-based measures (ABMs) evaluated on small ruminants concerning the feeding principle.

ABMs	*Assessment*	*Unit*	*Species*	*Evaluation Approach* [1]	*Country*	*Ref.*
Body condition	BCS [2]	score 1–4	sheep + goats	DA	AUS	[84]
		score 1–5	sheep	DA	AUS, ITA, GBR	[76,77,79, 82,85,86]
		score 0–5	sheep	DA	GBR	[87]
	body weight	kg	sheep	S	FRA	[88]
			sheep + goats	DA	AUS	[84]
Eating	grazing	% of time	sheep	DA + S	GBR	[80]
		% of time	sheep	S	ARG	[81]
Rumination	resting-rumination	% of time	sheep	S	ARG	[81]
	ruminating or regurgitating a bolus (standing or lying down)	% of time	sheep	DA + S	GBR	[80]
Searching food	searching for food	% of time	sheep	S	ARG	[81]
Rumen fill	evaluation of the animal's left-hand side (sunk or convex)	yes/no	sheep	DA	AUS	[79]

[1] direct assessment: DA; recording (audio and/or video): R; sensor: S. [2] BCS: subcutaneous fat stores based on visual evaluation of several body region.

Table 8. Animal-based measures (ABMs) evaluated on small ruminants concerning the health principle.

ABMs	*Assessment*	*Unit*	*Species*	*Evaluation Approach* [1]	*Country*	*Ref.*
Lameness	nodding of head, grazing on knees, uneven gait during locomotion, difficult rising, affected limb when standing	% of animals affected	sheep	DA	GBR	[78]
	locomotion score	score 0–3	sheep	DA	GBR, AUS	[76,77,79,82]
Integument alterations	skin lesions	number, location and score 1–4	sheep	DA	AUS	[82]
Cough	paroxysmal coughing, respiratory distress, breathing and wheezing	% of animals affected	sheep	DA	GBR	[78]
Pruritis	rubbing or scratching against objects, restlessness, stamping of feet, biting and nibbling	% of animals affected	sheep	DA	GBR	[78]
Wool loss	areas of fleece loss	% of animals affected	sheep	DA	GBR	[78]
Fleece	fleece condition	score 0–2	sheep	DA	AUS	[79,82]
	dag score	score 0–5	sheep	DA	AUS	[79,82]
Mastitis	physical inspection of the udder (presence of fibrosis, swelling, inflammation, abscesses)	score 0–4	sheep	DA	AUS	[82]
Tail length	tip of the vulva covered by the tail	yes/no	sheep	DA	AUS	[79,82]
Claw alterations	foot-wall integrity	score 0–3	sheep	DA	AUS	[79]
	hoof overgrowth	score 0–2	sheep	DA	AUS	[79]
	contagious ovine digital dermatitis	yes/no	sheep	DA	GBR	[76,77]
	footrot	yes/no	sheep	DA	GBR	[76,77]
	Interdigital dermatitis	yes/no	sheep	DA	GBR	[76,77]
	white line	yes/no	sheep	DA	GBR	[76,77]
	overgrown claws	yes/no	sheep	DA	GBR	[76,77]
	foot abscess	yes/no	sheep	DA	GBR	[76]
	granuloma	yes/no	sheep	DA	GBR	[76]
	interdigital hyperplasia	yes/no	sheep	DA	GBR	[76]
	injury	yes/no	sheep	DA	GBR	[76]
	joint infection	yes/no	sheep	DA	GBR	[76]

[1] direct assessment: DA; recording (audio and/or video): R; sensor: S.

For small ruminants, 20 ABMs were extracted from 14 studies carried out in Australia, the UK and, to a lesser extent, in Italy, France, and Argentina (Tables 5–8). Most of the studies (86%) were carried out on sheep, only one focused exclusively on goats (Grosso et al., 2016), and one paper dealt with both species (McGregor et al., 2008). This is probably due to the higher economic importance of sheep and to their management system, which is almost exclusively pasture-based, whereas goats are often raised in intensive or semi-intensive systems, especially in more developed countries. In most cases (71% of the articles), all the indicators were collected by direct assessment, whereas sensors were used for data collection in 21% of the studies, and in one study (McLennan et al., 2015), both approaches were adopted. The use of sensors based on omnidirectional accelerometers (McLennan et al., 2015; Di Virgilio et al., 2018; Sarout et al., 2018) was helpful for the assessment of activities related to comfort, behavior and feeding principles, and the integration with GPS devices (Di Virgilio et al., 2018) provided additional interesting and detailed results on spatial behavior and movements (that could be associated with feeding behavior), even in a very extensive context, without disturbing the animals. This is obviously much less time-consuming than carrying out direct or video-recorded observations, whose feasibility on farms can be considered quite low, due to the long observation time required to detect irregularities in behavioral rhythm that may be indicative of health and welfare issues. However, McLennan et al. (2015) suggest that the level of detail provided by accelerometer devices needs to be further improved, as in their study, high levels of accuracy could only be obtained for gross behavior categories (low vs. medium/high activity level).

It also has to be noticed that both (McLennan et al., 2015; Di Virgilio et al., 2018) present interesting methodological approaches for the collection of behavioral data using sensors, and mention the importance of monitoring behavior as a good indicator of animal welfare, but they do not provide clear indications as to how to interpret the results. Therefore, the validity of behaviors such as walking, grazing or searching for food as indicators of animal welfare has not been discussed in these studies. Within the behavior principle, the results of (Sarout et al., 2018) on the assessment of circadian rhythms of general activity using the Degree of Functional Coupling (DFC, which expresses the percentage of the measured behavior that is harmonically synchronized with environmental rhythms, over a 24-h period) provide reliable information on sheep welfare: high DFCs indicate high synchronization, which is considered a positive indicator of animal welfare (Mattiello et al., 2019).

Another interesting measure related to the behavior principle was used by Munoz et al. (2018) to investigate the quality of human–animal relationships: the ewe's response (flight distance and behavior reaction) to an unfamiliar human was evaluated in a small random sample of sheep in a holding pen. The execution of the test in the pen can be feasible; however, its validity and reliability under this specific situation have not been investigated.

As to the feeding principle, another promising application of sensors is described by the study of Gonzalez-Garcia et al. (2018), who used a remote weighing prototype based on the walk-over-weighing concept, combined with radio-frequency identification, that allowed them to record sheep body weight in extensive conditions, with no need to restrain the animals. The direct assessment of body weight was carried out by McGregor et al. (2008): these authors could not confirm the importance of live weight as a welfare indicator, but highlighted the importance of BCS, which was significantly correlated with mortality rate in Angora goats. Although not described in detail in this paper, both body weight and BCS probably implied restraining the individual animals, and were therefore time-consuming. The same time constraints apply to body condition scoring carried out by other authors (Angell et al., 2015, 2018; Munoz et al., 2018; Scocco et al., 2016a, 2016b; Morgan-Davies et al., 2008; González-García et al., 2018).

Furthermore, for other ABMs, such as cleanliness (Angell et al., 2015, 2018; Munoz et al., 2018a, 2018b) or health indicators (e.g., integument alterations, fleece conditions, or foot lesions (Angell et al., 2015, 2018; Munoz et al., 2018a, 2018b), the evaluation was carried out by assessors, and the animals had to be restrained in small holding pens to allow individual examination; for the evaluation of mastitis, restraining the animals in a crate was also required (Munoz et al., 2018). These operations were therefore time-consuming and probably induced some level of stress in animals that were not used to being handled due their extensive living conditions. In the case of Munoz et al. (2018), it is worth noticing that the selection of the individual animals to be inspected was grounded on an appropriate sampling scheme based on a power calculation assuming a 50% prevalence of the trait under observation. The selection of appropriate sampling schemes is very important, especially when dealing with large herds (as sheep often are) and when animals have to be herded for the inspection, which is a common situation in extensive farming systems. Angell et al. (2015, 2018) also included the evaluation of lameness, that was scored by a trained assessor in a holding pen, while Munoz et al. (2018a, 2018b) used a similar locomotion score but evaluated it when the sheep were released from the holding pen. Phythian et al. (2016) used a different approach for lameness evaluation in sheep, that did not require to herd the animals: a group-level assessment was performed by an assessor who briefly observed the flock at a distance for five minutes, and then counted the number of lame animals based on the observation of behavioral cues (e.g., nodding of head, grazing on knees, uneven gait, etc.), rather than assigning a lameness score as in Angell et al. (2015, 2018). Phythian et al. (2016) adopted the same practical approach for recording other ABMs: coughing, breech soiling, abdominal soiling, pruritis, wool loss, and “dull physical demeanour”.

Additionally, these authors applied a Qualitative Behavior Assessment, which only required an average time of 30 min/farm for flocks of up to 120 sheep, observed from a distance with no need to enter the field. Interestingly, some QBA descriptors were correlated with other welfare measures (e.g., the proportion of lame sheep and of sheep with “dull physical demeanour” was correlated with descriptors like distressed, dull and dejected), providing evidence of the concurrent validity of these measures. QBA was also applied on goats, using a similar feasible procedure, and highlighted interesting differences between the emotional state of goats on pasture vs. indoor housing, with a good inter-observer reliability (Grosso et al., 2016).

Additional information about the reliability of ABMs for small ruminant welfare assessment is provided by Munoz et al. (2018), who found poor agreement for rumen fill, foot-wall integrity, and hoof overgrowth, and considered fleece cleanliness not be meaningful for extensive systems. Based on these considerations, the authors suggest the use of body condition score, fleece condition (based on lumpiness or signs of ectoparasites), skin lesions, tail length, dag score and lameness for on-farm welfare assessments of extensive managed sheep, as all these measures are also feasible due to the fact that they do not require any specialized equipment. Tail length was listed as an ABM (2018a, 2018b) despite the fact that it may be considered as a risk factor for several conditions such as rectal prolapse, flystrike and bacterial arthritis. Furthermore, Munoz et al. (2018) consider that most of these measures (e.g., thin body condition, lameness and dag score) can be visually recorded from a distance viewing sheep in their paddock, rather than in holding pens, with minimal interference with farm work. This suggestion is supported by the successful collection of similar measures by Phythian et al. (2016), as reported above. Furthermore, Munoz et al. (2018) suggest that the lactation period may not be the best time to carry out the evaluation due to the presence of lambs.

3.1.4 Conclusions

This study aimed at compiling a list ABMs of welfare for domestic ruminants raised on outdoor/extensive systems by means of a systematic review. The results showed that welfare data were often collected applying different methodologies. Considering the growing interest in pasture-based or grass-fed products, and not neglecting the role of suitable structures or management, it is suggested that welfare assessment in outdoor/extensive farming systems is carried out with selected ABMs following shared approaches, to provide evidence for the higher animal welfare claims that these products often imply. In addition, the use of sensors has become more and more common in recent years. The development of these tools is a very promising opportunity to record welfare measures in extensive/pasture-based systems, where it is often difficult to have direct and close access to the animals, and where the collection of individual records might require time-consuming and potentially stressful operations, such as herding and restraining. It is probably not a coincidence that the number of these studies has increased since 2015, when the use of sensors became more common. Furthermore, sensors do not require the presence of an observer, which can bias the results of the assessment. It is expected that in the future, the tools of "precision livestock farming" adopted and developed for indoor systems will be extensively applied to pasture-based systems in order to further improve the productive and reproductive performance of animals, together with their health and welfare.

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3.2 Animal welfare and farmers' satisfaction in small-scale dairy farms in the Eastern Alps: a "One Welfare" approach

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3.2.1 Introduction

Farm animal welfare is an ever-evolving multidimensional concept, not easy to define and evaluate (McCulloch, 2013), however public awareness of this issue has progressively increased in recent decades (von Keyserlingk and Weary, 2017). Animal welfare as a 'formal discipline' started with the publication of the "five freedoms" proposed by the Brambell Report (1965). Much progress has since been proposed. Broom (1996) linked animal welfare to the attempts to cope with the environment and Webster (2005) introduced also the concept of physical and mental health. Furthermore, Fraser (2008) focused on the possibility that animals suffer from the mere fact of being kept under "unnatural" conditions. A very large amount of research has been carried out about animal welfare, particularly working on the development of welfare assessment methods in different environments (Carenzi et al., 2009). Many of these research findings contributed to the assessment protocols produced by the Welfare Quality project (Welfare Quality®, 2009), the largest study carried out in the EU to develop scientifically based measures for farm animal welfare and to convert these into accessible and understandable information (Blokhuis et al., 2010). The Welfare Quality assessment protocol combines animal-based, resource-based and management-based measures in order to distinguish four principles -good feeding, good housing, good health and appropriate behavior - and identify an overall level of welfare. While Welfare Quality protocol is the basis of the most recent assessment methods used in Europe, it is mainly suited for indoor and intensive livestock farming systems and the proposed measures are often very difficult to collect in extensive and small-scale farming systems as in mountain area. For this reason and in order to address the lack of information regarding animal welfare in these contexts, the European Food Safety Authority (EFSA) published a scientific opinion on the feasibility of current welfare assessment methods in so-called “non-conventional small-scale dairy farming settings” (characterized by e.g., maximum 75 lactating cows, local breeds, family-run farms) (EFSA, 2015). One of the outcomes of the scientific opinion was a protocol that relies mainly on animal-based measures (ABM) for the evaluation of well-being and not on the changing housing and management strategies that characterize these livestock systems. The approach has also been used by the World Organization of Animal Health (OIE, 2015) and by the International Standard Organization (ISO, 2016). Mountain farms represent one example of small-scale livestock farming (Zuliani et al., 2017), where animal welfare assessment can be carried out on-farm (Burow et al., 2013; Andreasen et al., 2013) but also at pasture (Wagner et al., 2018; Spigarelli et al., 2020). In mountain regions, livestock farming has traditionally been of great importance for the vitality of rural economies (Wymann von Dach et al., 2013, Zuliani et al., 2021). Livestock systems help to shape mountain landscapes providing ecosystem services (Bernués et al., 2014). In the Alpine region, mountain farming has profoundly changed during the recent decades as a consequence of dissimilarities in local polices and socio-economics conditions. As reported by Battaglini et al. (2014) farm abandonment in unfavorable locations versus intensification of farm operations in favorable sites has often weakened the link between livestock, breeders and grasslands resources. Farmers’ knowledge, attitudes, skills and familiarity with livestock are important, but broader aspects, such as job motivation and satisfaction, working conditions and rules, relationship with co-workers and the wider community, play a key role in viable farming (Coleman & Hemsworth, 2014). Farming is considered a stressful occupation because of its workload, financial difficulties, overwhelming administrative procedures and new regulations (Hansen et al., 2019; Kolstrup et al., 2013). In addition, dealing with unfavorable weather (Fennell et al., 2016) as well as lack of understanding from non-agricultural community are also among stressors reported (Hansen, 2019). Some research has also highlighted the importance of loneliness and geographical isolation as sources of stress since farmers have even fewer opportunities and means to control external factors (Karasek et al., 1979; Kolstrup et al, 2013). It has been suggested that farmers job satisfaction and motivation may have also high influence on an animal's welfare status (Anneberg et al., 2019). A recent Canadian study reports the associations between animal welfare outcomes and productivity and profitability of farming (Villettaz Robichaud et al., 2019). The recognition of the link between animal and human welfare has paved the way to the development of the "One Welfare" approach (Garcia Pinillos, et al., 2016) as an interdisciplinary concept of welfare. This approach helps to empower the animal welfare and human wellbeing fields to address the connections between science and policy more effectively in various areas of human society, including environmental science and sustainability (Garcia Pinillos et al., 2017). Considering the proposed "One Welfare" framework , this study aims to investigate the relationship between animal welfare outcomes, farmers' satisfaction and the overall farm performance in small-scale dairy farms in Eastern Alps.

3.2.2 Material and Methods

3.2.2.1 Farm characteristics, animal welfare assessment and farmers' satisfaction

The study was conducted in 69 dairy farms in Eastern Alps conferring milk to dairy cooperatives: Friuli Venezia Giulia (n = 20), Veneto (n = 17), Trentino Alto Adige (n = 12) in Italy and Carinthia (n = 20) in Austria. Mountain farms involved were members of the Breeders association and took part to the milk recording programme. Farms were selected based on the main characteristics of the small-scale farms as listed by EFSA (2015). During the first visit, the farmer was interviewed to retrieve data on farm characteristics and farm records. Data collection focused on the information regarding farmers' age and farm descriptors, in particular: the presence of product quality schemes (Reg. UE 1151/2012 and/or Reg. UE 834/2007), type of housing systems (loose-housing or tie-stall), farm production (i.e. kg FPCM, milk corrected to standard contents of 4.0% fat and 3.3% protein), milk price (€/kg excluding VAT), income from milk production on total income (% of total), stocking rate (LU/ha UAA), forage and feed self-sufficiency (%). During the second visit, animal welfare assessment was performed on 1584 cows during fall/winter seasons when all animals were in barn. The assessment protocol for Animal Based Measures (ABM) of welfare followed the aforementioned methodology proposed by EFSA for small-scale dairy farms (EFSA, 2015). The EFSA protocol differs from the Welfare Quality protocol as regards to some measures: record of coughing episodes was removed from the protocol as the EFSA working group considered the evaluation of this measure too time consuming. Instead, two additional measures were added as they were considered to be relevant for small scale systems: longevity (expressed as the percentage of cows in the fourth lactation or higher) and claw condition (classified in "good condition" or "overgrown"). The measure regarding ocular discharge was redefined by adding a new category (i.e. distinguishing between serous and purulent ocular discharge) and teats were considered separately from the rest of the udder when scoring for soiling. All ABMs were divided into ABMs observed (ABMo) and ABMs recorded (ABMr) from milk records. The former included body condition score (BCS), soiling, integument alterations (hairless patches, lesions, swellings and claw overgrowth) and clinical conditions (lameness/severe lameness, ocular discharge, nasal discharge, vulvar discharge, hampered respiration and diarrhea).

In terms of behavioral measures, Qualitative Behavior Assessment (QBA) and Avoidance Distance at the Feeding place (ADF) were collected. For QBA, 20 behavioral descriptors were weighted and aggregated into a QBA index ranging from 0 to 100 by computing the weighted sum described in Welfare Quality® (2009). The ADF was measured by assessing the flee distance in cm. Only the number of animals that were touched was collected. The ABMr aimed at retrieving information on longevity, incidence of downer cows, dystocia, sudden deaths or emergency slaughter/euthanasia (i.e. 'mortality') and milk somatic cell count (SCC > 400,000 cells/mL) from milk records during a "12-month-period". Animal-level measurements were collected according to WQ guidelines for sample size calculation. In order to describe the level of farmers' satisfaction, the participants were also asked to answer five questions based on a Likert scale (1=extremely unsatisfied - 5 =extremely satisfied) (Sullivan et al., 2013). The questions concerned: the perception about the amount of work (WL; question: is the work load a problem?), the land organization (LO; question: are you satisfied with the land organization of your farm?), the relationship with the non-agricultural community (RNAC; question: are you satisfied with the relationship with the municipality and the population?) or agricultural community (RAC; question: are you satisfied with the relationship with local economic operators and other farmers?) and finally the future of local agriculture (FA; question: how will the future of agriculture be for you here?).

3.2.2.2 Data analysis

Data were analyzed using R software (3.4.0 version, R core team, 2017). Prevalence were computed or all animal-based measures collected to identify critical or achievable levels applicable to small-scale mountain dairy farms (de Vries et al., 2013). Welfare variables were classified according to their position on the curve. To each quartile was assigned a value between 1 and 4, where 4 represents the highest level of welfare. Excluding ADF, QBA and longevity (assigned in increasing manner), values were sorted in a decreasing manner: the first quartile (low ABM prevalence) with a high welfare value (4) and in the last quartile (high ABM prevalence) a low welfare value (1). The overall animal welfare index was the result of the sum of all assigned values. The differences among the response categories related to farmers' satisfaction were assessed with exact multinomial test, post-hoc exact binomial tests with Holm correction for pairwise comparisons were also performed.

In order to explore the relationship between farmer' satisfaction and the variables describing farms characteristics, the Principal Component Analysis (PCA) was used. For this purpose, the levels of farmers' satisfaction based on a 5-points Likert scale were grouped into three categories: unsatisfied (low, Linkert scale 1 and 2), neutral (medium, Linkert scale 3), and satisfied (high, Linkert scale 4 and 5). Farm characteristics included in analysis were presence of quality certification scheme, type of housing systems, feed self-sufficiency and forage self- sufficiency, age of farmer, dairy income, stocking rate, milk yield and milk price. Only the components with eigenvalues greater than 1 were retained in the analysis. PCA was carried out with PCAmixdata package (Chavent et al., 2014) that allowed to consider both continuous and categorical variables, and also the PCArot function was considered in order to evaluate the possibility to improve the clarity of the data interpretation (Chavent et al., 2012).

3.2.3 Results and Discussion

3.2.3.1 Farm characteristics

The heterogeneity of farms sampled was representative of the dairy systems in Eastern Alps as reported by Sturaro et al. (2013) in terms of breed, productivity, available technology and market innovation. Descriptive statistics were generated for all variables in Table 1.

Table 1. Characteristics of dairy farms involved (n=69).

Explanatory variable	**Min**	**25 Perc**	**Median**	**75 Perc**	**Max**
Age of farmer (year)	21	35	45	55	73
Lactating cows/farm (n.)	4	13	22	30	70
Farm elevation (m a.s.l.)	280	604	776	969	1375
Milk production (kg FPCM)	3758	6483	7468	8699	10336
Milk price (€/kg)	0,32	0,40	0,46	0,56	0,82
Dairy income (% of total)	20	50	80	100	100
Forage self-sufficiency (%)	45	65,8	69,6	87,9	100
Feed self-sufficiency (%)	33	55,3	61,0	79,6	95,2
Stocking rate (LU/ha UAA)[1]	0.50	0.85	1.21	1.72	4.14

[1] Livestock Unit/Utilised Agricultural Area

As shown in Table 1, the median farmer's age was 45. Age potentially influences values, farming objectives, past management decisions, and future intentions. For Brown et al. (2019) the age range 40-49 is normally related to a lower willingness to take on-farm risks compared to younger age ranges. Milk yields have increased substantially over recent decades (IFCN Dairy Research Network, 2017). The most prevalent breed was Simmenthal and the majority of farms had a total annual milk yield/cow between 6000-8000 kg in accordance with the average milk production levels of Simmenthal breed (Perišić et al., 2009). Few farms breeding Holstein differed for milk yield (over 8000 kg per year) (Franzoi et al., 2019). Milk price ranged between 0.32 and 0.82 euro/kg because of the great variability among the regions in their economic and policy condition. For the majority of farmers, the income was exclusively or almost exclusively from farming, while for few farmers their income was based on other sources such as forestry and/or tourism. In this study cows were mainly housed in loose-housing systems, only 26 farms had tie-stall system. Mattiello et al. (2005) reported that older farmer usually own old structures and in this case, younger farmers had mostly loose-housing system. 78 % of farms were characterized by none certification, only 1 farms with TSG (Traditional Specialities Guaranteed) quality scheme for hay milk production, and 14 followed the organic farming practices. Even if labeling of food products is essential to inform consumers on mountain products, often requires high costs.

Therefore, dairies companies develop their own products as high-quality niche products, linked to the qualities of mountain environments and their methods of production, but often without a quality scheme. The majority of farms were forage self-sufficient. The median prevalence of self-sufficiency was 69,6 % with 33 farms higher than 90%; only 10 rely mostly on external inputs. Most farms had feed self-sufficiency levels greater than 50%. The feeding strategy of mountain farms, which focuses on a maximum utilization of forage, results in a high feed self-sufficiency. Increasing input self-sufficiency is often viewed as a target to improve sustainability of dairy farms similarly to stocking rate of LU/ha UAA ratio <2 (met by 80% of farms involved). As mentioned by Berton et al. (2021) farms with a lower stocking rate made greater use of pastures and less use of concentrates than farms with a higher stoking rate. Penati et al. (2013) argued that enhancing feed self-sufficiency by increasing mountain pasture exploitation, can be a suitable strategy in order to reduce the environmental impact of dairy farms. Preserving the self-sufficiency and the traditional forage-based systems can have positive effects on landscape quality and biodiversity, as well as on the conservative functions of managed areas (Streifeneder et al., 2007, Bernués et al., 2011).

3.2.3.2 Animal welfare assessment

Summary statistics for ABMo and ABMr are given in Table 2.

Table 2. Prevalence of animal-based measures (ABMs) observed or retrieved from farm records in 69 alpine dairy farms.

ABMs	**Min**	**25 Perc**	**Median**	**75 Perc**	**Max**
Very Lean	0	0	3	7	69
Dirty Legs	0	6	18	50	88
Dirty Teats	0	0	6	14	75
Hairless Legs	0	17	31	50	94
Hairless Body	0	6	14	32	71
Lesions and Swellings	0	3	9	17	58
Nasal Discharges	0	0	0	0	10
Ocular Discharges	0	0	0	3	38
Vulvar Discharges	0	0	0	0	8
Hampered Respiration	0	0	0	0	6
Diarrhoea	0	0	0	0	44
Severe Lameness	0	0	0	7	53
ADF[1]=0	10	69	81	92	100
QBA[2]	0	28	48	67	89
Longevity	0	20	29	38	78
Dystocia	0	0	0	4	18
Downer	0	0	0	6	22
SCC[3] > 400.000 cells/mL	0	4	8	12	29
Mortality	0	0	0	4	13

[1]Avoidance Distance at Feeding place.
[2]Qualitative Behavior Assessment; 3Somatic Cell Count.

The results showed a low prevalence of very lean cows on most farms. In fact the median prevalence of lean cows was 3%, the third quartile had a prevalence from 7% up to 69%. Higher prevalence were observed by Peric et al. (2017) and Corazzin et al. (2010) in transhumant systems in Eastern Alps. Dirtiness indicators and their median values (18% and 6% for legs and teats respectively) suggest that cows were clean in contrast to the findings reported by Zuliani et al. (2018) in similar conditions. Leg and most importantly teat cleanliness play a key role in preventing health and production issues, such as mastitis, high SCC in milk, and lameness (Cook, 2002; Breen et al., 2009). In fact, median prevalence of cows with high SCC count and severe lameness were also low (8% and 0%). On the other hand, the prevalence of integument alterations (hairless patches, lesion or swelling) on both legs and body was lower of what reported by Popescu et al. (2013) in tie-stall housing but higher compared to alterations on pasture (2018) . This may reflect the effect of certain environments where collisions are more likely to occur. In fact, median values were 31% of animals with hairless legs, 14 % with hairless body and 9 % of lesions and swellings with maximum values that also reached 94%, 71% and 58% of affected animals. Few cases of nasal, vulvar, ocular discharges, hampered respiration, diarrhea were observed. The median prevalence of discharges were 0%, except for the upper 25% of the farms with values from 3 to 38% of animals with ocular discharge. Similar results were obtained in several studies both in indoor systems with access to pasture (Coignard et al., 2013; de Vries et al., 2013) and outdoor farming systems (Zuliani et al., 2018). Regarding ADF assessment, the results showed a median prevalence with the 81% of animal touched and QBA index a median of 49 when range was from 0 to 100. Human-animal relationship and the emotional state of the animals were in line with previous findings describing a better status in small-scale and tie-stall systems compared to intensive and loose-housing farms (Mattiello et al., 2009; Zuliani et al., 2017). The prevalence of animal-based measures retrieved from milk or farmers' records (longevity, dystocia, downer cows and mortality) may be linked to the good clinical findings. In fact, low prevalence of severely lame cows, mastitis and problems at calving might have contributed to higher longevity (median was at 29% of animals above the third lactation).

3.2.3.3 Farmers' satisfaction

Overall, farmers showed highly variable levels of satisfaction concerning WL and FA with a similar percentage of respondents being satisfied and unsatisfied ($P>0.05$; Table 3). Conversely, for LO, RNAC and RAC farmers who were satisfied outweighed those who were unsatisfied. In particular, concerning LO, nearly 40% of farmers were extremely satisfied, a much greater percentage than that observed for extremely and slightly unsatisfied ($P<0.05$). No farmers were extremely unsatisfied with RNAC, and the percentage of extremely satisfied farmers was higher than the percentage of slightly unsatisfied farmers ($P<0.05$). Overall, farmers were also particularly satisfied with RAC, indeed the percentage of respondents who were slightly or extremely satisfied were significantly higher than the percentage of respondents who were slightly or extremely unsatisfied ($P<0.05$; Table 3).

Table 3. Farmers' satisfaction (frequency, %) in relation to different issues.

	Issues				
	WL	LO	FA	RNAC	RAC
Extremely unsatisfied	15.9	10.1^{a}	11.6	0.0^{a}	4.4^{a}
Slightly unsatisfied	20.3	8.7^{a}	21.7	13.0^{b}	4.4^{a}
Neutral	30.4	14.5^{ab}	29.0	21.7^{bc}	13.0^{ab}
Slightly satisfied	15.9	29.0^{ab}	23.2	26.1^{bc}	30.4^{bc}
Extremely satisfied	17.4	37.7^{b}	14.5	39.1^{c}	47.8^{c}
P-value	0.330	<0.001	0.148	<0.001	<0.001

[a,b:] Within column, values with different superscript letters differ at $P<0·05$; WL: amount of work; LO: land organization; RNAC: relationship with non-agricultural community; RAC: relationship with agricultural community; FA: future of local agriculture.

In order to visualize and explore the relationships between farmers' satisfaction and farm characteristics, PCA were performed. As showed in Figure 1 and 2, the principal components that showed the highest correlations with farmers' satisfaction and that were able to discriminate between satisfied and unsatisfied farmers explained a limited percentage of the total variance. The variables related to farms characteristics are moderately associated with these principal components. In other words, in general, the possibility to explain the differences in the categories of satisfaction of the respondents with the variables considered is often limited. Flores and Sarandon (2004) explained that farmers' satisfaction is strongly contributing to the overall sustainability of livestock farming. Coughenour and Swanson (1988) found a connection between satisfaction and farmers' perceptions of the economic and non-economic rewards of farming. However, Herrera et al. (2018) observed that the joint effect of farm-level variables such as working hours, age of assets, social engagements was able to explain less than 20% of the variance of the farmers' satisfaction.

WL is mainly linked to the second component (14% of the variance explained; Figure 1) with a squared loading (SL) of 0.36. WLh is discriminated by WLl mainly by farm certification (SL: 0.74) and housing system (SL: 0.36). In particular, WLh is associated with tie-stall not-certificated farms. The satisfaction about WL seems complex. It could be expected that the highest satisfaction could be associated with more free time for the farmer. Reissig et al. (2016) showed higher workload in organic certified than conventional no certificated farm. However, the association between WLh and tie-stall farms did not confirm this hypothesis. Indeed, Poulopoulou et al. (2018) reported in mountain farms a total working time requirement of 177 and of 113 manpower hours per cow and year in tie stall and loose housing systems, respectively. On the other hand, tie-stall farms are smaller in size and thus might be perceived as easier to manage. In addition, tie-stall farms were mainly owned by older farmers which might be more used to the traditional hardworking routine of dairy farming and perceive it as satisfying.

LO is mainly linked to the third component (12% of the variance explained, Figure 1) with a SL of 0.46. LOh is discriminated by LOl on the third component mainly by animal welfare (SL: 0.68) to which is positively associated. Land organization is a debated issue at mountain level, due to the strong land fragmentation affecting these areas (Sturaro et al., 2013). It is possible that farmers satisfied with LO had more time to spend in animal care.

FA is mainly linked to the second component (15% of the variance explained, Figure 1) with a SL of 0.43. FAh is discriminated by FAm and FAl on the second component mainly by farm certification (SL: 0.69) and housing system

(SL: 0.41). In particular, FAh is associated with certificated and loose-housed farms. Loose-housing is perceived as more natural for the animals than tie-stall and thus increasing social acceptance of farming (Kühl et al., 2019). On the other hand, also quality scheme certification is associated with social benefits (Bouttes et al., 2020; Meemken et al., 2020). Surprisingly, FA is related to lower milk price (SL: 0.14). Mzoughi (2014) highlighted that not only financial but also social compensation and recognition is essential for the satisfaction of the farmers. The above-cited authors explained that farmers try to reach personal satisfaction and recognition also by adopting and certifying ecologically-friendly practices.

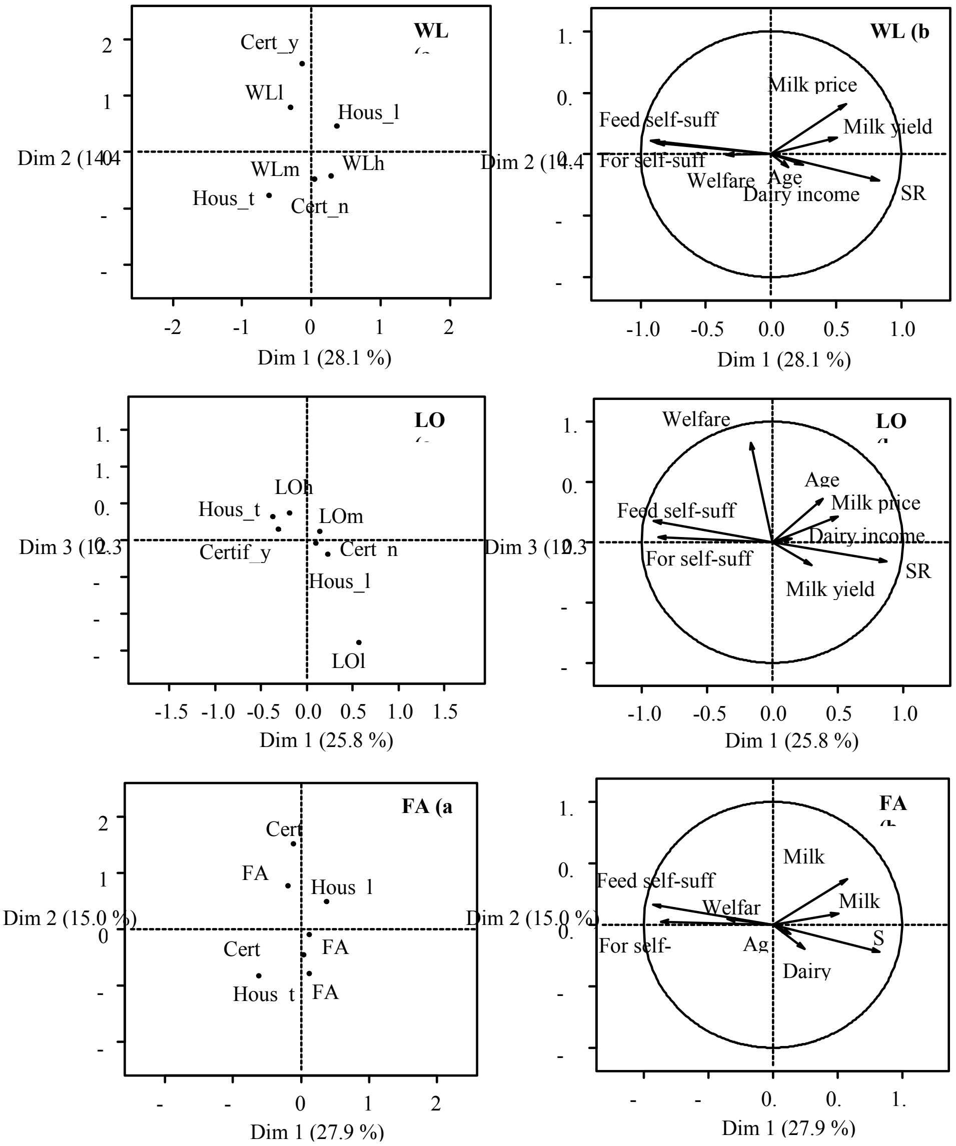

Figure 1. Results of the PCA analysis for the variable related to farmers' satisfaction (h: satisfied, m: neutral, l: unsatisfied) related to WL (amount of work), LO (land organization), and FA (future of local agriculture); a: component map with factor scores of levels; b: component map with factor scores of numerical variables. Cert_y: farms with a certification; Cert_n: farms without certification; Hous_t: tie-stall barn; Hous_l: loose housing farms; Feed self-suff: feed self-sufficiency of farms (%); For self-suff: forage self-sufficiency of farms (%); Welfare: index of animals welfare (points); Age: age of the farmer (years); Dairy income: farm incomes related to the milk production (%); SR: stocking rate (LU/ha UAA); Milk Yield: milk produced per animal per year (kg FPCM); Milk price: market price of the milk (€).

RNAC is mainly linked to the fourth component (12% of the variance explained, Figure 2) with a SL of 0.60. RNACh is discriminated by RNACl and RNACm on the fourth component mainly by animal welfare (SL: 0.57) with which it was positively related. RAC is mainly linked to the third component (12% of the variance explained, Figure 2) with a SL of 0.48. RACh is discriminated by RACm and RACl on the third component mainly by age of the farmer (SL: 0.30) and animal welfare (SL: 0.25) with which it was positively related. High satisfaction related to both RNAC and RNC is positively linked to animal welfare confirming that positive social engagement has an effect on animal care attitudes and practices.

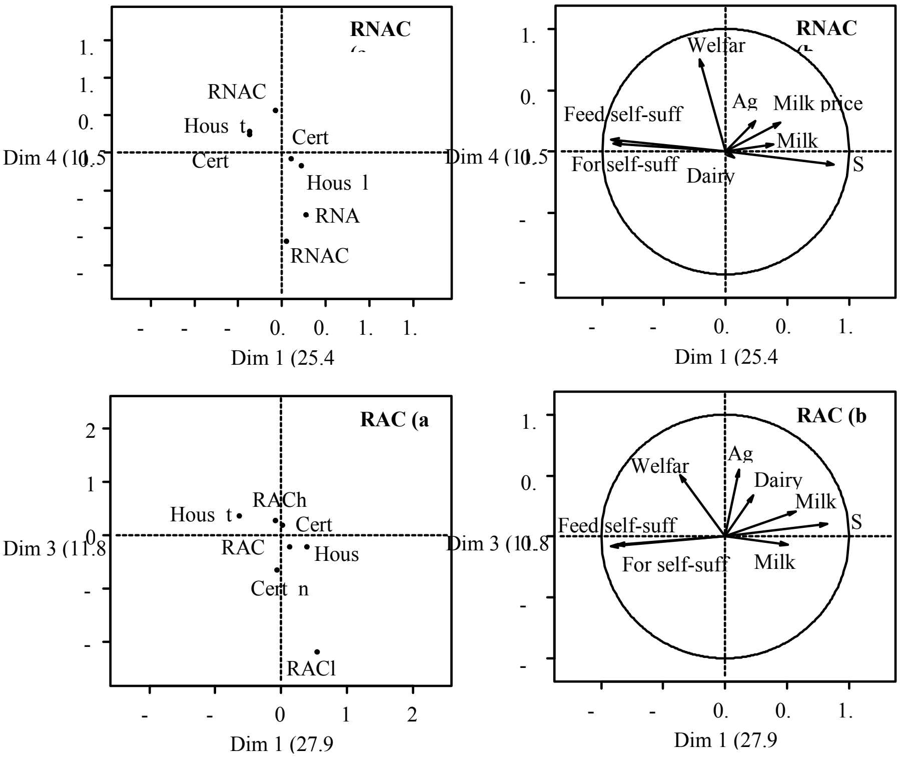

Figure 2. Results of the PCA analysis for the variable related to farmers' satisfaction (h: satisfied, m: neutral, l: unsatisfied) related to the relationship with the non-agricultural (RNAC) and agricultural community (RAC); a: component map with factor scores of levels; b: component map with factor scores of numerical variables. Cert_y: farms with a certification; Cert_n: farms without certification; Hous_t: tie-stall barn; Hous_l: loose housing farms; Feed self-suff: feed self-sufficiency of farms (%); For self-suff: forage self-sufficiency of farms (%); Welfare: index of animals welfare (points); Age: age of the farmer (years); Dairy income: farm incomes related to the milk production (%); SR: stocking rate (LU/ha UAA); Milk Yield: milk produced per animal per year (kg FPCM); Milk price: market price of the milk (€).

3.2.4 Conclusions

Despite the heterogeneity in the characteristics of the mountain small-scale dairy farms involved in this survey, the results displayed a general good level of animal welfare. Farmers are generally satisfied and in particular on land organization and their perceptions of agricultural and non-agricultural community. Animal welfare is higher in those farms were farmers have a positive engagement with both the agricultural and non-agricultural community and in those where farmers are satisfied of their land organization. These outcomes in a One Welfare perspective could be part of a communication campaigns to promote to enhance the global quality of mountain dairy products. Moreover, this approach could be applied at a larger scale to fully understand links between animal and human wellbeing in mountain areas.

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4. Environmental Sustainability

Environmental impacts of milk production and processing in the Eastern Alps: a "cradle-to-dairy gate" LCA approach

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4.1 Introduction

The European Union is one of the most important contributors to the global production of dairy milk, with a yield of almost 160 million tons in 2018, about 10% of which is produced in mountain areas (European Commission, 2019). In Italy, the 12,000 dairy farms located in mountain areas account for almost 43% of all dairy farms and 14% of total milk production (ISMEA, 2019). Alpine dairy farms account for nearly 40% of the milk produced in Italian mountain areas (ISMEA, 2019) and often belong to cooperative dairies producing high-value local and Protected Designation of Origin (PDO) cheeses (Battaglini et al., 2014). In the last decades, traditional Alpine dairy systems comprising small-scale, grassland-based farms, have experienced a strong decline driven by technical, social and economic factors (Strijker, 2005; Tasser et al., 2007). The Alpine dairy sector is now charachterized by a wide variation in farming systems, with small-scale, low-input traditional farms coexisting alongside recently established, large-scale, intensive farms (Sturaro et al., 2009, 2013). At the same time, dairy production chains have to deal with new social and policy demands, such as the increasing awareness of environmental issues characterising consumers' buying patterns (Feldmann and Hamm, 2015), the general concern for global climate change (Feucht and Zander, 2017), and the ongoing implementation of environmental criteria under the EU common agricultural policy (CAP) (Erjavec and Erjavec, 2015). This situation is particularly challenging for mountain dairy systems, which operate under tougher production conditions and run a greater risk of low profitability than lowland dairy systems (Bazin, 1995). Therefore, proactive actions are needed to place them in a favourable position with respect to consumers' opinions, market prices and the CAP. Fundamental requirements to achieve this will be the ability to mitigate their environmental impacts and to better integrate production systems with territorial resources (Ripoll-Bosch et al., 2014; Rivera-Ferre et al., 2016).

Life Cycle Assessment (ISO, 2006) is a commonly used method for evaluating the environmental impacts of a product throughout its life cycle, i.e., from the sourcing of its raw materials to its disposal. Most LCA studies evaluating the environmental footprint of milk production have considered only one impact category, i.e., global warming potential (GWP, expressed as kg CO2-eq/kg of milk) in lowland intensive farming systems (see Baldini et al., 2017 for a review). These studies agree in recommending increasing milk yield and feed energy conversion ratio (MJ in the feedstuffs needed to produce 1 MJ of milk) to reduce the GWP of dairy farms (e.g., Gerber et al., 2011). Mountain - and in particular Alpine – dairy systems have been less studied (Penati et al., 2013; Guerci et al., 2014; Salvador et al., 2016, 2017; Berton et al., 2020), but they are generally at a disadvantage compared with intensive lowland systems both in terms of GWP per unit of milk and feed energy conversion ratio because of their lower productivity. However, as GWP per unit of product is only one facet of the environmental impact of livestock systems, recent studies have included in their LCAs other impact categories (Penati et al., 2013; Berton et al., 2020) or functional units Ross et al., 2017. Furthermore, only a few studies have used LCA to identify the critical phases of Alpine dairy systems and hence the areas amenable to mitigation, such as using highland pastures during summer (Guerci et al., 2014) or modifying milk yields, stocking rates and feed self-sufficiency rates (Penati et al., 2013). At the same time, improvements in terms of feed energy conversion ratio in ruminant systems have been obtained by increasing the proportion of concentrates in animal diets. However, these improvements worsened ruminant systems' capacity to produce a net positive contribution to the human food balance (Ertl et al., 2015; Wilkinson and Lee, 2018). Moreover, LCA methodology usually failed to include the complex connections in the food system, for instance distinguishing the typology and the quality of the feedstuffs in terms of potential edibility for men (Van Hal et al., 2019). Consequently, the risk may be to propose mitigation strategies appropriate for the specific system but that exacerbate the environmental burdens at a more global level, posing the necessary to include potentially human-edible input-output food balance in the environmental assessment of food production systems (Van Zanten et al., 2018), especially when dealing with grassland based systems such as small-scaled alpine dairy farms.

Moreover, the integration of different aspects of food sustainability is the centre of the EU Farm-to-Fork strategy (European Commission, 2020). The overall environmental impact associated with dairy products is determined as the impact of milk production on the farms plus the impact of milk processing in the dairy factories. Different studies have analysed the environmental impacts of various dairy products, such as pasteurised milk, cheese and butter, using varied sets of impact categories (Djekic et al., 2014; Finnegan et al., 2018; Palmieri et al., 2017; Bava et al., 2018). However, to the best of our knowledge, no studies have yet taken a whole-chain (cradle-to-dairy gate) approach to analyse the environmental impact of dairy products produced by mountain supply chains.

This study used a cradle-to-dairy gate LCA model to evaluate the environmental footprint and feed energy conversion ratios of Alpine dairy chains in the Eastern Alps. We examined a large sample of farms located in different regions and included the dairy cooperatives to which they belonged with the aims of assessing the relative importance of the milk production and processing phases and identifying the farm management features that could be the target of mitigation measures in the production phase. To gain a more comprehensive insight into environmental sustainability, we considered different categories of impact using unit of milk and unit of land as the functional units and compared the efficiency of feed conversion into milk in terms of both total and human-edible gross energy.

4.2 Material and Methods

The LCA model, the data collection and editing followed the ILCD Handbook protocol (European Commission, 2010). The study was conducted in four different regions of the Eastern Alps (Veneto, Friuli Venezia Giulia and South Tyrol in Italy, and Carinthia in Austria). We examined 75 farms (55 in Italy, 20 in Austria) belonging to 10 dairy cooperatives (9 in Italy, 1 in Austria), which were typical of the dairy systems operating in the Eastern Alps, as described in Sturaro et al., 2009 and 2013. The study area is heterogeneous in land morphology conditions, with co-presence of areas with low elevations, gentler slopes and areas with higher elevation and steeper slopes, which determined great levels of land fragmentation and low suitability to crop production (Cocca et al., 2012). The environmental footprint was assessed for two reference units (Fig. 1): the farm (cradle-to-farm gate LCA) and the dairy (farm plus dairy processing, cradle-to-dairy gate LCA).

4.2.1 Goal and scope definition

The assessment of the farm unit was based on a cradle-to-farm gate model, with 1 kg of fat- and protein-corrected milk (FPCM, milk corrected to standard contents of 4.0% fat and 3.3% protein; Gerber et al., 2010) as functional unit (FU), following ISO (2006) guidelines, which prescribe that FU has to be related to the function of the production system. However, as Alpine dairy systems are mainly characterized by small-scale farms managing local meadows and pastures (Battaglini et al., 2014), and should be considered as multi-functional systems rather than single-function systems (OECD, 2001), as also targeted by the European CAP policies (European Commission, 2013), we were interested in analysing the environmental footprint using also a land-based perspective. For this reason, we used 1 m^2 of farmland occupation as second FU.

The system boundaries encompassed the processes and phases related to the production of the milk, which were partly “on-farm”, i.e., herd and manure management and on-farm production of feedstuffs, and partly “off-farm”, i.e., purchased inputs, such as fertilizers, off-farm produced feedstuffs, fuel, electricity and bedding materials, and related transport.

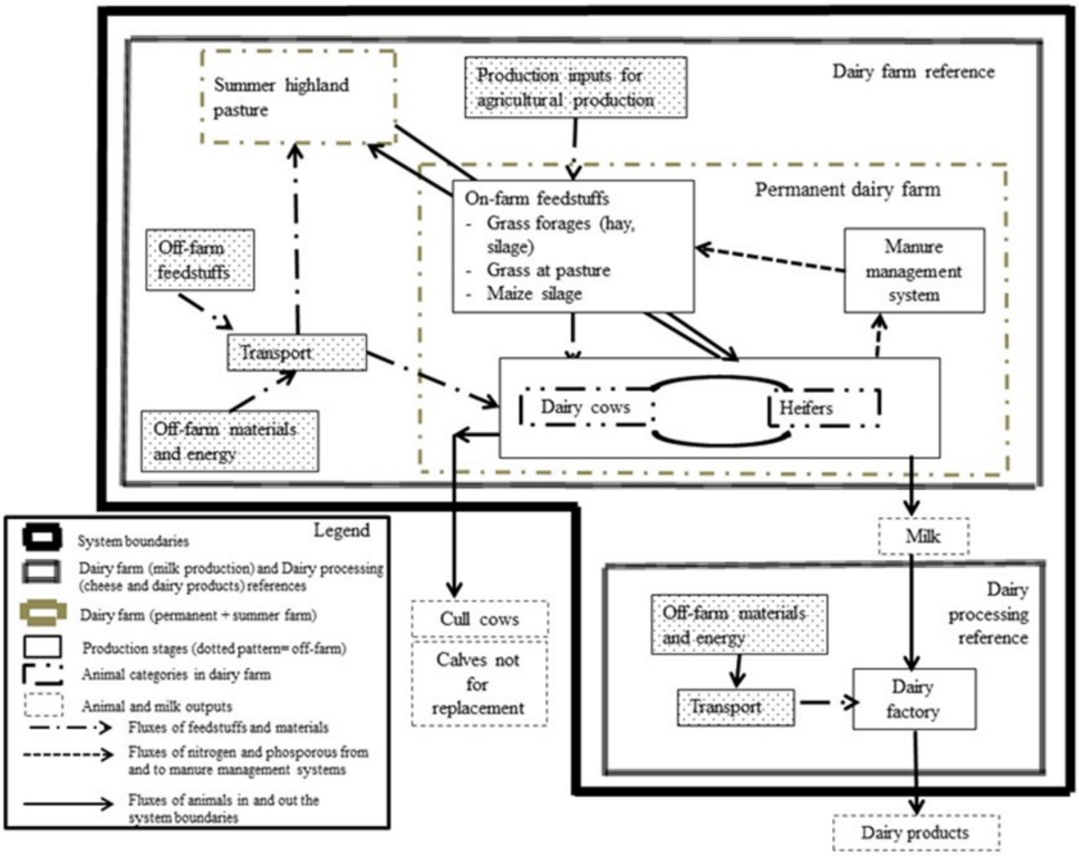


Fig. 1. Syste m boundaries for the cradle-to-dairy-gate Life Cycle Assessment of North-eastern Alps dairy systems (off-farm stages with dotted pattern).

Outputs were milk and animals (male and surplus female calves, culled cows). Impacts were allocated to these two co-products using the biophysical method (IDF, 2015). The impact categories assessed were global warming (GWP, kg CO_2-eq), acidification (AP, g SO_2-eq) and eutrophication (EP, g PO_4-eq) potentials, cumulative energy demand (CED, MJ) and land occupation (LO, m^2/y). For the farm unit, two efficiency indicators were also calculated: the feed gross energy (GE) conversion ratio of the total diet (ECR, MJ feed/MJ milk) and the feed GE conversion ratio of the fraction of the diet including potentially human-edible feedstuffs (HeECR, MJ feed/MJ milk), following Berton et al. (2017).

4.2.2 Life Cycle Inventory

Data were collected over a period of one year. Each farm was visited once by the same trained operator in a given region, each of whom used the same standardised questionnaire and procedure to minimize any operator-associated bias. The data collected to describe farm structure and management regarded housing (tie vs loose), manure management (slurry vs solid manure), manure storage (covered vs uncovered tank), calving management (seasonal vs non-seasonal), feeding (total mixed rations (TMR) vs traditional, i.e., forages administered ad libitum and concentrate supplements or part of forages administered in different amounts to each animal). We also recorded whether or not the farms used lowland pastures and practiced transhumance (i.e., movement of livestock to temporary units at high altitudes in summer to graze on Alpine grasslands), and, where relevant, the length of the grazing period. To measure herd sizes and composition, we referred to the monthly milk recordings to obtain the number of cows, the number of lactations, calving intervals, age at first calving and dry period length, and adopted the approach used by Berton et al. (2020) to model herd size on an annual basis. Livestock categories (lactating cows, dry cows, replacement heifers) were standardised as EU livestock units (LU; cattle > 2 years = 1 LU, cattle 6 months to 2 years = 0.6 LU, cattle < 6 months = 0.4 LU). To measure farm output, each farm's milk production was obtained from the records of the dairy cooperative to which it belonged, while the number of animals sold was obtained from the herd register of each farm. Data on feeding were collected separately for the winter period on the permanent farm and the grazing period on the permanent farm and/or the summer farm. Feed intake was estimated using the procedure described by Berton et al. (2020) based on the animals' energy requirements (NRC, 2001; IPCC, 2006) and the ingredient composition of the rations, with a distinction made between farms using TMR and those not. Gross energy and NE contents and the chemical composition of the feeds and the grass grazed were obtained from INRA (2007), except for the commercial compounds, where the values were listed on the labels. Nitrogen (N) and phosphorus (P) input-output flows were computed for all livestock categories according to Ketelaars and Van der Meer (1999). N and P intakes were computed as dry matter intake x N and P contents (% dry matter, DM), while their total retentions were computed as the sum of the retentions for milk (crude protein content derived from dairy data x 0.157), growth and pregnancy (retention coefficients per livestock category were derived from Ketelaars and Van der Meer (1999)). Excretion was calculated as intake - retention.

The farms produced part of the feedstuffs fed to their animals (mostly forages: hay, grass silages and grass at pasture from grassland, maize silage from cropland) and purchased the rest (mostly concentrates, but also some forages). The total amounts of each feedstuff used were measured differently according to whether they were on- or off-farm sourced. The total amount of each purchased feedstuff (off-farm) was calculated from records of the diet ingredients and commercial invoices. As the amounts of on-farm produced feedstuffs were not directly calculable and were subject to year-to-year variability, they were estimated on the basis of the size and agronomic management of the farm agricultural area (FAA) given over to producing each feedstuff.

Stocking rate (LU/ha FAA) was calculated excluding the period spent in summer farms, with the equation used in Sturaro et al. (2013). The other main inputs, such as electricity and fuel consumption and bedding materials (straw and sawdust), were obtained from farm invoices.

4.2.3 Calculation of impacts and efficiency indicators

The impacts of the farm unit were calculated separately for the winter in-house period and the grazing periods (on the permanent farm and/or on the summer farm). The general framework for emission calculation was taken from the IPCC (2006). Methane (CH_4) due to enteric fermentation was calculated using the equations suggested by Ramin and Huhtanen (2013), CH_4 and nitrous oxide (N_2O) resulting from manure management and fertilizer spreading using IPCC (2006) equations. Moreover, we included carbon dioxide (CO_2) emission associated with land-use change (LUC) due to deforestation in tropical areas which is mainly driven by agricultural expansion for producing soybean or pasture for animals (Morton et al., 2006; Gerber et al., 2013). The connection between the farms sampled here and such deforestation is the import of soybean meal from Brazil, the main source of soybean meal for Europe (FAOSTAT, 2019). For this reason, LUC emission in this study was associated with soybean meal included in the animal rations, using the value proposed by Caroet al. (2018) in a recent analysis.

Acidification potential was calculated on the basis of the emissions of Nolatilised as ammonia and of nitrogen oxides during manure storage and the spreading of fertilizers (organic and chemical) on the field. The emission factors for manure storage were obtained from ISPRA (2011) and for fertilizer application from the IPCC (2006). Assessment of the eutrophication potential included the contributions of the deposition of volatilised N (¼ N volatilised during manure storage and fertilizer spreading; IPCC 2006), N lost as nitrate through leaching (26% of N input; Bretscher, 2010), and P loss at the field (Nemecek and Kagi, 2007). For the impacts related to the background systems (production of fertilizers, pesticides and seeds for producing on-farm feedstuffs, and production and use of bedding materials, fuel, electricity), we used the impact factors (IFs) in the Ecoinvent database (v3.1, cut-off system model; Ecoinvent Centre, 2014) implemented in Simapro software v8.0.5, apart for the GWP of the use of 1 kg of fuel (EEA, 2013) and the GWP of the production of 1 kWh of electricity (ISPRA, 2011).

4.2.4 Life cycle impact assessment (LCA)

Within each impact category, the single substances emitted (for GWP, AP and EP) and single contributions (in terms of energy consumed for CED and of occupied land for LO) were standardized to the common unit of the related impact category. Characterization factors for GWP, AP, EP and LO were derived from the CML-IA method (Oers, 2016), whereas the Cumulative Energy Demand method, directly implemented in Simapro software, was used for CED.

4.2.5 Dairy unit

The dairy unit included the farm unit and the following dairy processing, with different dairy products (yogurt, ricotta, butter and different cheeses) as output. The FU for the dairy unit was 1 kg of dairy product. As data collection, data editing and impact computation regarding the milk production phase have been already described in section, here the information and methodological aspects strictly related to the dairy processing phase are reported. The dairy processing phase included the processes that take place at the dairy, from the arrival of the milk to the shipping of products to the retail stage, and took into account the milk flows within the plant for producing the various dairy products and the inputs other than milk, such as energy sources (electricity, fuel, methane), water, cleaning agents and packaging materials. The impact categories assessed were equal to those assessed for the farm unit. Each dairy factory was visited once. Inputs were recorded from official registers and invoices and included the amount of milk supplied by each farm as well as the energy sources (fuel, methane gas, electricity), cleaning agents and packaging materials (tetrapak, glass, food wrapping paper, plastic) used.

The transport of milk from farm to dairy factory was not included due to a lack of data. Output was recorded as the types and amounts of the various dairy products (i.e., cheese, butter, yogurt). The average yields (kg milk/kg product) of each product were used to allocate the corresponding amounts of milk. Milk-embedded impacts were computed for each dairy cooperative as the mean of the impact values of the member farms, weighted by each farm's share of the total milk collected. If the milk used to produce butter was reused to produce cheese, the total milk processed into cheese was calculated as the butter-residual milk (milk composition after deducting the solids recovered in the butter) plus the milk needed to cover the remaining amount allocated to cheese products. The other production inputs were allocated to each dairy product using the mass-allocation methodology.

The impacts related to the background systems of the dairy unit the production of the inputs used at the dairy unit were calculated using IFs from the Ecoinvent database (Ecoinvent Centre, 2014) for energy sources, cleaning agents and packaging materials, except for the GWP of 1 kWh of electricity (ISPRA, 2011). The impacts associated with the production of milk were derived from the results obtained from the farm unit. The LCIA procedure used in the dairy processing was equal to that use in the farm unit.

4.2.6 Interpretation and statistical analysis

We used hotspot analysis (European Commission, 2010) to assess the contribution of each phase and production process to the total impact from cradle to dairy gate. Based on the results, further statistical analyses were conducted only for the farm unit. We used principal component analysis (PCA; PROC PRINCOMP, SAS 2013) to identify the associations among a complex set of farm structural and management variables, impact values and efficiency indicators. The link between the features identified with PCA and the indicators of impact categories and energy conversion ratios was then assessed using a step-wise regression model (PROC REG, SAS 2013), adopting a P value of 0.05 as the threshold to retain a variable in the model. A preliminary test for the absence of collinearity (variance inflation factor < 2) between independent variables was carried out.

4.3 Results

4.3.1 Characteristics of farms, impacts and efficiency indicators

The main structural and management features of the farms are reported in Table 1. The mean total FAA was about 33 ha, located almost entirely at the permanent farm (86%) and managed as grassland (95%). Herd size averaged 38 LU, with 28 dairy cows (lactating or dry). The stocking rate averaged 1.37 LU/ha.

Table 1. Descriptive statistics of structural and management features of the farms sampled (variables subject to temporal variation are expressed on a per year basis).

Variable	Unit	Mean	SD	Min	Max
Farmland					
FAA[1] grassland permanent farm	ha	26.7	20.1	5.1	100.0
FAA cropland permanent farm	ha	1.9	3.7	0.0	16.3
FAA, permanent farm total	ha	28.6	21.0	5.1	100.0
Pasture area, summer farm	ha	4.5	6.8	0.0	32.5
FAA, total	ha	33.1	22.9	5.1	106.8
Altitude, permanent farm	m a.s.l.	790	281	280	1375
Cropland share	% FAA	5	10	0	48
Herd composition					
Dairy cows	LU[2]	28	19	4	99
Replacement	LU	10	7	1	36
Total	LU	38	25	5	123
Stocking rate	LU/ha	1.37	0.80	0.50	4.40
Farm management (0, absence; 1, presence)					
Loose stall	.	0.56	0.50	0.00	1.00
Total mixed ration	.	0.47	0.50	0.00	1.00
Pasture at permanent farm	.	0.64	0.48	0.00	1.00
Transhumance to summer farm	.	0.59	0.50	0.00	1.00
Energetic input					
Fuel	kg / LU	162	87	46	478
Electricity	kWh /	641	391	43	1684
Bedding materials					
Wheat straw	kg / LU	410	617	0	4732
Sawdust	kg / LU	154	387	0	1517
Total bedding	kg / LU	504	516	0	1851
Farm production					
Milk, per LU	kg	4749	1250	2095	7664
Milk, per dairy cow	kg	6400	1661	2543	10336
Milk, per ha FAA	kg	6628	4339	1249	24278
BW[3], per LU	kg BW	153	30	75	222
BW, per dairy cow	kg BW	210	54	89	356
BW, per ha FAA	kg BW	244	148	47	801

[1] FAA: farm agricultural area

[2] LU: livestock unit

[3] BW: body weight

Considerable variability was associated with these features, with coefficients of variation (CV) ranging between 58 and 70%. Loose stall and TMR were almost equally more frequent than tie stalls and traditional feeding. Around 60% of the farms used pasture on the permanent farm and/or the summer farms. Farm outputs were the milk and the animals sold to market (male and surplus female calves, culled cows). Mean milk yield was 6400 kg FPCM/cow/y (CV: 26%). Milk production intensity was 6630 kg FPCM/ha FAA (CV: 65%), showing a greater variation than in milk yield because of the inherent variability in the stocking rate. The animals sold amounted to a body weight of 153 kg per dairy cow (CV: 19.6%) and 244 kg per ha of FAA (CV: 60.8%).

Consumption of the different feeds and diet characteristics are reported in Table 2. Total feed consumption was nearly 6100 kg DM/LU per year (CV: 14%). Around 70% of the feedstuffs were produced on-farm, mostly hay and grazed grass. Off-farm purchased feeds comprised one-third of concentrates and two-thirds forages (hay, alfalfa hay and wheat straw) and raw materials for silages (grass and maize). Overall, hay represented half the diet and grass at pasture almost a quarter, the rest being silages and concentrates. There was a huge variation in the farms' production, purchase and use of different feeds (SDs always exceeded the mean values). The average diet contained 5.4 MJ of NE per kg DM, 2.1% DM of N and 0.3% DM of P. Understandably, the CVs were low (1-10%). The average impact values per unit of milk and unit of area as well as feed energy conversion ratios for the farm unit are shown in Table 3. The production of 1 kg FPCM was associated with the emission of nearly 1.2 kg CO_2-eq (+10% when including CO_2 emissions related to land-use change) on average and to the consumption of nearly 3 MJ of CED and 2 m^2/y of LO. Variability was lower for emissions (CVs: 17-21%) than for resource usage (CVs: 40-46%). Since producing 1 kg FPCM needed almost 2 m^2 of land, the management of 1 m2 of land showed mean values per impact category nearly halved with respect to means per 1 kg FPCM. However, the variation in impact values per unit of land was greater than those expressed per unit of milk, with CVs of 35-42% for emissions (GWP, AP and EP) and 55% for CED. Regarding feed energy conversion ratios, the production of 1 MJ in the milk required on average 6.55 MJ in the feedstuffs (whole diet) fed to the animals (CV: 21%), but only 0.48 MJ in potentially human-edible feedstuffs (CV: 77%).

Table 2 Descriptive statistics of feed intake (kg dry matter/LU/year), diet ingredient composition and chemical composition of the diets in the farms sampled.

Variable	Mean	SD	Min	Max
On-farm feeds intake	4247	1212	1588	7407
Hay	2081	1226	0	5066
Maize silage	294	605	0	2672
Grass silage	600	840	0	3098
Grass at pasture, permanent farm	888	914	0	3308
Grass at pasture, summer farm	384	550	0	2228
Off-farm feeds intake	1855	1443	9	5158
Hay	814	1228	0	4608
Wheat straw	25	97	0	661
Alfalfa hay	211	357	0	1433
Maize silage	130	367	0	1673
Grass silage	9	61	0	513
Maize flour	161	323	0	1753
Soybean	24	111	0	569
Compound feeds	481	602	8	2654
Total Feed intake	6102	835	4111	8225
Chemical composition (on a dry matter basis)				
Gross energy, MJ/kg	17.9	0.1	17.7	18.1
Net energy, MJ/kg	5.4	0.4	4.6	6.3
Nitrogen, %	2.10	0.19	1.68	2.54
Neutral detergent fibre, %	57.4	5.6	43.5	67.5
Phosphorus, %	0.31	0.03	0.26	0.45

Table 3. Descriptive statistics of impact and energy conversion values obtained for the dairy farm reference (cradle-to-farm-gate LCA). Functional units (FU) used were 1 kg of fat- and protein-corrected milk (FPCM) and 1 m^2 of farm agricultural area (FAA).

Variable	Unit	Mean	SD	Min	Max
FU: 1 kg FPCM					
Global warming potential	kg CO_2-eq	1.19	0.20	0.69	1.76
Global warming potential + land use change	kg CO_2-eq	1.31	0.27	0.69	2.00
Acidification potential	g SO_2-eq	17.30	3.15	11.05	25.26
Eutrophication potential	g PO_4-eq	6.04	1.06	3.83	8.96
Cumulative energy demand	MJ	2.70	1.08	0.85	5.26
Land occupation	m^2/y	2.08	0.96	0.92	5.71
FU: 1 m^2 FAA					
Global warming potential	kg CO_2-eq	0.52	0.18	0.21	1.10
Global warming potential + land use change	kg CO_2-eq	0.58	0.22	0.21	1.20
Acidification potential	g SO_2-eq	7.76	3.23	2.64	16.59
Eutrophication potential	g PO_4-eq	2.67	0.99	1.00	5.44
Cumulative energy demand	MJ	1.19	0.65	0.21	3.59
Energy conversion ratios					
Gross energy conversion ratio	MJ feed /	6.55	0.48	4.60	11.28
Potentially human-edible gross energy	MJ feed /	0.48	0.36	0.00	1.28

The results of the environmental assessment for the whole system (cradle-to-dairy gate model) are given in Table 4. For every 1 kg of product, the different cheeses (categorised as fresh, medium-ripened, ripened, and “caciotta”) evidenced mean impact values nearly 8-9 times (GWP, AP, EP and LO) and 13 times (CED) greater than those related to 1 kg of milk, accordingly to the mean yields of the different dairy products. The variation in impact values related to cheeses was quite low, CVs ranging 2-32% accordingly to the different impact categories. The impact values of ricotta and yogurt were in the ranges, respectively, of 34-50% and 12-16% of those of cheeses. The impacts of butter were 1.2-1.8 times greater than the impacts of cheeses.

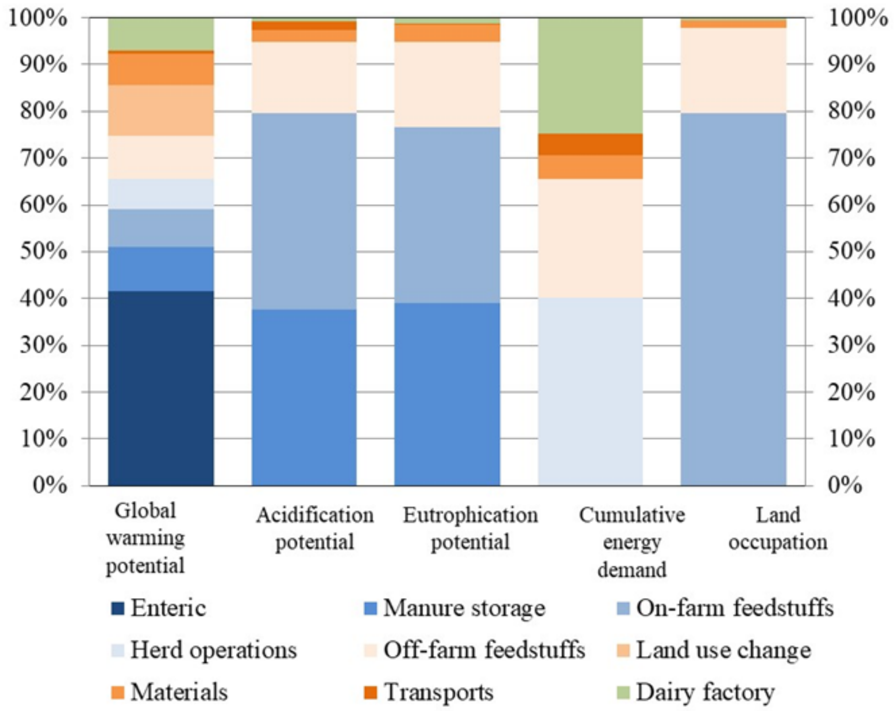
Table 4. Descriptive statistics of impact values of dairy products taken into account for the whole system (cradle-to-dairy-gate LCA). Functional unit used was 1 kg fat and protein corrected milk.

	Dairies (N)	Global warming potential, kg CO_2-eq / kg		Acidification potential, g SO_2-eq/kg		Eutrophication potential, g PO_4-eq /kg		Cumulative energy demand, MJ/kg		Land occupation, m^2/kg	
		mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Fresh cheese	6	10.1	0.9	138	20	49.9	5.8	32.9	6.2	17.4	5.5
Mid-ripened cheese	4	10.9	0.9	155	27	55.9	7.3	35.6	7.6	16.3	2.4
Ripened cheese	4	11.7	0.8	166	31	60.2	8.9	38.4	8.7	18.3	2.9
Caciotta	3	9.7	1.0	134	20	47.4	1.0	28.9	2.4	15.5	2.5
Ricotta	5	4.3	0.9	63	8	21.1	3.2	14.9	3.8	8.2	4.2
Butter	6	15.0	2.1	206	18	72.4	8.4	51.6	10.2	25.4	11.3
Yogurt	4	1.5	0.1	21	2	7.5	0.7	4.7	0.4	2.5	0.2

4.3.2 Hotspot analysis and determinants of impacts at the farm unit

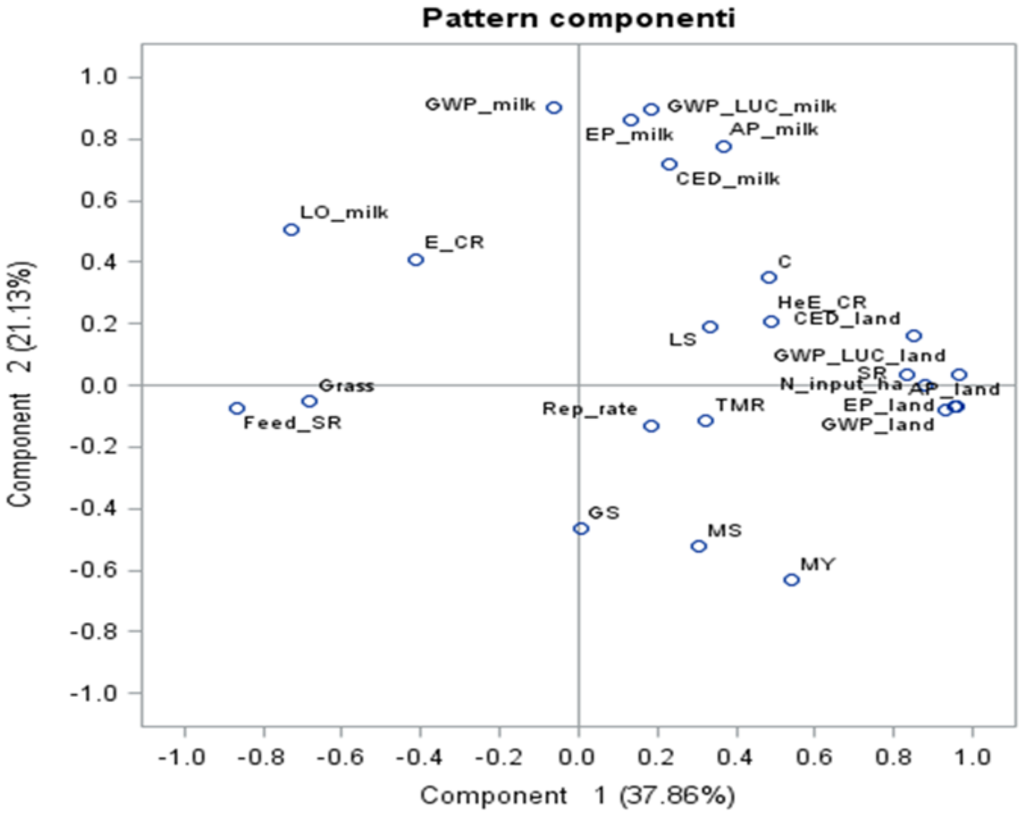
The results of the hotspot analysis (Fig. 2) showed that the farm unit accounted for 97-99% of the GWP, AP, EP and LO variations in the whole system, and 75% of the CED variation. Within the farm unit, on-farm stages contributed more than off-farm stages (from 53% for CED to 80% for AP and LO). The main contributors to the impacts were enteric fermentations on GWP (45%) and feedstuff production on AP, EP and LO (19-98%).

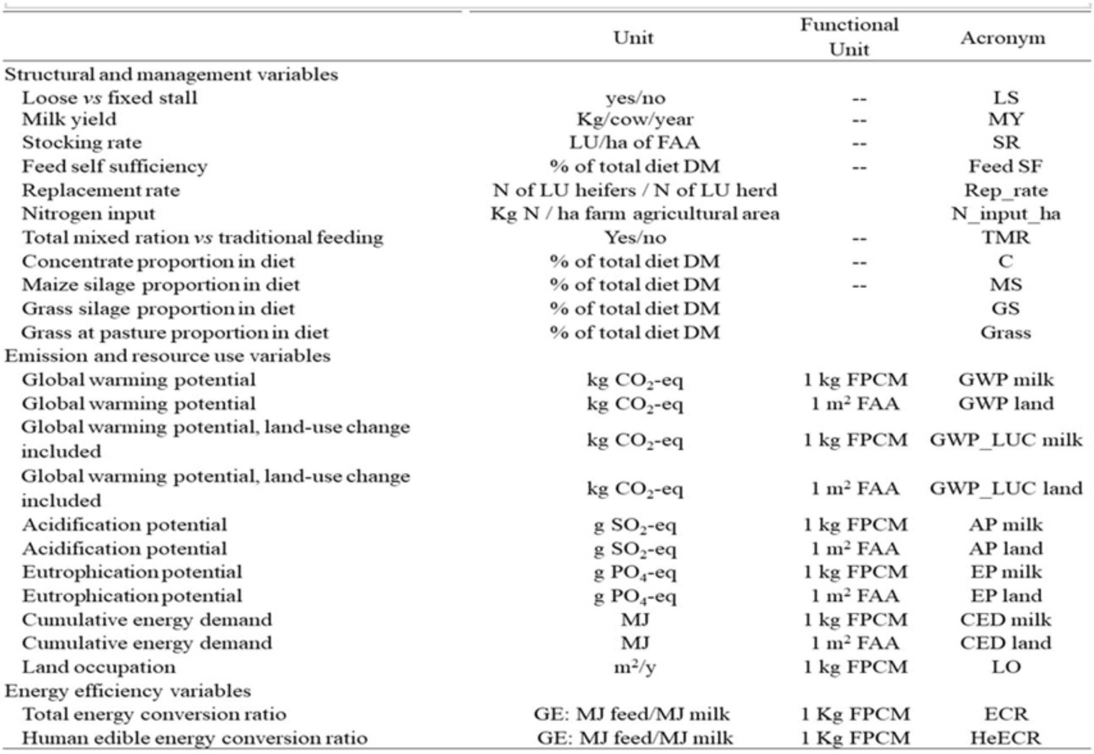
Figure 2. Hotspot analysis (scale of blue: on-farm production stages in farm unit; scale of orange: off-farm production stages in farm unit; green: dairy processing unit) for the cradle-to-dairy-gate Life Cycle Assessment of North-eastern Alps dairy systems.



Due to the dairy processing unit’s marginal contribution to the total impacts, further analyses were focused on the farm unit. The PCA of management indicators and impact values identified two components explaining almost 50% of the variability (Fig. 3). Adopting a threshold of 0.4, the first component correlated positively with stocking rate, milk yield, the proportion of concentrates in the diet, all the impact categories expressed per unit of land and HeECR, and negatively with feed self-sufficiency rate, grazed grass proportion in the diet, LO per unit of milk and ECR. The second component correlated positively with the impact values expressed per unit of milk and ECR, and negatively with milk yield and the proportions of maize and grass silages in the diet. Based on these results, we retained as indicators of the intensity of land and/or herd management those structural and management variables that met the following criteria: 1) absence of collinearity, 2) possibility to be managed/changed by the farmers.

Figure 3 Principal component analysis of the management features, impacts and efficiencies calculated for the farm unit.





	Unit	Functional Unit	Acronym
Structural and management variables			
Loose *vs* fixed stall	yes/no	--	LS
Milk yield	Kg/cow/year	--	MY
Stocking rate	LU/ha of FAA	--	SR
Feed self sufficiency	% of total diet DM	--	Feed SF
Replacement rate	N of LU heifers / N of LU herd		Rep_rate
Nitrogen input	Kg N / ha farm agricultural area		N_input_ha
Total mixed ration *vs* traditional feeding	Yes/no	--	TMR
Concentrate proportion in diet	% of total diet DM	--	C
Maize silage proportion in diet	% of total diet DM	--	MS
Grass silage proportion in diet	% of total diet DM		GS
Grass at pasture proportion in diet	% of total diet DM		Grass
Emission and resource use variables			
Global warming potential	kg CO_2-eq	1 kg FPCM	GWP milk
Global warming potential	kg CO_2-eq	1 m^2 FAA	GWP land
Global warming potential, land-use change included	kg CO_2-eq	1 kg FPCM	GWP_LUC milk
Global warming potential, land-use change included	kg CO_2-eq	1 m^2 FAA	GWP_LUC land
Acidification potential	g SO_2-eq	1 kg FPCM	AP milk
Acidification potential	g SO_2-eq	1 m^2 FAA	AP land
Eutrophication potential	g PO_4-eq	1 kg FPCM	EP milk
Eutrophication potential	g PO_4-eq	1 m^2 FAA	EP land
Cumulative energy demand	MJ	1 kg FPCM	CED milk
Cumulative energy demand	MJ	1 m^2 FAA	CED land
Land occupation	m^2/y	1 kg FPCM	LO
Energy efficiency variables			
Total energy conversion ratio	GE: MJ feed/MJ milk	1 Kg FPCM	ECR
Human edible energy conversion ratio	GE: MJ feed/MJ milk	1 Kg FPCM	HeECR

These indicators (stocking rate (SR), milk yield (MY), and proportions of concentrates (C), grass silage (GS) and maize silage (MS) in the diet), were used in a step-wise regression model to evaluate their relationships with impacts and feed ratios (Table 5). Clearly, MY has an inherent relationship with impact categories expressed per unit of milk and SR with those expressed per unit of area, but we included them as correction factors with respect to the other management variables and also to assess the strength of their link with (i.e., their power as indicators of) impact and efficiency ratios. The resulting models for the impact categories expressed per unit of milk and ECR had a lower R^2 (0.32-0.61) than the models for the impact categories per unit of land and HeECR (0.80-0.90). Milk yield, SR and C were the variables that best explained the variability in the impact categories and feed energy conversion ratios, while GS and MS were retained by few models and made a marginal contribution to R^2. In general, the explained variability was concentrated on the first and second variables entering the models, while the third variables had partial R^2 values of 0.01-0.06. As expected, MY and SR had notable relationships to the impact categories per unit of milk and unit of land, respectively. Regarding the impacts per unit of milk, GWP was mitigated firstly by an increase in MY (50% of the partial R^2) but also increased at an increasing SR, although with a modest partial R^2 (7%). Interestingly, when the land-use change was also included in the calculation of GWP, MY and C contributed almost equally to the total R^2 (55%), the former having a mitigating effect, the latter an aggravating effect.

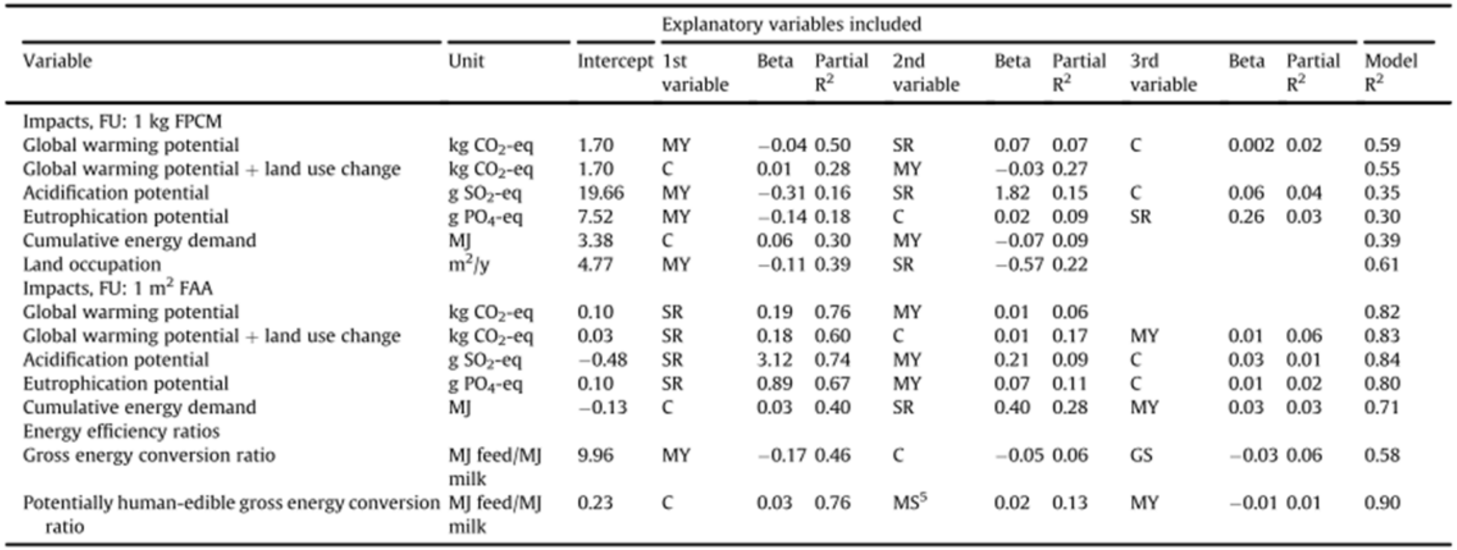
Around one-third of the variability in AP and EP was explained by the respective models. Acidification potential increased with SR and decreased with MY, with both variables contributing almost equally to the model R^2 . Eutrophication potential decreased with MY and increased with C, with MY explaining twice the variability explained by C. Cumulative energy demand was positively related with C and negatively with MY, but the contribution of C was triple that of MY. The land occupation was mitigated by both MY and SR, with MY having a partial R^2 (39%) almost twice that of SR (22%). Regarding the impacts per unit of land, GWP, GWP + land-use change, AP and EP were greatly increased by SR, which had remarkably high partial R^2 values (60-76%). For GWP, AP and EP the second variable included in the models was MY (partial R^2 = 6-11%), with an aggravating effect. For CED, the first retained variable was instead C, with an aggravating effect and a notable partial R^2 (40%), whereas the second one was SR (partial R^2 = 28%). Regarding the feed energy conversion ratios, ECR improved with an increase in MY (partial R^2 = 46%) and a decrease in C (partial R^2 = 6%), while HeECR improved with a decrease in C (partial R^2 = 76%).

4.4 Discussions

Life Cycle Assessment is an output-based methodology (Finnveden et al., 2009), since it assesses the environmental footprint of a production system for one unit of output, in our study either milk (farm unit) or dairy product (whole system, dairy farm plus dairy processing unit). We have clearly shown that the industrial phase of processing milk into cheeses and other dairy products made a negligible contribution to the impact of the whole system compared with the agricultural phase of milk production, with the partial exception of CED. These results are in agreement with other studies on lowland intensive (Kim et al., 2013; Bava et al., 2018) and grass-based extensive systems (Gonzàlez-García et al., 2013; Palmieri et al., 2017), and shows that even in small mountain dairy chains, where factories often process small or moderate amounts of milk, milk production is the dominant determinant of the environmental footprint of dairy products.

We examined a large group of farms with different structural and management conditions to reflect and represent the wide variation characteristic of current Alpine dairy systems (Sturaro et al., 2009, 2013). As a consequence, the impact values per unit of milk (farm unit) that we observed were also largely variable and covered the range reported by the few studies that have dealt with the GWP (1.0-1.7 kg CO_2-eq), EP (3.0-7.7 g PO_4-eq) and LO (1.4-3.2 m^2/y) per 1 kg FPCM of mountain dairy farms. Conversely, our AP (21.0-22.9 g SO_2-eq/kg FPCM) and CED (5.0-5.1 MJ/kg FPCM) values were slightly lower than those reported in other studies (Penati et al., 2013; Guerci et al., 2014; Kiefer et al., 2015; Salvador et al., 2016, 2017; Berton et al., 2020). More generally, the variability in the farms sampled in this study might explain why our mean impact values per unit of milk overlapped only partially with those reported in recently published studies for GWP (1.0-1.5 kg CO_2-eq), AP (12-28 g SO_2-eq), EP (6.0-8.5 g PO_4-eq) and CED (2.9-4.1 MJ) per 1 kg FPCM. On the contrary, the mean value of LO per unit of milk found in our study (2.1 m^2/y per 1 kg FPCM) was greater than those reported in recent studies (1.2-1.6 m^2/y) probably due to the presence in our sample of many extensive, grassland-basedfarms with a low stocking rate and low productivity per unit of land.

Table 5 Results of the step-wise regression analysis (intercept, beta coefficient, partial R2 and model R2) testing the relations of milk yield (MY, kg of fat and protein corrected milk/cow/d), stocking rate (SR, livestock unit/ha), proportion of concentrate (C, %), grass silage (GS, %) and maize silage (MS, %) with impact categories (functional units (FU) used: 1 kg FPCM and 1 m2 of farm agricultural area (FAA)) and energy efficiency ratios obtained for the dairy farm reference unit.



Variable	Unit	Intercept	Explanatory variables included									Model R^2
			1st variable	Beta	Partial R^2	2nd variable	Beta	Partial R^2	3rd variable	Beta	Partial R^2	
Impacts, FU: 1 kg FPCM												
Global warming potential	kg CO_2-eq	1.70	MY	−0.04	0.50	SR	0.07	0.07	C	0.002	0.02	0.59
Global warming potential + land use change	kg CO_2-eq	1.70	C	0.01	0.28	MY	−0.03	0.27				0.55
Acidification potential	g SO_2-eq	19.66	MY	−0.31	0.16	SR	1.82	0.15	C	0.06	0.04	0.35
Eutrophication potential	g PO_4-eq	7.52	MY	−0.14	0.18	C	0.02	0.09	SR	0.26	0.03	0.30
Cumulative energy demand	MJ	3.38	C	0.06	0.30	MY	−0.07	0.09				0.39
Land occupation	m^2/y	4.77	MY	−0.11	0.39	SR	−0.57	0.22				0.61
Impacts, FU: 1 m^2 FAA												
Global warming potential	kg CO_2-eq	0.10	SR	0.19	0.76	MY	0.01	0.06				0.82
Global warming potential + land use change	kg CO_2-eq	0.03	SR	0.18	0.60	C	0.01	0.17	MY	0.01	0.06	0.83
Acidification potential	g SO_2-eq	−0.48	SR	3.12	0.74	MY	0.21	0.09	C	0.03	0.01	0.84
Eutrophication potential	g PO_4-eq	0.10	SR	0.89	0.67	MY	0.07	0.11	C	0.01	0.02	0.80
Cumulative energy demand	MJ	−0.13	C	0.03	0.40	SR	0.40	0.28	MY	0.03	0.03	0.71
Energy efficiency ratios												
Gross energy conversion ratio	MJ feed/MJ milk	9.96	MY	−0.17	0.46	C	−0.05	0.06	GS	−0.03	0.06	0.58
Potentially human-edible gross energy conversion ratio	MJ feed/MJ milk	0.23	C	0.03	0.76	MS[5]	0.02	0.13	MY	−0.01	0.01	0.90

Productive land is a limited resource, especially in mountain areas due to their morphological, pedological and climatic conditions, and dairy farms in mountain context are multi-functional systems that by managing this land may provide different territorial benefits other than milk (Faccioni et al., 2019). Therefore, the inclusion of an area-based FU adds an important dimension to the assessment of the impacts of mountain, and more generally extensive, dairy systems. As stated by Ross et al. (2017), LCA studies using kg of milk as the sole FU of the dairy farm fail to grasp the complexity of dairy systems, and to do so requires the inclusion also of productive land as an FU. For instance, acidifying and eutrophying emissions are mostly local phenomena, which cannot be indexed by the unit of milk (Potting and Hauschild, 2006). Previous studies on Alpine dairy systems have generally not considered FUs other than 1 kg milk, with the partial exception of Penati et al. (2013), who were able to indirectly calculate the impact per unit of area, and of Berton et al. (2020), who reported the impacts per 1m^2 of FAA, although they did not take into account the grazing period on the permanent and/or summer farm. Although they used only mass-based FUs, Salvador et al. (2016) adopted a land-based approach taking into account the multi-functionality of mountain dairy farms and attributed the total greenhouse gas emissions not only to milk and meat but also to the ecosystem services provided. The hotspot analysis results (Fig. 2) showed that the most important impact sources of GWP, AP and EP were on-farm, in line with the findings of Penati et al. (2013), Guerci et al. (2014) and Salvador et al. (2016), thus highlighting the possibility that the farmers may be active agents in mitigating the impacts of their farms. However, most farms sampled in this study would be unable to achieve this mitigation through the options usually recommended, i.e., increasing the proportion of concentrates in the diet and shifting to more specialised breeds (Herrero et al., 2016). Indeed, the medium-small sized farms in the north-eastern Alps are often unable to access financially-onerous investments, while the constraints of climate and land morphology preclude the agricultural productivity gains achievable in lowland areas, which are necessary for exploiting the economies of scale underlying intensification processes (Weersink and Tauer, 1991).

Furthermore, our results indicate that increasing the concentrate proportion might actually increase the GWP if the land-use change is considered. In any case, profound changes in structures and management are not an assurance of improvement in environmental performance (Lorenz et al., 2019). In the short to medium term, feasible mountain-specific impact mitigation strategies could be developed on the basis of some existing good practices (Gerber et al., 2013). In this respect, we identified potential indicators through a PCA of a complex set of farm structural and management features and impact categories, and the subsequent step-wise regression analysis identified MY, SR and C as the variables most closely linked with impacts (see Table 5). Milk yield and SR were identified as valuable indicators also by Penati et al. (2013), together with feed self-sufficiency. Although PCA highlighted feed self-sufficiency as avariable associated with impact categories, we retained only SR because of the multi-collinearity criteria, it is easier to calculate and is a parameter well known to farmers.

Beyond the partly-expected indications that increasing MY could mitigate GWP (LUC excluded), AP, EP and LO per unit of milk and improve ECR, and that decreasing SR would mitigate GWP, AP, EP and CED per unit of land, our results showed the consequent mitigations to be also dependent on other variables, such as C and SR, which, in the case of the impacts per unit of milk, also had an opposite effect to MY. Particularly interesting, in our opinion, was the dominant effect of C in increasing GWP per unit of milk when LUC was included, which indicates that there might be a trade-off between global and local mitigation strategies (Schmitz et al., 2012). The role of C as an indicator is remarkable also for its dominant role in increasing CED, whether expressed as per unit of milk or unit of land, and in addressing the feed energy conversion ratios. In this respect, our results indicate that obtaining high yields with diets rich in concentrates improves the total feed gross energy ratio, although this was achieved with greater use of potentially human-edible feeds. The complex relationship between MY, SR and C that emerged from the results of this study evidences that mitigation strategies aiming to decrease the environmental footprint referred to milk and managed area in the same time should include

MY, SR and C jointly, looking to the best combination of these indicators able to minimize the impact values of the farms. In this regards, the farms associated with the lowest impact values (per unit of milk and area) were identified through a non-hierarchical cluster analysis based on MY, SR and C as cluster criteria (4 clusters; FASTCLUS procedure in SAS (2013), number of clusters optimized on the basis of the cubic clustering criterion indicator). The combination of MY, SR and C values in the farms with the lowest impacts showed averaged or good values of MY associated with low values of SR and C (MY value from 13 to 22 kg FPCM/cow/d, with <2.1 LU/ha of SR and <16% of C, data not shown). Farms with MY, SR and C values within these ranges, with respect to farms outside these ranges, showed a decrease in the environmental footprint up to 32%, according to the different impact categories. So, efforts aiming to extend these good practices to all the farms could lead to an important improvement in the environmental footprint of the alpine dairy system, in line with the Food and Agricultural Organization recommendations (FAO, 2013). However, a unique and specific combination of MY, SR and C values to be proposed as target is probably not useful, since the farms sampled in this study are connected to different value chains and agroecosystems. Besides, the level of farm management features could depend also on the goals and objectives of each farmer (Karali et al., 2013) as well as the constraints of the territory where farms are located, such as the presence of protected areas (Piermattei, 2013). Nevertheless, these results can provide useful information to farmers, and to each dairy to which farmers are associated, to plan future management intended to include environmental issues, that have been increasingly including in the CAP policy (Erjavec and Erjavec, 2015).

The farmers' possibility to intervene in the levels of MY, SR and C is quite different. If C is under the control of the farmer and MY is more a response than an input, the modification in terms of SR depends on both the farmer and land availability. Moreover, SR, as a measure of the number of animals managed per unit of farmland, is closely related to how land is managed and the types of relationship holding between livestock systems and their territory. The PCA results revealed that farms with a lower SR made greater use of pastures and less use of concentrates than farms with a higher SR. However, the Alpine dairy systems has shown an opposite pathway, with the (partial) substitution of grazing with off-farm purchases of forages and concentrates (Battaglini et al., 2014). Therefore, a divergence between environmental mitigation outcomes (reduction of SR) and on-going productive trends may arouse. Managing grasslands with a low SR can have different positive effects on soil and water quality (Anzai et al., 2016), by reducing nutrients (N and P) pressure on land determined by external inputs (fertilizers and purchased feedstuffs), biodiversity (Humbert et al., 2016) and conservation of valued landscapes with tourism benefits (Zoderer et al., 2016). On the other hand, grassland-based rations were partially associated with a lower MY (Pearson $r = -0.32$, $P < 0.05$), which could make farmers reluctant to adopt this type of management. However, the alternative, i.e., increasing concentrate supplementation, did not have a strong association with MY ($r = 0.21$, $P= 0.08$) and had a negative effect on CED, while the consequent off-farm cropland expansion could worsen LUC-related CO2 emissions (Tonini et al., 2016) and reduce biodiversity (e.g., Newbold et al., 2015). The use of maize silage, although effective in sustaining MY ($r = 0.48$, $P < 0.01$), was limited to the farms in the lower valleys. Any on-farm increase in this crop would be restricted by the scarcity of suitable agricultural land; moreover, transforming grasslands into arable crops has negative effects on mountain agroecosystems (Marini et al., 2009). Besides, as expected, farms with low SR and high feed self-sufficiency were able to produce their own feedstuffs from grass-land that has little or no suitability for arable crops and contributed positively to the potentially human-edible food balance (HeECR<1). Consequently, they would firmly decouple milk production from competitive resources and more efficiently recycle nutrients from non-human-edible resources (Wilkinson, 2011). Feed-food competition is a key issue for the future sustainability of the livestock sector, and in this regard evaluating the ability of ruminants to convert feed sources or wastes that monogastric livestock and humans are unable to use into high-value protein and energy plays a crucial role (Van Zanten et al., 2018). Additionally, in valuable environments such as the Alpine areas, assessment at a regional scale, beyond farm-scale, could give important insights on sustainability of the production systems (Loiseau et al., 2012), and future studies should investigate the effects of low-SR farms on services provided by the territory (ecosystem services), combining different sustainability assessment methodologies.

4.5 Conclusions

This study confirms that for all impact categories, with the partial exception of cumulative energy demand, the role of the dairy farm in the environmental footprint of dairy products is predominant. Therefore, the identification of farm management features that could be the target of mitigation measures has a notable importance in the reduction of the environmental footprint of dairy production. When addressing impact mitigation actions in Alpine or, more generally, mountain farming systems, it is necessary to take into account their wide diversity in size, structure, milk yields and animal and farmland management. This diversity in turn gives rise to a remarkable variability in terms of impacts (per unit of milk and land) and feed ratios indicators. This study found that milk yield, stocking rate and proportion of concentrates in the diet are the farm traits, when jointly considered, that can explain better impacts and feed ratios variability and that could be a target of mitigation measures. For this purpose, stocking rate and milk yield are simple and easily accessible indicators at the farm scale and could be used as proxies for the impact categories per unit of area in the former case and unit of milk in the latter. It is recommended to include both these functional units in LCA studies; this can help to assess the trade-offs between indicators of production efficiency and sustainable management of grassland, which is particularly important for mountain dairy cattle systems strongly linked to local forages. In this respect, stocking rate was informative of other variables related to farming sustainability, such as feed self-sufficiency and the role of farming practices in maintaining grasslands and the Alpine landscape in general. Moreover, we found that when we took into account the proportion of concentrates in the diet -another simple indicator of farm management intensity- we were able to better evaluate the global warming potential including land-use change and to address feed-food competition in terms of the energy conversion efficiency of grassland-based farms. From the results obtained in this study, impact minimum was associated with a sufficient but not excessive milk yield (13e22 kg FPCM/cow/d), with a low stocking rate (<2.1 LU/ha) and concentrates proportion in the diet (<16%). These data can be used to formulate recommendations for mountain dairy production to favour the reduction of the environmental impact up to one-third. Although the precise combination of the values of these indicators should be assessed taking into account the farm context, this study provides and quantifies the relationships between milk yield, stocking rate and concentrates proportion in the diet with the impact indicators and feed ratios, that could be useful to farmers and dairies to which farmers are associated to plan their management in a more environmental-friendly way. Besides, these results could give a positive contribution in addressing the policymakers' decisions, to address future policies intended to sustain the Alpine dairy system in a more comprehensive perspective that includes productive, environmental and territorial issues. Future research, moreover, should consider other issues, such as ecosystem services, to obtain a more comprehensive evaluation of the sustainability of mountain dairy systems.

4.6 References

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5. Plant Biodiversity

Biodiversity patterns of mountain grassland as influenced by farm management.

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5.1 Introduction

Grasslands provide many ecological functions as conservation of biodiversity, regulation of physical and chemical fluxes in ecosystems, mitigation of pollution, and preservation of landscapes (e.g. Gibon, 2005; Lemaire et al., 2005; Pornaro et al., 2017). Grasslands include two management categories: pastures and meadows, which are important for their high plant species richness, especially when compared with shrub or forest vegetation (MacDonald et al., 2000; Pornaro et al., 2013; Koch et al., 2015). Their botanical composition depends mainly on environmental factors such as temperature (Buxton and Fales, 1994; Ziliotto et al., 2004), water deficit (Halim et al., 1989; Ziliotto et al., 2004), solar radiation (Buxton and Fales, 1994), and soil nutrient availability influenced by fertilization (Buxton and Fales, 1994; Gibon, 2005). However, as semi-natural habitats, they are also influenced by anthropogenic activities leading to changes in the plant community.

At the end of the last century, agriculture in Europe's mountain areas has experienced radical changes, with a decrease in farm numbers and the abandoning of traditional extensive farming in favor of highly mechanized and intensive production practices (Caraveli, 2000; Höchtl et al., 2005; Strijker, 2005). Cattle have reached high milk yields, while feeding rations earned higher energy and protein contents, often by purchasing concentrates from plain areas or using not only meadows located in mountain areas (Sturaro et al., 2009; Battaglini et al., 2014). On the other hand, some farms remain true to their traditional system (Scotton et al., 2014). These farms have relatively small herds, and dairy farming is sometimes integrated with other agricultural or job activities. They are still considered compatible with the sustainable management of semi-natural grasslands (Dietl and Lehmann, 2004). Farm intensification leads to a reduction in cut meadow surfaces and the production of fertilizer amounts exceeding the receptor potential of the still managed grasslands (Scotton et al., 2014). As a result of these socio-economic shifts, pastures and meadows have gone through a profound degradation process (Bätzing, 2015). The intensification of grassland management affects species composition of meadows and favors the replacement of semi-natural grasslands with re-sown grassland used to plow in the excessive amounts of manure produced in the farms. On the other hands, the vegetation characteristics and biodiversity of the pasture areas can be influenced by the animal management, and in particular by different levels of stocking density and/or feeding supplements (Gianelle et al., 2018). However, the consequences of livestock systems intensification occur mainly on the most accessible and productive meadows. This causes the eutrophication of coenoses and the loss of plant diversity due to the invasion of nitrophilous species (Marini et al., 2008) which replace most of the species characteristic of traditional meadows (Prosser, 2001).

Within agricultural practices, the fertilization appears to have a primary rule on the botanical composition and species richness, whilst the intensity of exploitation influences mainly the forage quality (Mrkvička and Veselá, 2002; Hrabě and Knot, 2011). It is well-documented that the concentrations of soil nutrients, mainly nitrogen, affect plant diversity (Güsewell et al., 2012; Gardarin et al., 2014). An increased amount of nitrogen in the soil causes rapid shifts in the sward composition, supporting the growth of tufted grasses at the expense of legumes and other forbs (Silvertown et al., 2006). Even though, high nutrient concentration promotes the dominance of nitrophilous plants in the sward, low concentration favors the dominance of oligotrophic species (Aerts and Chapin, 1999; Iussig et al., 2015; Orlandi et al., 2016). In addition to soil nutrient status, plant species richness is affected by harvest frequency or grazing intensity. However, few studies have investigated on these aspects. Bassignana et al. (2003) reported a negative effect relationship between species richness and number of cuts on a study conducted in six experimental trial dislocated in the Italian arch and involving permanent meadows. Changes in botanical composition due to different number of cuts per year were documented also by Hejcman et al. (2010). They investigated a long-term grassland extensification of a fertilized and mown grassland comparing species richness and botanical composition of meadow cut two or four time per year, and they found that mowing frequency affected botanical composition but not number of species. Plant richness and composition is also affected by environmental variables such as elevation and slope. Both of the latter are negatively correlated with number of species (Bruun et al., 2006; Marini et al., 2007) and they influence especially botanical composition (Argenti et al., 2020; Ziliotto et al., 2004). Most of our acknowledgments on the effect of farm management on plant species richness and composition refer to plot trials.

Understanding the patterns of biodiversity at different scales has become important in ecology and landscape conservation. The present study aimed to deepen knowledge on the impact of farm management on plant species richness and composition investigation two levels of precision: farm and plot level. This research is part of an Interreg project (Interreg V-A Italy-Austria 2014-2020 TOPValue - The added value of mountain products) whose purpose is to specify and quantify the ecosystem services in order to show an added value on product market positioning.

5.2 Material and Methods

5.2.1 Study area and experimental design

The study was conducted during the year 2018 in three Regions of the Eastern Alps (Veneto, Friuli Venezia Giulia, and Trentino Alto Adige). Forty-nine farms representative of the different farming systems present in the study area were selected through dairy farmers' organization. All the milk produced was processed by local cooperative dairies. All farms were located in mountain areas and met the criteria to be considered small-scale farms according to the EFSA (2015) definition. During the study period, each farm was visited two times for administering a questionnaire to farmer and for performing an on-site botanical assessment.

5.2.2 Information about farm

Data were collected by interviewing farmers. The questionnaire was devised to collect information on productive aspects of the farms surveyed and the following parameters examined were: elevation (meter above sea level), housing system type (loose-housing or tie-stall), presence or absence of a quality scheme (Reg. UE 1151/2012 and/or Reg. UE 834/2007), overall farm productivity (i.e. average ton milk/cow/year), income from milk production out of the total farm income (%), and stocking rate (Livestock Unit (LU)/Utilized Agricultural Area (UAA)). On the basis of above, farm characteristics are shown in Table 1.

Table 1. Farm characteristics through explanatory variables.

Explanatory variable	Evaluation	Farms (n.)
Farm elevation (m a.s.l.)	<500	10
	500-1000	28
	>1000	11
Housing system	loose-housing	29
	tie-stall	20
Quality certification	product certification	5
	organic method	2
	no certification	42
Milk yield (t/cow/year)	<6	8
	6-8	19
	>8	22
Dairy income (% of total)	<50	4
	50-75	17
	>75	28
Stocking rate (LU/UAA)[1]	< 2	39
	> 2	10

[1] Livestock Unit (LU)/Utilized Agricultural Area (UAA)

5.2.3 Botanical surveys

In each farm, botanical assessments were performed in 3 different plots, except for one farm having little farmland surface where only 2 surveys were made. After a site inspection, two of the three selected plots were chosen as representative of botanical composition of the farmland vegetation. The third was the plot with highest species richness in the farmland. A total of 149 botanical surveys were performed (Fig. 1). Each survey consisted in recording all species found walking the two diagonals of the plot. Species and family nomenclature followed Aeschimann (2004). Furthermore, for each plot additional aspects were also recorded, such as elevation, slope, type of utilisation (pasture, meadow, meadow with grazing after the first cut), number of cuts [from 1 to 4, and not assigned (NA) for pastures], and type of fertilisation (manure, mineral, slurry, no fertilisation) (Table 2).

Fig.1. Maps of botanical surveys performed in the study.

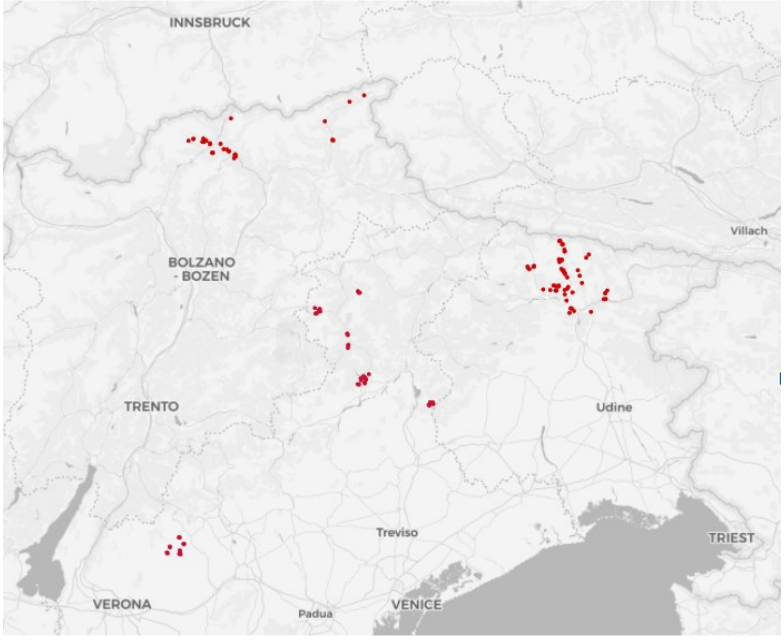


Table 2. Grasslands characteristics through explanatory variables.

Explanatory variable	Evaluation	Surveys (n.)
Survey elevation (m a.s.l.)	<500	31
	500-1000	79
	>1000	38
Slope (%)	<15	85
	15-30	30
	>30	34
Utilisation type	pasture	10
	meadow	113
	meadow grazed after first cut	26
Cuts (n.)	1	18
	2	70
	3	48
	4	3
	NA[1]	10
Fertilisation type	manure	69
	mineral	1
	slurry	69
	no fertilisation	10

[1] NA: Not Assigned

5.2.4 Data analysis

Data obtained with botanical surveys were used to build matrices to describe biodiversity comparing plots. The matrices were then handled merging surveys of each farm to have matrices to describe biodiversity comparing farms. The analysis of biodiversity comparing plot or farm deals with the study issue involving two levels of precision. The term plot level is used below for plant richness and composition derived from plot dataset comparison, while farm level is used for plant richness and composition derived from farm dataset comparison. Species having ecological and botanical similarity were pooled in families and in phytosociological classes according to Aeschimann et al. (2004). Three matrices for both plot and farm datasets were used for the analysis: (i) matrix with species (presence/absence), (ii) matrix with number of species for each botanical family, (iii) matrix with number of species for each phytosociological class. Species, family, and class richness were calculated as the number of species, families, and classes in each plot survey and in each farm survey.

Generalized linear mixed models were built to explain variation in species, family, and class richness depending on environmental (elevation and slope) and management descriptors (type of utilisation, number of cuts, fertilisation) at plot level. Models were compared based on Akaike's Information Criterion (Akaike, 1974). Significances of variables were determined by likelihood-ratio tests (LRT) of reduced versus full models. Fisher's Protected LSD test was used at the 0.05 level of probability to identify significant differences between means for significant variables. To investigate the effects of environmental (elevation and slope) and management descriptors (type of utilisation, number of cuts, fertilisation) on plant community composition (plant species, families, and class) a constrained correspondence analysis (CCA) was performed. Permutation tests were carried out to evaluate significances of explanatory variables.

Generalized linear models were built to explain variation in species, families, and class richness depending on elevation and farm descriptor (product quality scheme, housing system, milk yield, dairy income and stocking rate) at farm level. Significances of variables were determined by likelihood-ratio tests (LRT) of reduced versus full models. To investigate the effects of elevation and farm indicators (product quality scheme, housing system, milk yield, dairy income and stocking rate) on plant community composition (plant species, families, and class) a constrained correspondence analysis (CCA) was performed. Permutation tests were carried out to evaluate significances of explanatory variables. All statistical analyses were performed with R 3.4.2 (R Core Team, 2017) using libraries vegan and nlme.

5.3 Results

5.3.1 Farm and vegetation description

Agricultural management practices were often different among farms. Number of cuts and fertilization were influenced by elevation, slope, and botanical composition of the plot's vegetation especially in farms having scattered and/or faraway land.

The total plant species identified were 339 belonging to 44 families and 29 phytosociological classes (Tables 3 and 4). Ninety-eight species brought back to Molinio-Arrhenatheretea class, and the second most representative class was Festuco-Brometea (48 species). Botanical surveys revealed a minimum of 8 and 0, a mean of 20 and 3, and a maximum of 32 and 20 species for Molinio-Arrhenatheretea and Festuco-Brometea respectively (Table 2). In some surveys, species belonging to class Stellarietea mediae and Artemisietea vulgaris were found for a total of 26 and 21 species, respectively. These classes include annual and perennial species respectively that are weed or pioneer ruderal and nitrophilous species. However, they were mainly linked to a regional distribution as they were found in the western study area where a mean of 18.5% per of species survey belonged to these classes against a mean of 11.1% of the other areas. In contrast, species belonging to shrubs or forest habitats (Carpino-Fagetea sylvaticae, Carpino- Fagetea, Quercetea robori-sessiliflorae, Crataego-Prunetea, Quercetea pubescentis) were 25 in total. These classes include species associated with a degradation of botanical composition; however, they contribute to the species richness with a maximum of 10 species per survey.

The study included surveys with a large range of elevation and slope; however, they were mainly performed on plots located below 1000 m a.s.l. and with a slope lower than 15%. The primary type of utilization of the investigated farms was permanent meadow (113 surveys), and only 10 plots were regularly grazed, and 26 plots were grazed after the first hay cut. Meadows were mainly subjected to 2 and 3 cuts per season, while 4 cuts was limited to one farm.

Table 3. Number of species (total, mean, minimum and maximum) belonging to phytosociological classes.

Family	Tot	Mean	Min-Max
Asteraceae	40	4.73	1-10
Poaceae	35	7.34	3-14
Fabaceae	28	3.60	1-10
Cyperaceae	24	0.44	0-9
Lamiaceae	21	1.34	0-5
Scrophulariaceae	18	1.11	0-4
Rosaceae	15	0.55	0-4
Caryophyllaceae	13	1.40	0-4
Ranunculaceae	13	1.39	0-4
Apiaceae	11	2.11	0-5
Liliaceae	11	0.46	0-4
Brassicaceae	10	0.34	0-2
Orchidaceae	10	0.15	0-4
Polygonaceae	10	1.34	0-3
Rubiaceae	9	0.94	0-5
Campanulaceae	8	0.21	0-3
Geraniaceae	7	0.56	0-4
Juncaceae	7	0.21	0-3
Dipsacaceae	6	0.38	0-3
Primulaceae	5	0.13	0-1
Boraginaceae	4	0.39	0-1
Plantaginaceae	3	0.85	0-3
Polygalaceae	3	0.05	0-1
Crassulaceae	2	0.03	0-2
Equisetaceae	2	0.03	0-1
Euphorbiaceae	2	0.05	0-1
Gentianaceae	2	0.01	0-1
Hypericaceae	2	0.04	0-1
Iridaceae	2	0.05	0-1
Violaceae	2	0.03	0-1

Betulaceae	1	0.01	0-1
Chenopodiaceae	1	0.02	0-1
Cistaceae	1	0.01	0-1
Convolvulaceae	1	0.19	0-1
Fagaceae	1	0.01	0-1
Linaceae	1	0.01	0-1
Lythraceae	1	0.01	0-1
Onagraceae	1	0.01	0-1
Orobanchaceae	1	0.05	0-1
Polypodiaceae	1	0.01	0-1
Salicaceae	1	0.01	0-1
Saxifragaceae	1	0.01	0-1
Urticaceae	1	0.13	0-1
Valerianaceae	1	0.01	0-1

Table 4. Number of species (total, mean, minimum and maximum) belonging to phytosociological classes.

Phytosociological class	Tot	Mean	Min-Max
Molinio-Arrhenatheretea	98	19.97	8-32
Festuco-Brometea	48	2.67	0-20
Stellarietea mediae	26	1.84	0-10
Artemisietea vulgaris	21	1.82	0-6
Elyno-Seslerietea variae, Juncetea trifidi	18	0.26	0-8
Scheuchzerio-Caricetea fuscae	15	0.14	0-10
Juncetea trifidi	13	0.28	0-5
Trifolio-Geranietea sanguinei	11	1.06	0-4
Carpino-Fagetea sylvaticae	9	0.08	0-3
Mulgedio-Aconitetea	9	0.46	0-3
Nardetea strictae	9	0.36	0-4
Carpino-Fagetea	8	0.23	0-3
Koelerio-Corynephoretea	8	0.28	0-4
Filipendulo-Convolvuletea	7	0.13	0-2
Phragmito-Magnocaricetea	6	0.05	0-3

Epilobietea angustifolii	5	0.10	0-2
Quercetea robori-sessiliflorae	5	0.07	0-1
Agropyretea intermedii-repentis	4	0.05	0-1
Trifolio-Geranietea	4	0.41	0-2
Crataego-Prunetea	2	0.19	0-2
Montio-Cardaminetea	2	1.00	1-1
Calluno-Ulicetea	1	1.00	1-1
Elyno-Seslerietea	1	1.00	1-1
Erico-Pinetea	1	1.00	1-1
Quercetea pubescentis	1	1.00	1-1
Scheuchzerio-Caricetea	1	1.00	1-1
Thlaspietea rotundifolii	1	1.00	1-1
Not assigned	5	0.07	0-1

Manure and slurry were used as fertilizer in 69 plots each, and only 10 grasslands did not receive any fertilization. As well as surveys, all farms were based in mountain areas, and the majority were located below 1000 m a.s.l.. The farm housing system was balanced between the two different systems (loose-housing or tie-stall), with a slightly predominant of the system where the animals are allowed to move freely. The 86 % of farms were characterized to have none certification: only 2 farms have TSG (Traditional Specialities Guaranteed) product quality scheme, and 5 followed the organic farming practices. Most farms presented an amount of total annual milk yield for each dairy cow over 6 tons. In particular, 22 farms differ for high milk yield with 8-10 tons per year, normally related to dairy cows -suitable breeds- with a high health and fertility status. It is interesting to note that for 28 farmers the income was exclusive or almost exclusive from the farm activities while 4 and 17 farmers referred an income below 50 and between 51 and 75 respectively; so, their income is related to other sources as forestry and/or tourism. Stocking rate was guaranteed by 80% of farms involved with a LU/UAA ratio <2.

5.3.2 Plant richness and composition of surveys

Plant data were analyzed by including farms as a random effect in the generalized linear mixed models as they resulted in being the most parsimonious models. These suggested that farms are characterized by areas with a high number of species alternated with areas with few species, families, or classes. Farm was also added to the models as random effects, but they did not improve the models as assessed by Akaike's information criterion (AIC).

Among management variables, type of utilization and number of cuts were significant for species, family, and class richness, while fertilization and slope significantly affected only class richness and species richness respectively (Table 5).

Table 5. Significances based on likelihood-ratio tests of explanatory variables in generalized linear mixed models for number of species, families, and classes (plant richness) and significances based on permutation test of the effect of explanatory variables for species, family, and class composition (plant composition) at a survey scale.

	Plant richness			Plant composition		
	Species	Family	Class	Species	Family	Class
Pasture/ Meadow	<0.01	<0.01	<0.01	<0.001	<0.05	<0.001
Number of cuts	<0.0001	<0.0001	<0.0001	<0.01	<0.001	<0.001
Fertilisation	n.s.	n.s.	<0.05	<0.001	<0.001	<0.001
Elevation	n.s	n.s.	n.s.	<0.001	<0.05	<0.001
Slope	<0.05	n.s.	n.s.	<0.001	<0.05	<0.05

We found that number of species, but also families, and classes were higher in pastures than in meadows including those grazed after the first cut (Fig.s 2a, 2c, 2e). Furthermore, our results displayed a decrease of species and class richness and more lightly of number of families, with the increase of number of cuts (Fig.s 2b, 2d, 2f). The large differences in number of species, families, and classes were found between meadows cut only once and meadows cut 3 times. Moreover, the lowest number of classes occurred in plots fertilized with slurry (Fig. 2g). No significant effect of fertilization type was observed for number of species and families. It is interesting to note that the widely known relationship between elevation and species richness was not observed in this study. In contrast, slope had a positive relationship with number of species.

Differently than in plant richness, all explanatory variables resulted in being significant in plant composition. The ordination biplots based on CCA demonstrated a strong response of grasslands to management and environmental variables (Fig. 3). Axis 2 clearly separated pastures by meadows based on presence/absence of species, while meadows grazed after first cut had a botanical composition similar to pastures (Fig. 3a). Type of utilization affected also family composition with pastures having more species belonging to Caryophyllaceae and Polygalaceae (Fig. 3b). It is interesting to look at the differences on phytosociological class composition (Fig. 3c). A deep characterization of plant community was obtained by using the number of species grouped for phytosociological classes which gives less weight to individual species, especially those belonging to the classes with higher frequency (Molinio-Arrhenatheretea and Festuco-Brometea). The separation between pastures and mown/grazed meadows, showed in Fig. 3c, was due to the absence in the latter of species belonging to Elyno-Seslerietea, Trifolio-Geranietea, Nardetea strictae, and Trifolio-Geranietea sanguinei. Axis 1 clearly separated number of cuts for species, families, and class composition. Plots with no assigned number of cuts were rightly related to pastures. Taking into account species, family, and class composition, plots cut once and twice per year did not differed as much as plots cut three times (Fig. 3). Axis 1 clearly separated also plots fertilized with slurry and plots fertilized with manure. Type of fertilization did not affect species richness; however, a different composition in terms of presence/absence of species was found. Plots fertilized with manure had higher number of species belonging to almost all phytosociological classes. These results suggested a simplification of botanical composition of plots fertilized with slurry compared with plots fertilized with manure. The environmental variables involved in this study revealed opposite directions in species, family, and class composition ordination confirming to be main drivers of botanical composition due to their strong effect on temperature, and consequently on the length of the growing season.

Fig. 2. Number of species (a, b), families (b, c), and classes (e-g) as affected by type of utilisation (Pa= pasture, Me= meadow, Pa/Me= meadow grazed after the first cut), number of cuts (1 to 4, NA= not assigned), fertilisation (No= absence of fertilization).

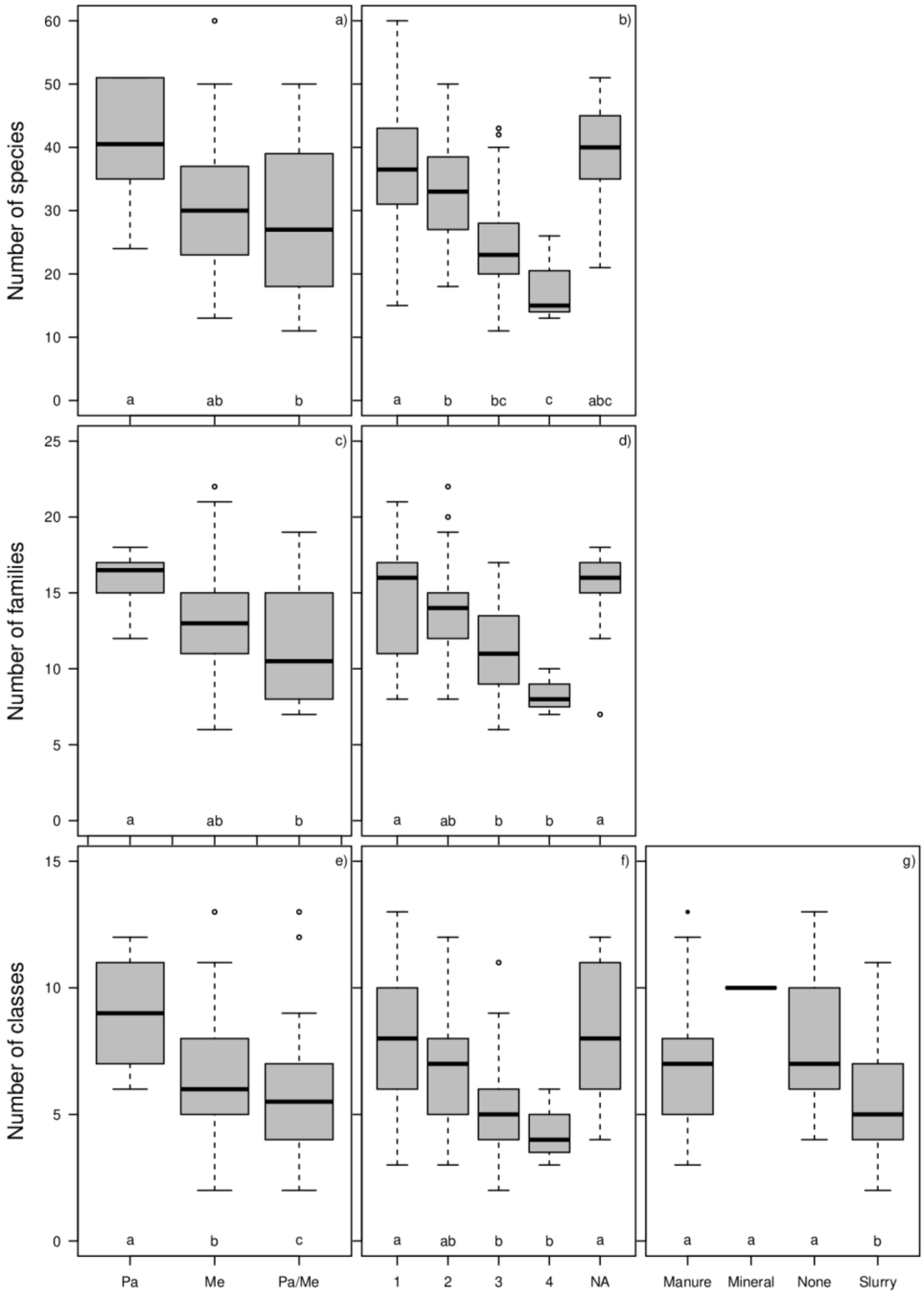
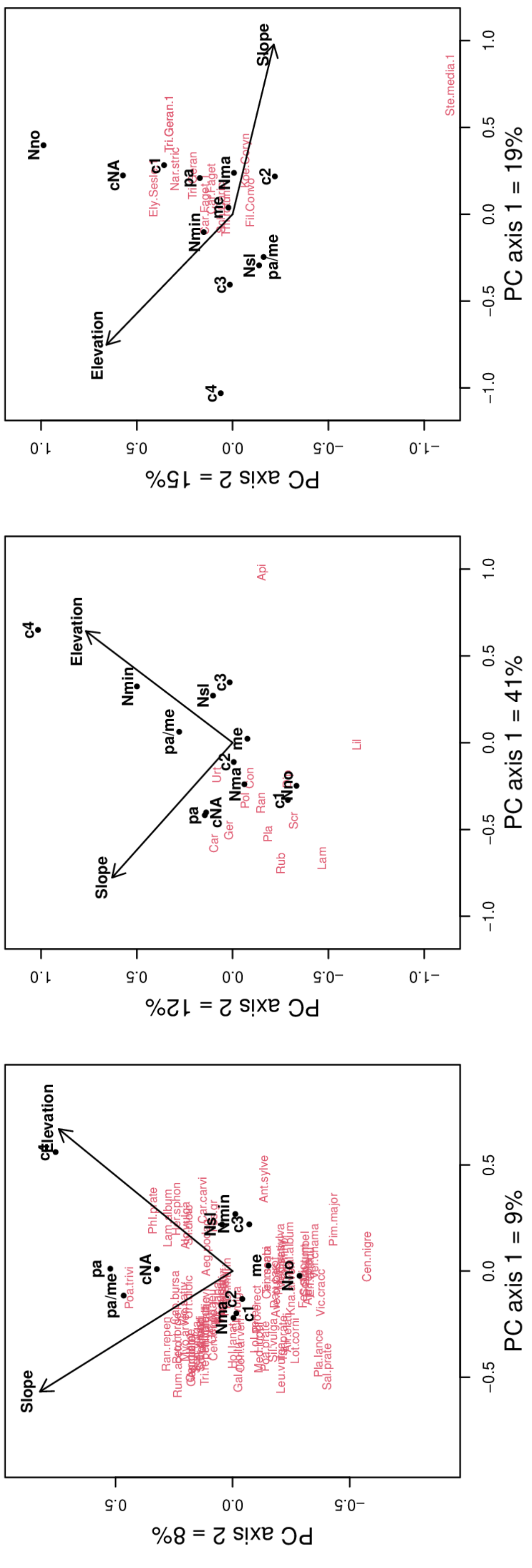


Fig. 3. Canonical Correspondence Analysis of vascular plant species (a), families (b), and phytosociological classes (c), and explanatory variables along the first two axes of CCA constrained with the significant variables. Only species (a) with a goodness of fit above 20% are shown, and families (b) and classes (c) with a goodness of fit above 5%. Data derived from 149 grasslands in the Italian Alps. Abbreviations of variables: Pa = pasture; Me = meadow; Pa/Me = meadows grazed after first cut; c1-c4 = plot cut from one to four time per year; Nma = plot fertilised with manure; Nmin = plot fertilised with mineral fertiliser; Nno = no fertilised plot; Nsl = plot fertilised with slurry. Abbreviation of species: Aeg.podag = Aegopodium podagraria, Agr.capil = Agrostis capillaris, Aju.repta = Ajuga reptans, Alc.vulga = Alchemilla vulgaris (agg.), Ant.sylve = Anthriscus sylvestris, Arr.elati =Arrhenatherum elatius, Ave.sativ =Avena sativa, Ave.pubes = Avenula pubescens, Bro.erect = Bromopsis erecta, Bro.horde = Bromus hordeaceus, Cap.bursa = Capsella bursa-pastoris, Car.carvi = Carum carvi, Cen.nigre = Centaurea nigrescens subsp. nigrescens, Cen.nigre.1 = Centaurea nigrescens subsp. transalpina, Cen.scabi = Centaurea scabiosa, Cer.glome = Cerastium glomeratum, Cli.vulga = Clinopodium vulgare, Col.autum = Colchicum autumnale, Con.arven = Convolvulus arvensis, Cru.laevi = Cruciata laevipes, Dau.carot = Daucus carota, Eri.annuu = Erigeron annuus, Fes.gr = Festuca gr. rubra, Fes.stric = Festuca stricta subsp. sulcata, Gal.album = Galium album, Gal.mollu = Galium mollugo, Ger.disse = Geranium dissectum, Ger.molle = Geranium molle, Ger.phaeu = Geranium phaeum, Ger.sylva = Geranium sylvaticum, Her.sphon = Heracleum sphondylium, Hol.lanat = Holcus lanatus, Hor.murin = Hordeum murinum, Hyp.radic = Hypochaeris radicata, Kna.arven = Knautia arvensis, Lam.album = Lamium album, Leu.vulga = Leucanthemum vulgare, Lol.multi = Lolium multiflorum, Lol.peren = Lolium perenne, Lot.corni = Lotus corniculatus, Med.lupul = Medicago lupulina, Med.sativ = Medicago sativa, Myo.arven = Myosotis arvensis, Orn.umbel = Ornithogalum umbellatum, Phl.prate = Phleum pratense, Pim.major = Pimpinella major, Pim.saxif = Pimpinella saxifraga, Pla.lance = Plantago lanceolata, Poa.prate = Poa pratensis, Poa.trivi = Poa trivialis, Ran.repen = Ranunculus repens, Rhi.alect = Rhinanthus alectorolophus, Rhi.minor = Rhinanthus minor, Rum.aceto.1 = Rumex acetosella, Sal.prate = Salvia pratensis, Sch.arund = Schedonorus arundinacea, Sen.vulga = Senecio vulgaris, Sil.dioic = Silene dioica, Sil.vulga = Silene vulgaris, Tra.prate = Tragopogon pratensis, Tri.dubiu = Trifolium dubium, Tri.monta = Trifolium montanum, Tri.repen = Trifolium repens, Urt.dioic = Urtica dioica, Ver.chama = Veronica chamaedrys, Vic.cracc = Vicia cracca, Vic.faba = Vicia faba, Vic.hirsu = Vicia hirsuta, Vic.sativ = Vicia sativa. Abbreviation of families; Api = Apiaceae, Ast = Asteraceae, Car = Caryophyllaceae, Con = Convolvulaceae, Dip = Dipsacaceae, Fab = Fabaceae, Ger = Geraniaceae, Lam = Lamiaceae, Lil = Liliaceae, Pla = Plantaginaceae, Poa = Poaceae, Pol = Polygalaceae, Ran = Ranunculaceae, Rub = Rubiaceae, Scr = Scrophulariaceae, Urt = Urticaceae. Abbreviation of phytosociological classes: Car.Faget = Carpino-Fagetea, Car.Faget.1 = Carpino-Fagetea sylvaticae, Ely.Sesle.1 = Elyno-Seslerietea variae, Fil.Convo = Filipendulo-Convolvuletea, Koe.Coryn = Koelerio-Corynephoretea, Nar.stric = Nardetea strictae, Sch.Caric = Scheuchzerio-Caricetea, Ste.media.1 = Stellarietea mediae, Thl.rotun = Thlaspietea rotundifolii, Tri.Geran = Trifolio-Geranietea, Tri.Geran.1 = Trifolio-Geranietea sangunei.


PC axis 1 = 9%
PC axis 2 = 8%
Elevation
Slope
c4
pa
pa/me
cNA
Nsl
Nmin
c3
me
Nno
Nma
c2
c1
Poa.trivi
Phl.prate
Lam.album
Ant.sylve
Pim.major
Cen.nigre
Ran.repen
Pla.lance
Sal.prate
Lot.corni
Vic.cracc
Leu.vulga
PC axis 1 = 41%
PC axis 2 = 12%
Api
Lil
Lam
Rub
Pla
Scr
Ran
Con
Pol
Ger
Car
Urt
PC axis 1 = 19%
PC axis 2 = 15%
Nno
Ste.media.1
Tri.Geran.1
Nar.stric
Ely.Sesle
Fil.Compo
c4
1.0
0.5
0.0
−0.5
−1.0

5.3.3 Plant richness and composition of farms

When surveys were merged for each farm, number of species resulted affected by farm management and elevation. Considering the plot-level biodiversity, we had a high variability within each farm, which was only slightly due to variation in management. In contrast, using the farm-level biodiversity, all the explanatory variables, with the exception of housing system, affected number of species (Table 6). It is interesting that no differences were detected between organic and non-organic farms. Only one farm with TSG product quality scheme had lower number of species then other farms, but this information cannot be representative of the whole system. With the increase of milk yield, dairy income, and stocking rate, there is a decrease in number of species. The increase of milk yield negatively affected also number of classes.

Elevation, quality scheme, housing system and dairy income were significant also for species composition (Table 6). Family composition was affected only by housing system while class composition by milk yield and stocking rate. The ordination biplots based on CCA demonstrated a strong response of species composition to elevation, certification type, housing system and dairy income (Fig. 5a). Axis 2 clearly separated farms with organic or conventional certification scheme, and farms with loose housing or tie-stall housing systems. Elevation and income affected species composition while housing system family composition (Fig. 5b). It is interesting to look at the differences on phytosociological class composition (Fig. 3c). Axis 1 shows changes in botanical composition linked to milk yield and stocking rate. The shift of botanical composition with the increase of these two variables was due to a gradual loss of species as shown in Fig. 4. For this reason, we observed a general decrease in the number of species belonging to all phytosociological classes, which was particularly pronounced in Trifolio-Geranietea sanguinei, Elyno-Seslerietea variae, Nardetea strictae, and Trifolio-Geranietea.

Table 6. Significances based on likelihood-ratio tests of explanatory variables in generalized linear mixed models for number of species, families, and classes (plant richness) and significances based on permutation test of the effect of explanatory variables for species, family, and class composition at a farm scale.

	Plant richness			Plant composition		
	Species	Family	Class	Species	Family	Class
Farm elevation	<0.05	n.s.	n.s.	<0.01	n.s.	n.s.
Housing system	n.s.	n.s.	n.s.	<0.05	<0.01	n.s.
Certification	<0.01	n.s.	n.s.	<0.05	n.s.	n.s.
Milk yield	<0.0001	n.s	<0.01	n.s.	n.s.	<0.05
Dairy income	<0.01	n.s.	n.s.	<0.01	n.s.	n.s.
Stocking rate	<0.0001	n.s.	n.s.	n.s.	n.s.	<0.05

Fig. 4. Number of species as affected by product quality certification (qual = product quality scheme, no = farm with none certification, org = farm with organic practices), milk production, dairy income and stocking rate.

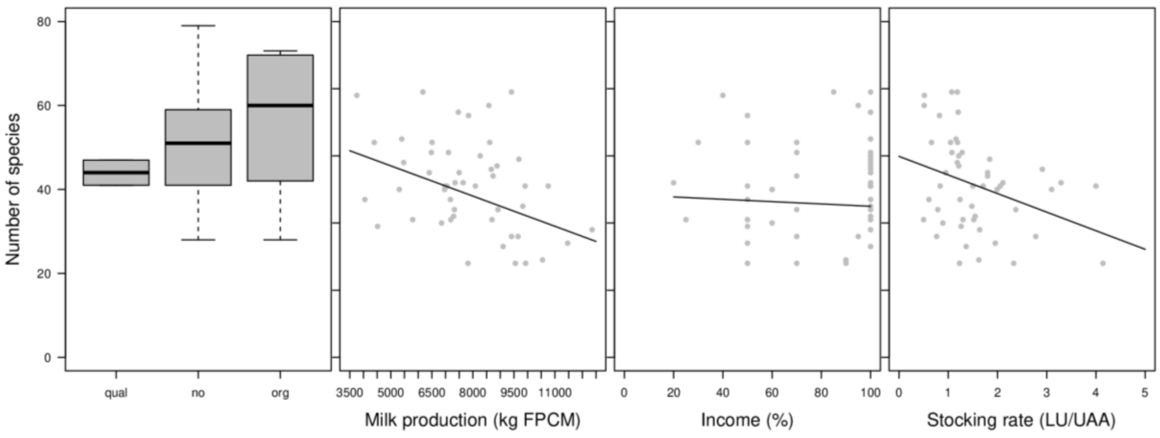
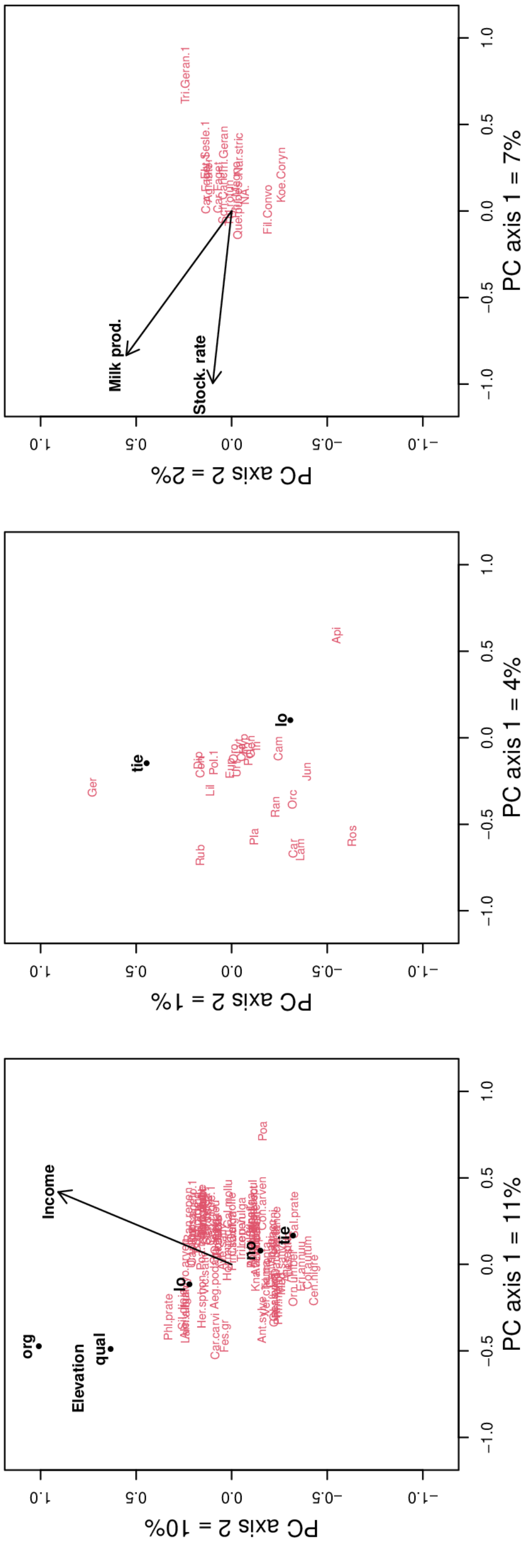


Fig. 5. Canonical Correspondence Analysis of vascular plant species (a), families (b), and phytosociological classes (c), and explanatory variables along the first two axes of CCA constrained with the significant variables. Only species (a) with a goodness of fit above 20% are shown, and families (b) and classes (c) with a goodness of fit above 5%. Abbreviations of variables: qual = quality scheme; org = organic practices; no = none certification; lo = loose-housing; tie = tie-stall housing. Abbreviation of species: Aeg.podag = Aegopodium podagraria, Agr.capil = Agrostis capillaris, Aju.repta = Ajuga reptans, Alc.vulga = Alchemilla vulgaris (agg.), Ant.sylve = Anthriscus sylvestris, Arr.elati =Arrhenatherum elatius, Ave.sativ =Avena sativa, Ave.pubes = Avenula pubescens, Bro.erect = Bromopsis erecta, Bro.horde = Bromus hordeaceus, Cap.bursa = Capsella bursa-pastoris, Car.carvi = Carum carvi, Cen.nigre = Centaurea nigrescens subsp. nigrescens, Cen.nigre.1 = Centaurea nigrescens subsp. transalpina, Cen.scabi = Centaurea scabiosa, Cer.glome = Cerastium glomeratum, Cli.vulga = Clinopodium vulgare, Col.autum = Colchicum autumnale, Con.arven = Convolvulus arvensis, Cru.laevi = Cruciata laevipes, Dau.carot = Daucus carota, Eri.annuu = Erigeron annuus, Fes.gr = Festuca gr. rubra, Fes.stric = Festuca stricta subsp. sulcata, Gal.album = Galium album, Gal.mollu = Galium mollugo, Ger.disse = Geranium dissectum, Ger.molle = Geranium molle, Ger.phaeu = Geranium phaeum, Ger.sylva = Geranium sylvaticum, Her.sphon = Heracleum sphondylium, Hol.lanat = Holcus lanatus, Hor.murin = Hordeum murinum, Hyp.radic = Hypochaeris radicata, Kna.arven = Knautia arvensis, Lam.album = Lamium album, Leu.vulga = Leucanthemum vulgare, Lol.multi = Lolium multiflorum, Lol.peren = Lolium perenne, Lot.corni = Lotus corniculatus, Med.lupul = Medicago lupulina, Med.sativ = Medicago sativa, Myo.arven = Myosotis arvensis, Orn.umbel = Ornithogalum umbellatum, Phl.prate = Phleum pratense, Pim.major = Pimpinella major, Pim.saxif = Pimpinella saxifraga, Pla.lance = Plantago lanceolata, Poa.prate = Poa pratensis, Poa.trivi = Poa trivialis, Ran.repen = Ranunculus repens, Rhi.alect = Rhinanthus alectorolophus, Rhi.minor = Rhinanthus minor, Rum.aceto.1 = Rumex acetosella, Sal.prate = Salvia pratensis, Sch.arund = Schedonorus arundinacea, Sen.vulga = Senecio vulgaris, Sil.dioic = Silene dioica, Sil.vulga = Silene vulgaris, Tra.prate = Tragopogon pratensis, Tri.dubiu = Trifolium dubium, Tri.monta = Trifolium montanum, Tri.repen = Trifolium repens, Urt.dioic = Urtica dioica, Ver.chama = Veronica chamaedrys, Vic.cracc = Vicia cracca, Vic.faba = Vicia faba, Vic.hirsu = Vicia hirsuta, Vic.sativ = Vicia sativa. Abbreviation of families; Api = Apiaceae, Cam = Campanulaceae, Car = Caryophyllaceae, Con = Convolvulaceae, Cra = Crassulaceae, Dip = Dipsacaceae, Eup = Euphorbiaceae, Gen = Gentianaceae, Ger = Geraniaceae, Hyp = Hypericaceae, Iri = Iridaceae, Jun = Juncaceae, Lam = Lamiaceae, Lil = Liliaceae, Lyt = Lythraceae, Orc = Orchidadeae, Oro = Orobanchaceae, Pla = Plantaginaceae, Poa = Poaceae, Pol = Polygalaceae, Pol.1 = Polygonaceae, Ran = Ranunculaceae, Ros = Rosaceae, Rub = Rubiaceae, Urt = Urticaceae. Abbreviation of phytosociological classes: Agr.inter = Agropyretea intermedii-repentis, Car.Faget = Carpino-Fagetea, Car.Faget.1 = Carpino-Fagetea sylvaticae, Ely.Sesle.1 = Elyno-Seslerietea variae, Fil.Convo = Filipendulo-Convolvuletea, Koe.Coryn = Koelerio-Corynephoretea, Nar.stric = Nardetea strictae, Phr.Magno = Phragmito-Magnocaricetea, Que.pubes = Quercetea pubescentis, Sch.Caric = Scheuchzerio-Caricetea, Thl.rotun = Thlaspietea rotundifolii, Tri.Geran = Trifolio-Geranietea, Tri.Geran.1 = Trifolio-Geranietea sangunei, NA = not assigned.


PC axis 1 = 7%
PC axis 2 = 2%
Milk prod.
Stock. rate
Tri.Geran.1
Koe.Coryn
Fil.Convo
PC axis 1 = 4%
PC axis 2 = 1%
Api
lo
tie
Ger
Cam
Jun
Ran
Orc
Ros
Pla
Car
Lam
Rub
Lil
Pol.1
PC axis 1 = 11%
PC axis 2 = 10%
Income
org
Elevation
qual
lo
no
tie
Poa
Phl.prate
Car.carvi
Fes.gr
Gal.prate
Ant.sylve
-1.0
-0.5
0.0
0.5
1.0

5.4 Discussion

5.4.1 Biodiversity described by plot comparison

Farms were included in the model in order to take into account spatially correlated environmental variables (Borcard et al., 1992) and spatial components linked to historical processes (Svenning and Skov, 2005). We found significant farm effect in the model. This result confirmed the high variability in botanical composition at plot level observed in other studies in a similar environment (Pornaro et al., 2019) as the surveys data model analysis suggested that farms are characterized by high plot diversity in plant richness.

Klimek et al. (2007), in a study analysing relative importance of management and environmental factors on grassland vegetation, demonstrated that type of utilisation is the main factor affecting plant species richness and composition. According with them we found that species, families, and classes richness at plot level are higher in pastures than in meadows or in meadows either mown and grazed (Fig. 2). Differences in botanical composition of pastures and meadows are widely known (Klimek et al., 2007) and are associated with plants' response to grazing or mowing regime. Differences observed in phytosociological class composition are not very clear. Using number of species grouped for phytosociological classes we give less weight to individual species and especially to the species belonging to the classes with higher frequency (Molinio-Arrhenatheretea and Festuco-Brometea). The separation between pastures and meadows grazed after first cut reported in Fig. 3c was due to the absence of species belonging to Elyno-Seslerietea, Trifolio-Geranietea, Nardetea strictae, and Trifolio-Geranietea sanguinei.

Our results about number of cuts agreed with those of other studies (Bassignana et al., 2003; Hejcman et al. 2010) demonstrated a reduction of species richness increasing management intensity of grasslands. However, we believe that this result is due primarily to the productivity of these coenoses as productivity and species richness are negatively related (Gough et al., 2000; Jacquemyn et al., 2003; Maurer et al., 2006). Taking into account species, family, and class composition, plots cut once and twice per year did not differ as much as plots cut three times (Fig. 3). Meadows receiving 2 and 3 cuts per year did not show differences in plant richness, but they were different for species, families, and class composition (Fig. 3) with a general simplification of botanical composition. Changes in botanical composition due to different number of cuts per year were documented also by Hejcman et al. (2010) who stressed the influence of cuts on the competition for light (Louault et al. 2005; Pavlů et al. 2007) and nutrient (Elberse & Berendse 1993; Liu et al. 2010). A change in botanical composition could also be related to physiological response of plants to mowing stress that influence not only the vegetation but also soil characteristics (Francioni et al., 2020). We also observed changes in botanical composition for meadows cut four times, but since only three meadows over 113 were subjected to this cutting regime, the result has limited impact.

The decrease of species number due to the increase of fertilisation has been well documented for both pastures and meadows (Gough et al., 2000; Jacquemyn et al., 2003; Maurer et al., 2006), while limited information is available regarding the effect of fertilisation type on number of species. In this study, manure was compared with slurry. The slurry is commonly used fertilizer in grasslands, but its effect on plant species has been little studied (Duffková et al., 2013; Liu et al. 2010). Nevertheless, these studies documented that vegetation fertilised for a long time with slurry is subjected to a slight decrease of species richness. Similarly, we found less number of classes in plots fertilised with slurry than plots fertilized with manure or not fertilized (Fig. 2g). Duffková et al. (2013) reported a change in the botanical composition not caused by changes in species composition but in relative abundance of species. This maintenance of the most species in plant composition, as reported in the literature and in Fig. 2, could justify the no significant effect of fertilisation type we observed on number of species and families. Ordination plots also separated plots fertilised with slurry and plots fertilised with manure, confirming that a different type of fertilisation affects plant composition (Klimek et al., 2007). Differently, Duffková et al. (2013) observed, in a long-term study, a shift in relative abundance of species as a consequence of fertilisation with slurry without a significant loss of species. Our results showed also that plots fertilised with manure had higher number of species belonging to almost all phytosociological classes, suggesting a simplification of botanical composition in consequence of slurry distribution.

It should also be noted that the widely documented relationships between elevation and vegetation richness or between slope and vegetation richness were not observed in this study. This is probably because most of the variation in plant species, family, and class richness could be primarily captured by the explanatory variables reflecting field management. In contrast, the environmental site conditions and large-scale spatial trends variation have minor influence (Klimek et al., 2007). As a large range of elevations and slopes were compared, we can say that their effect on plant richness was clouded by field management effect. Nevertheless, environmental variables confirmed to be the main drivers on botanical composition due to their strong effect on temperature, and consequently, on the length of the growing season (Marini et al., 2007).

5.4.2 Biodiversity described by farm comparison

As already mentioned in material and methods section, the farms considered in the study were very heterogeneous including conventional and organic systems, with or without quality certification, different housing system, levels of stocking rate and percentage of dairy income.

It is often assumed that organic farms have larger and better-quality grasslands (Aude et al. 2004). However, observing plant diversity, there were no significant differences in plant species richness between organic and conventional farms (Gibson et al., 2007). The farm with quality scheme had lower number of species then other farms, but as only one farm uses this system, this information cannot be considered representative of the whole quality system. Species composition resulted also different between organic or conventional certification type, and farms with a and b housing system. We do not think that housing system could induce differences in plant composition. The correlation between quality scheme and housing system suggests that organic farms promote the use of a housing system, thus differences in botanical composition between housing systems are the result of farm management choice.

We have demonstrated the decrease of number of species and classes in consequence of the increase of milk yield, dairy income and stocking rate. This result would imply that herds are fed with high-concentrate diets causing an excessive return of nutrients to the soil with consequent nitrification of grasslands. This was confirmed by the negative effect of stocking rate on biodiversity guarantee as a consequence of complex interactions between environmental and management factors (Pierik et al., 2017). The higher was the stocking rate the lower was the farm ability to sustain animals with their farm productions. The negative impact of farms on species richness was lower for farms having the 100% income coming from the farm. However, based on plant species, botanical composition was not affected by milk yield or stocking rate, but based on phytosociological classes, it was. The shift of botanical composition with the increase of these two variables was due to a gradual loss of species as shown in Fig. 4. For this reason, we observed a general decrease of species belonging to all phytosociological classes, especially for Trifolio-Geranietea sanguinei, Elyno-Seslerietea variae, Nardetea strictae, and Trifolio-Geranietea. There are no studies in literature looking specifically at the relationship between milk yield or stocking rate with plant richness or composition. However, our results were in line with studies investigating the relationship between plant richness or composition and increasing fertilization (Crawley et al., 2005; Honsovà et al., 2007). This strengthens the theory that farm intensification leads to over-fertilization of grasslands.

5.5 Conclusions

Farm management strongly influences plant richness and composition of grasslands. Type of fertilization and mowing frequency affect richness and composition based on species, families, and classes, also within farms themselves, favoring into the farmland the presence of areas with higher biodiversity than others. Our results also show that grasslands of dairy farms on mountain areas have a decrease of species richness and phytosociological classes botanical composition due to the increase milk yield and stocking rate. However, also productive mountain dairy farms preserve high biodiversity areas. The use of concentrate and forages coming from the plain should not be completely opposed but rather weighted to the production system need. In this way, defending farms and their economic subsistence, is the only way to maintain biodiversity at plot level and, on the other hand, to develop a scheme that allows even farmers themselves to audit their own farms. A multidimensional approach is recommended to analyze the efficiency of the system, taking into account the benefits of different farming managerial choices.

5.6 References

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6.Conclusions and future directions

Cattle, and ruminants in general, play a crucial and unique ecological role of "nutritional mediation". As a matter of fact, they are able to transform plant materials rich in fiber – almost indigestible for humans – into food with high biological value, such as milk and meat.

However, this quality – which has undoubtedly justified their breeding – entails alleged negative implications, stigmatized by environmental movements in terms of energy and water consumption, as well as gas emissions altering climate. Many analyses carried out using Life Cycle Assessment (LCA) approaches point out opportunities in the further intensification of livestock. On the one hand, the possibility to respond to the increasingly pressing demands for animal products and, on the other hand, to reduce costs and environmental impact per product unit. However, in certain fragile and varied territorial contexts such as mountain ones, the intensification of livestock systems seems impractical and risks being scarcely sustainable for several reasons: the progressive loss of the multifunctional calling, that is the ability to provide useful services to the entire community, the risk of underestimating products and, in general, the strong impact per unit area. The intensification of livestock production systems have also consequences for animal welfare, biodiversity and land use. The simplified indicators approach used in this study plays a key role in monitoring the variation of sustainability outcomes throughout the year, resulting from the change in context and to address the main issues characterizing each context. Recently a new approach has emerged that using benchmarking of on-farm data as a way to induce change by identifying critical thresholds at which action is needed based on data collected in a sample of farms. The best- and worst-performing groups are defined by data distribution (e.g., quartiles), and sustainability improvement is pursued by targeting achievable outcomes as obtained by peers. The choice of relevant attributes and related thresholds should be based on best-available science in a given context and should be clearly stated in the promotion strategy selected by each dairy cooperative in order to develop a solid private scheme.

The numerous surveys on consumer perception in this regard highlight a willingness to recognize (and pay for) these “external” qualities attributes, especially in local products, without prejudice to the need to guarantee products with high nutritional, organoleptic or dietetic value. At the same time, the interest of the community in recognizing the services offered by the production chain (agri-environmental payments) requires virtuous choices from manufacturers, as well as precise and effective information. Innovative approaches to improve business competitiveness and an economic revitalization of the mountain livestock sector should go at the same pace than conservation goals for good practices.

It is therefore desirable to get an overall change in competitive strategy and the implementation of public and private measures aimed at improving consumer information related to choices with a multifunctional purpose. In this context, the parameters of environmental and social sustainability of cattle breeding must be reconsidered and linked to forage and food self-sufficiency, the possibility of enhancing double-purpose breeds, the ability to provide ecosystem services, also the chance of generating tourism incomes. The future of grassland-based systems will depend not only on remuneration from high added-value products but also regulation and compensation of external quality attributes. From this perspective, animal welfare, environmental sustainability and plant biodiversity could be seen as an opportunity (competitive advantage) rather than a constraint. These concepts are easily understood by the consumer and the monitoring is based on simplified and repeatable scientific methods. Incentives can take various forms – ranging from regulatory (permits, laws, quotas) to voluntary (certification, labelling) – and can be packaged in various combinations. Moreover, they can be conveyed through the product label in combination with other pieces of information (see brands Reg. 1151 / 12, Solo di PRI, etc., or in the context of "umbrella brands" e.g., Süd Tiroler Qualität, etc.). While public schemes outline minimum welfare standards defined by the EU legislation on animal welfare, private schemes are meant to exceed these minimum standards responding to higher societal and consumer expectation and demand for assurance of humane animal handling. For example, good practices payment can be provided by private-sector entities that benefit directly from a given service, as a means of ensuring that supply is maintained. Public transfer payments or subsidies can help bring about systematic changes in livestock systems. A sustainable future for the community is one of the objectives established also by the European Union Agenda 2030. The growing environmental sensitivity to the issues of food production, distribution and responsible consumption ways cannot be overlooked for sustainability achievement, as well as the relative perception and awareness of the consumer. Yet while the relationship between animal welfare, environmental well-being and human development is increasingly researched and evidenced, there remains very little recognition of this relationship and the crucial role external attributes plays in sustainable development for people.

Citizens are increasingly sensitive, which can sometimes become a driver for product choice, price and market opportunities. Highlight a diversified food supply chains in terms of their contribution to overall external quality are central when it comes to knowing the mountain lives.