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Dairy farming systems and environment in mountainous areas

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Abstract

For several decades, the practice of farming in mountain areas has played a key role to the proper management of the landscape, the conservation of the biodiversity as well as the soil protection. Moreover, it has significantly contributed to the protection of those areas from avalanches and fires, while at the same time it keeps reinforcing the local economy, thereby acting as a counterweight to abandonment. The mountain animal husbandry is by definition multifunctional and multidisciplinary. In fact, mountainous farming consists of a complex and dynamic system. The harmony and the balance between human activities and nature requires some of the most precious human skills, like patience, self-abnegation, endurance to handiwork and frugality, to name some, but above all, love for mother nature. These are characteristics that ensure continuity and vitality of the mountain for both humans and the surrounding nature. In Italy, almost half of the total land is classified as mountainous (47.5%). Nevertheless, farmers in mountainous regions (representing 30.9% of the national total) face several limitations. These limitations, linked to the existence of natural handicaps, cannot be easily overcome with investments. For example, in mountains the average temperatures are lower, resulting in shorter vegetative period. Moreover, the excessive fractionation, the major gradients and roughness of the lands and at the same time the lower fertility of soils, create the need for special machinery (often more expensive than those used in mainland farms) as well as increased labor and extra inputs for the farms. These factors can lead to a lower land (and consequently farm) productivity, which can be translated into a limited competitiveness of the mountain farms, compared to mainland. In addition, the difficulty of access and the distance of individual dairy farms from the lowland as well as the fewer processing facilities and their small size, create higher transportation costs and lower economies of scale.

Thus, the overall objective of this thesis was to verify some parameters of sustainability that are of great importance for animal husbandry in the mountain areas. The province of Trento was selected as a model area for this type of research. More precisely, we have analyzed the relationship between dairy farms and management of the Alpine pastures, in the light of the environmental value of semi-natural grasslands. The first and second contributions are related to this goal. In the last part a survey was carried out to assess the environmental footprint of dairy farms of Trento province, focusing on innovative aspects of nutrition and management of the animals bred.

More specifically, the goal of the first contribution was to analyze the role of the mountain livestock sector. At a first step, data were collected from the Veterinary Services of the province concerning the structures and the management of 395 Alpine summer pastures either with cattle (83 with only heifers and 262 including dairy cows) or sheep and goats (50 summer pastures). All the heifers and more than one third of dairy cows that kept on permanent farms of the province were brought to the temporary farms on the Alpine pastures during the summer season, with a frequency greater for cows of local and dual purpose breeds than specialized breeds (*e.g.* Holstein Friesian). Of the 610 permanent dairy farms associated with the Provincial Federation of Farmers, we have analyzed the differences between the dairy farms that move/do not move the lactating cows to Alpine summer pastures: *i.e.* the traditional dairy farms (small and medium size), with tied stall, local breeds and with low productivity, frequently using the summer pasture were compared to modern dairy farms of the same province. Results showed that the practice of transhumance to summer pasture has an important role for the dairy sector of Trento province, although the farmers changed the reasons why they choose to move the animals. In fact, the role of grazing as production support in the summer is relevant just for the traditional small and medium dairy farms, while in all cases it is important to access public subsidies that are undifferentiated between lactating cows, dry cows and replacement. The study displayed the fact that there is still the need to maintain the link between dairy farms and Alpine pastures, giving particular attention to the quality of the pasture management and the multi-functionality of services that can be provided by mountain farms.

The second part aimed in evaluating the effect of pasturing of dairy cows on milk yield and quality. To this purpose, a many of traits was considered. Body Condition Score (BCS), milk production and quality, milk coagulation properties, different set of parameters and information relating to dairy processing were recorded and analyzed. In total, date regarding 799 lactating cows were collected and analyzed during 2012 from 15 temporary farms on Alpine summer pastures located in the region of Trentino. The cows were reared in 109 permanent dairy farms. Effects of the breed, parity and days in milk were taken into account. The effects of Alpine summer pasture, and in particular of the amount of compound feed given to cows, were also considered. Information was gathered not only during the period that the cows spent at the Alpine summer pasture, but also before and after the alpine season, with the objective to evaluate the changes due to the environmental changes. Results showed that the summer transhumance had an effect more or less relevant in determining a decrease in production, but also depending upon the breed. Specialized breeds, with higher production levels in permanent dairy farms, suffer a greater drop in production than the local and dual purpose breeds. This was somehow expected, since local breeds have a greater adaptability and lower nutrients requirements.

Even the body condition score has been strongly influenced from the summer Alpine pasture. A decline in the first phase of the pastures and a subsequent recovery at the end of the pasture period was observed. Differences between breeds existed, with those specialized breeds showing a greater decrease in body condition.

After the return from the Alpine pastures a decline in the percentage of fat content in milk (more evident in specialized breeds) was observed, while the protein content remained constant. Regarding the technological properties of milk, significant differences were found with the change of environment (after the reaching of temporary summer farms and after the return to permanent farms). The major differences for lactodynamographic properties as well as the individual cheese yields were observed between June and September. In summary, this work highlighted the better adaptation of local and dual purpose breeds in the Alpine environment and their good performance under environmental changes as well as the special conditions of the farming system in summer pasture.

The last part of this thesis aimed to evaluate the environmental footprint of mountain dairy cattle farms. The study was conducted in a specific area of the Province of Trento. Data were collected from 38 dairy cattle farms of mixed breeds using different farming systems. Data on the general farm management, diet, the production performance, the agronomic management of the surfaces, the management of waste, and the energy consumption were collected. A specific questionnaire was developed and tested to this purpose. This specific questionnaire could also be used for further investigation in mountain region.

The above mentioned data were used to calculate the carbon footprint of the herds using the Life Cycle Assessment (LCA) approach. The study included the entire product life, *i.e.* from production of raw materials and their processing till the final product (the functional unit was the kilogram of milk). All the inputs and outputs associated to the functional unit were taken into account. Three categories of environmental impact of the farms were considered: i) carbon footprint (contribution to the production of greenhouse gases), ii) acidification and iii) eutrophication.

The values obtained for the three impact categories had large variability, with mean and standard deviation equal to 1.46 ± 0.58 kg for CO_2 equivalent (eq), 27.18 ± 8.34 g for SO_2

eq. and 7.91 ± 2.31 g for PO_4^{3-} eq. per kg of milk (fat and protein corrected). The values obtained are comparable with previous studies carried out in mountain areas. The overall impact was divided between on-farm and off-farm components, and was shared according to mass allocation between milk and meat. Analysis of variance showed that the considered effects of housing (free *vs* fixed) and feed administration (traditional *vs* TMR), even if appeared statistically significant for some traits, slightly affected the high variability of the impact categories that can be observed among different dairy farms of the same group. This means that there are margins to mitigate the impact and increase the efficiency of farms with different structures and management.

Overall, the results of the present thesis provided with some interesting insights on the sustainability assessment of dairy farming systems in mountainous areas, adopting innovative methodological approaches. Looking ahead, the results obtained from experimental approaches could be expanded on a large pool of dairy farms to identify the indicators of reference for the evaluation of the sustainability and multi-functionality of mountain farms.

Riassunto

La pratica dell'allevamento nel territorio montano ha avuto un ruolo fondamentale per la corretta gestione del paesaggio, la conservazione della biodiversità e la protezione del suolo. Inoltre svolge notevoli positività anche in termini di protezione dalle valanghe e dagli incendi, nel contrasto all'abbandono e soprattutto per lo sviluppo dell'economia locale. La zootecnia montana è per definizione multifunzionale e multidisciplinare. Infatti, spesso è artefice di uno sviluppo più complesso e dinamico, in grado di integrare altri comparti economici quali ad esempio il turismo o il sociale, assicurando continuità e vitalità alla montagna. In Italia quasi la metà del territorio è classificato come montano (47.5%) dove gli agricoltori presenti (30.9% sul totale nazionale) devono affrontare diverse limitazioni, legate all'esistenza di svantaggi naturali, che non sono facilmente affrontabili con investimenti. Le temperature medie inferiori, con conseguente periodo vegetativo più breve, l'eccessivo frazionamento, le maggiori pendenze e asperità dei suoli e allo stesso tempo la minore fertilità dei suoli stessi, la necessità di macchinari spesso più costosi come pure i tempi di lavoro più lunghi, hanno come conseguenze una minore produttività della terra, tradotto in una limitata competitività e produttività del lavoro. In aggiunta, la difficoltà di accesso e la lontananza delle singole aziende dal fondovalle, un minor numero di strutture di trasformazione e le loro ridotte dimensioni, sono la causa di maggiori costi di trasporto e minori economie di scala.

L'obiettivo generale di questa tesi è di verificare alcuni parametri di sostenibilità di notevole rilievo per la zootecnia montana nella Provincia Autonoma di Trento. Nello specifico, sono state analizzate le relazioni tra bovinicoltura da latte e gestione degli alpeggi, alla luce della valenza ambientale delle praterie semi-naturali; il primo e il secondo contributo sono relativi a questo obiettivo. Nell'ultimo contributo è stata svolta un'indagine per calcolare l'impronta ambientale della bovinicoltura da latte trentina, con un innovativo focus sugli aspetti di nutrizione e gestione degli animali allevati.

Nello specifico l'obiettivo del primo contributo è di analizzare il ruolo delle malghe nel comparto zootecnico montano. Sono stai raccolti dal servizio veterinario della Provincia i dati riguardanti le strutture e il management di 395 malghe dove erano presenti bovini da latte (83 solo manze e in 262 anche bovini adulti) e ovicaprini (50 strutture). Praticamente tutte le manze e più di un terzo delle vacche da latte allevate negli allevamenti di fondovalle della provincia sono portate al pascolo durante la stagione estiva, con una frequenza maggiore per le vacche di razze locali e a duplice attitudine rispetto a quelle specializzate. Delle 610 aziende di fondovalle associate alla Federazione allevatori, sono state analizzate le differenze tra le aziende che praticano/non praticano la monticazione delle vacche in lattazione: le aziende tradizionali di dimensioni medio-piccole, con stabulazione fissa, razze locali e con bassa produttività, usano più frequentemente la pratica dell'alpeggio rispetto alle aziende moderne. I risultati evidenziano come la pratica dell'alpeggio mantenga un ruolo importante per la zootecnia trentina, nonostante siano cambiate le motivazioni per cui gli allevatori scelgono di monticare gli animali. Il ruolo del pascolamento come supporto alla produzione nel periodo estivo rimane rilevante per le aziende tradizionali medio-piccole, mentre in tutti i casi riveste una particolare importanza, la possibilità di accedere a contributi indifferenziati tra bovini in lattazione, asciutta e rimonta. Si devono creare le condizioni perché il legame tra aziende e malghe possa essere mantenuto, con particolare attenzione alla qualità della gestione dei pascoli e alla multifunzionalità di servizi che possono essere forniti dalle aziende zootecniche montane.

Il secondo contributo mira a valutare l'effetto della monticazione delle vacche da latte su caratteri produttivi e sulla condizione corporea, nello specifico: body condition score (BCS), produzione, qualità e proprietà di coagulazione del latte, e i parametri relativi alla trasformazione casearia. In totale sono stati raccolti e analizzati i dati di 799 vacche in lattazione, monticate nel 2012 su 15 malghe trentine che allevavano capi di diverse razze provenienti da 109 aziende permanenti. I parametri oggetto di studio sono stati messi in relazione alla razza, all'ordine di parto e ai giorni di lattazione, tenendo conto dell'effetto malga, e in particolar modo della quantità di mangime somministrato alle vacche. Il lavoro ha analizzato non solo il periodo di permanenza delle vacche in alpeggio ma anche prima e dopo la stagione di malga con l'obiettivo di valutare i cambiamenti dovuti al cambio di ambiente.

I risultati evidenziano come la monticazione abbia un effetto più o meno rilevante nel determinare un calo di produzione a seconda delle razze. Le razze specializzate, con livelli produttivi più elevati nelle aziende permanenti, soffrono un maggior calo di produzione rispetto a quelle locali o a duplice attitudine, che si adattano meglio alle condizioni di alpeggio.

Anche la condizione corporea degli animali è fortemente influenzata dall'alpeggio, con un calo nella prima fase della monticazione e un recupero successivo. Emergono delle differenze tra razze, con quelle specializzate che presentano un maggior calo di condizione corporea.

Dopo la monticazione si è assistito ad un calo del contenuto percentuale di grasso nel latte (particolarmente evidente nelle razze specializzate), mentre il contenuto di proteine è rimasto costante. Per quanto riguarda le caratteristiche tecnologiche del latte, si sono riscontrate significative differenze sia dopo la monticazione, sia dopo il periodo estivo con il ritorno in azienda. Le maggiori differenze si sono però riscontrate tra giugno e settembre sia in termini di lattodinamografia sia in termini di rese.

In conclusione, il lavoro evidenzia la migliore adattabilità delle razze locali e a duplice attitudine al cambiamento di ambiente e alle condizioni di allevamento in malga.

Il terzo contributo ha l'obiettivo di valutare l’impronta ambientale di allevamenti montani di bovini da latte. È stato condotto un approfondito studio sul territorio della provincia di Trento, considerando un campione di 38 allevamenti di vacche da latte di razze miste con differenti sistemi di allevamento. Tramite visite aziendali sono stati raccolti dati relativi alla gestione e alimentazione dei bovini, alle prestazioni produttive, alla gestione agronomica delle superfici, alla gestione dei reflui e ai consumi energetici. A questo fine è stato sviluppato e testato un questionario specifico che potrà essere proposto per ulteriori indagini in ambito montano.

La mole di dati raccolti è stata utilizzata per calcolare l’impronta ecologica degli allevamenti con approccio Life Cycle Assessment (LCA). Lo studio comprende l’intera vita del prodotto, dalla produzione delle materie prime, alla loro lavorazione e utilizzo finale considerando tutti gli input e gli output associati all’unità funzionale (il kg di latte). In questo studio sono state considerate tre categorie di impatto: carbon footprint (contributo alla produzione di gas serra), acidificazione ed eutrofizzazione, relative all’anno 2013.

I valori ottenuti per le tre categorie di impatto presentano un’ampia variabilità, con medie e DS pari a: 1.46 ± 0.58 kg CO_2 eq, 27.18 ± 8.34 g SO_2 eq. e 7.91 ± 2.31 g PO_4^{3-} eq. per kg FPCM. I valori ottenuti sono in linea con quanto riportato da altre ricerche condotte in ambito montano. L’impatto complessivo è stato diviso tra componenti on-farm e off-farm, e sono stati ripartiti gli impatti con allocazione di massa tra latte e carne. L’analisi della varianza ha messo in evidenza come gli effetti considerati (stabulazione, libera *vs* fissa, e modalità di somministrazione degli alimenti, tradizionale *vs* unifeed), pur significativi in alcuni casi, influiscano in maniera poco rilevante sulla variabilità delle categorie di impatto mentre esiste una rilevante variabilità dei risultati tra aziende diverse dello stesso gruppo. Ci sono quindi margini per mitigare l’impatto e aumentare l’efficienza degli allevamenti, anche con strutture e gestioni diverse.

Nel complesso, i risultati della tesi offrono degli interessanti spunti sulla valutazione della sostenibilità della bovinicoltura da latte nelle aree montane, con approcci metodologici innovativi. In prospettiva, i risultati ottenuti dagli approcci sperimentali condotti potranno essere ampliati su un pool ampio di aziende al fine di identificare degli indicatori di riferimento per la valutazione della sostenibilità e multifunzionalità degli allevamenti montani.

General introduction

For many decades, the landscape of the European mountains had been characterized by the coexistence of human activities and livestock, while the economy in mountainous area was driven by this harmonic cohabitation (Viazzo, 1989; Baldock *et al.*, 1996; MacDonald *et al.*, 2000). For example, in the Alpine area, the primary objective of dairy farming was the protection of the landscape. This care for the local environment was back paid in economic benefits for the dairy farmers. As a result, a long-lasting equilibrium between human activities and nature was developed. Nevertheless, during the last decades dairy farming in eastern Italian Alps has undergone a progressive abandonment of high altitude pastures (from 600 to 2,500 m asl), and modernization and intensification of agricultural practices typical of the lowland (MacDonald *et al.*, 2000; Strijker, 2005).

In Italy, the incidence of mountain areas on total surface is very high (47.5% of the total area), as the percentage of mountainous farmers (30.9% for Italy *vs* 17.8% of the average of EU-27) (Santini *et al.*, 2013).

Agriculture in the mountain areas suffers several limitations that discourage new investments. Local climate, *e.g.* low temperature and limited length of the crop growing period, combined with the harsh physical landscape, *e.g.* steep slopes and less fertile soils, there is the need for complex machinery and extra labor. This results in a lower total productivity with a higher labor time than lowland farms. Those two parameters, in turn, are heavily discouraging for new and especially young farmers. Moreover, such limitations pose restrictions on the productive sectors that farmers can invest in. In addition, mountainous farms are smaller, on average, compared to modern farms of the plain areas. Also, poor accessibility of the mountains by modern means of transport increases the difficulties of both mountain farms as well as the food industries (*e.g.* due to increased collection and transport costs for the dairy industries). On the other hand, the existence of mountain communities, with their local traditions and the “knowhow” relating to agricultural, on this harsh environment is a guarantee for the sustainability of these areas. Traditional products produced, integrating the long historic culture of those communities together with new opportunities for touristic facilities can provide an extra reinforce of the local economy (Santini *et al.*, 2013).

Several reasons, like socioeconomic, technical and cultural changes have been identified as main causes for the abandonment of mountainous regions, in which livestock farming has been of great importance and the driven force of rural economies (Baldock *et al.*, 1996). At the same time intensification of farming is increasing in the most favorable valleys (MacDonald *et al.*, 2000; Strijker, 2005). A typical example from the Alpine region is the decrease of both the number of farms (by 40%) and the Livestock Units (LU) (by 17%) between 1980 and 2000, while in most remote regions this decrease reached up to 70% (Streifeneder *et al.*, 2005; Tasser *et al.*, 2007).

Followed from the above, the province of Trento has been proposed as a good example to study the recent evolution of the Alpine dairy systems (Sturaro *et al.*, 2013a). For instance, the number of dairy farms decreased from 5,749 to 1,071 between 1980 – 2010, whereas at the same time the average size of the herds increased from 5 to 23 dairy cows (ISTAT, 2010).Despite the severe change of the farming system the last years, dairy production is still an important economic activity in the Alps. It is strongly connected to the production of typical, or Protected Designation of Origin (PDO) cheeses whose added-value helps to maintain a satisfactory income for farmers. For instance, the most important dairy product (4,000 t/yr) in Trento province (eastern Italian Alps) is Trentingrana PDO cheese (Bittante *et al.*, 2011). In this Alpine area the livestock systems have been classified in two main categories: "Modern" and "Traditional" (Sturaro *et al.*, 2013a). The first type is characterized by modern facilities and management, mainly focusing on maximization of production. These farms rear cows specialized for milk production, and this leads to a detriment of local breeds, which are more adapted to the mountainous areas (Stefanon, 2000; Bovolenta *et al.*, 2008). The number of animals per farm in "modern" dairy systems has been increased much more than in traditional farming system. Moreover, available resources are no longer in the focus of the farm, like it used to be in the traditional farming. Instead, the number of dairy cows, the capital resource and labor availability is of major importance and first priority in modern farms (Stefanon, 2000). The second type of farming system consists of a strongly interconnected system between the local environment and livestock activities. Actually, the extensive dairy systems are today recognized as sources of many positive functions (Gibon, 2005), including i) aesthetics of the landscape (Ziliotto *et al.*, 2004), ii) accessibility of tourist and entertainment environments (Thiene and Scarpa, 2008; Amanor-Boadu *et al.*, 2009), iii) control of forest re-growth (Mottet *et al.*, 2006; Cocca *et al.*, 2012), iv) maintenance of the land and cultural tradition (Hunziker, 1995; Baudry and Thenail, 2004; Kianicka *et al.*, 2010), and v) preservation of biodiversity (Marini *et al.*, 2009 and 2011). Moreover, the size of the farm and the stocking rate are proportional to the local forage resources, and the production (milk, calves) compensates the cost of hay. A typical feature of the traditional system is that animals are kept indoors in the lowland for the most part of the year, while during the summer period part of the animals (or all of them) are transferred to the highland pastures (Penati *et al.*, 2011).

The abandonment of mountainous and marginal areas has caused almost the ending of small, typical farm activities. This has also reinforced by the fact that large dairy companies have been focused only on the increase of the production, putting aside the quality improvement of the dairy products. Apart from abandonment, the shift towards intensive systems has profoundly affected the livestock sector, and has generated a lot of alarms concerning the environmental as well as the dairy farming sustainability of the mountainous regions (Berger *et al.*, 2006). For example, the reduced highland grazing has been associated with soil degradation, reforestation, loss of biodiversity and landscape esthetic quality (Streifeneder *et al.*, 2007; Ramanzin *et al.*, 2009; Sturaro *et al.*, 2009). For these reasons, the Alpine mountain farming activity is highly supported in order to protect the flora and fauna and to preserve cultural landscapes. Due to the purposes of the tourism sector, for *e.g.*, care of "man-made landscapes" has become an important slogan, and the farmers have been recognized as necessary landscapers (Orland, 2004). Moreover, public subsidies subvene the economic viability of extensive farming systems (Uthes *et al.*, 2010), especially for small farms, through the "multi-functionality" aspect of the farms (Wilson, 2008).

In addition, the lower productivity of extensive production practices could be compensated by an increase of the farm income through direct processing and marketing of products, agro-tourism activities, and public contribution for the landscape maintenance and use of environmentally friendly practices (MacDonald *et al.*, 2000; Bonsembiante and Cozzi, 2005). However, policies developed to promote the multi-functionality of livestock farming require deep knowledge of the existing production systems and the ability to differentiate income sources from protected or developed landscape practices.

Moreover, the practice of the summer pasture, that is a special characteristic of the extensive models, seems to be beneficial for the cattle welfare as well (Ketelaar-de Lauwere *et al.*, 1999). Summer pastures have been related to an improvement of cows' health, due to the change in the physical environment and diet. In fact, incidence of lameness decrease during the grazing season (Leaver, 1988) compared to cows kept indoors that have a greater prevalence of claw disorders and lameness (Smits *et al.*, 1992; Gitau *et al.*, 1996).

In addition, a status of nutritional imbalance may be related to a negative effect on the milk production, milk composition, fertility, and health (Roche *et al.*, 2009). However, individual recording such as food intake and fertility is difficult, time consuming, and expensive. Thus, as a useful tool for the general management of dairy herds, related to health and production, body condition score (BCS) has been proposed (Edmonson *et al.*, 1989). BCS is one of the biological traits related to farm costs and easy to measure in field conditions (Gallo *et al.*, 2001). BCS is a subjective method to assess body reserves of dairy cows. The method is based on visual and tactile appraisal of the amount of fat stored by the cow, particularly over the bony prominence of the back and pelvic regions (Ferguson *et al.*, 1994). Generally, BCS value decreases at increasing genetic merit of cows, and mobilization of body reserves during lactation is higher and more prolonged at increasing dairy merit of cows (Gallo *et al.*, 1996).

Another negative effect derived from the abandoning of traditional extensive farming in favor of highly mechanized and intensive production practices, is the huge production of polluting nutrients (Caraveli, 2000; Höchtl *et al.*, 2005; Strijker, 2005). The large amounts of concentrates used to sustain high milk production and the excessive use of fertilizers and pesticides in maize production result in a surplus of nitrogen and phosphorus (Penati *et al.*, 2011), thereby increasing the risk of soil and water contamination. For that reason, at the end of the last century some measures for the protection of waters against contamination caused by nitrates from agricultural sources were adopted by the EU (European Directive 91/676/EEC, Italy aligned with legislative decree of 11 May 1999.152 and the Ministerial Decree of 7 May 2006).

In literature, several research studies have focused on the environmental impact of agricultural activity and its products related to the dairy sector (*e.g.* Kristensen *et al.*, 2011; Pirlo and Carè 2013; Guerci *et al.*, 2013; Battaglini *et al.*, 2014). It is worthwhile to mention that during the half past century global milk production has been raised by 86%, while both the number of dairy cows as well as the individual cow milk have increased (by 42% and

31%, respectively). In 2013, the Food and Agriculture Organization (FAO) (Gerber *et al*.) published the "Tackling climate change through livestock". In that report they estimated the livestock sector's contribution to Greenhouse gas (GHG) emissions at a global scale. Taking into account the entire livestock food chain, the study estimated this contribution to be about 14.5% of total anthropogenic emissions. More precisely, livestock account for 5% of total carbon dioxide (CO_2) emissions, 44% of methane (CH_4) and 53% of nitrous oxide (N_2O) of global anthropogenic emissions.

For studying the environmental impact of agricultural activity, Life Cycle Assessment (LCA) is a common approach. It provides with extra knowledge on the identification of the different life cycle stages that, in turn, helps in developing a more sustainable production system. Several recent LCA studies investigated the environmental impact of different farming systems, for instance organic *vs.* conventional (Cederberg and Mattson, 2000; de Boer, 2003; Thomassen *et al.*, 2008; Kristensen *et al.*, 2011) or confinement *vs.* grass-based (Belflower *et al.*, 2012; O'Brien *et al.*, 2012). Nevertheless, there is still a lack of knowledge in identifying the "best system", especially when the impact is estimated on the product base. Recently, FAO estimates on the sector's contribution to global anthropogenic GHG emissions highlighted the differences among different animal production species with beef production contributing about 5.5% of total global anthropogenic emissions, while milk and pork contribute 2.8% and 1.9%, respectively (Opio *et al.*, 2011).

It is widely recognized that improving animal productivity has a positive environmental impact, because the animals can reach the same level of production with lower feed intake, and consequently secreting less polluting nutrients (Hermansen and Kristensen, 2010; de Boer *et al.*, 2011; Opio *et al.*, 2011). Equivalently, a high milk production can be achieved with less cows, since milk yield per cow is higher (Capper *et al.*, 2008). However, in industrialized countries with highly intensive farming systems combined with an already high animal productivity, breeding for growth rate or annual milk production per cow can have a negative effect on animal fertility. This can create a negative public opinion on animal production systems (de Boer *et al.*, 2011). Several authors investigated the effect of increasing milk productivity on Global Warming Potential (GWP) of different farming systems. Rotz *et al*. (2010) highlighted the benefits of improved animal genetics and feeding management on milk production and farm environmental performances: milk production was increased for the given feeding scheme, feed intake was also increased to face the nutrient requirements of the higher producing animals, and this intensified CH_4 and CO_2 emissions. In addition, more manure was produced, which increased manure storing emissions. Overall, the net GHG emission was increased by 6%, but the greater milk production reduced the carbon footprint by 8%. Also, de Boer *et al.* (2011) observed that manure management reduces mainly N_2O and CH_4 emissions by changes in livestock structures, manure storage services and treatment, and grazing management. Also, O'Brien *et al.* (2012) estimated that storing manure in solid rather than liquid systems reduced the environmental impacts for a confinement farming system compared to the grass-based system, because of the longer housing period.

Regarding the land management, Smith *et al.* (2008) estimated the potential of several different practices to mitigate GHG emissions, among of which were the renovation of organic soils as well as the management of cropland and grassland. Measures that increase carbon input into the soil include i) the use of manure on crop instead of grassland, ii) improved rotations with higher carbon input to soil (catch crop) iii) increased crop yield and hence the related crop residues, for *e.g.*, by better plant breeding, crop husbandry, irrigation or fertilization and conversion from arable land to grassland or grazing management (de Boer *et al.*, 2011). Crosson *et al.* (2011) reported an important effect of permanent grassland soils in sequestering carbon, particularly where improved grazing strategies have been adopted.

Moreover, Soussana *et al.* (2010) suggested that grasslands range from sinks to sources depending on climate, management and site characteristics such as the characteristics of soil.

Regarding the CO_2 and N_2O emissions from production of feed ingredients, they can be reduced through a highly productive crops selection (or lower N demand per unit output) (de Boer *et al.*, 2011). Plant breeding can potentially improve digestibility as well as reduce CH_4. In fact, improving forage quality can simultaneously improve animal performance and reduce CH_4 production. Alternatively, it can improve efficiency of farm carbon footprint by reducing CH_4 emissions per unit of animal product (Eckard *et al.*, 2010).

In the study of Vellinga *et al.* (2011) it was shown that when more feed is produced at the farm, the total emissions, at a regional scale, are reduced. Belflower *et al.* (2012) analyzed the effect of removing free stall barns and let all cattle on pasture throughout the year. The use of grazing had a relatively small impact on the carbon footprint when land currently used for annual ryegrass and corn silage production was converted to perennial pastures. This was a consequence of a reduction in milk production.

Despite the importance of all the above mentioned aspects in Alpine areas, it has not been fully explained how the processes of intensification and abandoning have influenced the traditional link between permanent farms and summer farms (Sturaro *et al.*, 2013b). Also no studies have considered these processes inside their life cycle pathway, as a key strategy to maintain the Alpine marginal areas.

Therefore, the research conducted during my PhD studies and presented in this thesis aimed at analyzing three aspects regarding dairy farming system and environmental in mountainous areas. In particular the Eastern Italian Alps was adopted to investigate these aspects. This thesis is composed by 3 chapters:

In the first chapter, the analysis of the role of summer transhumance to Alpine pasture and temporary farms in the dairy farming systems is presented. For this study, data on 395 active summer farms of Trento Province were collected from the veterinarian services of the Province: From those, 345 summer farms keep dairy cattle (83 only replacement, and 262 also lactating cows). Almost all the replacement cattle and more than one third (8,775 out of 24,934 heads) of the dairy cows reared in the permanent farms of the province are still moved to highland pastures during summer.

The second chapter focuses on the effect of transhumance to highland summer pastures on i) body condition score of the cows, ii) several milk traits (*e.g.* fat, protein, urea, milk somatic cells,…), iii) milk technological traits strongly related to cheese production, such as coagulation properties and vi) direct cheese measures, e.g., percentage of cheese yield and milk nutrients recovery in the curd. All milk and cheese traits were measured at an individual cow level through Fourier spectroscopy. Moreover, differences among breeds were assessed.

The last part of this thesis aimed to evaluate the environmental footprint of mountain dairy cattle farms. The study was conducted in a specific area of the Province of Trento. Data were collected from 38 dairy cattle farms of mixed breeds using different farming systems.

References

Amanor-Boadu, V.R., Marletta, P., Biere, A., 2009. Entrepreneurial supply chains and strategic collaboration: the case of Bagòss cheese in Bagolino, Italy. Int. Food Agribusiness Manage. Rev. 12:49-68.

Baldock, D., Beaufoy, G., Brouwer, F., Godeschalk, F., 1996. Farming at the margins: abandonment or redeployment of agricultural land in Europe. Institute for European Environmental Policy. Agricultural Economics Research Institute, London/The Hague.

Battaglini, L., Bovolenta, S., Gusmeroli, F., Salvador, S., Sturaro, E., 2014. Environmental sustainability of Alpine livestock farms. Ital. J. Anim. Sci. 13:431-443.

Baudry, J., Thenail, C., 2004. Interaction between farming systems, riparian zones, and landscape patterns: a case study in western France. Landsc. Urban. Plann. 67:121-129.

Belflower, J.B., Bernard, J.K., Gattie, D.K., Hancock, D.W., Risse, L.M., Rotz, C.A., 2012. A case study of the potential environmental impacts of different dairy production systems in Georgia. Agr. Syst. 108:84-93.

Berger, T., P. Schreinemachers, and J. Woelcke. 2006. Multiagent simulation for the targeting of development policies in less-favored areas. Agricultural Systems 88:28-43.

Bittante, G., A. Cecchinato, N. Cologna, M. Penasa, F. Tiezzi, and M. De Marchi. 2011. Factors affecting the incidence of first-quality wheels of Trentingrana cheese. J. Dairy Sci. 94:3700-3707.

Bonsembiante, M., Cozzi, G., 2005. L'allevamento nella montagna veneta come sistema produttivo e strumento di difesa ambientale. In: Longo O. e Viola F. (editors). La montagna veneta tra rilancio territoriale e nuova identità economica. Ed. Franco Angeli, Milano.

Bovolenta, S., E. Saccà, M. Corazzin, F. Gasperi, F. Biasioli, and W. Ventura. 2008. Effects of stocking density and supplement level on milk production and cheese characteristics in Brown cows grazing on mountain pasture. J. Dairy Res. 75. 357-364.

Capper, J.L., Castan, Castañeda-Gutiérrez, E., Cady, R.A., Bauman, D.E., 2008. The environmental impact of recombinant bovine somatotropin (rbST) use in dairy production. Proc. Natl. Acad. Sci. U.S.A. (PNAS). Vol. 15, No. 28, 9668-9673.

Caraveli, H., 2000. A comparative analysis on intensification and extensification in Mediterranean agriculture: dilemmas for LFAs policy. J. Rural. Stud. 16:231-242.

Cederberg, C., Mattsson, B., 2000. Life cycle assessment of milk production – a comparison of conventional and organic farming. J. Clean. Prod. 8:49-60.

Cocca, G., Sturaro, E., Gallo, L., Ramanzin, M., 2012. Is the abandonment of traditional livestock farming systems the main driver of mountain landscape change in Alpine areas? Land Use Policy 29:878– 886.

Crosson, P., Shalloob, L., O'Brien, D., Laniganc, G.J., Foleyd, P.A., Bolandd, T.M., Kennya, D.A., 2011. A review of whole farm systems models of greenhouse gas emissions from beef and dairy cattle production systems. Anim. Feed Sci. Tech. 166-167, 29-45.

De Boer, I.J.M., 2003. Environmental impact assessment of conventional and organic milk production. Livest. Prod. Sci. 80:69-77.

De Boer, I.J.M., Cederberg, C.., Eady, S., Gollnow, S., Kristensen, T., Macleod, M., Meul, M., Nemecek, T., Phong, L.T., Thoma, G., van der Werf, H.M.G., Williams, A.G., Zonderland-Thomassen, M.A., 2011. Greenhouse gas mitigation in animal production: towards an integrated life cycle sustainability assessment. Curr. Opin. Environ. Sustainability. 3, 423–431.

Eckard, R.J., Grainger, C., de Klein, C.A.M., 2010. Options for the abatement of methane and nitrous oxide from ruminant production: A review. Livest. Sci. 130, 47–56.

Edmonson A. J., Lean L. J., Weaver L. D., Farver T., Webster G. 1989. A body condition scoring chart for Holstein dairy cows. J. Dairy Sci. 72:68–78.

Ferguson J. D., Galligan T. D., Thomsen N. 1994. Principal descriptors of body condition score in Holstein cows. J. Dairy Sci. 77:2695–2703.

Gallo L., Carnier P., Cassandro M., Dal Zotto R., and Bittante G. 2001. Test-Day Genetic Analysis of Condition Score and Heart Girth in Holstein Friesian Cows. J. Dairy Sci. 84:2321–2326.

Gallo L., Carnier P., Cassandro M., Mantovani R., Bailoni L., Contiero B., and Bittante G., 1996. Change in body condition score of Holstein cows as affected by parity and mature equivalent milk yield. J. Dairy Sci. 79:1009–1015.

Gerber PJ, Steinfeld H, Henderson B, Mottet A, Opio C, Dijkman J, Falcucci A and Tempio G 2013. Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of United Nations (FAO), Rome (Rome, Italy).

Gibon, A., 2005. Managing grassland for production, the environment and the landscape. Challenges at the farm and the landscape level. Livest. Prod. Sci. 96:11-31.

Gitau T., McDermott J. J., Mbiuki S. M., 1996. Prevalence, incidence and risk factors for lameness in dairy cattle in small scale farms in Kikuyu Division, Kenya. Prev. Vet. Med. 28:101–115.

Guerci, M., Bava, L., Zucali, M., Sandrucci, A., Penati, C., Tamburini, A., 2013. Effect of farming strategies on environmental impact of intensive dairy farms in Italy. J. Dairy Res. 80:300-308.

Hermansen, J.E. and Kristensen, T., 2011. Management options to reduce the carbon footprint of livestock products. Anim. Front. 1, 33–39.

Höchtl, F., Lehringer, S., Konold, W., 2005. “Wilderness”: what it means when it becomes a reality-a case study from the southwestern Alps. Landsc. Urban Plann. 70, 85-95.

Hunziker, M., 1995. The spontaneous reforestation in abandoned agricultural lands: perception and aesthetic assessment by locals and tourists. Landsc. Urban Plann. 3:399-410.

ISTAT, Istituto Nazionale di Statistica (2010). VI Censimento generale dell’Agricoltura. Roma.

Ketelaar de Lauwere C.C., Ipema A.H., van Ouwerkerk E.N.J., Hendriks M.M.W.B., Metz J.H.M., Noordhuizen J.P.T.M., Schouten W.G.P., 1999. Voluntary automatic milking in combination with grazing of dairy cows. Milking frequency and effects on behaviour. Appl. Anim. Behav. Sci. 64:91-109.

Kianicka, S., Knab, L., Buchecker, M., 2010. Maiensäss - Swiss Alpine summer farms - an element of cultural heritage between conservation and further development: a qualitative case study. Int. J. Heritage Stud. 16:486-507.

Kristensen, T., Mogensen, L., Trydeman Knudsen, M., Hermansen, J.E., 2011. Effect of production system and farming strategy on greenhouse gas emissions from commercial dairy farms in a life cycle approach. Livest. Sci. 140:136-148.

Leaver, J. D. 1988. Management and welfare of Animals. 3rd ed. Bailliere Tindall, London, UK

MacDonald, D., Crabtree, J.R., Wiesinger, G., Dax, T., Stamou, N., Fleury, P., Gutierrez Lazpita, J., Gibon, A., 2000. Agricultural abandonment in mountain areas of Europe: environmental consequences and policy response. J. Environ. Manage. 59:47-69.

Marini, L., Fontana, P., Klimek, S., Battisti, A., Gaston, K.J., 2009. Impact of farm size and topography on plant and insect diversity of managed grasslands in the Alps. Biol. Conserv. 142:394-403.

Marini, L., Klimek, S., Battisti, A., 2011. Mitigating the impacts of the decline of traditional farming on mountain landscapes and biodiversity: A case study in the European Alps. Environ. Sci. Policy 14:258-267.

Mottet, A., Ladet, S., Coqué, N., Gibon, A., 2006. Agricultural land-use change and its drivers in mountain landscapes: a case study in the Pyrenees. Agric. Ecosyst. Environ. 114:296-310.

O'Brien, D., Shalloo, L., Patton, J., Buckley, F., Grainger, C., Wallace, M., 2012. Evaluation of the effect of accounting method, IPCC vs. LCA, on grass-based and confinement dairy systems' greenhouse gas emissions. Animal 6:1512-1526.

Opio, C., Gerber, P., Steinfeld, H. 2011. Livestock and the environment: addressing the consequences of livestock sector growth. Adv. Anim. Biosci. 2:3, 601–607.

Orland, B., 2004. Alpine Milk: Dairy Farming as a Pre-modern Strategy of Land Use. Environ. Hist. 10:327–364.

Penati, C., Berentsen, P.B.M., Tamburini, A., Sandrucci, A., de Boer, I.J.M., 2011. Effect of abandoning highland grazing on nutrient balances and economic performance of Italian Alpine dairy farms. Livest. Sci. 139:142-149.

Pirlo, G., Carè, S., 2013. A simplified tool for estimating carbon footprint of dairy cattle milk. Ital. J. Anim. Sci. 12:e81: 497-506.

Ramanzin, M., Battaglini, L., Morbidini, L., Pauselli, M., Pulina G., 2009. Evoluzione dei sistemi zootecnici e trasformazione del paesaggio. It. J. Agron. 3, 19-23.

Roche J. R., Friggens N. C., Kay J. K., Fisher M. W., Stafford K. J., Berry D. P. 2009. Invited review: Body condition score and its association with dairy cow productivity, health, and welfare. J. Dairy Sci. 92 :5769–5801.

Rotz, C.A., Montes, F., Chianese D.S., 2010. The carbon footprint of dairy production systems through partial life cycle assessment. J. Dairy Sci. 93, 1266–1282.

Santini F., Fatmir G., Gomez y Paloma S. 2013. Scientific and policy reports. Labelling of agricultural and food products of mountain farming. European commission. Joint Research Centre. EUR 25768 EN.

Santini, F., Guri, F., and Gomez y Paloma, S. (2013) Labelling of agricultural and food products of mountain farming, JRC Scientific and Policy Reports, EUR 25768 EN

Smith, P., Martino, D., Cai, Z., Gwary, D., Janzen, H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F., Rice, C. et al., 2008. Greenhouse gas mitigation in agriculture. Philos. Trans. R. Soc. 363, 789-813.

Smits M. C. J., Frankena K., Metz J. H. M., Noordhuizen J. P. T. M., 1992. Prevalence of digital disorders in zero-grazing dairy farms. Livest. Prod. Sci. 32:231–244.

Soussana, J. F. , Tallec, T., Blanfort, V., 2010. Mitigating the greenhouse gas balance of ruminant production systems through carbon sequestration in grasslands. Animal, 4:3, 334–350.

Stefanon B., 2000. Sistemi zootecnici estensivi ed intensivi in zona alpina, Agribusiness Paesaggio & Ambiente, 2: 109-119.

Streifeneder, T., Ruffini, F.V., Eiselt, B., 2005. Evaluating future land-cover structures in the Alps – the project “Agralp”. Eurac Conference on sustainable land use. Eurac Research, European Academy Bolzano.

Streifeneder, T., Tappeiner, U., Ruffini, F.V., Tappeiner, G., Hoffmann, C., 2007. Selected aspects of the agricultural structure change within the Alps—a comparison of harmonised agri-structural indicators on a municipal level within the Alpine Convention Area. Revue de Geographie Alpine-J. Alpine Res. 95:41–52.

Strijker, D., 2005. Marginal lands in Europe—causes of decline. Basic Appl. Ecol. 6, 99–106.

Sturaro, E., Cocca, G., Gallo, L., Mrad, M., Ramanzin, M., 2009. Livestock systems and farming styles in Eastern Italian Alps: an on farm survey. It. J. Anim. Sci. 8, 541-554.

Sturaro, E., Marchiori, E., Cocca, G., Penasa, M., Ramanzin, M., Bittante G., 2013a. Dairy systems in mountainous areas: farm animal biodiversity, milk production and destination, and land use. Livest. Sci. 158:157-168.

Sturaro, E., Thiene, M., Cocca, G., Mrad, M., Tempesta, T., Ramanzin, M., 2013b. Factors influencing summer farms management in the Alps. Ital. J. Anim. Sci. 12:e25.

Tasser, E., Walde, J., Tappeiner, U., Teutsch, A., Noggler, W., 2007. Land-use changes and natural reforestation in the Eastern Central Alps Agriculture, Ecosystems and Environment. 118:115-129.

Thiene, M., Scarpa, R., 2008. Hiking in the Alps: exploring substitution patterns of hiking destinations. Tourism Econ. 14:263-282.

Thomassen, M.A., Dalgaard, R., Heijungs, R., de Boer, I., 2008. Attributional and consequential LCA of milk production. Int. J. Life Cycle Ass. 13:339-349.

Uthes, S., Piorr, A., Zander, P., Bienkowski, J., Ungaro, F., Dalgaard, T., Stolze, M., Moschitz, H., Schader, C., Happe, K., Sahrbacher, A., Damgaard, M., Toussaint, V., Sattler, C., Reinhardt, F.J., Kjeldsen, C., Casini, L., Muller, K., 2010. Regional impacts of abolishing direct payments: An integrated analysis in four European regions. Agric. Syst. 104 :110-121.

Vellinga, Th.V., de Haan, M.H.A., Schils, R.L.M., Evers, A., van den Pol–van Dasselaar, A., 2011. Implementation of GHG mitigation on intensive dairy farms: Farmers' preferences and variation in cost effectiveness. Livest. Sci. 137, 185–195.

Viazzo, P.P., 1989. Upland Communities. Environment, Population and Social Structure in the Alps since the Sixteenth Century. Cambridge University Press, Cambridge.

Wilson, G.A., 2008. From ‘weak’ to ‘strong’ multifunctionality: conceptualizing farm-level multifunctional transition pathways. Journal of Rural Studies 24 (3), 367–383.

Ziliotto U., Scotton M., Da Ronch F. (2004). I pascoli alpini: aspetti ecologici e vegetazionali, in Quaderni SoZooAlp n.3, Trento, Nuove Arti Grafiche, pp.41-50.

Chapter 1

Highland summer pastures play a fundamental role for dairy systems in mountainous areas

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Summary

In the Alps, summer farms are temporary units where the livestock herds are moved during summer to graze on highland pastures. This study aimed to analyze the role of summer farms in the dairy farming systems of the Trento province, in the eastern Italian Alps. Data on the structures and management of the 395 active summer farms were collected from the veterinarian services of the province: 345 summer farms keep dairy cattle (83 only replacement, and 262 also cows on milk). Almost all the replacement cattle and more than one third (8,775 *vs* 24,934 heads) of the dairy cows reared in the permanent farms of the province are still moved to highland pastures during summer. Cows on milk of local and dual purpose breeds are moved to highland pastures more frequently than those of specialized breeds. On 610 permanent farms, we analyzed the differences between the units moving/not moving the cows on milk to summer farms. The traditional farms, with tie stalls, local breeds, small-medium herd size and low productivity used more frequently summer pastures than the "intensive" farms. Transhumance still plays a fundamental role for the dairy sector in this alpine areas, because it allows access to public contribution and is complementary to the management of traditional farms. To better assess its sustainability, these functions should be further investigated in relation with the role of summer farms in the conservation of biodiversity, cultural landscape, and touristic attractiveness.

Key words: dairy systems, summer farms, mountainous areas, highland pastures

Aim

In the Alps, the seasonal transhumance of livestock herds to highland summer farms, following the seasonal and altitudinal variability of vegetation growth, has been for centuries an essential practice for complementing the forage budget of the permanent traditional farms (Orland, 2004). However, in the last decades many traditional farms have been converted to intensive farms, or abandoned (Cocca et al., 2012; Streifeneder et al., 2007). Knowledge on how these processes of intensification and abandoning have influenced the traditional link between permanent farms and summer farms is necessary for devising locally effective agricultural policies, but is surprisingly scarce (Sturaro et al., 2013). The aim of this work was to investigate the role of summer farms in the dairy farming systems of the Trento province, taken as an example for the Alpine areas where livestock farming is still an important economic activity.

Material and methods

The Autonomous Province of Trento, in the north eastern Italian Alps, covers a surface of 6,212 km2, with an elevation of ranging from 66 to 3769 m asl. The utilized agricultural area (UAA) has an extension of 1372 km2, mainly composed by grassland and pastures (81%), followed by orchards and vineyards (17%), while the arable crops represent only 2% (ISTAT, 2010). Dairy cattle farming is the most important livestock system of the Province; the majority of dairy farms are associated in cooperative dairies that produce typical and Protected Designation of Origin (PDO) cheeses (mainly “Trentingrana” PDO cheese, Bittante et al., 2011a and b; Endrizzi et al., 2013). Data on number of livestock heads (year 2011) in permanent and summer farms were provided by the veterinarian services of the Province. Livestock was classified according to species and, for cattle, category (for dairy cattle: cows on milk and replacement) and breed. In addition, data for summer farms included elevation, amount of milk produced and of milk in situ processed for cheese making. We compared the numbers of replacement heifers and dairy cows and the proportions of breeds (dairy cows only) farmed in the permanent dairy farms with the numbers and proportions of breeds moved to the summer farms. Our expectation was that highly specialized breeds were moved to summer farms less frequently than dual purpose or local breeds. We also tested the correlation between breed composition of the herd and elevation of summer farms. Our hypothesis was that, with a "traditional" pasture management, the most productive breeds were more frequent in lower (and more productive) pastures.

One aim of the study was also to characterize the permanent farms using summer farms for cows on milk in comparison with those that have abandoned this practice. For this purpose, we used data from a survey on 610 dairy farms (57% of total dairy farms), for a total of 19,531 dairy cows (78% of the total number of cows in the Trento Province), concerning the following structural and management features: type of stalling (tied *vs* free), use of Total Mixed Rations (TMR), use of silages, use of summer farms for replacement and/or dairy cows. Data of composition and milk production and the main destination of produced milk (dairy factories producing/not producing PDO cheese) were obtained from the Consortium of Cooperative Dairies of the Trento Province (CONCAST). The farms were divided into farms using and farms not using summer pastures for dairy cows (see results and discussion for this classification). To test the differences between the two groups we used a GLM analysis (PROC GLM, SAS 2008) for normally distributed variables (elevation, milk yield and quality) and log-transformed variables (number of cows on milk, herd size, agricultural surface and stocking rate). A one-way non parametric analysis (PROC NPAR1WAY, SAS 2008) was used to analyse the mean percentage incidence of breeds within herd; a chi-square test (PROC FREQ, SAS 2008) was used for the frequencies (use of total mixed ration, use of silages, tie stalls and number of farm conferring to PDO cheese dairy factories).

Results

Descriptive statistics for summer farms are given in Table 1. Of the 395 units still active, 345 (87%) keep dairy cattle, and 50 keep sheep and goats. These latter summer farms are located at higher elevations than those with cattle, and use pastures unsuitable for large ruminants. All the summer farms with cattle keep dry cows and replacement cattle, and 262 (75%) keep also cows on milk. The average herd size is between 40 and 70 livestock units (LU), which is higher than the average herd size of permanent farms (approximately 30-40 LU). This is because summer farms are publicly owned (mostly by municipalities), and each unit keeps livestock from different permanent farms (on average, each summer farm receives cattle from 4.3±3.9 different permanent farms). On a total of 24,894 cattle heads moved to the summer farms of the Trento province, 20,564 came from permanent farms of the same Province (11,789 replacement cattle and 8,775 dairy cows), while the rest came from permanent farms of the bordering provinces. Considering only the Trento province, the total number of heifers moved to summer pastures account for more than 90% of those farmed in permanent farms (11,789 *vs* 13,280), while dairy cows account for 35% of the total (8,775 *vs* 24,934). The milk produced in summer farms is processed in situ in 92 units (35% of those producing milk), for a minor proportion (36%) of the total production (Table 1). Dairy factories collect the rest. Only 32 summer farms, all of which produce their cheese for direct marketing, offer agro-tourism services (*i.e.* bar/restaurant/accommodation for tourists).

The composition of dairy cows herds in summer farms differed from that of herds in permanent farms (Figure 1). Specialized breeds, and especially Holstein Friesian, were less frequent in summer than in permanent farms, while the opposite was true (Chi square =3,809; df=5; P<0.001) for dual purpose (Simmental) and local (Alpine Grey, Rendena) breeds (Bittante, 2012). This was clearly because only part of the permanent farms with specialized breeds moved dairy cows to summer farms, while almost all the farms with dual purpose and local breeds moved the entire herd (see below).

In contrast with our expectation, the elevation of summer farms did not show any relationship with the proportion of specialized and local-dual purpose breeds in their herds (specialized breeds r=-0.06, P=0.35; local-dual purpose breeds: r=-0.07, P=0.29). Probably, the use of supplementary feeding in summer farms permits the transhumance of high productive cows also to higher elevation (Bovolenta et al., 2009).

The permanent farms moving dairy cows to summer farms showed significant structural and management differences from the farms that do not move their dairy cows (Table 2). The first group showed smaller herd sizes, with a lower proportion of specialized breeds and a higher proportion of dual purpose/local breeds, and a lower milk yield. The differences between groups in terms of milk quality, although statistically significant, were small and practically irrelevant. In accord with the smaller herd size, farms moving the dairy cows to highland pastures managed smaller land surfaces as respect to the other group (13.9 *vs* 21.9). However, stocking rates were also lower (2.27 *vs* 2.70 LU/ha), partly because moving the herd, or part of it, to summer farms reduced the average LU presence in the lowland managed area. These farms, finally, were characterized by tie stalls (273 of the 334 farms) and by a traditional feeding strategy, with a negligible use of total mixed ration and silages (Table 2). The percentage of farms conferring milk to cooperative dairies producing PDO cheese was significantly higher for those moving the cows on milk to highland pastures.

Discussion and conclusion

The summer farms in the Trento Province are still important for the permanent dairy farms, although for different reasons than in the past. The practice of transhumance is here supported by public contributes, with no differentiation between cows on milk or replacement/dry cows. To take advantage of this opportunity, almost all the dairy farms move their replacement cattle to highland pastures during summer. Dairy cows, in contrast with replacement, can be highly demanding in terms of feeding and milking practices and general environmental conditions (Bovolenta et al., 2009). Our results indicate that a large percentage of the traditional, extensive farms move their cows on milk to summer pastures, while a relevant number of intensive, modern farms have abandoned this practice. Traditional farms rear more dual purpose, local breeds that are more suitable than the Holstein Friesian breed kept especially by intensive farms to moving and feeding on highland pastures. The Brown Swiss, that is the most frequently reared breed in the region, is present both in traditional and modern farms, because of the good productivity and the very good milk composition and technological properties (Cecchinato et al., 2013; Macciotta et al., 2012), accompanied by a quite good fertility (Tiezzi et al., 2012). Even if the fat and protein content of the milk yielded by dual purpose and local breeds is intermediate between the two specialized breeds, their cheese-making ability is similar or better to Brown Swiss cows (Bittante et al., 2012; De Marchi et al., 2007). In addition, traditional farms often keep their cows in tie stall, which has two consequences: the animals are used to the milking equipment of summer farms (milking parlours typical of intensive permanent farms are seldom found in summer farms), and the period of free movement during the stay in summer farms is beneficial for their health (Mattiello et al., 2005).

The transhumance of cows on milk to summer farms, when associated to cheese making and direct selling through agro-touristic activities, may significantly increase the added value of the milk (Penati et al., 2011). This opportunity is, however, scarcely exploited in the Trento province. Similarly to what found in the bordering Veneto region (Sturaro et al., 2013), only a minority of the summer farms have been renovated and equipped with the necessary facilities. However, we also suppose that many farmers who sell their milk to PDO cheese dairies are not encouraged to venture into the complications of cheese making and selling, because they already obtain a high price from their milk (in 2012, the average price of 1 kg of milk reached 0.60 Euros).

In synthesis, our results suggest that the use of summer farms by the dairy permanent farms is now sustained by the access to public contributions and by the traditional dairy farms that still resist to intensification or abandonment. The future CAP reform after 2013 will link the public subsidies to the environmental services of farming (Kaley and Baldock, 2011). To this purpose, transhumance may be beneficial because it reduces the burden of animal biomass on the lowlands, and may contribute to the conservation of grassland habitats that are important for the cultural landscape and biodiversity (Giupponi et al., 2006). In this study we did not address the issue of pasture management in summer farms, but the fact that their elevation, which can be retained as a proxy of productivity, was unrelated to the category and breed of livestock summered suggests that the traditional link between livestock needs and pasture maintenance might have relaxed (Sturaro et al., 2013). In addition, summer farms have value also because they are part of the cultural heritage (Kianicka et al., 2010) and contribute to the touristic attractiveness (Gios et al., 2006). For these purposes, it is important that the traditional practices of milk production and local processing are not dismissed, which seems however an on-going tendency.

In conclusion, the link between permanent and summer farms must be maintained, with particular attention to the quality of the pasture management and to the multifunction services that dairy cows can provide in mountainous areas.

References

Bittante G. (2011). Italian animal genetic resources in the Domestic Animal Diversity Information System of FAO. Ital. J. Anim. Sci. 10: 151-158

Bittante G., Cecchinato A., Cologna N., Penasa M., Tiezzi F., De Marchi M. (2011a). Factors affecting the incidence of first-quality wheels of Trentingrana cheese. J. Dairy Sci. 94: 3700-3707

Bittante G., Cologna N., Cecchinato A., De Marchi M., Penasa M., Tiezzi F., Endrizzi I., Gasperi F. (2011b). Monitoring of sensory attributes used in the quality payment system of Trentingrana cheese. J. Dairy Sci. 94: 5699-5709

Bittante G., Penasa M., Cecchinato A. (2012). Invited review: Genetics and modeling of milk coagulation properties. J. Dairy Sci. 95: 6843-6870

Bovolenta S., Corazzin M., Saccà E., Gasperi F., Biasioli F., Ventura W. (2009). Performance and cheese quality of Brown cows grazing on mountain pasture fed two different levels of supplementation. Livest. Sci. 124: 58-65

Cecchinato A., Cipolat-Gotet C., Casellas J., Penasa M., Rossoni A., Bittante G. (2013). Genetic analysis of rennet coagulation time, curd-firming rate, and curd firmness assessed on an extended testing period using mechanical and near-infrared instruments. J. Dairy Sci., 96: 50-62

Cocca G., Sturaro E., Gallo L., Ramanzin M. (2012). Is the abandonment of traditional livestock farming systems the main driver of mountain landscape change in Alpine areas? Land Use Policy 29: 878–886

De Marchi M., Dal Zotto R., Cassandro M., Bittante G. (2007). Milk coagulation ability of five dairy cattle breeds. J. Dairy Sci. 90: 3986-3992

Endrizzi I., Aprea E., Biasioli F., Corollaro ML., Demattè ML., Penasa M., Bittante G., Gasperi F. (2013). Implementing sensory analysis principles in the quality control of PDO products: a critical evaluation of a real-world case study. J. Sensory Studies 28: 14–24

Gios G., Goio I., Notaro S., Raffaelli R. (2006). The value of natural resources for tourism: a case study of the Italian Alps. Int. J. Tourism Res. 8: 77–85

Giupponi C., Ramanzin M., Sturaro E., Fuser S. (2006). Climate and land use changes, biodiversity and agri-environmental measures in the Belluno Province, Italy. Environ. Sci. Policy 9:163-173

ISTAT, Istituto Nazionale di Statistica (2010). VI Censimento generale dell'Agricoltura. Roma.

Kaley H., Baldock D. (2011). Greening the CAP: Delivering Environmental Outcomes Through Pillar One. Institute for European Environmental Policy, p. 26

Kianicka S., Knab L., Buchecker M. (2010). Maiensäss - Swiss Alpine summer farms - an element of cultural heritage between conservation and further development: a qualitative case study. Int. J. Heritage Stud. 16: 486-507

Macciotta N.P.P., Cecchinato A., Mele M., Bittante G. (2012). Use of multivariate factor analysis to define new indicator variables for milk composition and coagulation properties in Brown Swiss cows. J. Dairy Sci. 95: 7346-7354

Mattiello S., Arduino D., Tosi M.V., Carenzi C. (2005). Survey on housing, management and welfare of dairy cattle in tie-stalls in western Italian Alps. Acta Agr. Scand. AAN. 55: 31-39

Orland B. (2004). Alpine Milk: Dairy Farming as a Pre-modern Strategy of Land Use. Environ. Hist. 10: 327–364

Penati C., Berentsen P.B.M., Tamburini A., Sandrucci A., de Boer I.J.M. (2011). Effect of abandoning highland grazing on nutrient balances and economic performance on Italian Alpine dairy farms. Livest. Sci. 139: 142-149

SAS Institute. (2008). SAS/STAT User's Guide. Version 9.2. SAS Institute Inc., Cary, NC.

Streifeneder T., Tappeiner U., Ruffini F.V., Tappeiner G., Hoffmann C. (2007). Selected aspects of the agricultural structure change within the Alps-a comparison of harmonized agri-structural indicators on a municipal level within the Alpine Convention Area. Revue de Geographie Alpine 95: 41–52

Sturaro E., Thiene M., Cocca G., Mrad M., Tempesta T., Ramanzin M. (2013). Factors influencing summer farm management in the Alp. Ital. J. Anim. Sci. 12: 153-161

Tiezzi F., Maltecca C., Cecchinato A., Penasa M., Bittante G. (2012). Genetic parameters for fertility of dairy heifers and cows at different parities and relationships with production traits in first lactation. J. Dairy Sci. 95: 7355-7362

Tables and figures

Table 1: Descriptive statistics of summer farms

Variable	Number	Elevation (mean ± SD)	LU/unit (mean ± SD)
Total summer farms (n)	395	1664 ± 250	55 ± 52
Summer farms with dairy cattle	345		
- only replacement heifers	83	1653 ± 287	42 ± 35
- also cows on milk	262	1651 ± 245	67 ± 43
- with cheese making	92	1661 ± 235	72 ± 43
- with agro-tourism (bar, restaurant, accommodation...)	39		
Milk processed/milk produced in summer farms (tons)	2,362/6,527		
Summer farms for sheep and goat (n)	50	1799 ± 202	96 ± 83

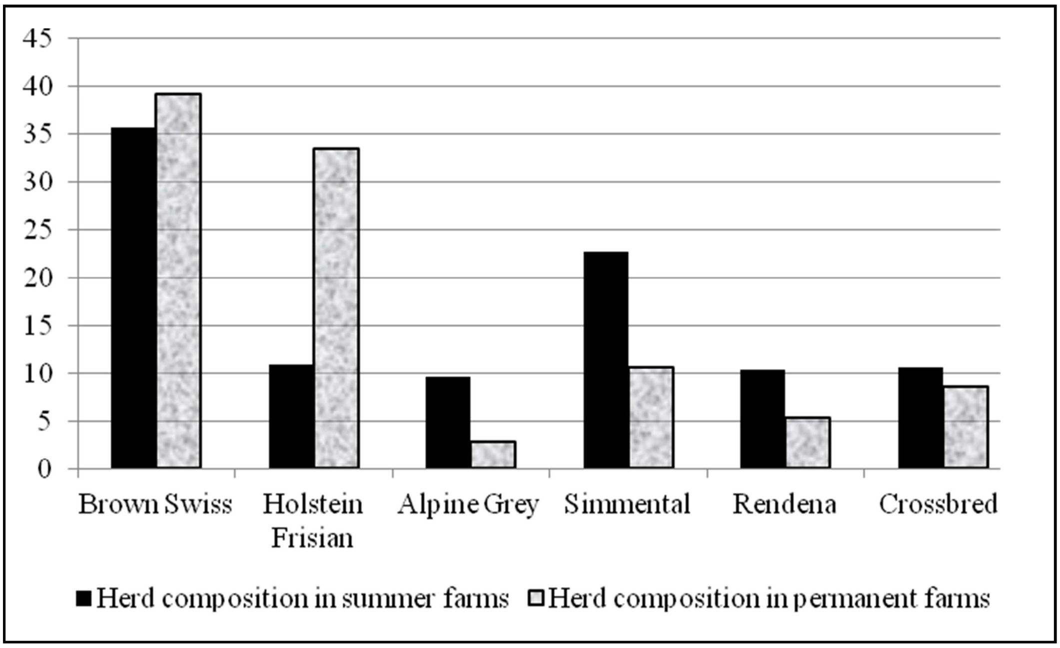
Table 2: Analysis of differences (LSmeans and frequencies) between permanent farms using/not using summer highland pastures for dairy cows

Variable	Farms using summer pastures	Farms without summer pastures	P	R^2 (%)/ χ^2
Number of permanent dairy farms	334	276		
Cows on milk (number)	23.3	42.4	<0.001	8.3
Herd size (Livestock Unit, LU)	30.9	55.4	<0.001	7.9
Brown Swiss (% of LU)	48.8	42.6	0.036	-
Holstein Friesian (% of LU)	9.4	36.1	<0.001	-
Simmental (% of LU)	12.2	7.9	0.007	-
Rendena (% of LU)	11.2	2.6	<0.001	-
Alpine Grey (% of LU)	9.8	2.9	<0.001	-
Crossbreed (% of LU)	8.5	8.0	0.530	-
Elevation of permanent farms (m asl)	879	731	<0.001	5.4
Agricultural surface (ha, highland pastures excluded)	13.1	21.9	<0.001	9.1
Stocking rate (LU/ha)**	2.27	2.70	0.067	0.6
Use of total mixed ration (frequencies)	23/334	95/276	<0.001	*73.4*
Use of silages (frequencies)	13/334	82/276	<0.001	*76.6*
Tie stalls (frequencies)	273/334	171/276	<0.001	*29.8*
Milk yield (kg/day/head)	19.1	21.9	<0.001	7.9
Fat content (%)	3.91	3.97	<0.001	1.8
Casein (%)	2.70	2.73	<0.001	1.3
SCS	3.23	3.19	0.528	0.1
Farms producing milk for PDO cheese	203/334	118/276	<0.001	*19.7*

*: the value of R^2 was reported for variables with normal distributions; χ^2 value was reported for frequencies

**: calculated with exclusion of LU moved to summer farms, for the relative summering period, as: total LU – LU moved to summer farms* summering periods (months)/12.

Figure 1. Percentage composition of cows on milk per breed in permanent farms (grey columns) and in summer farms (black columns)



Chapter 2

Transhumance of dairy cows to highland summer pastures interacts with breed to influence body condition, milk yield, quality and coagulation properties, cheese yield, and nutrient recovery in curd

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Abstract

Summer transhumance of livestock to highland pastures on temporary farms is a traditional practice across Alps, with potential multifunction positive externalities. This paper aimed in evaluating the effect of pasturing of dairy cows on milk yield and quality. Data on 799 lactating cows were collected and analyzed during 2012 from 15 temporary farms on Alpine summer pastures located in the Autonomous Province of Trento. The cows were reared in 109 permanent dairy farms. The following traits were considered: Body Condition Score (BCS), milk production and quality, milk coagulation properties, and different set of parameters and information relating to dairy processing were recorded and analyzed. Effects of the breed, parity and days in milk were taken into account. The effects of Alpine summer pasture, and in particular of the amount of compound feed given to cows, were also considered. Information was gathered not only during the period that the cows spent at the Alpine summer pasture, but also before and after the alpine season, with the objective to evaluate the changes due to the environmental changes. Results showed that the summer transhumance had an effect more or less relevant in determining a decrease in production, but also depending upon the breed. Specialized breeds, with higher production levels in permanent dairy farms, suffer a greater drop in production than the local and dual purpose breeds. This was somehow expected, since local breeds have a greater adaptability and lower nutrients requirements.

Even the body condition score has been strongly influenced from the summer Alpine pasture. A decline in the first phase of the pastures and a subsequent recovery at the end of the pasture period was observed. Differences between breeds existed, with those specialized breeds showing a greater decrease in body condition.

After the return from the Alpine pastures a decline in the percentage of fat content in milk (more evident in specialized breeds) was observed, while the protein content remained

constant. Regarding the technological properties of milk, significant differences were found with the change of environment (after the reaching of temporary summer farms and after the return to permanent farms). The major differences for lactodynamographic properties as well as the individual cheese yields were observed between June and September. In conclusion, the reserach highlighted the better adaptation of local and dual purpose breeds in the Alpine environment and their good performance under environmental changes as well as the special conditions of the farming system in summer pasture.

Introduction

Summer transhumance to highland pastures on temporary farms (hereafter called "summer farms") has been practiced since pre-historic times and is still widespread in the mountain livestock farming systems of the European Alps and other mountainous regions (Vandvik and Birks, 2004; Noel and Finch, 2010; Mack et al., 2013; Sturaro et al., 2013b.). This practice is important for farmers because it supplements the annual forage budget, allows access to public subsidies (Mack et al., 2013; Zendri et al., 2013; Battaglini et al., 2014), and can increase revenue through processing of the milk into high-value traditional cheeses (Sturaro et al., 2013a). In addition, the cultural landscape of the summer farms provides positive externalities by increasing local tourist attractiveness (Thiene and Scarpa, 2008; Dausgstad and Kirkengast, 2013), maintaining cultural heritage and traditions (Hunziker, 1995; Baudry and Thenail, 2004; Kianicka et al., 2010, Eriksson, 2011), and by conserving the biodiversity of farmed livestock (Sturaro et al., 2013a) and natural habitats and species of high conservation value (Vandvik and Birks, 2004; Marini et al., 2009, 2011).

The practice of transhumance to summer farms has declined over recent decades (Mack et al., 2013; Sturaro et al., 2013b) following the general process of agricultural intensification in productive areas (Sturaro et al., 2013b) and abandonment of farming in marginal areas (Bernués et al., 2011; Caraveli, 2000; García-Martinez et al., 2009; Strijker, 2005). Sustaining traditional, extensive livestock systems and high nature value grasslands is now given priority in agricultural and biodiversity policies, and for this reason maintaining their links with the summer farms is essential. Information on the sustainability of summer farms is, however, limited, and is related to the effects of abandonment or intensity of grazing on natural biodiversity, the environmental impact of farming (Penati et al., 2011; Guerci et al., 2014), the effects of grazing conditions on animal health and welfare (Leaver, 1988; Smits et al., 1992; Gitau et al., 1996; Ketelaar-de Lauwere et al., 1999; Bertoni and Calamari, 2001;

Mattiello et al., 2005; Corazzin et al., 2010; Comin et al., 2011), and the influence of pasture on the sensorial and nutraceutical properties of milk (Martin et al., 2005).

The effects of transhumance to summer farms on the nutritional status of animals, their milk production and quality, and cheese yields are important issues, given that the milk is often processed into high-value products in mountain areas, yet so far they have been addressed in few experiments (Bovolenta et al., 1998; Leiber et al., 2006; Bovolenta et al., 2009; Romanzin et al., 2013; Farruggia et al., 2014). When moved to summer pastures, cows experience a change in diet, increased energy expenditure due to the movement associated with grazing, interactions with unknown individuals in the case of mixed herds, and a general need to adapt to a new environment. These conditions could result in nutritional imbalance, which in turn will affect milk production and composition, and ultimately cheese yield. Normally, supplement concentrates are provided (Leiber et al., 2006; Bovolenta et al., 2009), but compensating for the nutritional deficiencies of pasture is a difficult task where animals graze in heterogeneous swards and are free to move over wide areas. This is of particular concern when comparing highly-specialized breeds with dual-purpose or local breeds, characterized by lower productive potentials and requirements, but by better adaptation to the difficult conditions of mountain pastures. Dairy systems are highly diversified in mountain regions, where a variety of different breeds are reared, often in multi-breed farms (Sturaro et al., 2009 and 2013b; Mattiello et al., 2011).

This study aimed to estimate the effects of the transhumance of lactating cows to summer farms on their nutritional condition and general welfare as indexed by body condition scores (Gallo et al., 1996 and 2001; Roche et al., 2009), on milk yield, quality and coagulation proprieties, and on cheese yields. For these purposes, different breeds, individual conditions (parity and days in milk), and amounts of supplementary compound feeds were compared in a large sample of summer farms and the permanent farms that use them.

Material and methods

This study is part of a large project aimed at establishing new phenotypes in dairy cow breeding, with particular emphasis on mountainous environments (Cowplus project).

Alpine highland pastures and cows sampled

Study area

The study area was the highland summer pastures of Trento Province in the north eastern Italian Alps. It has a surface area of 6,212 km2, and elevation ranging from 66 to 3769 m asl. The utilized agricultural area (UAA) covers an area of 1372 km2, and is mainly composed of grassland and pastures (81%), followed by orchards and vineyards (17%), while arable crops accounts for only 2% (ISTAT, 2010). Dairy cattle represents the Province's largest livestock sector: of the 1403 cattle farms counted in the 2010 census, 1071 raised dairy herds. The majority of dairy farms are members of cooperatives producing local and Protected Designation of Origin (PDO) cheeses, mainly "Trentingrana", and are subject to strict regulations (Bittante et al., 2011a and 2011b). Cows producing milk for the production of Trentingrana cannot be fed on silages and genetically modified feeds.

Pastures for dairy cows cover a larger surface area than meadows (50,000 *vs* 30,000 ha), and are very important for the entire livestock sector in mountain areas. Summer farms (malga in Italian) are temporary units where the livestock herds are moved to during summer to graze on highland pastures. In Trento Province, the summer farms are mainly owned by public institutions (district councils), and each unit keeps livestock from several permanent farms. Almost all dairy farms use summer farms for heifers and around 50% also move lactating cows (Sturaro et al., 2013a).

Summer farm sampling

The data used in this study were collected from 15 summer farms and the 109 permanent farms that transport part or all of their lactating cows to summer farms. The summer farms were chosen on the basis of three parameters: geological substrate (acid magmatic rock or calcareous rock), altitude (1200 to 2000 m asl), and the amount of supplementary compound feed given to the cows (low: ≤ 4 kg/d; high > 4 kg/d). Information on pasture area and stocking rate was retrieved from the Veterinarian Services of Trento Province.

Collection of data from the cows

Body condition score (BCS)

Two trained operators collected BCSs from 1018 lactating cows in July, after adaptation following arrival on the summer farms, and in September. Scoring was according to 5 classes (from 1, emaciated, to 5, obese), as described by Edmonson et al. (1989) for dairy breeds and adapted to dual-purpose breeds.

Milk recording

All the cows were registered in the Italian Herd Books of their breed, and in the milk recording system (AT4) of Trento Province. Monthly milk recordings (excluding August) were collected from the Breeders Federation of Trento and comprised the last sampling in the permanent farms (in May) before transhumance to the summer farms, samplings on the summer farms (June, July and September), and the first sampling after the cows returned to the permanent farms (October). Data on daily milk yield, milk composition (fat, protein, casein, lactose, urea), and somatic cell count (SCC) were retrieved. Fat/protein and casein/protein ratios were calculated, and somatic cell scores (SCS) were obtained through logarithmic transformation of SCC.

Other information

All the information on individual cows (breed, date of birth and calving, number of lactations, days in milk) was retrieved from the national cattle population register. The study investigated two specialized dairy breeds: Holstein Friesian (90 cows), and Brown Swiss (314 cows); three dual-purpose breeds: Simmental (241 cows), Rendena (26 cows), and Grey Alpine (97 cows); and crossbreds (31 cows). Given the low number of cows belonging to the last three genotypes, and their similar body sizes and productivity, they were grouped together as “Local Breeds” (154 cows) for statistical analyses. Cows of other breeds and cows not registered in the Herd Books were excluded from the analyses. A total of 799 dairy cows were included in the final dataset.

The three major transboundary breeds (Holstein, Brown Swiss and Simmental) reared in Trento Province are almost all bred using artificial insemination with semen from sires obtained from either the national selection programs of the three Italian breeders associations (ANAFI, Cremona, for Holsteins; ANARB, Bussolengo-Verona, for Brown Swiss; and ANAPRI, Udine, for Simmental), which use the best of internationally available sires, or from semen imported from abroad. A detailed description of the genetic background of the three breeds in the Trento Province is found in Cecchinato et al. (2015a). No specific selection for low-input dairy systems is practiced in the province. In the case of the two local breeds, semen is provided by the two national breeders associations (ANARE, Trento, for Rendena, and ANAGA, Bolzano/Bozen, for Grey Alpine) as part of a program of young bull selection based on pedigree information for milk yield and quality, and type traits, and on performance testing for beef production. Natural mating is also practiced with the Rendena breed, using the same young bulls as for semen production (Mantovani et al., 1997).

FTIR spectral data

Spectral data for this study were provided by the Breeders Federation of Trento Province. In Italy, FTIR spectroscopy is used to predict the composition of individual milk samples collected during routine milk recording (ICAR, 2012). Since 2010, FTIR spectra of all samples collected from dairy herds in Trento Province for milk recording purposes and analyzed using a MilkoScan FT6000 (Foss Electric, Hillerød, Denmark) have been stored by the local Breeders Federation (FPA, Trento). The calibration and the sets of population spectra were obtained by analyzing all individual milk samples over the spectral range 5000 to 900 wave number × cm-1; the spectra are stored as absorbance (A) using the transformation A = log(1/T), where T is transmittance. Two spectral acquisitions were carried out for each sample and the results averaged prior to data analysis.

A preliminary analysis (Cecchinato et al., 2015a) was carried out in order to identify outlier spectra by calculating Mahalanobis distances [global H (GH)], H-outliers being those spectra with large distances (GH > 10). Given that the prediction equations had been obtained from Brown Swiss cows, averages of the spectral absorbance of Mahalanobis distance were tested for differences among the different breeds. The Mahalanobis distances of the FTIR spectra were very similar in the different breeds.

Of the entire spectra set, only those spectra of the 799 cows that were at summer pasture during 2012 were considered. A total of 1879 spectra were used for the predictions.

Milk coagulation, curd firming, and syneresis predictions

Trait definition

All milk coagulation, curd firming, and syneresis traits are based on laboratory simulated cheese-making using a computerized lactodynamograph continuously recording the resistance of a pendulum immersed in the milk contained in an oscillating vessel after heating and rennet addition (McMahon and Brown, 1982). The instrument was tested on a reference population of 1264 Brown Swiss cows from 85 herds kept under the different dairy systems (from very traditional to modern) in Trento Province (Cipolat-Gotet et al., 2012).

Traditional, single point observations of milk coagulation properties (MCP) have been defined (Annibaldi et al., 1977) as:

- **RCT**, the time (min) from rennet addition to milk gelation;
- $\mathbf{k_{20}}$, the time (min) from milk gelation to curd firmness equivalent to 20 mm;
- $\mathbf{a_{30}}$ ($\mathbf{a_{45}}$), curd firmness (mm) recorded after 30 (45) min from rennet addition.

The phenotypic and genetic parameters of MCP in the reference population have been previously reported (Cipolat-Gotet et al., 2012; Cecchinato et al., 2013).

The parameters for modeling all curd firming and syneresis point observations with time ($\mathbf{CF_t}$ model) of each individual milk sample have been defined (Bittante, 2011; Bittante et al., 2013b) as:

- $\mathbf{RCT_{eq}}$, like traditional RCT (min) but from modeling all observations and not as a single point trait;
- $\mathbf{CF_P}$, potential asymptotic curd firmness (mm) at infinite time attainable in absence of syneresis;
- $\mathbf{k_{CF}}$, instant curd firming rate constant (%/min) measured after RCT_{eq} leading curd firmness toward CF_P at infinite time;

- **k_{SR}**, instant syneresis rate constant (%/min) measured after RCT_{eq} leading curd firmness toward null value at infinite time;

Two more traits derived from CF_t individual equations have been defined (Bittante et al., 2013b) as:

- **CF_{max}**, the maximum curd firmness (mm) attained by CF_t individual equations;
- **T_{max}**, the time (min) at which CF_{max} is attained.

All MCP and CF_t model parameters and derived traits are depicted in Figure 1.

The CF_t model parameters and derived traits for the reference population have been studied from both the phenotypic and genetic perspectives in previous works (Bittante et al., 2015; Cecchinato et al., 2015b).

FTIR prediction equations

Calibration models were developed using the spectra collected from the Brown Swiss reference population as the calibration set. As described by Ferragina et al. (2013) for predicting %CY and REC traits, the WinISI II software (Infrasoft International LLC, State College, PA) was also used for MCP and CF_t parameters and derived traits. The chemometric algorithm for calibrating the traditional MCP and the modeled parameters was calculated using modified partial least square regression (MPLS). Spectra were used without pre-treatment and with various pre-treatments, including standard normal variate (SNV), standard normal variate and detrend (SNVD), multiplicative scatter correction (MSC), and first and second derivatives. FTIR spectra were analyzed across the whole interval (from 5000 to 900 wavenumber×cm^{-1}) and without the two portions known to have very high phenotypic variability: the transition region between the short-wave to mid-wave infrared (SWIR-MWIR or NIR-MIR, 3,669 to 3,052 cm^{-1}) and region MWIR-2, from 1698 to 1586 wavenumber×cm-1 (Bittante and Cecchinato, 2013). A combination of these pre-treatments was also used.

Samples with a much larger difference between the reference and predicted values than the standard error of cross-validation (SEC_{cv}) were considered T-outliers (the T value was set at 2.5). Cross-validation using four groups of samples from the calibration set was used to assess calibration robustness. In addition, the standard error of cross-validation (SEC_{cv}), and the coefficient of correlation of cross-validation (R_{VAL}) were calculated to compare the effectiveness of the calibration models.

The best prediction equations (lower SEC_{CV} and higher R_{VAL}) obtained from the tested chemometric models for traditional MCP and modeled CF_t parameters and derived traits were used to predict the traits on the sets of population spectra. Predictions of traits with a R_{VAL} <0.60 (CF_P and k_{SR}) were not used in the present study.

Cheese yield and nutrient recovery predictions

Trait definition

All cheese yields and nutrient recovery traits are based on a laboratory model cheese-making procedure using 1500 mL milk samples from individual cows and involving milk heating, culturing, and renneting, and curd cutting, straining, pressing, and salting (Cipolat-Gotet et al., 2013).

The traits examined were:

- **$\%CY_{CURD}$**, representing the percentage ratio between the weight of the fresh curd after salting and the weight of the milk processed;
- **$\%CY_{SOLIDS}$**, representing the percentage ratio between the weight of the curd dry matter and the weight of the milk processed;
- **$\%CY_{WATER}$**, representing the percentage ratio between the weight of the water retained in the curd after salting and the weight of the milk processed;
- **REC_{FAT}**, representing the percentage ratio between the weight of the fat in the curd after salting and the weight of the fat in the milk processed;

- **REC$_{PROTEIN}$**, representing the percentage ratio between the weight of the protein in the curd after salting and the weight of the protein in the milk processed;
- **REC$_{SOLIDS}$**, representing the percentage ratio between the weight of the dry matter in the curd after salting and the weight of the dry matter in the milk processed;
- **REC$_{ENERGY}$**, representing the percentage ratio between the energy content of the curd after salting and the energy content of the milk processed.

The %CY and REC traits in the reference populations have been studied from the phenotypic and genetic perspectives in previous papers (Cipolat-Gotet et al., 2013; Bittante et al., 2013a). The phenotypic, additive genetic, herd, and residual correlations between the measured %CY and REC traits and the MCP and CFt model parameters and derived traits in the same population have also been previously studied (Cecchinato and Bittante, 2015).

FTIR prediction equations

Prediction of %CY and REC traits was carried out as described by Ferragina et al. (2013) using the same methodology described for MCP and CF_t parameters and derived traits. The predicted traits were compared with those measured in the reference population from phenotypic and genetic perspectives (Bittante et al., 2014a). The prediction equations were then applied to all the test day milk spectra stored in Trento Province, and the resulting genetic parameters of the Holstein, Brown Swiss, and Simmental populations were estimated (Cecchinato et al., 2015a).

Statistical analysis

All the data referring to the cows' BCS, and milk yield, composition and cheese-making aptitude were analyzed using the MIXED procedure (SAS Institute Inc., Cary, NC).

The following fixed effects were tested: compound feed is the fixed effect of the class of feed supplement (class 1: <4 kg/cow/d; class 2: >4 kg/cow/d); breed is the fixed effect of the class of breed (class 1: Holstein Friesian, class 2: Brown Swiss, class 3: Simmental, class 4: Local Breeds); parity is the fixed effect of the class of parity of the cow (class 1: primiparous, class 2: pluriparous); initial DIM is the fixed effect of the class of DIM at the time the cow is transported to the summer farm (class 1: <120 d, class 2: 121–180 d, class 3: 181–240 d; class 4: >241 d); month is the fixed effect of the class of month (for BCS: class 1: July; class 2: September; for all the other traits: class 1: May; class 2: June; class 3: July; class 4: September; class 5: October). Summer farm (15 units, nested within class of feed supplement) and cow (799 dairy cows, nested within class of feed supplement, summer farm, breed, parity, and initial DIM) were considered random effects. After a preliminary analysis of the effects of the different interactions, the following interactions were also included in the statistical model: compound feed × breed, breed × month, initial DIM × month. Summer farm was the error line for testing compound feed, cow was the error line for testing breed, parity, initial DIM, and compound feed × breed, and the residual was the error line for testing month, breed × month, and initial DIM × month.

Orthogonal contrasts were used to compare the classes of fixed effects as follow:

Month: 1) May *vs*. June, 2) June *vs*. September, 3) July *vs*. June + September, 4) September *vs*. October.

For DIM, the linear, quadratic and cubic trends of the LSM classes were tested.

Breed: 1) Holstein Friesian + Brown Swiss *vs*. Simmental + Local Breeds, 2) Brown Swiss *vs*. Holstein Friesian, 3) Local Breeds *vs*. Simmental

Results

The main characteristics of temporary summer farms

Descriptive statistics of the management characteristics of the summer farms are shown in Table 1. Fifteen summer farms were sampled, and a total of 799 cows from 109 permanent dairy farms were used for the study. In addition to grazing the Alpine pastures, the cows received a compound feed supplement, distributed at milking: an average of 3.4 ± 0.6 kg/d on summer farms classified as “low level” (n=10), and 5.6 ± 1.2 kg/d on “high level” summer farms (n=5). The two groups of farms were homogeneous for other characteristics: elevation, surface area, herd size, and stocking rate.

Estimates of the actual amount of daily compound feed administered per breed are reported in Figure 2. Only cows of Local Breeds (Rendena, Alpine Gray, and crossbred) received a lower average amount of compound feed, because they were mostly reared in traditional “low level” summer farms. The average amounts given to the other breeds were similar, but with greater variability with the Simmental cows.

Sources of variation of traits studied

The results of the mixed linear models for the traits studied are reported in Table 2. The sources of variation related to individual cow characteristics (breed, parity, and initial DIM) included in the mixed linear model significantly affected almost all the traits analyzed, as did monthly variation within cow. The interactions of breed and initial DIM with month were also almost always significant.

The amount of compound feed administered on the summer farms significantly affected only some milk quality traits (caseins and lactose %) and some technological parameters, but in general the statistical significance of these effects was low, especially for the traits with a high degree of variability among summer farms within compound feed level (used as the error term for testing the effect of compound feed level).

The interaction compound feed × breed was significant for few traits, mainly those regarding traditional single point MCP.

The effect of month (moving to, permanence in, and return from temporary summer farms)

The effect of month is presented in Table 3. This combines the effect of summer transhumance with the effect of advancing lactation stage within each cow, and also with changes in seasonal conditions.

To facilitate interpretation of the results regarding the variations observed in the period studied, a first comparison was made between data collected in May and data collected in June, and represents, together with one month advancement in lactation, the main effect of moving cows from permanent lowland farms to summer farms. The change was large and negative for both production traits, very small for quality traits, favorable for lactodynamographic properties, negative for $\%CY_{CURD}$, due to a decrease in water retention in curd (increased syneresis), and varying for nutrient recovery, being negative for protein, positive for fat, and negligible for total solids and energy.

The second comparison was between data obtained in June and data obtained in September, *i.e.*, the initial and final phases of summer transhumance. It mainly reflects, together with a 3 month advancement in lactation, adaptation of the cows to the new environment, and the difference in environmental conditions with particular emphasis on the change in pasture quality and availability. There were large differences between the initial and final stages of the summering season for all trait categories, with the exception of lactodynamographic properties. The trends in variation were as expected with the advancement of lactation, but sometimes to a larger degree than anticipated. This is especially true for the decreases in daily milk (-42%) and fat+protein (-36%) yields, the increase in milk fat (+8%), protein (+7%), and SCS (+34%) contents, and the decreases in the casein index (-3.5%) and in lactose content (-5.5%).

The third comparison was between the data collected in July and the averages of those obtained in June and September during summer pasturing, and reflects possible non-linear trends in observed traits from the beginning to the end of the summer transhumance. A non-linear trend was indeed observed, especially for milk quality traits, traditional single point MCP, and REC traits, while a linear change over time was more common for production traits, CFt parameters and derived traits, and %CY traits. The traits deviating the most from linearity were protein and casein contents, which slightly decreased from June to July and increased to September. Traditional MCP, as well as CF_{max}, and REC traits improved from June to July and worsened thereafter.

The last comparison (September *vs*. October) reflects, together with a further advancement of lactation, the effect of the cows returning to the lowland permanent farms, an indoor environment, and a more controlled feeding regime based on preserved feedstuffs. Milk production generally improved on return to the permanent farms, in both quantity and quality; milk gelation tended to be slower but curd firming was faster; all %CY and REC traits improved.

Variability among summer farms and the effect of compound feed

The effects of compound feed and of variance among summer farms on total variance are presented in Table 4.

The differences in the LSMs of BCS between the group of summer farms supplementing lactating cows with high amounts of compound feed and those supplementing with low amounts was modest; also the variability in BCS among different summer farms within supplement level was very low, representing only about one fifteenth of total variance (the sum of farm, animal and residual variances).

The difference in daily production of the cows between the two groups of summer farms was high but not significant (+17% at the “high” level of supplementation for both milk yield and milk fat + protein yield). A reason for this could be that it was tested on a very large variance (almost one third of total variance) among individual summer farms within each group for both traits.

Variability among summer farms within groups was very low for milk quality traits, being less than one tenth for all traits with the exception of milk urea content (one sixth) and SCS (one eighth). Cows on the “high level” summer farms produced milk with more casein, expressed both as milk weight (casein percentage) and as total protein (casein index). The lactose content of milk was also greater on “high level” summer farms (Table 4).

Variability among summer farms within supplementation group was very low for all lactodynamographic traits, generally less than one twentieth of total variance, with the exception of a_{45} among the traditional single point MCPs (about one fifteenth), and CF_{max} among the CF_t derived traits (one eleventh). Supplement level also had a modest influence, with a favorable effect on k_{20} (decreased), a_{45} (increased) and CF_{max} (increased).

As with lactodynamographic characteristics, cheese-making (%CY and REC) traits were also characterized by a modest effect of individual summer farm (from about one fortieth to one fifteenth of total variance), and a favorable effect of “high level” of supplementary compound feed on $\%CY_{CURD}$ and REC_{FAT} (Table 4).

Variability among animals and the effect of parity

The effect of animal variance on total variance, and the LSMs of the effect of parity are shown in Table 4, together with the figures for summer farms and compound feed supplementation.

Primiparous cows had higher BCS, despite the fact that animal variance (with respect to parity) represented about two thirds of total variance. As expected, the opposite effect (lower values with primiparous than with multiparous cows) was found with the two daily production traits. Animal variance on these traits represented slightly more than a quarter of total variance.

The individual animal was an important source of variability in all milk quality traits, ranging from about one seventh for the fat/protein ratio and urea content, almost a quarter for milk fat and one third for the casein index, to almost one half for the other traits (protein, casein, lactose, and SCS). Lower milk production in primiparous cows was paralleled by a favorable effect on some quality traits (protein, casein, casein index, lactose, and SCS).

Variability among individual cows was substantial for lactodynamographic traits, ranging from almost a fifth of total variance for k_{CF} to almost a half for RCT and RCT_{eq}. The effect of parity was not very substantial on this trait, and was significant only in the case of k_{CF} (greater for multiparous) and CF_{max} (greater for primiparous).

Lastly, animal variability ranged from about a quarter to a third for all %CY and REC traits (Table 4), while parity affected some of these traits, the milk of primiparous cows having a greater $\%CY_{CURD}$, mainly due to greater $\%CY_{WATER}$ and $REC_{PROTEIN}$.

Effect of stage of lactation at the beginning of summer pasture

The effect of initial days in milk is presented in Table 5. This factor does not represent the effect of advancing lactation within each cow, but shows the differences between cows at different stages of lactation when they were moved to summer farms for transhumance to Alpine pastures.

Only few traits were not affected by initial DIM of the cows (RCT, RCT_{eq}, t_{max}, and $REC_{PROTEIN}$). A strong linear trend was observed for all affected traits, with some smaller quadratic and cubic effects for some of the traits exhibiteing a greater difference between the first (<120 DIM) and the second (121-180 DIM) class of DIM at the beginning of summer pasturing than between the third (181-240 DIM) and the fourth (>240 DIM) classes. As expected, the effect of initial DIM was positive for BCS, negative for production traits, positive for milk quality traits, except lactose, urea and the two ratios examined, favorable for lactodynamographic properties and for %CY and REC traits.

The effect of cow breed

The effect of breed is presented in Table 6. The comparisons clearly show that there were greater differences between the two specialized dairy breeds (Holstein Friesian and Brown Swiss) and between the two dual-purpose breed groups (Simmental and local breeds), although to a lesser extent, than there were between the group of specialized breeds and the group of dual-purpose breeds.

The effect of breed, within summer farm and corrected for the effects of parity, initial DIM and month of scoring, on BCS was a considerable. The LSM for BCS was very low for HF, intermediate for BS and higher for dual-purpose breeds, especially local breeds.

Production traits were not highly influenced by breed because the slight superiority of specialized over dual-purpose breeds was due to the 10% lower yield of milk and solids in local breeds.

There was no difference in milk quality between the two specialized breed groups. Within the specialized dairy breeds, however, the milk from Brown Swiss cows was more concentrated (more fat, protein, casein and lactose) than that from Holstein Friesians, and milk urea was higher. Within dual-purpose breeds, Simmental cows produced milk with more fat (as % and as ratio with protein) and with a lower SCS than the local breeds.

Moving to lactodynamographic properties, the small differences between the two specialized breeds and the dual-purpose breeds was always attributable to the milk produced by Holstein Friesian cows having worse coagulation and curd firming rates than the milk from Brown Swiss cows. The only differences within the dual-purpose breeds were the slight superiority of Simmental cows over local breeds with respect to k_{20} and a_{30}.

In the case of %CY and REC traits, the inferiority of specialized breeds with respect to dual-purpose breeds was entirely due to Holstein Friesians having lower cheese yields and nutrient recovery than Brown Swiss cows. No substantial differences were noted among dual-purpose breeds.

Interactions between sources of variation

Many interactions between the sources of variation studied were statistically significant, as can be seen from Table 2. Due to readability and space issues, the corresponding LSMs could not be included in the tables. However, the import of several interactions is described in the discussion session, and the highest ones are depicted in figures.

Discussion

Milk production and body condition

Summer transhumance of cows from lowland permanent farms to summer farms involves a change from mostly indoor rearing with a constant ration of hay and concentrates or a total mixed ration (Sturaro et al., 2013a), to outdoor rearing and feeding on pasture. Many of the old barns on traditional summer farms have been transformed into milking parlors, so the cows live outdoors day and night and only return to the barn for milking (Zendri et al., 2013).

From an animal feeding point of view, Alpine pastures are characterized by low productivity, a short vegetative season, and a marked variation in grass availability, botanical proportion, and chemical composition (Bovolenta et al., 1998). The cows are required to walk long distances, often on steep, stony inclines covered with shrubs, so they eat less grass and are also susceptible to the negative effects of anoxia (Leiber et al., 2006). Moreover, the cows are normally given a compound feed supplement during milking, but the amount and composition are quite variable, as also observed in our study. The compound feed is sometimes modified during summer grazing to increase the crude protein content (Leiber et al., 2006). Sometimes a source of roughage (mature hay or straw) is given at the beginning of the grazing season to compensate for the low fiber and high protein contents of grass.

From the environmental and nutritional points of view, summer transhumance causes physiological, metabolic and even psychological (because of mixing of cows from different permanent farms) stress during the first period of grazing (Zemp et al., 1989). The stressful conditions are confirmed by a progressive decrease in milk production, leading to the daily yield being almost halved in four months (Table 3), and by the recovery of production functions after the cows return to the permanent farms. In addition, moving from lowland pastures (~ 400 m asl) to Alpine pastures (~ 2000 m asl) may give rise to a decrease in feed intake, milk production, and body weight of cows, as shown by Leiber et al. (2006). Farruggia et al. (2014), found a decrease in milk production from May to September of about 35% for cows grazing a rotational productive pasture, and 60% for cows on a continuous permanent pasture characterized by low productivity.

An important outcome of the present study was evidence regarding the different effects of summer transhumance on the milk yield of cows of different breeds (interaction between breed and month). Figure 3 clearly shows how the breeds were ranked according to their expected daily milk yield in May (Holstein Friesian > Brown Swiss > Simmental > Local Breeds) and that this was almost unchanged in June, at the beginning of summer grazing, whereas one month later production of the cows of the two specialized dairy breeds dropped rapidly to the level of the local breeds. In the following two months, production of the Simmental cows also decreased a little, so that in September all breeds were very similar in terms of the quantity of milk produced. It is also worth noting that the positive effect of returning to permanent farms was very similar across breeds and did not privilege the more specialized ones, there being no compensation for the large production loss they experienced at the beginning of the grazing season. As a consequence, over the whole period daily production of fat and protein was very similar across breeds, with the exception of cows of the local breeds, whose production was slightly lower (~10%) (Table 6).

In a trial investigating the effect of concentrate supplementation on a low-input mountain experimental farm practicing pasturing without summer transhumance, Horn et al. (2014a) compared a specialized dairy breed (Austrian Brown Swiss) with a Friesian strain selected for life-time milk yield and fitness traits in a low-input environment. These authors observed that over the whole experimental period the specialized dairy breed was not able to express its productive potential in this dairy system, so that the average milk yield was similar for the two breeds even though it was higher in the specialized dairy breed at the beginning of lactation.

A similar, but somewhat weaker, interaction was noted in a study also looking at initial DIM and month. Cows in early lactation experienced a more evident decrease in milk yield than cows in mid- and late-lactation (data not shown). Horn et al. (2014b) observed an effect of interaction between breed and initial DIM on milk yield and body weight change.

The decrease in milk production on the whole averted a dramatic depletion of body fat depots. It is well known hat body fat depots are important in maintaining milk yield at the beginning of lactation, but less so during mid- and late-lactation (Roche et al., 2009; Remppis et al., 2011). In fact, the LSM of BCS was very low in July (Table 3) and increased a little during the following two months, but without reaching the values typical of the last stage of lactation (Gallo et al., 1996 and 2001). The differences among breeds with respect to this trait were even larger than with respect to daily milk yield, and the ranking of breeds was, as expected, reversed (Table 6). The breed × month interaction was also significant in this case, but much less so than for milk yield. Figure 4 shows that at the end of the summer transhumance Holstein Friesian cows, despite a great drop in production and despite being the cows with the greatest increase in BCS from July to September, were still characterized by a very low level of body reserves, which probably prevented recovery to the desired level before the following parturition.

To limit the negative effects of summer transhumance on milk yield and body condition, the amount of supplementary compound feed is usually increased during the summer, especially with specialized dairy breeds (Bovolenta et al., 1998 and 2002). In the present study, an increase in the concentrate supplement had no significant effect on production traits and on BCS, which is due to the fact that the observation unit is the summer farm so the number of independent observations (and degrees of freedom) was limited.

However, the increase in milk yield (+17%) was not much different numerically from that obtained in trials comparing cows of the same summer farm fed on different amounts of concentrates (Bovolenta et al., 1998 and 2008). In their investigation into the effect of concentrate supplementation on a low-input mountain experimental farm practicing pasture without summer transhumance, Horn et al. (2014a) found an increase in total lactation milk yield of about 10% for cows receiving a higher concentrate supplementation. As in the present study, these authors found only a small effect of concentrate level on BCS.

Milk quality

The effects of changes in environment, nutrition, and cow management due to summer transhumance are reflected in modifications to quality traits of the milk produced before, during and after transhumance (Table 3). After moving to summer farms on Alpine grassland, milk fat content decreased while protein content remained constant. This could be due to an impairment of rumen fermentation brought about by a decrease in dry matter intake, along with a decrease in fiber content resulting from the presence of grass at a very early vegetative stage, but it could also be due to an increased intake of vaccenic acid and conjugated linoleic acid (CLA) isomers. In particular, the increased availability of C18:2*t*10*c*12 isomer seems to be the main factor responsible for milk fat depression (Bauman et al., 2008; Shingfield et al., 2010). This drop in the milk fat content of milk produced at the beginning of summer pasturing was particularly evident in cows of the specialized dairy breeds (Holstein Friesian and Brown Swiss) but not in dual-purpose cows (Figure 3); it was not, however, evident in Brown Swiss cows moving to Alpine pastures from lowland pastures (Leiber et al., 2006) rather than from closed barns.

During the following months, the milk fat content increased, as expected with the advancement of lactation, while milk protein and casein contents decreased in July and increased thereafter (in fact, the fat/protein ratio peaked in July). This pattern could be due to a prolonged shortage of energy that only led to a decrease in milk yield and an increase in milk protein and casein contents in the mid-term (Table 3). This pattern of milk protein content was also observed by Leiber et al. (2006) after cows were moved from lowland to Alpine pastures. This interpretation is consistent with the effect of a high level of concentrate supplementation, which contributed to increasing the casein content, as well as the casein/protein ratio, and the lactose content of milk (Table 4). Bovolenta et al. (1998) found similar results for milk protein content. Further confirmation comes from the observation that the decrease in the milk protein percentage in July occurs in cows in early- and mid-lactation, but not in those in late-lactation (Figure 5), and in cows belonging to specialized dairy breeds (Holstein Friesian and Brown Swiss) but not dual-purpose breeds (Figure 3).

Variations in milk lactose and SCS during summer transhumance are greater than expected as a result of lactation advancement, and could be an indicator of the increased incidence of subclinic mastitis in highland pastures (Leiber et al., 2006). Different patterns in SCS before, during and after summer transhumance were noted for cows of specialized dairy and dual-purpose breeds (Figure 6).

Milk coagulation and curd firming

To understand the effect of summer transhumance on milk coagulation and curd firming processes it is important to mention that these traits are characterized by a curvilinear evolution during lactation, worsening at the beginning of lactation and improving toward the end, in both intensive (Malchiodi et al., 2014) and mountain (Bittante et al., 2015) rearing conditions. As cows in very early lactation are not normally moved to summer farms, the expected pattern of coagulation and curd firming traits of the cows in this study is stable with a tendency for improvement in the last months. This is indeed the case with respect to the milk characteristics of cows with different DIMs at the beginning of lactation (Table 5), but this source of variation does not take into account the effect of advancement of lactation during the observation period when the effects of changes in environment, management, and feeding of cows are added to those of changing lactation stage.

It should also be mentioned that pasture increases ingestion of vaccenic acid and the availability of rumenic acid and other conjugated linoleic acid isomers (Kelly et al., 1998). The latter substances have been found to have a negative effect on milk coagulation and curd firming processes in both ewes (Bittante et al., 2014b) and cows (unpublished results). On the other hand, there was no short-term effect of moving to summer pastures on coagulation time but there was a favorable effect on the curd firming process, with maximum curd firmness greater and attained more quickly than before the move (Table 3). The improvement continued during the first phase of summer pasturing and worsened in the second phase, returning to the initial values. The return to permanent farms was accompanied by a delay in coagulation and an improvement in curd firmness. Both Macheboef et al. (1993) and Leiber et al. (2006) observed that moving cows from barn feeding based on silage and concentrates to lowland pasture had a favorable effect on traditional MCP in experimental stations, but Leiber et al. (2006) found the effect to be unfavorable in moving from lowland grassland to Alpine pastures.

The cows that were moved to summer pastures and received more concentrates during milking on average produced milk with similar coagulation times but better curd firming aptitude than those receiving fewer concentrates (Table 4), confirming a pattern observed with traditional MCP by Bovolenta et al. (1998 and 2009).

It is interesting that this effect was not common across breeds. The differences in the LSM of the effect of breed observed in the present study is similar to the results reviewed by Bittante et al. (2012), highlighting the inferiority of milk from Holstein Friesian cows with respect to cows of breeds of Alpine origin. Martin et al. (2009) compared Holstein and Montbeliarde cows at pasture and obtained similar results with respect to MCP in favor of the Alpine breed.

What has not previously been observed is the interaction between the level of compound feed administered and breed. In fact, increasing concentrates was accompanied by a clear worsening of the coagulation time of milk produced by Brown Swiss cows, a smaller negative effect for Holstein Friesian and Simmental cows, and a small positive effect on local breeds (Figure 7). Concentrates had a favorable effect on curd firming and curd firmness traits with all breeds excluding Brown Swiss (Table 7).

Cheese yield and milk nutrient recovery in curd / loss in whey

The literature contains some studies on the quality (Bovolenta et al., 2008) and sensory traits (Bovolenta et al., 2009) of cheeses produced on temporary summer farms or from milk obtained from summer pastures on Alpine grassland and processed in artisanal or industrial factories, whereas information on variations in cheese yield and curd nutrient recovery is very scarce.

As mentioned by several authors, after the peak in milk production fresh cheese yield ($\%CY_{CURD}$) tends to increase with DIM because of a simultaneous increase in milk fat and casein contents, and this concerns an increase both in solids ($\%CY_{SOLIDS}$) and in water retained in cheese ($\%CY_{WATER}$), as described by Cipolat-Gotet et al. (2013). Regarding milk nutrient recovery in cheese, the same authors found an increase in the recovery of total solids (REC_{SOLIDS}) and of milk energy (REC_{ENERGY}), mainly because of the lower proportion of lactose to total solids with advancement of lactation. Variations in fat and protein recoveries were smaller and curvilinear. In the present study, %CY and REC traits increased almost linearly with initial DIM of cows at the beginning of summer pasturing due to the absence of cows in the very early phase of lactation (Table 5).

Comparing the %CY traits predicted on the milk samples collected in the permanent farms in May with those after moving to temporary summer farms in June, instead of an increase due to the advancement of lactation, a decrease in $\%CY_{CURD}$ was observed (Table 3). This negative change seems not to be attributable to a change in milk composition (only fat and lactose were marginally affected) but mainly to a lower retention of water in cheese. The predicted REC_{SOLIDS} and REC_{ENERGY} were not affected by moving to summer pastures, while $REC_{PROTEIN}$ decreased and REC_{FAT} increased (Table 3). As a result, $\%CY_{SOLIDS}$ remained almost constant. During the summer, the expected change related to advancement of lactation was found (increases in all %CY traits and in REC_{SOLIDS} and REC_{ENERGY}), and this increase was particularly evident in the first phase of summer pasturing, probably due to the cows adapting after the initial stressful changes. The return to permanent farms also occasioned an improvement in all %CY and REC traits, more pronounced than expected from advancement of lactation (Cipolat-Gotet et al., 2013), indicating here, too, the effect of an improvement in the cows' conditions, especially their feeding.

Those cows moved to temporary summer farms and receiving more concentrates produced milk characterized by improved $\%CY_{CURD}$ and REC_{FAT} (Table 4).

Regarding the effect of breed (Table 6), the data confirmed the ranking observed in the long term on all the farms in the province of Trento independently of summer transhumance (Cecchinato et al., 2015a): lower %CY traits predicted from Holstein Friesian cows as a consequence of a lower content of solids and also of all REC traits in the milk. What is especially interesting, is that the two specialized breeds showed a similar pattern during the observation period, with a constant superiority of Brown Swiss cows over Holsteins, as shown in Figure 8. The dual-purpose breeds also displayed similar patterns of cheese yield traits, but these were different from the specialized dairy breeds, with all traits tending to improve from the middle of the summer period. In a studying on processing milk for Cantal cheese production, Martin *et al*. (2009) found Montbeliarde cows to have a higher cheese yield than Holsteins reared at pasture.

Conclusions

The present study was carried out not only during the period spent by cows on temporary summer farms on Alpine grassland, but also during the previous and subsequent periods spent in permanent lowland farms, allowing analysis to be made of the changes due to moving to and returning from summer farms. Moreover, the study was carried out on several summer farms under different management schemes and, in particular, administering different quantities of compound feed to the cows, while each temporary farm reared cows of different breeds in the same environment. Finally, it combined monitoring of the nutritional status of cows with changes within a set of parameters describing the entire milk production and transformation processes.

This approach provided confirmation that moving to summer farms and adapting to the new environment and to pasture is a stressful period for cows, affecting milk yield and composition as well as body fat reserves. These negative changes are greater with cows moved during the first stage of lactation and cows of specialized dairy breeds, particularly Holstein Friesians, than cows of dual-purpose breeds. In the final part of the period on summer farms, milk production was similar across breeds, and recovery of milk yield after returning to the permanent farms was also similar. Holstein cows had similar yields, but lower milk quality and lower body condition compared with Brown Swiss and Simmental cows, and also local dual-purpose breeds (Alpine Grey, Rendena, and crossbred).

New information was gathered on the effects of summer pasture on milk coagulation and curd firming properties, cheese yield, and milk nutrient recovery in the curd or loss in the whey with cows of different breeds. Again, an interaction was found between breed and month of recording, confirming the superiority of the breeds of Alpine origin over the Holstein Friesian breed, and the greater adaptability of dual-purpose breeds to Alpine grassland conditions.

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References

Annibaldi, S., F. Ferri, and R. Morra. 1977. Nuovi orientamenti nella valutazione tecnica del latte: Tipizzazione lattodinamografica. Sci. Tecn. Latt. Cas. 28:115–126.

Battaglini, L., S. Bovolenta, F. Gusmeroli, S. Salvador, and E. Sturaro. 2014. Environmental sustainability of Alpine livestock farms. Ital. J. Anim. Sci. 13:3155.

Baudry, J., Thenail, C., 2004. Interaction between farming systems, riparian zones, and landscape patterns: a case study in western France. Landsc. Urban. Plann. 67:121-129.

Bauman, D.E., J.W. Perfield, K.J. Harvatine, and L.H. Baumgard. 2008. Regulation of fat synthesis by conjugated linoleic acid: lactation and the ruminant model. J. Nutr. 138:403-409.

Bernués, A., R. Ruiz, A. Olaizola, D. Villalba, and I. Casasús. 2011. Sustainability of pasture-based livestock farming systems in the European Mediterranean context: Synergies and trade-offs. Livest. Sci. 139:44-57.

Bertoni G., Calamari L., 2001. Animal welfare and human needs: are they contradictory? pp 23-30 in Proc. 3rd Eur. Congr. EurSafe, Firenze, Italy.

Bittante, G. 2011. Modeling rennet coagulation time and curd firmness of milk. J. Dairy Sci. 94:5821-5832.

Bittante, G., A. Cecchinato, N. Cologna, M. Penasa, F. Tiezzi, and M. De Marchi. 2011a. Factors affecting the incidence of first-quality wheels of Trentingrana cheese. J. Dairy Sci. 94:3700-3707.

Bittante, G., A. Ferragina, C. Cipolat-Gotet, and A. Cecchinato. 2014a. Comparison between genetic parameters of cheese yield and nutrient recovery or whey loss traits measured from individual model cheese-making methods or predicted from unprocessed bovine milk samples using Fourier-transform infrared spectroscopy. J. Dairy Sci. 97:6560-6572.

Bittante, G., and A. Cecchinato. 2013. Genetic analysis of the Fourier-transform infrared spectra of bovine milk with emphasis on individual wavelengths related to specific chemical bonds. J. Dairy Sci. 96:5991-6006

Bittante, G., B. Contiero, and A. Cecchinato. 2013b. Prolonged observation and modelling of milk coagulation, curd firming, and syneresis. Int. Dairy J. 29:115-123.

Bittante, G., C. Cipolat-Gotet, and A. Cecchinato. 2013a. Genetic parameters of different measures of cheese yield and milk nutrient recovery from an individual model cheese-manufacturing process. J. Dairy Sci. 96:7966–7979.

Bittante, G., C. Cipolat-Gotet, F. Malchiodi, E. Sturaro, F. Tagliapietra, S. Schiavon, and A. Cecchinato. 2015. Effect of dairy farming system, herd, season, parity and days in milk on modeling of the coagulation, curd firming and syneresis of bovine milk. J. Dairy Sci. 98:2759-2774.

Bittante, G., E. Pellattiero, F. Malchiodi, C. Cipolat-Gotet, M. Pazzola, G.M. Vacca, S. Schiavon, and A. Cecchinato. 2014b. Quality traits and modeling of coagulation, curd firming, and syneresis of sheep milk of Alpine breeds fed diets supplemented with rumen-protected conjugated fatty acid. J. Dairy Sci. 97: 4018–4028.

Bittante, G., N. Cologna, A. Cecchinato, M. De Marchi, M. Penasa, F. Tiezzi, I. Endrizzi, and F. Gasperi. 2011b. Monitoring of sensory attributes used in the quality payment system of Trentingrana cheese. J. Dairy Sci. 94:5699-5709.

Bittante, G., Penasa, M., Cecchinato, A. 2012. Invited review: Genetics and modeling of milk coagulation properties. J. Dairy Sci, 95: 6843-6870.

Bovolenta S. Corazzin M., Saccà E., Gasperi F., Biasioli F., Ventura W., 2009. Performance and cheese quality of Brown cows grazing on mountain pasture fed two different levels of supplementation. Livestock Science 124, 58–65.

Bovolenta, S., E. Saccà, M. Corazzin, F. Gasperi, F. Biasioli, and W. Ventura. 2008. Effects of stocking density and supplement level on milk production and cheese characteristics in Brown cows grazing on mountain pasture. J. Dairy Res. 75. 357-364.

Bovolenta, S., W. Ventura, and F. Malossini. 2002. Dairy cows grazing an alpine pasture: effect of pattern of supplement allocation on herbage intake, body condition, milk yield and coagulation properties. Anim. Res. 51:15-23.

Bovolenta, S., W. Ventura, E. Piasentier, and F. Malossini. 1998. Supplementation of dairy cows grazing an alpine pasture: Effect of concentrate level on milk production, body condition and rennet coagulation properties. Ann. Zootech. 47:169-178.

Caraveli, H., 2000. A comparative analysis on intensification and extensification in Mediterranean agriculture: dilemmas for LFAs policy. J. Rural. Stud. 16:231-242.

Cecchinato A., S. Chessa, C. Ribeca, C. Cipolat-Gotet, T. Bobbo, J. Casellas and G. Bittante. 2015b. Genetic variation and effect of candidate-gene polymorphisms on coagulation properties, curd firmness modeling and acidity in milk from Brown Swiss cows, Anim. In press.

Cecchinato, A., A. Albera, C. Cipolat-Gotet, A. Ferragina, and G. Bittante. 2015a. Genetic parameters of cheese yield and curd nutrient recovery or whey loss traits predicted using Fourier-transform infrared spectroscopy (FTIR) of samples collected during milk recording on Holstein, Brown Swiss and Simmental dairy cows. J. Dairy Sci. in press.

Cecchinato, A., and G. Bittante. 2015. Genetic, herd, and environmental relationships of different measures of individual cheese yield and curd nutrients recovery/whey loss and coagulation properties of bovine milk. J. Dairy Sci. Submitted.

Cecchinato, A., C. Cipolat-Gotet, J. Casellas, M. Penasa, A. Rossoni, and G. Bittante. 2013. Genetic analysis of rennet coagulation time, curd-firming rate, and curd firmness assessed over an extended testing period using mechanical and near-infrared instruments. J. Dairy Sci. 96:50–62.

Cipolat-Gotet, C., A. Cecchinato, C., M. De Marchi, and G. Bittante. 2013. Factors affecting variation of different measures of cheese yield and milk nutrients recovery from an individual model cheese-manufacturing process. J. Dairy Sci. 96:7966–7979.

Cipolat-Gotet, C., A. Cecchinato, M. De Marchi, M. Penasa, and G. Bittante. 2012. Comparison between mechanical and near-infrared optical methods for assessing coagulation properties of bovine milk. J. Dairy Sci. 95 :6806–6819.

Comin, A., Prandi, A., Peric, T., Corazzin, M., Dovier, S., & Bovolenta, S. 2011. Hair cortisol levels in dairy cows from winter housing to summer highland grazing. Livestock Science, 138: 69-73.

Corazzin M., Piasentier E., Dovier S., Bovolenta S., 2010. Effect of summer grazing on welfare of dairy cows reared in mountain tie-stall barns. Ital. J. Anim. Sci. 9, 304-312.

Daugstad,K., and Kirchengast, C. 2013. Authenticity and the pseudo-backstage of agri-tourism. Annals of Tourism Research, 43: 170-191.

Edmonson A. J., Lean L. J., Weaver L. D., Farver T., Webster G. 1989. A body condition scoring chart for Holstein dairy cows. J. Dairy Sci. 72:68–78.

Eriksson, C. 2011. What is traditional pastoral farming? The politics of heritage and'real values' in Swedish summer farms (fäbodbruk). Pastoralism, 1(1), 1-18.

Farruggia, A.; D. Pomiès, M. Coppa, A. Ferlay, I. Verdier-Metz, A. Le Morvan, A. Bethier, F. Pompanon, O. Troquier, and B. Martin. 2014. Animal performances, pasture biodiversity and dairy product quality: How it works in contrasted mountain grazing systems. Agric. Ecosyst. Env. 185:231-244.

Ferragina, A., C. Cipolat-Gotet, A. Cecchinato, and G. Bittante. 2013. The use of Fourier-transform infrared spectroscopy to predict cheese yield and nutrient recovery or whey loss traits from unprocessed bovine milk samples. J. Dairy Sci. 96:7980-7990.

Gallo L., Carnier P., Cassandro M., Dal Zotto R., and Bittante G. 2001. Test-Day Genetic Analysis of Condition Score and Heart Girth in Holstein Friesian Cows. J. Dairy Sci. 84:2321–2326.

Gallo L., Carnier P., Cassandro M., Mantovani R., Bailoni L., Contiero B., and Bittante G., 1996. Change in body condition score of Holstein cows as affected by parity and mature equivalent milk yield. J. Dairy Sci. 79:1009–1015.

García-Martínez, A., Olaizola, A., & Bernués, A. 2009. Trajectories of evolution and drivers of change in European mountain cattle farming systems. Animal, 3(01), 152-165.

Gitau T., McDermott J. J., Mbiuki S. M., 1996. Prevalence, incidence and risk factors for lameness in dairy cattle in small scale farms in Kikuyu Division, Kenya. Prev. Vet. Med. 28:101–115.

Guerci M., Bava L., Zucali A., Tamburini A., Sandrucci A., 2014. Effect of summer grazing on carbon footprint of milk in Italian Alps: a sensitivity approach. Journal of Cleaner Production 73: 236-244.

Horn, M., A. Steinwidder, R. Pfister, J. Gasteiner, M. Vestergaard, T. Larsen, and W. Zollitsch. 2014a. Do different cow types respond differently to a reduction of concentrate supplementation in an Alpine low-input dairy system? Livest. Sci. 170:72-83.

Horn, M., A. Steinwidder, W. Starz, R. Pfister, and W. Zollitsch. 2014b. Interactions between calving season and cattle breed in a seasonal Alpine organic and low-input dairy system. Livest Sci. 160: 141-150.

Hunziker, M., 1995. The spontaneous reforestation in abandoned agricultural lands: perception and aesthetic assessment by locals and tourists. Landsc. Urban Plann. 3:399-410.

International Committee for Animal Recording (ICAR). 2012. International agreement of recordings practices – Guidelines approved by the general assembly held in Cork, Ireland on June 2012. ICAR. Rome, Italy.

ISTAT, Istituto Nazionale di Statistica (2010). VI Censimento generale dell'Agricoltura. Roma.

Kelly, M. L., Kolver, E. S., Bauman, D. E., Van Amburgh, M. E., & Muller, L. D., 1998. Effect of intake of pasture on concentrations of conjugated linoleic acid in milk of lactating cows. J. Dairy Sci. 81:1630-1636.

Ketelaar de Lauwere C.C., Ipema A.H., van Ouwerkerk E.N.J., Hendriks M.M.W.B., Metz J.H.M., Noordhuizen J.P.T.M., Schouten W.G.P., 1999. Voluntary automatic milking in combination with grazing of dairy cows. Milking frequency and effects on behaviour. Appl. Anim. Behav. Sci. 64:91-109.

Kianicka, S., Knab, L., Buchecker, M., 2010. Maiensäss - Swiss Alpine summer farms - an element of cultural heritage between conservation and further development: a qualitative case study. Int. J. Heritage Stud. 16:486-507.

Leaver, J. D. 1988. Management and welfare of Animals. 3rd ed. Bailliere Tindall, London, UK.

Leiber, F., M. Kreuzer, H. Leuenberger, H-R Wettstein. 2006. Contribution of diet type and pasture conditions to the influence of high altitude grazing on intake, performance and composition and renneting properties of the milk of cows. Anim. Res. 55:37-53.

Macheboeuf, D., J-B. Coulon, and P. D'Hour. 1993. Aptitude à la coagulation du lait de vache. Influence de la race, des variants génétiques des lactoprotéines du lait, de l'alimentation et du numéro de lactation. INRA Prod. Anim. 6:333-344.

Mack, G., Walter, T., & Flury, C. 2013. Seasonal alpine grazing trends in Switzerland: economic importance and impact on biotic communities. Environmental Science & Policy, 32: 48-57.

Malchiodi, F., A. Cecchinato, M. Penasa, C. Cipolat-Gotet, and G. Bittante. 2014. Milk quality, coagulation properties, and curd firmness modeling of purebred Holsteins and first- and second-generation crossbred cows from Swedish Red, Montbéliarde, and Brown Swiss bulls. J. Dairy Sci. 97:4530–4541.

Mantovani R., Gallo L., Carnier P., Cassandro M., and Bittante G. 1997. The use o a juvenile selection scheme for genetic improvement of small populations: the example of Rendena breed. Proceedings of 48th EAAP meeting, Wien 25th – 28th August 1997. pp 1-5.

Marini, L., Fontana, P., Klimek, S., Battisti, A., Gaston, K.J., 2009. Impact of farm size and topography on plant and insect diversity of managed grasslands in the Alps. Biol. Conserv. 142:394-403.

Marini, L., Klimek, S., Battisti, A., 2011. Mitigating the impacts of the decline of traditional farming on mountain landscapes and biodiversity: A case study in the European Alps. Environ. Sci. Policy 14:258-267.

Martin, B., D. Pomiès, P. Pradel, I. Verdier-Metz, and B. Rémond. 2009. Yield and sensory properties of cheese made with milk from Holstein or Montbéliarde cows milked twice or once daily. J. Dairy Sci. 92 :4730–4737.

Martin, B., Verdier-Metz, I., Buchin, S., Hurtaud, C., Coulon, J.-B. 2005. How do the nature of forages and pasture diversity influence the sensory quality of dairy livestock products? Animal Science, 81: 205-212.

Mattiello, S., Arduino, D., Tosi, M.V., Carenzi, C., 2005. Survey on housing, management and welfare of dairy cattle in tie-stalls in western Italian Alps. Acta Agric. Scand. Sect. A 55: 31-39.

Mattiello, S., Battini, M., Andreoli, E., and Barbieri, S., 2011. Short communication: Breed differences affecting dairy cattle welfare in traditional alpine tie-stall husbandry systems. J. Dairy Sci., 94: 2403-2407.

McMahon, D. J., and R. J. Brown. 1982. Evaluation of Formagraph for comparing rennet solutions. J. Dairy Sci. 65:1639-1642.

Noel, N. M., & Finch, O. D., 2010. Effects of the abandonment of alpine summer farms on spider assemblages (Araneae). Journal of insect conservation, 14(5):427-438.

Penati, C., Berentsen, P.B.M., Tamburini, A., Sandrucci, A., de Boer, I.J.M., 2011. Effect of abandoning highland grazing on nutrient balances and economic performance of Italian Alpine dairy farms. Livest. Sci. 139:142-149.

Remppis, S., H. Steingass, L. Gruber, and H. Schenkel. 2011. Effects of energy intake on performance, mobilization and retention of body tissue, and metabolic parameters in dairy cows with special regard to effects of pre-partum nutrition on lactation - A review. Asian-Aust. J. Anim. Sci. 24:540-572.

Roche J. R., Friggens N. C., Kay J. K., Fisher M. W., Stafford K. J., Berry D. P. 2009. Invited review: Body condition score and its association with dairy cow productivity, health, and welfare. J. Dairy Sci. 92 :5769–5801.

Romanzin, A., Corazzin, M., Piasentier, E., & Bovolenta, S. 2013. Effect of rearing system (mountain pasture vs. indoor) of Simmental cows on milk composition and Montasio cheese characteristics. Journal of Dairy Research, 80: 390-399.

SAS 2012. SAS 9.3. SAS Institute Inc., Cary (New York, USA).

Shingfield, K.J., L. Bernard, C. Leroux and Y. Chilliard. 2010. Role of trans fatty acids in the nutritional regulation of mammary lipogenesis in ruminants. Anim. 4:1140-1166.

Smits M. C. J., Frankena K., Metz J. H. M., Noordhuizen J. P. T. M., 1992. Prevalence of digital disorders in zero-grazing dairy farms. Livest. Prod. Sci. 32:231–244.

Strijker, D., 2005. Marginal lands in Europe—causes of decline. Basic Appl. Ecol. 6, 99–106.

Sturaro, E., Cocca, G., Gallo, L., Mrad, M., Ramanzin, M., 2009. Livestock systems and farming styles in Eastern Italian Alps: an on-farm survey. Ital. J. Anim. Sci. 8, 541-554.

Sturaro, E., E. Marchiori, G. Cocca, M. Penasa, M. Ramanzin, and G. Bittante. 2013a. Dairy systems in mountainous areas: farm animal biodiversity, milk production and destination, and land use. Livest. Sci. 58:157-168.

Sturaro, E., Thiene M., Cocca G., Mrad M., Tempesta T., Ramanzin M., 2013b. Factors influencing summer farms management in the Alps. Ital. J. Anim. Sci. 12, 153-161.

Thiene, M., Scarpa, R., 2008. Hiking in the Alps: exploring substitution patterns of hiking destinations. Tourism Econ. 14:263-282.

Vandvik, V; Birks, HJB; 2004. Mountain summer farms in Røldal, western Norway–vegetation classification and patterns in species turnover and richness. Plant Ecology, 170, 2:203-222.

Zemp, M., H. Leuenberger, N. Künzi, and W. Blum. 1989. Influence of high altitude grazing on productive and physiological traits of dairy cows. I. Influence on milk production and body weight. J. Anim. Breed. Genet. 106:278-288.

Zendri F., Sturaro E., Ramanzin M., 2013. Highland Summer Pastures Play a Fundamental Role for Dairy Systems in an Italian Alpine Region. Agriculturae Conspectus Scientificus 78. No. 3: 295-299.

Tables and figures

Table 1: Number and characteristics of temporary summer farms.

Variable	Daily compound feed during summer pasture:	
	Low level (≤ 4 kg/d)	High level (>4 kg/d)
Permanent Dairy farms of origin of cows (n)	77	32
Temporary summer farms - highland pasture (n)	10	5
Elevation of temporary dairy farms (m asl)	1,723 ± 194	1,645 ± 247
Pasture surface (ha/temporary summer farms)	76.0 ± 67.9	86.9 ± 72.7
Dairy cows per temporary summer farms (n)	62.3 ± 31.1	76.8 ± 49.6
Stocking rate (LU/ha)	1.05 ± 0.59	1.14 ± 0.54
Average compound feed (kg/head/day)	3.4 ± 0.6	5.6 ± 1.2

LU : Livestock Units follow EU livestock schemes where cattle > 2 years =1 livestock unit, cattle 6 months to 2 years = 0.6 LU and cattle < 6 months= 0.4 LU

Table 2: Analysis of variance of BCS and milk traits with F-*value* and significance of fixed effects and square root of variance of random effects (each random effect is placed soon after the fixed effects for which is was used as error line).

	Feed[1]	Temporary farm (random)	Breed	Feed x Breed	Parity	Initial DIM	Cow (random)	Month	Breed x Month	Initial DIM x Month	Residual (random)
BCS (score)	2.9	±0.080	43.0***	1.3	7.0**	30.0***	±0.248	21.4***	3.7**	1.8	±0.164
Daily production:											
Milk, kg/d	2.4	±3.074	2.7*	0.8	13.8***	20.8***	±3.031	461.9***	8.2***	8.6***	±4.124
Fat+protein, kg/d	2.5	±0.228	5.9***	1.0	6.4*	5.1**	±0.220	353.9***	6.2***	4.3***	±0.292
Milk quality:											
Fat, %	0.4	±0.226	4.6**	1.5	0.5	17.8***	±0.334	20.9***	3.4***	2.0*	±0.616
Protein, %	4.1	±0.077	20.5***	1.2	4.8*	72.5***	±0.228	142.1***	7.6***	9.9***	±0.238
Fat/protein, ratio	2.7	±0.064	2.1	1.5	0.1	5.3***	±0.072	8.7***	5.0***	1.0	±0.174
Casein, %	5.4*	±0.064	20.8***	0.8	11.6***	65.9***	±0.178	96.7***	7.4***	8.8***	±0.181
Casein/protein, %	3.2	±0.297	0.2	2.4	67.7***	11.4***	±0.586	308.9***	3.4***	5.4***	±0.990
Urea, mg/100mL	0.1	±3.406	15.0***	4.3**	0.7	5.1**	±3.064	25.2***	4.8***	1.7	±6.679
Lactose, %	9.6**	±0.042	3.1*	1.7	80.1***	4.1**	±0.137	198.7***	6.6***	4.1***	±0.149
SCS	0.0	±0.611	2.2*	1.1	30.1***	4.2**	±1.233	60.2***	2.4**	2.6***	±1.231
Single point MCP:											
RCT, min	2.5	±0.348	1.9	6.7***	0.3	1.9	±3.066	15.6***	3.8***	4.7***	±3.293
k_{20}, min	4.6	±0.263	11.4***	6.1***	0.1	9.6***	±0.743	69.8***	7.4***	3.2***	±1.033
a_{30}, mm	1.1	±1.797	7.1***	4.7**	0.0	6.0***	±6.231	71.2***	7.3***	2.6**	±7.358
a_{45}, mm	8.0*	±1.114	23.2***	0.2	1.6	34.5***	±2.377	28.7***	5.1***	1.7	±3.457
CF_t parameters:											
RCT_{eq}, min	3.3	±0.437	1.8	6.3***	0.2	1.6	±2.731	18.4***	3.5***	5.0***	±2.976
k_{CF}, %/min	0.7	±0.855	4.3**	0.5	13.2***	4.8**	±1.638	8.6***	2.3**	2.8***	±3.285
CF_t derived traits:											
CF_{max}, mm	4.7*	±1.434	17.3***	2.3	5.1*	21.5***	±2.439	100.9***	3.3***	2.3**	±3.558
t_{max}, min	2.0	±1.258	1.9	3.1*	3.6	1.1	±4.927	93.1***	3.1***	4.3***	±6.246
Cheese yield (%CY):											
$\%CY_{CURD}$	8.0*	±0.341	14.3***	1.1	8.0**	44.8***	±1.072	119.7***	5.5***	4.2***	±1.342
$\%CY_{SOLIDS}$	1.8	±0.245	8.3***	1.1	1.2	38.6***	±0.501	77.0***	3.8***	3.8***	±0.730
$\%CY_{WATER}$	3.0	±0.244	19.3***	0.8	24.6***	34.8***	±0.501	308.7***	6.7***	3.2***	±0.761
Curd recovery (REC):											
$REC_{PROTEIN}$, %	0.1	±0.693	14.8***	0.8	79.2***	2.0	±1.541	100.8***	4.3***	0.8	±1.826
REC_{FAT}, %	9.1**	±0.368	10.7***	1.7	3.0	6.5***	±1.196	43.5***	5.0***	5.2***	±1.939
REC_{SOLIDS}, %	1.1	±0.863	9.3***	1.6	1.1	41.9***	±1.635	146.8***	3.3***	4.2***	±2.615
REC_{ENERGY}, %	0.8	±0.881	10.0***	1.8	1.1	19.8***	±1.672	47.6***	4.3***	1.7	±2.427

*=P<0.05; **=P<0.01; ***=P<0.001

[1]: Effect of class of temporary summer farms according the average daily amount of compound feed given to lactating cows (≤4.0 *vs* >4.0 kg).

Table 3: Effect of the month of recording on BCS and milk and cheese traits.

	Month LSM					Contrast P-*value*			
	May Permanent farm	June Summer farm	July Summer farm	September Summer Farm	October Permanent farm	May *vs* June	June *vs* September	July *vs* (June + September)	September *vs* October
BCS (score)	-	-	2.77	2.82	-	-	21.4***[1]	-	-
Daily production:									
Milk, kg/d	22.6	20.4	15.9	11.4	14.4	65.8***	903.6***	0.0	75.8***
Fat+protein, kg/d	1.59	1.43	1.15	0.87	1.11	66.5***	688.2***	0.0	94.1***
Milk quality:									
Fat, %	3.70	3.61	3.79	3.96	3.95	4.6*	56.6***	0.0	0.0
Protein, %	3.45	3.45	3.39	3.66	3.79	0.1	142.0***	116.0***	36.3***
Fat/protein, ratio	1.08	1.06	1.12	1.07	1.06	2.8	1.5	28.8***	0.7
Casein, %	2.72	2.72	2.66	2.80	2.93	0.0	36.4***	86.8***	69.9***
Casein/protein, %	78.8	79.0	78.4	76.7	77.6	3.7	945.4***	74.0***	120.6***
Urea, mg/100mL	21.1	22.0	21.3	24.3	25.3	4.9*	19.9***	18.9***	3.5
Lactose, %	4.88	4.81	4.68	4.60	4.71	45.4***	355.6***	5.3*	69.8***
SCS	2.73	2.89	3.58	3.90	3.55	3.4	122.4***	5.8*	11.4***
Single point MCP:									
RCT, min	20.8	20.5	19.1	18.7	20.3	1.6	20.8***	2.9	15.2***
k_{20}, min	5.02	4.54	3.69	4.07	4.31	35.9***	14.5***	55.0***	3.3
a_{30}, mm	28.6	30.4	36.2	35.4	36.8	9.9**	32.0***	30.8***	2.4
a_{45}, mm	30.7	31.1	29.5	30.3	32.6	1.5	3.2	18.0***	26.9***
CF_t model parameters:									
RCTeq, min	21.9	21.9	21.3	20.7	23.2	0.0	11.73***	0.0	45.1***
k_{CF}, %/min	6.84	6.37	6.07	8.07	7.22	3.1	17.4***	17.14***	3.8
CF_t derived traits:									
CF_{max}, mm	35.9	38.2	40.2	40.5	41.6	68.0***	30.45***	8.4**	5.3*
t_{max}, min	41.8	40.5	39.7	38.4	48.9	7.7**	7.5**	0.2	174.4***
Cheese yield (%CY):									
$\%CY_{CURD}$	14.48	14.19	14.81	15.43	16.48	7.6**	61.6***	0.0	38.5***
$\%CY_{SOLIDS}$	6.10	6.12	6.55	6.96	6.95	0.1	95.6***	0.1	0.0
$\%CY_{WATER}$	8.30	7.82	7.90	8.26	9.88	66.3***	23.9***	5.0*	282.3***
Curd recovery (REC):									
$REC_{PROTEIN}$, %	77.9	76.6	76.4	77.1	79.2	75.2***	4.5*	10.8***	80.8***
REC_{FAT}, %	83.4	84.4	84.9	84.5	85.5	45.5***	0.1	9.0**	17.4***
REC_{SOLIDS}, %	47.3	47.3	49.5	51.0	51.6	0.0	148.3***	2.2	2.7
REC_{ENERGY}, %	62.4	62.4	63.8	64.8	64.3	0.2	70.1***	1.2	2.5

*=P<0.05; **=P<0.01; ***=P<0.001

[1]: July *vs* September

Table 4: Effect of class of temporary summer farms according amount of compound feed given to cows (Feed) and of parity of cows and percentage incidence of variance of temporary farm, within class of feed, and of cow on total variance on BCS and milk traits.

	Feed LSM		Temporary farm,%	Parity LSM		Cow[1] %
	Low level	High level		Primiparous	Pluriparous	
BCS (score)	2.75	2.84	6.7	2.82[B]	2.76[A]	65.0
Daily production:						
Milk, kg/d	15.6	18.3	26.5	16.3[A]	17.6[B]	25.8
Fat+protein, kg/d	1.13	1.33	28.1	1.20[A]	1.26[B]	26.0
Milk quality:						
Fat, %	3.84	3.76	9.4	3.82	3.79	20.6
Protein, %	3.50	3.60	5.2	3.57[a]	3.52[b]	45.3
Fat/protein, ratio	1.11	1.05	10.2	1.08	1.08	13.2
Casein, %	2.72[a]	2.81[b]	5.6	2.80[B]	2.74[A]	46.5
Casein/protein, %	77.9[A]	78.2[B]	6.2	78.3[A]	77.8[B]	24.3
Urea, mg/100mL	22.6	23.0	17.7	22.9	22.6	14.3
Lactose, %	4.69[A]	4.78[B]	4.2	4.80[B]	4.67[A]	43.9
SCS	3.30	3.36	10.9	2.99[A]	3.66[B]	44.6
Single point MCP:						
RCT, min	19.5	20.2	0.6	20.0	19.8	46.2
k_{20}, min	4.52[b]	4.13[a]	4.1	4.32	4.34	32.7
a_{30}, mm	32.8	34.2	3.4	33.5	33.5	40.4
a_{45}, mm	29.9[a]	31.8[b]	6.6	31.0	30.7	30.0
CF_t model parameters:						
RCT_{eq}, min	21.4	22.2	1.2	21.9	21.8	45.2
k_{CF}, %/min	7.15	6.68	5.1	6.49[A]	7.48[B]	18.9
CF_t derived traits:						
CF_{max}, mm	38.3[a]	40.2[b]	9.9	39.6[b]	39.0[a]	28.8
t_{max}, min	41.2	42.5	2.4	42.4	41.3	37.4
Cheese yield (%CY):						
$\%CY_{CURD}$	14.74[a]	15.41[b]	3.8	15.25[B]	14.91[A]	37.4
$\%CY_{SOLIDS}$	6.43	6.64	7.1	6.57	6.50	29.7
$\%CY_{WATER}$	8.30	8.57	6.3	8.59[B]	8.27[A]	32.9
Curd recovery (REC):						
$REC_{PROTEIN}$, %	77.4	77.5	7.8	78.2[B]	76.7[A]	38.4
REC_{FAT}, %	84.0[A]	84.9[B]	2.5	84.7	84.4	26.9
REC_{SOLIDS}, %	49.0	49.6	7.3	49.2	49.4	26.1
REC_{ENERGY}, %	63.3	63.8	8.2	63.7	63.4	29.5

a,b= $P<0.05$; A,B= $P<0.01$;

[1] percentage of variability explained by the random effect of cow

Table 5: Effect of DIM at the transport of cows to temporary summer farms on BCS and milk traits.

	Initial days in milk LSM				Contrast P-*value*		
	<120	121 – 180	181 – 240	>241	Linear	Quadratic	Cubic
BCS (score)	2.64	2.77	2.82	2.94	83.6***	0.0	3.1
Daily production:							
Milk, kg/d	19.2	16.9	15.9	15.8	56.1***	10.7**	0.1
Fat+protein, kg/d	1.31	1.22	1.19	1.20	12.0***	4.6*	0.2
Milk quality:							
Fat, %	3.59	3.73	3.95	3.94	47.2***	3.7	3.5
Protein, %	3.28	3.52	3.64	3.75	215.4***	7.5**	1.2
Fat/protein, ratio	1.10	1.07	1.09	1.05	7.3**	0.8	6.6**
Casein, %	2.57	2.74	2.84	2.92	196.0***	8.3**	0.4
Casein/protein, %	78.3	78.1	78.1	77.8	29.2***	0.6	2.8
Urea, mg/100mL	23.3	23.8	21.8	22.2	8.1**	0.0	7.4**
Lactose, %	4.77	4.74	4.74	4.70	10.6***	0.1	1.0
SCS	2.95	3.37	3.45	3.54	11.2***	2.0	0.5
Single point MCP:							
RCT, min	19.5	20.6	19.8	19.7	0.2	2.9	3.5
k_{20}, min	4.58	4.54	4.19	4.00	25.8***	0.8	1.5
a_{30}, mm	32.4	31.7	34.4	35.4	13.3***	1.6	2.7
a_{45}, mm	28.6	30.4	31.7	32.7	103.3***	1.3	0.0
CF_t model parameters:							
RCT_{eq}, min	21.6	22.4	21.6	21.7	0.1	1.7	3.4
k_{CF}, %/min	6.45	6.50	7.13	7.58	12.6***	0.7	0.6
CF_t derived traits:							
CF_{max}, mm	37.7	38.6	39.9	40.9	63.7***	0.0	0.3
t_{max}, min	41.8	42.7	41.5	41.4	0.9	0.9	1.6
Cheese yield (%CY):							
$\%CY_{CURD}$	14.03	14.79	15.51	15.98	133.9***	1.5	0.2
$\%CY_{SOLIDS}$	6.05	6.38	6.78	6.93	113.5***	2.4	1.3
$\%CY_{WATER}$	7.94	8.29	8.63	8.87	104.3***	0.7	0.1
Curd recovery (REC):							
$REC_{PROTEIN}$, %	77.2	77.4	77.7	77.4	1.2	3.4	1.1
REC_{FAT}, %	84.3	84.1	84.8	84.9	12.1***	1.7	5.6*
REC_{SOLIDS}, %	47.6	48.8	50.1	50.8	124.4***	2.2	0.7
REC_{ENERGY}, %	62.4	63.1	64.2	64.4	56.2***	1.4	2.4

*=P<0.05; **=P<0.01; ***=P<0.001

Table 6: Effect of breed of cows on BCS and milk traits.

	Breed LSM:				Contrast P-*value*:		
	Holstein Friesian (HF)	Brown Swiss (BS)	Simmental (SI)	Local breeds (LB)	(HF+BS) *vs* (SI+LB)	BS *vs* HF	LB *vs* SI
BCS (score)	2.54	2.72	2.90	3.01	128.2***	20.8***	6.6**
Daily production:							
Milk, kg/d	17.6	17.3	17.2	16.0	4.8*	0.2	5.1*
Fat+protein, kg/d	1.23	1.30	1.26	1.13	5.6*	2.9	8.6**
Milk quality:							
Fat, %	3.73	3.91	3.85	3.69	0.6	6.4*	5.9*
Protein, %	3.41	3.69	3.55	3.55	0.0	55.1***	0.0
Fat/protein, ratio	1.09	1.08	1.09	1.05	1.4	1.1	5.3*
Casein, %	2.65	2.88	2.77	2.77	0.1	56.8***	0.0
Casein/protein, %	78.1	78.0	78.1	78.1	0.1	0.4	0.1
Urea, mg/100mL	21.0	25.2	23.0	21.9	1.5	34.8***	2.2
Lactose, %	4.69	4.74	4.73	4.77	4.6*	5.5*	2.7
SCS	3.57	3.25	3.05	3.44	1.1	2.3	3.1*
Single point MCP:							
RCT, min	20.3	20.1	19.2	19.9	2.3	0.2	1.6
k_{20}, min	4.88	4.12	3.99	4.31	9.0**	26.1***	3.8
a_{30}, mm	30.5	35.0	35.6	32.8	2.7	15.5***	4.8*
a_{45}, mm	28.5	32.6	31.1	31.3	3.2	69.0***	0.1
CF_t model parameters:							
RCTeq, min	22.3	21.9	21.2	21.8	2.5	0.9	1.4
k_{CF}, %/min	6.01	7.49	7.19	6.97	1.0	12.8***	0.2
CF_t derived traits:							
CF_{max}, mm	37.0	40.6	39.9	39.6	6.2*	51.4***	0.3
t_{max}, min	43.2	41.6	40.8	41.9	1.9	3.0	1.1
Cheese yield (%CY):							
$\%CY_{CURD}$	14.29	15.61	15.32	15.09	2.4	41.8***	1.0
$\%CY_{SOLIDS}$	6.29	6.78	6.60	6.47	0.0	22.2***	1.4
$\%CY_{WATER}$	7.95	8.78	8.58	8.43	2.4	56.3***	1.4
Curd recovery (REC):							
$REC_{PROTEIN}$, %	76.7	78.4	77.4	77.3	1.1	34.7***	0.0
REC_{FAT}, %	83.5	84.9	84.8	84.8	8.9**	30.4***	0.0
REC_{SOLIDS}, %	48.3	50.1	49.7	49.2	0.6	26.0***	1.7
REC_{ENERGY}, %	62.5	64.4	63.8	63.5	0.5	29.1***	0.3

*=P<0.05; **=P<0.01; ***=P<0.001

Figure 1: Representation of traditional single point coagulation properties represented by open circles (RCT, k_{20}, a_{30} and a_{45}), and CFt model parameters (RCT_{eq} coincides with RCT, CF_P, k_{CF} and k_{SR}) and derived traits (CF_{max} and t_{max}), modified from Bittante et al. (2012).

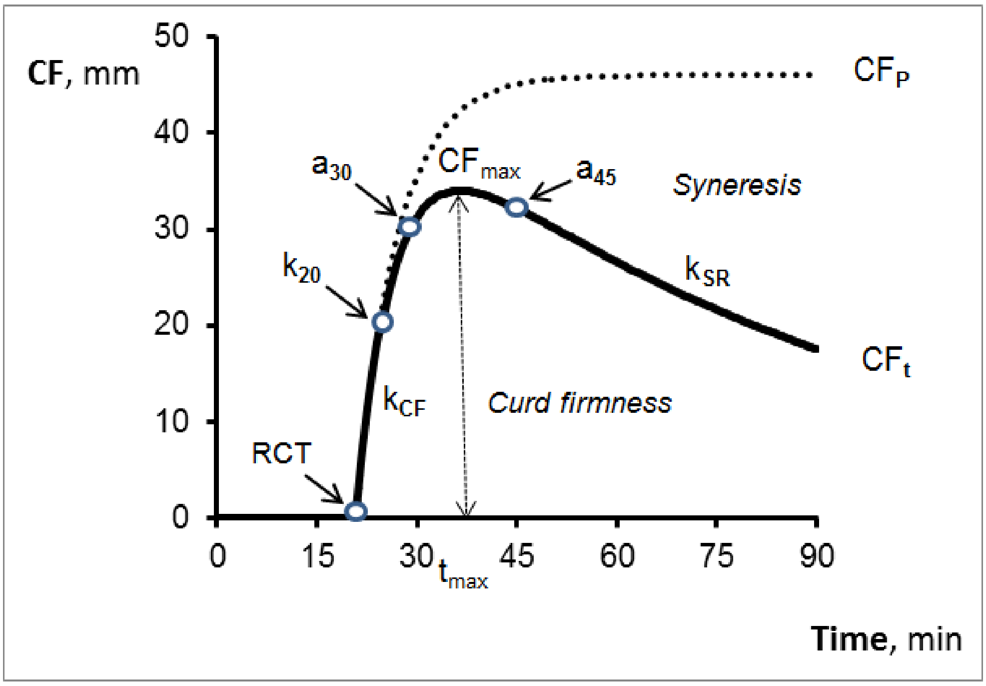


Figure 2: Estimated compound feed availability during summer transhumance for cows of different breeds according to their distribution in the different temporary summer farms.

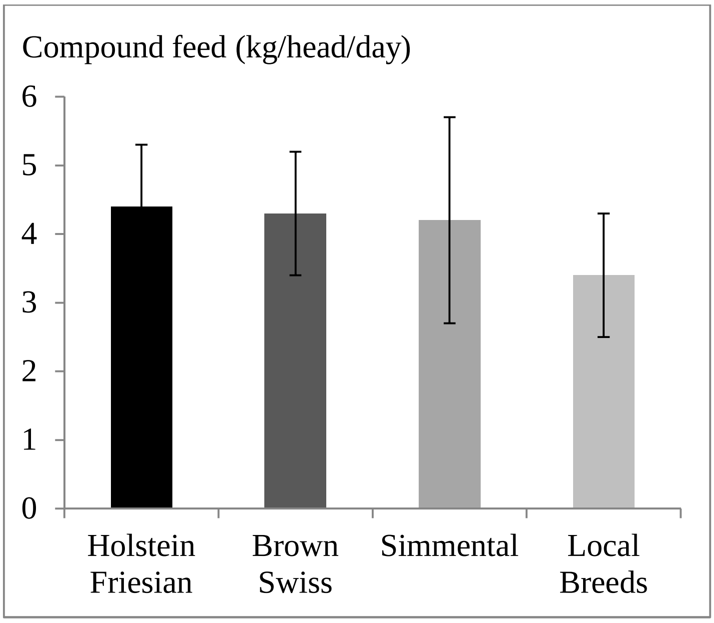


Figure 3: Milk yield, milk fat and protein content of cows of different breeds before during and after summer transhumance.

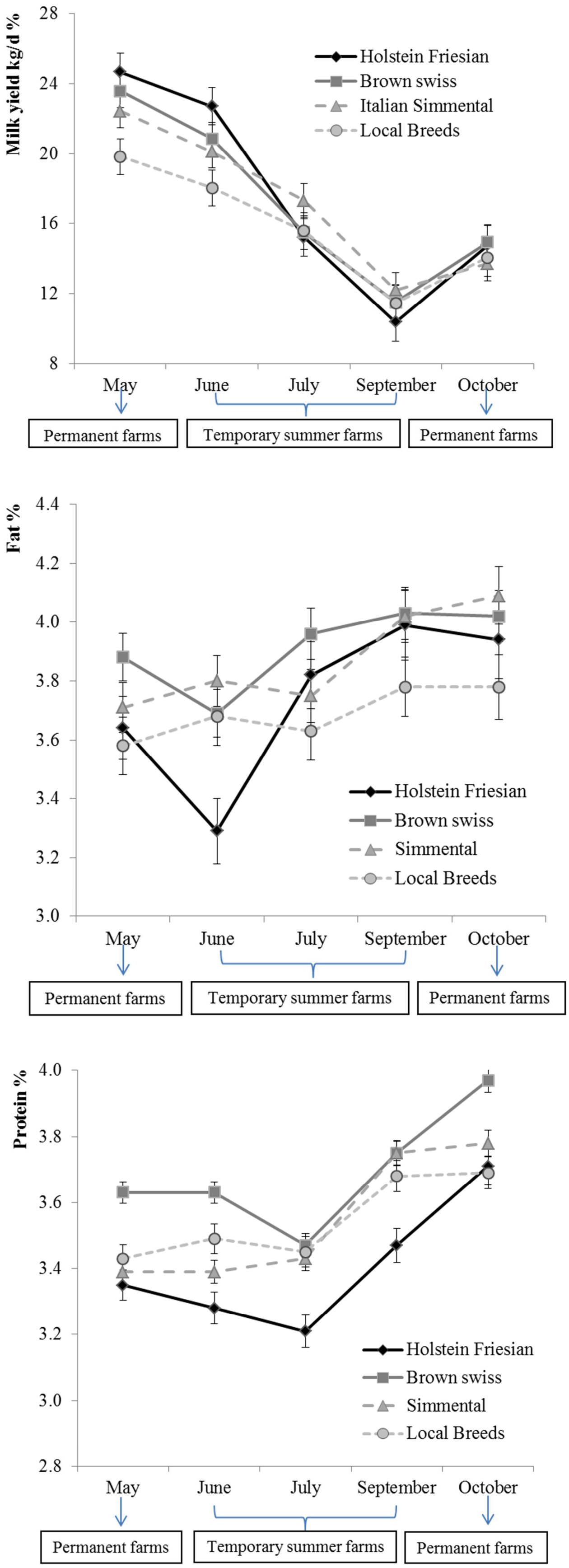


Figure 4: BCS of cows of different breed after the adaptation and at before the end of summer transhumance (interaction breed × month, P<0.05).

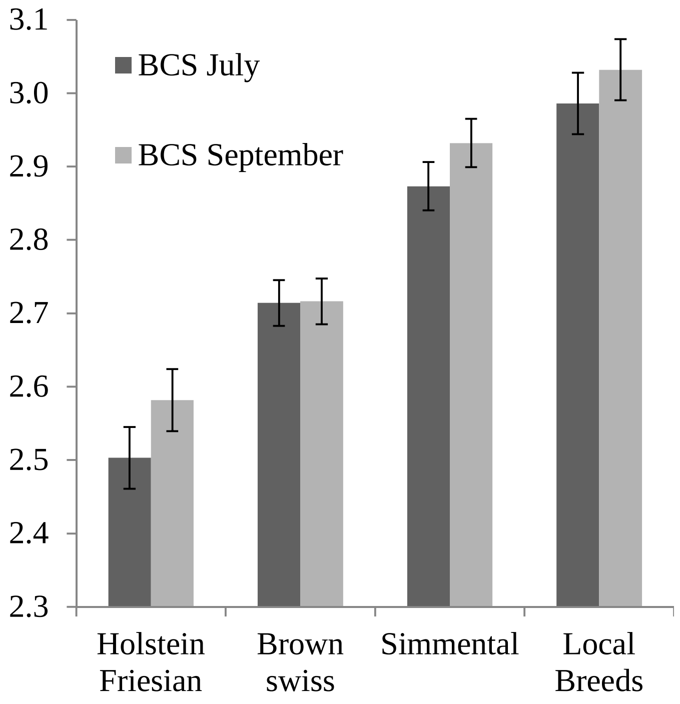


Figure 5: Protein content of milk of cows with different days in milk at the beginning of summer transhumance.

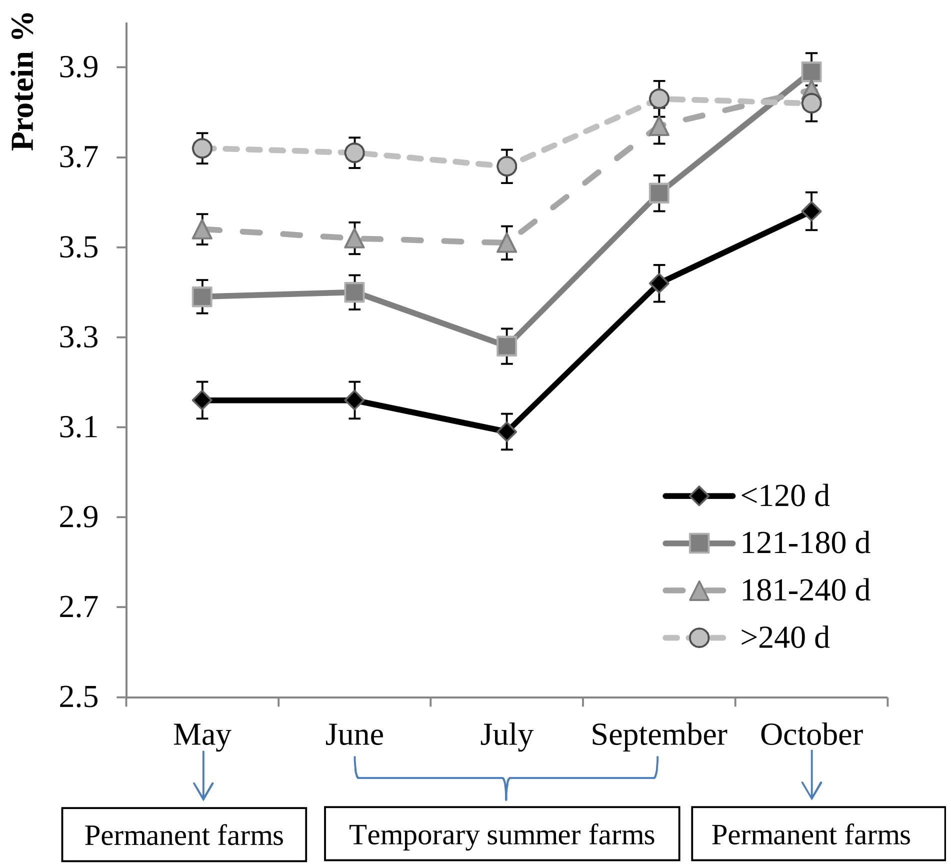


Figure 6: Somatic cell score of milk from cows of different breeds before, during and after summer transhumance.

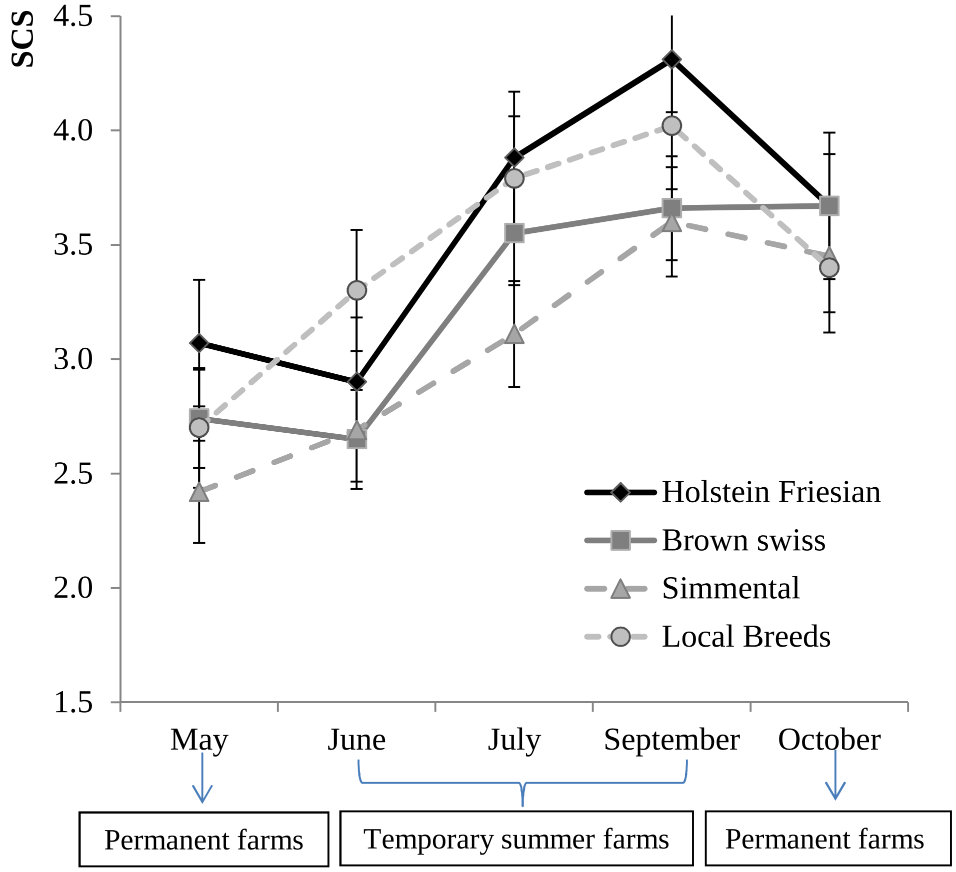


Figure 7: Rennet coagulation time predicted by CFt model of cows of different breeds going to temporary summer farms distributing a low (< 4.0 kg/d) or high (> 4.0 kg/d) compound Feed.

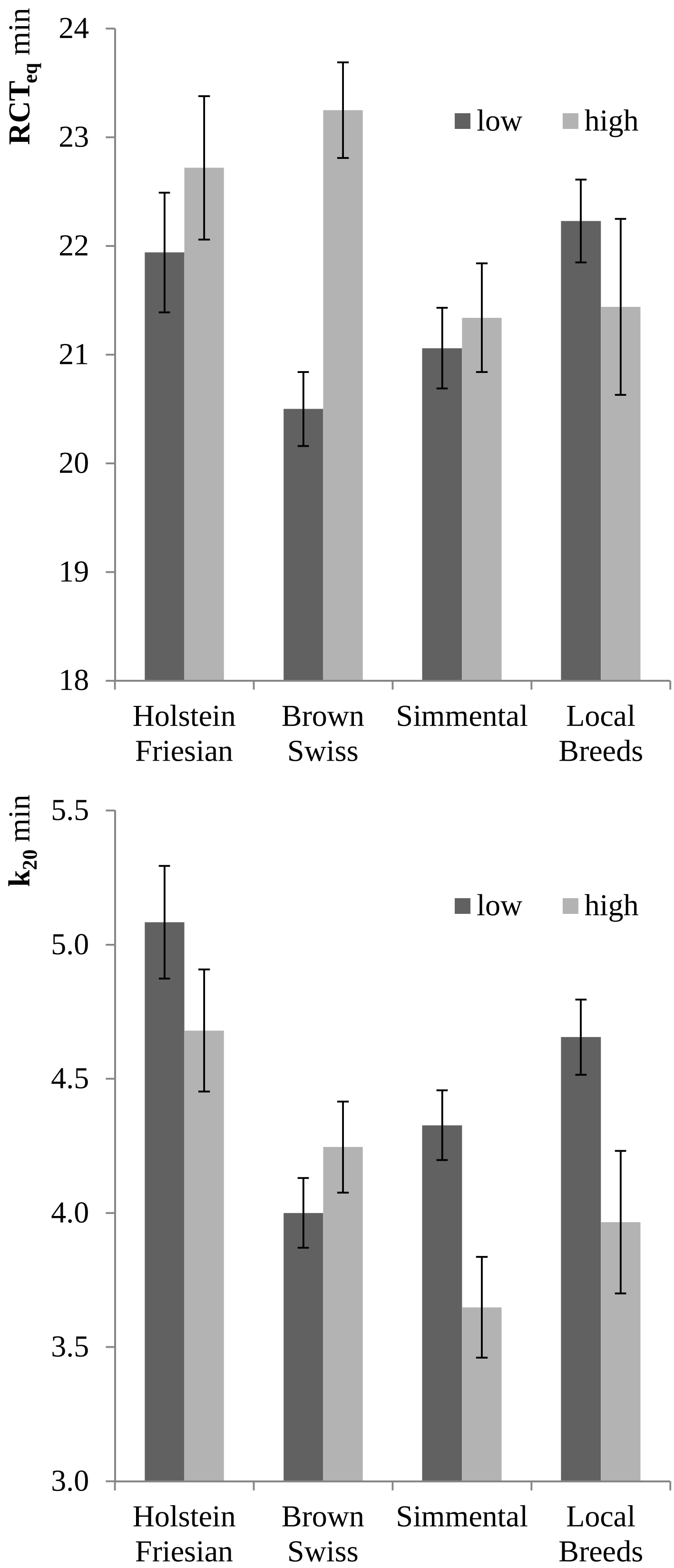
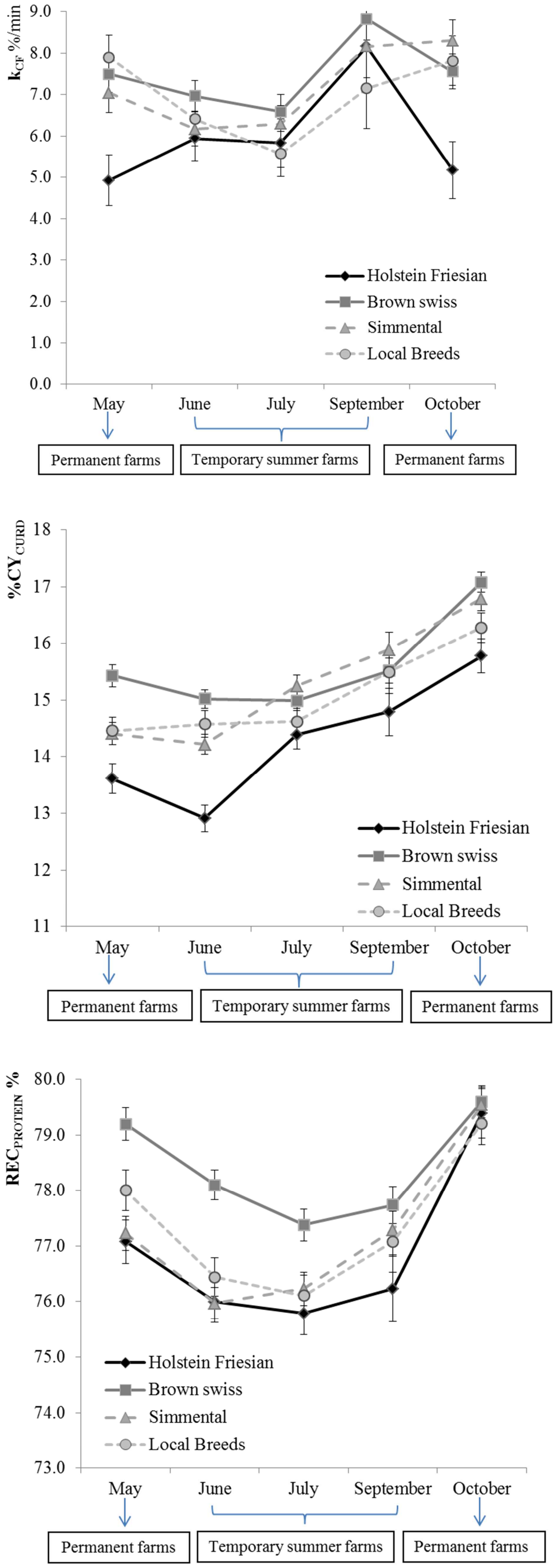


Figure 8. Curd firming rate constant (k_{CF}), fresh cheese yield ($\%CY_{CURD}$) and milk protein recovery in curd ($REC_{PROTEIN}$) of milk of cows of different breeds before, during and after summer transhumance.



Chapter 3

Environmental footprint of mixed breed dairy herds in mountainous areas: cradle-to-gate LCA approach

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Abstract

The objective of this study was to evaluate the environmental footprint of dairy cattle mountain farms. Life Cycle Assessment (LCA) approach was used to assess the environmental impact of 38 dairy cattle farms located in the Autonomous Province of Trento.

Data were collected from mixed breed dairy cattle farms that use different type of farming systems. Information regarding the general farm management, the diet, the production performance, the agronomic management of the surfaces, the management of waste, and the energy consumption was collected. Moreover, a specific questionnaire was developed and tested. The questionnaire might also be useful for further research in mountain region farming.

All data were used to calculate the carbon footprint of the herds using the Life Cycle Assessment (LCA) approach. The entire product life, *i.e.* from production of raw materials and their processing till farm gate (the functional unit was the kilogram of milk) was used. All the inputs and outputs relate to the functional unit were taken into account. Three categories of environmental impact of the farms were considered: i) carbon footprint (contribution to the production of greenhouse gases), ii) acidification and iii) eutrophication.

The values obtained for the three impact categories had large variability, with average (and standard deviation) equal to 1.46 (0.58) kg for CO_2 equivalent (eq), 27.18 (8.34) g for SO_2 eq. and 7.91 (2.31) g for PO_4^{3-} eq. per kg of milk (fat and protein corrected). These values are comparable with previous studies that have been also carried out in mountain areas. The overall impact was allocated between on-and off-farm components and was shared according to mass allocation between milk and meat. Analysis of variance showed that the considered effects of housing (free *vs* fixed) and feed administration (traditional *vs* TMR), even if it appeared to be statistically significant for some traits, slightly affected the high variability of the impact categories that can be observed among different dairy farms of the same group.

Thus, there are margins to mitigate the impact and increase the efficiency of farms with different structures and management.

Overall, the study has provided with some interesting insights on the sustainability assessment of dairy farming systems in mountainous areas, adopting innovative methodological approaches. Results obtained from the experimental approach could be expanded on a large pool of dairy farms to identify the indicators of reference for the evaluation of the sustainability and multifunctionality of mountain farms.

Introduction

According to the Food and Agriculture Organization (FAO) report “Tackling climate change through livestock” (Gerber *et al.*, 2013), livestock sector contributes considerably to Greenhouse gas (GHG) emissions (14.5% of the total anthropogenic emissions). However, the calculation of environmental impact of farms is a complicated issue. Thus, several methods have been proposed for the evaluation of farm environmental impacts (Von Wirén-Lehr, 2001; Van der Werf and Petit, 2002; Halberg *et al.*, 2005). These methods constitute a helpful tool for farmers (Goodlass *et al.*, 2003), researchers (De Koeijer *et al.*, 2002), and political decision makers (Schröder *et al.*, 2004), towards a more sustainable agricultural production systems (Hansen, 1996). Among these methods, Life Cycle Assessment (LCA) has taken a considerable place. LCA considers all the inputs and outputs associated with a specific product, process, or activity within a defined system boundary, and allows for improvement of the environmental performances, while considering multiple parameters of the process (Gerber *et al.*, 2010). In recent years, some European countries (*e.g.* France, Germany, Ireland, the Netherlands, Sweden, and UK) have used the LCA approach to assess environmental impacts of milk production (Yan *et al.*, 2011). Milk is one of the most important dairy products in Europe, and it is well known that dairy farms are responsible for releasing in the environment a considerable amount of both minerals (mainly nitrogen and phosphorus) and gases. Nitrogen (N) pollution from dairy farms affects water, by nitrate leaching, which, in turn, contributes to the phenomenon of eutrophication in the rivers. Moreover, N air pollution happens through the produced emissions of gaseous N compounds such as NH_3 and N_2O and NO_x (Tamminga, 1992).

Regarding the agriculture and livestock systems in the mountainous areas, the intensification of the livestock sector and land utilization, together with the progressive abandonment of traditional summer transhumance, can have negative effects on the environment. For instance, reduced highland grazing has been associated with soil degradation, reforestation and loss of biodiversity as well as with reduction in the quality and attractiveness of the mountainous landscape (Streifeneder *et al.*, 2007; Sturaro *et al.*, 2009). Moreover, the environmental sustainability of traditional alpine farming systems can be negatively affected by opening new nutrient cycles. As an example, the large amounts of concentrate feed needed to sustain high milk production and the extensive use of fertilizers and pesticides for growing maize in the valley floors are leading to a surplus of N and phosphorus (P) (Penati *et al.*, 2011), thus, increasing the risk of soil and water pollution. Especially in the Alps, the environmental effect, as a product of changes in agricultural systems, need to be closely monitored to avoid any risk of drastically altering the fragile ecosystem. Nevertheless, so far only few studies investigated the environmental impact of milk production in mountain areas. Some of those studies were focused on farm nutrient balances (Giustini *et al.*, 2007; Penati *et al.*, 2011) while very few estimated the carbon footprint (CF) of milk production (Penati *et al.*, 2011; Pirlo, 2012). In general, the milk production system produces multiple products (milk, meat, manure, etc.). Thus, the task of estimating the emissions solely created by milk production activities (milk and co-products) becomes complex and difficult to be assessed. For example, for the dairy farm system, where the main focus is on production of milk, the meat generated from surplus calves and cull dairy cows is an important co-product. It is, therefore, necessary to also consider the inclusion of beef and meat in the LCA approach, and to allocate the emissions between milk and meat (IDF, 2010).

The estimating and allocating emissions is further complicated by the fact that in the mountains many local and dual purpose bovine breeds are reared. In fact the majority of studies published deals with single breeds and especially with Holstein Friesian breed. The different muscularity and body condition of cows belonging to local and dual purpose breeds affects not only allocation of emissions between milk and meat, but also estimates of nutrient requirements and feed intake.

Thus, the objective of this study was to develop procedures taking into account multibreed operations and to assess the environmental footprint of 38 mixed breed dairy farms belonging to different farming systems located in Trento province (North-East Alps of Italy). The mass allocation at the farm gate was used for this purpose. This approach allows for a more fair comparison between farms with different management or feed administration. From the methodological point of view, the environmental footprint of the sampled farms has been calculated using the LCA approach with a specific focus on animal management and nutrition.

Material and methods

Study area and sampled farms

This study is part of a large project (Cowplus) aiming in the identification and incorporation of new phenotypes in dairy cattle farms and industry, giving special emphasis to the mountainous environment. The study area corresponds to the territory of Autonomous Province of Trento, located in the northeast Italian Alps. The utilized agricultural area (UAA) of Trento has an extension of 1,372 km^2 and is mainly composed by grassland and pastures (81%), followed by orchards and vineyards (17%), while the arable crops represent only 2% of the total agricultural area (ISTAT, 2010). Dairy cattle is the most important livestock system of the Province, with 1,071 out of 1,403 total cattle herds registered as dairy farms. The majority of the dairy farms are associated to cooperative dairies that focus in the production of typical of the region cheese or cheese labelled as Protected Designation of Origin (PDO), mainly "Trentingrana".

In total, 38 mixed breeds farms were included in the study. The variability in terms of herd size, management (feed administration, structures, equipment, …) and reared cattle breeds is representative of the local dairy sector. In fact, most of the active farms (around 70 %, Sturaro *et al.*, 2013) have mixed breed herds with different proportions of Holstein Friesian, Brown Swiss, Simmental, Rendena and Grigio Alpina cows. The size of the sampled farms ranged between 17 to 169 lactating cows. Half of them use total mixed ration for feed administration and the other half administrate mainly hay and compound feeds, while only a small proportion uses silages (silages are not allowed for Trentingrana PDO cheese production); one third of the barns are free stall and the remaining are keeping the cows tied.

Life Cycle Assessment

The environmental footprint of the sample farms was assessed by using a cradle to gate Life Cycle Assessment (LCA) approach. The methods description follow the scheme of the LCA: goal and scope definition, Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA), data interpretation.

Goal and scope definition

The general objective of this study was to assess the environmental footprint of dairy farms of the Trento Province.

Thus, for each dairy farm a cradle-to-farm-gate LCA, describing the life cycle of milk production from the beginning of the production stage till the farm gate, was applied. The transportation of the milk as well as milk processing were excluded from the study.

Functional unit

A functional unit (FU) is the unit associated with an emission produced. For *e.g.*, this could be an animal, a farm, a crop, a surface, etc. The FU used in this work were milk and meat at the farm gate.

The milk was corrected for its fat and protein content (FPCM) to a standard of 4.0% for fat and 3.3% for the protein. This is a general standard used for comparing milk with different fat and protein contents. It is a commonly used approach for evaluating and comparing milk production of different dairy breeds. All milk was converted to FPCM using the equation: FPCM (kg) = milk yield (kg) × (0.337 + 0.116 × Fat content (%) + 0.060 × Protein content (%)) from Gerber *et al.* (2010).

Allocation

For dairy farms, whose main focus is milk production, the meat generated from surplus calves and culled dairy cows, is an important co-product. Therefore, it is necessary to evaluate the total emissions and to correctly allocate them between milk and meat (IDF, 2010). In this study, the co-product has been considered and the mass allocation method was adopted. The Allocation Factor (AF) for milk and meat was calculated using the equation of ISO, 2006: $AF = 1 – 5.7717 \times R$, where AF is the allocation factor for milk, $R = M_{meat} / M_{milk}$, M_{meat} is the sum of live weight of all animals sold including bull calves and culled mature animals and M_{milk} is the sum of milk sold corrected for fat and protein as described above.

The mean live body weight is defined as the sum of the body weight of newborn calves sold (at an average age of 1 month) and the body weight of cows at the end of their production period. The mean body weight in our study was found 65 kg/head for calves and 627 kg/head for cows, respectively.

System boundary and delimitations

This work studied the dairy farms from cradle-to-farm-gate for a one-year period (2013), *i.e.* the studied system includes the physical farm and defines the dairy production system. It includes forages and cereal produced on-farm, herd management and associated upstream processes, emissions from the animals and stored manure. The management, storages and application of manure for meadows and cereals is included. In this study boundary was extended in order to include also the emissions related to the imported resources such as feed and fertilizer. These latter resources are referred to as off-farm. The transport of milk to dairy industry and that of the animals to slaughterhouse are not included. Veterinary medicines, detergents, disinfectants and plastic are not included. For the dairy farms moving animals to temporary summer farms, only the environmental impact due to permanent farms was considered.

Life Cycle Inventory - LCI

We visited at least two times the sampled farms. At farm level, a questionnaire was filled with the farmers to collect data on feeding strategies, management and building, land and crop management and the energy consumption (table 1). At individual level, body weight and Body Condition Score were evaluated by a unique panelist and the chest girth of cows was measured. Data on herd size composition, reproductive and productive performance were recorded by Breeder Federation of Trento Province during official milk recording and implemented in our database (table 2).

Animal nutrition: net energy and diets

The half of the sampled dairy farms used the total mixed ratio (TMR) and the other 50% is still using the traditional feeding administration. For the first group the estimated dry matter intake (DMI) is the ratio between the net energy requirements of the cow and the net energy of the diet. For estimating net energy (NE) requirements the procedure described in NRC (2001) was followed. Briefly, the total NE is partitioned in NE for maintenance, lactation, activity, pregnancy and for growth (tables 3 and 4). The net energy of the diet is the sum of the net energy available in each feed multiplied the quantity administered.

For the second group, *i.e.* with the traditional feeding, it was not possible to know intake of forages. So the net energy of forages was calculated as the difference between the total NE required by the average animal and the NE of the compound feed (table 5). This procedure was used for lactating cows, replacement and dry cows.

Nitrogen and phosphorus balance

The efficiency in nitrogen (N) and phosphorus (P) use affect the environmental impact in terms of eutrophication and acidification potential. The N and P balances were calculated, with the procedure suggested by ERM (2001) and by the requirement of NRC (2001) (tables 6). N excretion was calculated as difference between N intake with the diet and N retention for growth, pregnancy and milk. This procedure was used for lactating cows, replacement and dry cows.

Emission factor

For the total on-farm emissions estimation the following parameters were considered: i) cattle enteric fermentation, ii) manure management (storage and handling as well as field application), iii) emissions caused by the use of chemical fertilizers and iv) fuel combustion. The methods and the emission factors used are summarized in Tables 7 and 8.

According to the Kyoto Protocol, the livestock respiration is not considered a net source, due to equivalence of the absorbed and emitted quantities (Steinfeld *et al.*, 2006). Emissions from livestock respiration are part of a rapidly cycling biological system, where the biomass consumed is itself created through the conversion of atmospheric CO_2 into organic compounds.

Tables 7 and 8 shows the emission factors (EF) used for calculating the primary emissions of CH_4 and N_2O for each pollutant. In previous studies enteric methane emission has been estimated using equations from Kirchgessner *et al.* (1995), IPCC (2006) Moraes *et al.* (2013) and Tagliapieta (unpublished). For this study Ramin and Huhtanen (2013) equation was used to estimate enteric methane emission. This equation takes into account four parameters, namely feed intake, diet digestibility, the concentration of the fat and the carbohydrate composition. CH_4 emissions from stored manure were calculated based on the

IPCC guidelines, following the Tier 2 method (IPCC, 2006). The amount of manure handled within a system is based on the daily number of livestock unit housed in each system, on their average feed intake and on digestibility of the diet.

The direct and indirect N_2O emissions caused by ammonia (NH_3) and NO_3 were calculated from the nitrogen excreted. The emission factors used are those proposed by IPCC (2006) for solid manure and liquid slurry storage systems. Indirect emissions of N_2O from manure storages, which are mainly due to volatilization of NH_3 were estimated using the EF value according to IPCC (2006).

Apart from NH_3 and NO_3, emissions of N_2O also occur in the field after the application of fertilizer, either organic or inorganic. Thus, direct N_2O field emissions were estimated from the amounts of N included in mineral and organic fertilizers, crop residues and N mineralization (IPCC, 2006).

Following IPCC (2006), N emissions from manure storage were calculated by multiplying the amount of N excreted by the emission factors. To estimate the volatilization of N in the forms of NH_3 and NO_x, that occurs during the application of organic and mineral fertilizers, the default emission factors proposed by IPCC (2006) were used. Mineral fertilizers and manure are considered the two main N sources in agricultural land. It was assumed here that 30% of the N from fertilizer and manure ex storage is lost in the form of nitrate (NO_3) through leaching (IPCC, 2006). The method of Nemecek and Kägi (2007) was used to estimate the phosphorus loss (in the form of phosphate PO_4^{3-}). Briefly, this method estimates the amount of phosphorus excreted by the animals and applied to the field as well as the input from chemical fertilizers.

The amount of on-farm use of petrol, gas and electricity were taken into account to estimate the carbon dioxide (CO_2) emissions related to energy consumption.

Concerning the off-farm emissions, they include almost everything purchased by the farm, such as feed (*e.g.* hay, alfalfa and supplementation feed). The estimation of off-farm emissions also included the production of roughages and bedding material (straw and sawdust) purchased including transportation, the production of diesel, petrol, gas and electricity, the production of chemical fertilizers and herbicides but not the related transportation. Emission factors for off-farm feed, roughages and bedding material, chemical fertilizers, herbicides, and lubricant were derived by Ecoinvent 3.1 (Ecoinvent Centre, 2014) and Agri-footprint 1.0 database (Blonk Agri-footprint, 2014) provided with Simapro software. Fuel emission were taken into account using EF provided by European Environmental Agency (EEA) report (EEA, 2013), while for electricity production, Italian electricity web handling society and Italian Environmental Agency (ISPRA) data were used (ISPRA, 2011)

Life Cycle Impact Assessment (LCIA)

The environmental impact categories considered for the study were (see Table 11):

- Global warming potential (kg CO_2 eq. 100-year horizon): estimated for a 100-year time period by converting all GHG to CO_2 equivalents (CO_2-eq.), which on a weight basis gives 1 kg CH_4=25 and 1 kg N_2O-N=298 CO_2-eq (IPCC, 2006).
- Acidification (g SO_2 eq.): Sulphur dioxide (SO_2), ammonia (NH_3), nitrogen oxides (NO_x) acidifying pollutants were considered (Table 9).
- Eutrophication (g PO_4^{3-} eq.): nitrate (NO_3), ammonia (NH_3) and P were considered (Table 10).

Data interpretation and statistical analysis

The impact categories were compared with the results of other studies considering dairy farming systems, in particular with data obtained on mountainous study areas.

With the aim to investigate the variability of the impact categories due to farm management, the effects of diet administration (TMR *vs* traditional) and housing (tied *vs* free stalls) were tested with a general linear model (PROC GLM, SAS 2012) including the two fixed effects and their interaction. Type I *F* and *P* values were considered for the evaluation of the considered effects.

Results

The descriptive statistics of the 38 dairy farms sampled in Trento Province are shown in Table 12. Structure and management of the sampled farms showed a large variability and were representative of the situation of Trento province. The questionnaire used to collect data was corrected, updated and tailored for these dairy cattle systems, and the final version is reported in Appendix as first result of the research. The average number of lactating cows per farm was 42.0 ± 28.8, with a considerable variation (from 13.9 to 143). The age at first calving was 32.4 month on average and the days in milk 189.2 with a range between 114.6 and 238.6.

Concerning milk production, the mean milk yield was 23.0 kg per day and also in this case there was large variability (11.2 *vs* 39.5). Fat and protein percentages were 3.48 ± 0.16 and 3.84 ± 0.21, respectively.

The descriptive statistics of body weight and condition of cattle evidenced a large variability due to the differences among the proportions of different breeds reared and among management systems.

In table 13 the chemical composition and energy content of the feed used in cow and replacement diets are depicted. For forages, cereals and other raw materials the reference chemical composition values were taken from literature and previous studies conducted in the study area, whereas for compound feeds the values from commercial feed label are reported. Since forages are the main ingredients of diets for traditional farms, a low level of protein and a high level of fiber characterize the ration of these herds. For the farms using TMR on average a higher protein and energy level was achieved, as expected.

The descriptive statistics of diet characteristics, nitrogen and phosphorus balance and methane emissions of dairy cows are shown in Table 14. The estimated dry matter intake of cows was 16.3 ± 2.2 kg/d with 14.5 ± 1.7 % of crude protein content. Other characteristics of the diet are: NDF 26.6 ± 4.1 %; EE 3.27 ± 0.58 %; starch 15.35 ± 5.80.

The nitrogen and phosphorus balance were calculated: on average the intake was 138.4 ± 28.7 and 24.0 ± 6.6 kg/cow/year, respectively; most of the retained nitrogen and phosphorus is secreted in milk (45.8 ± 13.9 and 7.52 ± 2.15). The amounts of annual nitrogen and phosphorus excreted in feces and urine were 90.5 ± 17.3 and 16.08 ± 5.25 respectively. The table shows also the enteric methane emission predicted with different approaches. Different equations gave results correlated (coefficient r ranged from 0.36, Ramin and Huhtanen (2013) with Kirchgessner *et al.* (1995), to 0.96, Ramin and Huhtanen (2013) with IPCC, 2006), but the mean value showed large differences. We choose the equation of Ramin and Huhtanen (2013) because was the most complete and tailored for dairy cattle.

The descriptive statistics of diet characteristics, nitrogen and phosphorus balance and methane emissions for replacement are shown in Table 15. The replacements were fed with diets with a high fiber content and low energy and nutrient contents: average crude protein content was 12.6 ± 1.5% of DM; NDF 53.3 ± 7.0 %, ADF 34.1 ± 5.1% and starch 7.32 ± 8.09%.

For replacement cattle, we found an intake of nitrogen expressed as kg/head/y equal to 40.6 ± 5.2. A small part of this nitrogen was retained for pregnancy (0.43 ± 0.07 kg/head/y) and for growth (3.94 ± 0.61 kg/head/y), while the major part of nitrogen (36.3 ± 5.0 kg/head/y), as expected, was excreted (Table 15).

We also calculated the phosphorus balance of replacement. It is worth to note that the animals ingested 6.79 ± 1.30 kg/head/y of phosphorus. In this study we reported that 1.37 ± 0.22 kg/head/y was retained, while 5.42 ± 1.28 kg/head/y were excreted with the waste (Table 15).

The table 16 displays of the results of LCA of environmental footprint per kilogram of milk corrected for fat and protein. The CO_2 equivalent on average was 1.46 ± 0.58 with a large range of variability (0.83 to 3.42) and two-thirds of the total (0.99 ± 0.37) was due to on-farm emissions. Regarding the acidification on average 27.18 ± 8.34 g SO_2 equivalent were products from dairy farms and almost the 86% were on-farm (23.43 ± 7.46 g). The eutrophication in term of g PO_4^{3-}equivalent per kg FPCM was estimated and on average 7.91 ± 2.31 g were produced. Almost 70% of total eutrophication it is given by the on farm emissions.

The results of the statistical analysis of the main impact category between farms grouped according to stall system and feeding technic are summarized in Table 17. The differences between LSmeans were generally low and in few cases statistically significant. As expected, milk yield was affected both from stall ($P < 0.05$) and feeding strategies ($P < 0.01$), with higher milk production observed for herds with free animals (24.6 kg/d) and a diet based on the use of TMR (24.8 kg/d).

Stall system and feeding administration influenced largely also N excreted ($P < 0.01$) and CH_4 emissions ($P < 0.001$). Free stalls exhibited higher excretion of N and methane emissions in comparison to the tied stalls (96.4 *vs* 82.7 kg/cow/year and 126.5 *vs* 115.2 kg/cow/year, respectively); the same pattern was observed for farms based on the use of TMR in comparison to a traditional feeding system.

Conversely, P excreted, CO_2 eq., SO_2 eq. and PO_4^{3-} eq. per kg FPCM were not affected by the two effects considered in the model. Only the feeding strategy showed a negligible effect ($P < 0.05$) on the total PO_4^{3-} eq. per kg FPCM.

Finally, the interaction stall × feeding was not significant for all the analyzed traits.

The last step was the allocation of impact categories between milk and meat; the descriptive statistics are reported in table 18. As respect to the values without allocation, the relevance of the impact due to the milk production was 27.4% lower for CO_2 eq., 26.5% for SO_2 eq. and 26.4 PO_4^{3-} eq. The analysis of source of variation (Table 19) shows some differences with the one performed for no allocated data. Considering the allocation for milk, the differences between tied *vs* free stall and traditional *vs* TMR were generally less relevant for the impact categories, except for eutrophication and acidification in tied and free stall: with allocation, the impact was higher for free than tied stall, although not significant. The main source of variation for impacts due to meat production was the feeding systems, with lower value for TMR with respect to the traditional feeding.

Discussion and conclusion

In this study the environmental footprint of mountainous dairy farms was calculated adapting the traditional LCA approach to the analyzed productive system. Information on animal production, nutrition and management were obtained by using both on-farm survey and data from previous studies conducted in the same study area. This approach was finalized to improve the accuracy of the evaluation of the environmental impact due to “animal” and “diet” components with respect to IPCC or other methods. The results obtained showed a large variability between methods, especially for the evaluation of methane from enteric fermentation and for the calculation of nutrient flows (phosphorus and nitrogen). These data were used as basis for the successive steps of LCA analysis: this is an important improvement of the method, which is usually based on standard coefficients obtained by official databases or literature.

The quantification of the environmental impact of dairy farms in Trento Province can be compared with other studies, in particular with those analyzing livestock systems in mountainous areas, although with some differences by the methodological point of view. The comparison of our results with literature reviews on environmental footprint of FPCM evidenced higher values of carbon footprint with respect the intensive systems (De Vries and De Boer 2010, Kristensen *et al.*, 2011, Guerci *et al.*, 2013). The same trend was observed for acidification (Thomassen *et al.*, 2008; De Vries and De Boer 2010; Guerci *et al.*, 2013) whereas the eutrophication was similar to other studies (De Vries and De Boer 2010; Guerci *et al.*, 2013). As expected, dairy farms in mountainous areas are less productive and efficient than intensive dairy farms, and as logical consequence the ratio between global impact and milk yield penalize them. In the Alps, few studies calculated the environmental footprint produced by dairy farms (Penati *et al.*, 2013; Guerci *et al.*, 2014; Salvador *et al.*, 2014), and the values of impact categories are comparable with our results. The dairy sector of Trento

Province are characterized by a large variability of farming systems (Sturaro *et al.*, 2013), with production oriented farms and traditional low input farms. The variability of our results reflects this situation. For this reason, the effects of different management systems were tested. Stall systems and diet administration were considered to classify the sampled dairy farms. Only mild differences were found, showing that strategy aimed at mitigating the environmental impact of dairy farms in Trento Province do not depend mainly from livestock systems.

In perspective, some important issues can be addressed. First of all, the evaluation of environmental footprint should consider the partition between "organic" and "fossil" impact. For example, in mountainous dairy farms the basis of the diet is represented by forages; the main land use category is meadow and crops are limited. Livestock farms contribute to the maintenance of agro-ecosystems, and in mountain areas offers several positive externalities. For these reasons, environmental footprints of dairy farms should not be examined one-dimensionally based on the amount of milk and meat that is produced on the farm. Rather, a broader perspective is necessary that takes into account the multi-functionality of dairy farms especially in countries where a wide range of ecosystem services is provided (Ripoll Bosch *et al.*, 2013; Battaglini *et al.*, 2014; Kiefer *et al.*, 2015).

References

Andrew, S.M., H.F.Tyrrell, C.K.Reynolds, and R.A. Erdman. 1991. Net energy for lactation of calcium salts of long-chain fatty acids for cows fed silage-based diets. J. Dairy Sci. 74:2588– 2600.

Battaglini L., Bovolenta S., Gusmeroli F., Salvador S., Sturaro E. 2014. Environmental sustainability of Alpine livestock farms. It. J. Anim. Sci. 13, 431-443.

Bell, A.W., R. Slepetis, and R.A. Ehrhardt. 1995. Growth and accretion of energy and protein in the gravid uterus during late pregnancy in Holstein cows. J. Dairy Sci. 78:1954– 1961.

Blonk Agri-footprint BV 2014. Agri-Footprint - Part 1 - Methodology and basic principles - Version D1.0. Gouda, Netherlands.

De Koeijer, T.J., Wossink, G.A.A., Struik, P.C., Renkema, J.A., 2002. Measuring agricultural sustainability in terms of efficiency: the case of Dutch sugar beet growers. J. Environ. Manage. 66, 9–17.

De Vries M and de Boer IJM 2010. Comparing environmental impacts for livestock products: A review of life cycle assessments. Livestock Science 128, 1-11.

Ecoinvent Centre 2014. Ecoinvent data v3.1 - Final report Ecoinvent no 15. Swiss Centre for Life Cycle Inventories, Dübendorf, Switzerland. In: SimaPro PhD 8.0.4.26/Database/Professional/Ecoinvent.

EEA 2013. EMEP/EEA air pollutant emission inventory guidebook – Technical Report 12/2013, European Environmental Agency, Copenhagen (Copenhagen, Denmark).

ERM, 2001. ERM (Environmental Resources Management Institute) Livestock Manures - Nitrogen Equivalents European Commission DG Environment, Brussels, Belgium.

Gerber PJ, Steinfeld H, Henderson B, Mottet A, Opio C, Dijkman J, Falcucci A and Tempio G 2013. Tackling climate change through livestock – A global assessment of emissions and mitigation opportunities. Food and Agriculture Organization of United Nations (FAO). Rome, Italy.

Gerber, P., Vellinga, T., Opio, C., Henderson, B., Steinfeld, H., 2010. Greenhouse Gas Emissions from the Dairy Sector, A Life Cycle Assessment. FAO Food and Agriculture Organization of the United Nations, Animal Production and Health Division, Rome.

Giustini L., Acciaioli A., Argenti G., 2007. Apparent balance of nitrogen and phosphorus in dairy farms in Mugello (Italy). Ital. J. Anim. Sci. 6:175-185.

Goodlass, G., Halberg, N., Verschuur, G., 2003. Input output accounting systems in the European community—an appraisal of their usefulness in raising awareness of environmental problems. Eur. J. Agron. 20, 17– 24.

Guerci, M., Bava, L., Zucali, M., Sandrucci, A., Penati, C., Tamburini, A., 2013. Effect of farming strategies on environmental impact of intensive dairy farms in Italy. J. Dairy Res. 80:300-308.

Guerci, M., Bava, L., Zucali, M., Tamburini, A., & Sandrucci, A. 2014. Effect of summer grazing on carbon footprint of milk in Italian Alps: a sensitivity approach. Journal of Cleaner Production, 73: 236-244.

Guinée JB, Gorree M, Heijungs R, Huppes G, Kleijn R, de Koning A, Van Oers L, Wegener Sleeswijk A, Suh S, Udo de Haes HA, de Brujin H, Van Duin R and Huijbregts

MAJ 2002. Handbook on Life Cycle Assessment - an operational guide to the ISO standards. Kluwar Academic Publishers, Dordrecht, (Dordrecht, The Netherlands).

Halberg, N., Verschuur, G., Goodlass, G., 2005. Farm level environmental indicators; are they useful? An overview of green accounting systems for European farms. Agric. Ecosyst. Environ. 105, 195–212.

Hansen, J.W. 1996. Is sustainability a useful concept? Agricultural Systems, 50, 117-43.

Heijungs, R., J.B. Guinée, G. Huppes, R.M. Lankreijer, H.A. Udo de Haes, A. Wegener Sleeswijk, A.M.M. Ansems, P.G. Eggels, R. van Duin & H.P. de Goede, 1992: Environmental Life Cycle Assessment of products. Guide and Backgrounds. Centre of Environmental Science (CML), Leiden University, Leiden.

IDF, 2010. A Common Carbon Footprint for Dairy, the IDF Guide to Standard Life cycle Assessment Methodology for the Dairy Industry. International Dairy Federation.

IPCC, 2006. Intergovernmental Panel on Climate Change. Guidelines for National Greenhouse Gas Inventories. Vol. 4: Agriculture, Forestry and Other Land Use.

ISO, 2006. Environmental Management - Life Cycle Assessment - Requirements and Guidelines. ISO 14044. International Organization for Standardization, Geneva, Switzerland.

ISPRA 2011. Emissioni nazionali in atmosfera dal 1990 al 2009 – rapporto 104/2011, Istituto superiore per la protezione e la ricerca ambientale, Rome (Rome, Italy).

ISTAT, Istituto Nazionale di Statistica 2010. VI Censimento generale dell’Agricoltura. Roma.

Kiefer L.R., Menzel F., Bahrs E. 2015. Integration of ecosystem services into the carbon footprint of milk of South German dairy farms. J. of Environmental Management 152, pp 11e18

Kirchgessner M., Windisch W., Muller H.L. 1995. Nutritional factors for the quantification of methane production, in: Engelhardt W.V., Leonhard-Marek S., Breves G., Giesecke D. (Eds.), Ruminant physiology: Digestion, metabolism, growth and reproduction, Proceedings of the Eighth International Symposium on Ruminant Physiology, Ferdinand Enke Verlag, Stuttgart. pp. 333–348.

Kristensen, T., Mogensen, L., Trydeman Knudsen, M., Hermansen, J.E., 2011. Effect of production system and farming strategy on greenhouse gas emissions from commercial dairy farms in a life cycle approach. Livest. Sci. 140:136-148.

Moraes, L. E., D. Casper, A. B. Strathe, J. G. Fadel, and E. Kebreab. 2013. Predicting enteric methane emissions from dairy cattle using Bayesian methods. In: Proc. of the Greenhouse Gases and Animal Agriculture Conference, Dublin, Ireland.

Nemecek T, Kägi T 2007. Life cycle inventories for Swiss and European Agricultural production system – Final report Ecoinvent no 15. FAL Reckenholz, FAT Tanikon, Swiss Centre for Life Cycle Inventories, Dübendorf, (Dübendorf, Switzerland).

NRC, 2001. NRC (National Research Council) Nutrient Requirements of Dairy Cattle (7th rev. ed.) Natl. Acad. Press, Washington, DC, USA.

Penati C. A., Tamburini A., Bava L., Zucali M., Sandrucci A. 2013. Environmental impact of cow milk production in the central Italian Alps using Life Cycle Assessment. It. J. Anim. Sci. 12, 584-592.

Penati, C., Berentsen, P.B.M., Tamburini, A., Sandrucci, A., de Boer, I.J.M., 2011. Effect of abandoning highland grazing on nutrient balances and economic performance of Italian Alpine dairy farms. Livest. Sci. 139, 142e149.

Pirlo G. 2012. Cradle-to-farm gate analysis of milk carbon footprint: A descriptive review. Ital. J. Anim. Sci. 11, pp 109-118.

Pré Consultants, 2012. Simapro 7.3.3 PhD. Pré Consultants, Printerweg, Amersfoort, Netherlands.

Ramin, M., Huhtanen, P., 2013. Development of equations for predicting methane emissions from ruminants. J. Dairy Sci. 96:2476-2493.

Ripoll-Bosch R., de Boer I.J.M., Bernués A., Vellinga T.V. 2013. Accounting for multi-functionality of sheep farming in the carbon footprint of lamb: A comparison of three contrasting Mediterranean systems. Agricultural Systems 116. 60–68.

Salvador S., Corazzin M. Bovolenta S. 2014. Sostenibilità ambientale della zootecnia da latte in ambiente alpino. Il caso della val rendena. in Quaderni SoZooAlp n.8, Trento, Nuove Arti Grafiche, pp.61-68.

SAS 2012. SAS 9.3. SAS Institute Inc., Cary (New York, USA).

Sauvant, D., J.M. Perez and G. Tran, 2004. Tables of composition and nutritional value of feed materials: pigs, poultry, cattle, sheep, goats, rabbits, horses, fish. D. Sauvant, J.M. Perez & G. Tran (Eds). Wageningen Academic Publishers, Wageningen and INRA Editions, Versailles.

Schröder, J.J., Scholefield, D., Cabral, F., Hofman, 2004. The effects of nutrient losses from agriculture on ground and surface water quality: the position of science in developing indicators for regulation. Environ. Sci. Policy 7, 15–23.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., de Haan, C. 2006. Livestock's Long Shadow - Environmental Issues and Options. Food and Agriculture Organization of the United Nations, Rome, Italy.

Streifeneder, T., Tappeiner, U., Ruffini, F.V., Tappeiner, G., Hoffmann, C., 2007. Selected aspects of agro-structural change within the Alps. A comparison of harmonized agro-structural indicators on a municipal level. J. Alpine Res. 3, 41e52.

Sturaro, E., Cocca, G., Gallo, L., Mrad, M., Ramanzin, M., 2009. Livestock systems and farming styles in Eastern Italian Alps: an on-farm survey. Ital. J. Anim. Sci. 8, 541e554.

Sturaro, E., Marchiori, E., Cocca, G., Penasa, M., Ramanzin, M., Bittante G., 2013. Dairy systems in mountainous areas: farm animal biodiversity, milk production and destination, and land use. Livest. Sci. 158:157-168.

Tamminga S., 1992. Nutrition management of dairy cows as a contribution to pollution control. Journal of Dairy Science, 75 (1), 345-357.

Thomassen, M.A., Dalgaard, R., Heijungs, R., de Boer, I., 2008. Attributional and consequential LCA of milk production. Int. J. Life Cycle Ass. 13:339-349.

Van der Werf, H.M.G., Petit, J., 2002. Evaluation of the environmental impact of agriculture at the farm level: a comparison and analysis of 12 indicator-based methods. Agric. Ecosyst. Environ. 93, 131–145.

Von Wire´n-Lehr, S., 2001. Sustainability in agriculture—an evaluation of principal goal-oriented concepts to close the gap between theory and practice. Agric. Ecosyst. Environ. 84, 115–129.

Yan, M-J., Humphreys, J., Holden, N.M., 2011. An evaluation of life cycle assessment of European milk production. J. Environ. Manage. 92, 372–379.

Tables and figures

Table 1: Data collected on farm.

Animal	**Farms Products**	**Feeding**
Cows in production, n.;	Milk sold, kg/year; Milk protein and fat, %;	Feeding system;
Cow body weight (BW); Cow’s chest girth and BCS;	Culled cows sold/year;	Ingredient composition of rations;
Purchased replacing animals, n./year.	Calves, n. and type, sold/year.	Purchased feeds, kg/year; Purchased forages, kg/year.
Management and buildings	**Land and Crop Management**	**Energy consumption**
Manure management system;	Kind of crops and forages;	Electricity used, kWh/y;
Type of stalls;	Land used for crops/forages, ha;	Diesel used, kg/year;
Buildings type and surface.	Chemical fertilizers, kg/ha/year;	Petrol used, kg/year;
	Pesticides kg/year.	Methane and LPG used, m^3/year.

Table 2: Main traits regarding cows and replacements.

Parameter	Unit	Acronym	Computation	Time period	Reference / source of data
Cows per farm, n.:					
Lactating	n.	cow	average of monthly records	year	milk recording
Dry	n.	dc	average of individual data	year	milk recording
Milk production:					
Milk yield per cow	kg/d	MY	average of monthly records	year	milk recording
Milk fat	%	Fat	average of monthly records	year	milk payment syst.
Milk protein	%	Prot	average of monthly records	year	milk payment syst.
Fat Protein corrected milk	kg/h/d	FPCM	= MY×(0.337+ (0.116×Fat) + (0.06×Prot))	year	Gerber *et al.*, 2010
Body size of cows:					
Chest girth	cm	CowCG	average of individual data	once	skilled technician
Estimated body weight	kg	CowBW	average of individual data	once	skilled technician
Body condition score	scores	BCS	average of individual data	once	skilled technician
Life phases of cows:					
Age first calving	month	AFC	average of individual data	year	milk recording
Number of lactations	N	LacN	average of individual data	year	milk recording
Calving Interval	d	CI	average of individual data	year	milk recording
Dry Period	d	DP	average of individual data	year	milk recording
Days in milk	d	DIM	average of individual data	year	milk recording
Lactation to calving	%	Time	= 100 ×(CI – DP) / CI	year	milk recording
Replacement:					
Replacement rate	%	RR	= 1/LacN × 365 / CI	year	milk recording
Replacement heifers	n.	rep	= cow × RR × AFC / 12	year	milk recording

Table 3a: Computation of net energy (NE) requirement for maintenance, lactation, activity and pregnancy of dairy cows.

Parameter	**Unit**	**Acronym**	**Computation**	**Reference/ source of data**
Maintenance requirements:				
Metabolic weight	kg	CowMW	$= CowBW^{0.75}$	-
NE for maintenance	MJ/d	NEm	= (0.073 × CowMW) × 4.184	NRC, 2001
Lactation requirements:				
NE content of milk	MJ/kg	MilkEn	=(0.0929×fat + 0.0547×protein + 0.192)×4.184	NRC, 2001(eq 2-16)
NE for lactation	MJ/d	NE_L	= MilkEn × MY	-
Activity requirements:				
Farms with tied cows	MJ/d	NEa	= 0	-
Farms with loose cows	MJ/d	NEa	= NEm × 0.10	NRC, 2001
Pregnancy requirements:				
Weight of calf at birth	kg	CalfWB	= CowBW × 0.06275	NRC, 2001 pg 321
Gestation age	d	GAge	= from conception	-
Fetus daily energy growth	Mcal/d	dFetusEn	= 0.00318 × (GAge-190) – 0.0352	Bell *et al.*, 1995
Fetus energy retention	Mcal	FetusEn	= (0.00318 × (235-190) – 0.352) × 90	NRC, 2001[a]
NE_L for pregnancy	MJ/calf	$FetusNE_L$	= FetusEn /0.218 × 4.184	NRC, 2001[a]
NE_L for pregnancy, adjusted	MJ/calf	$AdjFetusNE_L$	= $FetusNE_L$ × (CalfBW/45)	NRC, 2001[a]
Daily $AdjFetusNE_L$ req.	MJ/d	NEp	= $AdjFetusNE_L$ / CI	-

[a] Modified

Table 3b: Computation of body composition, NE requirement for growth and total NE requirement of dairy cows.

Parameter	**Unit**	**Acronym**	**Computation**	**Reference/ source of data**
Body composition of cows:				
Empty BW of cows		CowEBW	= CowBW × 0.85	NRC, 2001
Fat on empty BW	ratio	$Fat/CowEBW_9$	$= 0.037683 \times BCS_{9scores}$	NRC, 2001 (eq. 2-20)
Protein on empty BW	ratio	$Prot/CowEBW_9$	$= 0.200886 - 0.0066762 \times BCS_{9scores}$	NRC, 2001 (eq. 2-21)
Scale BCS 5 to 9 scores	score	$BCS_{9scores}$	$= ((BCS_{5scores} - 1) \times 2) + 1$	NRC, 2001 (eq.2-22)
Scale BCS 9 to 5 scores	score	$BCS_{5scores}$	$= ((BCS_{9scores} - 1)/2) + 1$	-
Fat on empty BW	ratio	$Fat/CowEBW_5$	$= 0.07537 \times BCS_{5scores} - 0.0377$	-
Protein on empty BW	ratio	$Prot/CowEBW_5$	$= -0.01335 \times BCS_{5scores} + 0.2076$	-
Water/ash on empty BW	ratio	$WA/CowBW_5$	$= -0.06191 \times BCS_{5scores} + 0.8301$	-
Body fat proportion	ratio	$Fat/CowBW_5$	$= 0.06397 \times BCS_{5scores} - 0.0320$	-
Body protein proportion	ratio	$Prot/CowBW_5$	$= -0.01134 \times BCS_{5scores} + 0.1764$	-
water/ash on empty BW	ratio	$WA/CowEBW_5$	$= -0.05262 \times BCS_{5scores} + 0.7056$	-
Growth requirements:				
Energy content of fat	MJ/kg fat	FatHeat	38.49	Andrew *et al.*, 1991[a]
Energy content of protein	MJ/kg prot	ProtHeat	23.22	Andrew *et al.*, 1991[a]
Body energy as fat	MJ/kg BW	EnCowBWfat	$= 2.516 \times BCS_{5scores} - 1.258$	-
Body energy as protein	MJ/kg BW	EnCowBWprot	$= - 0.264 \times BCS_{5scores} + 4.097$	-
Total body energy content	MJ/kg BW	EnCowBW	$= 2.252 \times BCS_{5scores} + 2.839$	-
BW at first calving	kg	$CowBW1^{st}$	= CowBW × 0.82	NRC, 2001 (eq. 11-9)
Body energy at first calving	MJ	$CowEn1^{st}$	= EnCowBW × CowBW1st	-
Body energy of mature cow	MJ	CowEnM	= EnCowBW × CowBW	-
Daily body energy retention	MJ/d	EnRet	= (CowEnM - CowEn1st) / (LacN × CI)	-
NE_L for growth	MJ/d	NEg	= EnRet × 0.64 / 0.75	NRC, 2001[a]
Total NE_L requirements	MJ/d	$NE_L tot$	$= NEm + NE_L + NEa + NEp + NEg$	-

[a] Modified

Table 4: Computation of net energy (NE) requirement for the replacement cattle.

Net energy	**Unit**	**Acronym**	**Computation**	**Reference / source of data**
Maintenance and activity requirements:				
BW of replacement	kg	Repl.BW	= (CowBW1st + 1stCalfWB) / 2	
Metabolic weight	kg	Repl.MW	= Repl.BW$^{0.75}$	
NE for maintenance and activity	MJ/d	$NEm_{rep.}$	= Repl.MW × 0.96 × 0.086 × 4.184	NRC, 2001
Pregnancy requirements:				
Weight of 1st calf at birth	kg	1stCalf WB	= CowBW1st × 0.06275	
Gestation age	d	GAge	= from conception	
Fetus daily energy growth	Mcal/d	dFetusEn	= 0.00318 × (GAge-190) – 0.0352; if the result is >0, otherwise = 0	Bell *et al.*, 1995
Fetus energy retention	Mcal	FetusEn	= (0.00318 × (235-190) – 0.352) × 90; if the result is >0, otherwise = 0	NRC, 2001[a]
NE_L for pregnancy	MJ/calf	$FetusNE_L$	= FetusEn /0.218 × 4.184	NRC, 2001[a]
NE_L for pregnancy, adjusted	MJ/calf	$AdjFetusNE_L$	= $FetusNE_L$ × (1stCalfBW/45)	NRC, 2001[a]
Daily $AdjFetusNE_L$ req.	MJ/d	1st NEp	= $AdjFetusNE_L$ /(AFC × 30)	NRC, 2001
Growth requirements:				
Equivalent empty body weight	kg	EQEBW	= (Repl.BW × 0.96 × (478/(CowBW × 0.96)) × 0.891	NRC, 2001
Average daily-BW gain	kg/d	$ADG_{rep.}$	= (CowBW1st - 1stCalfBW)/(AFC × 30)	
NE_L for growth	MJ/d	$NEg_{rep.}$	= 0.0635 × EQEBW$^{0.73}$ × ($ADG_{rep.}$ × 0.956)$^{1.007}$ × 4.184	NRC, 2001
Total NE_L requirements:	MJ/d	NE_Ltot_{rep}	= $NEm_{rep.}$ + 1stNep + $NEg_{rep.}$	NRC, 2001

Table 5: Estimation of feed intake according to the feeding system.

Parameter	Acronym	Unit	Computation	Reference / source of data
Farm with Total Mixed Ration for cows and for replacement				
NE of feed ingredients	$FeedNE_L$	MJ/kg	= NE_L content of feed ingredients[1]	Sauvant *et al.*, 2004; Pecile (unpublished)[2]
NE of diet	$NE_L diet$	MJ/d	= $\Sigma(feed \times NE_L feed)$	
Dry Matter Intake	DMI	kg/d	= $NE_L tot / NE_L diet$	
Farm without Total Mixed Ration for cows and for replacement				
Daily intake of compound feeds	CFI	kg/d	= Σ(daily intake of compound feeds)	
NE of compound feeds	$CFeedNE_L$	MJ/kg	equations based on chemical composition[1]	Sauvant *et al.*, 2004
Forages NE value	$ForNE_L$	MJ/kg	equations based on chemical composition[1]	Sauvant *et al.*, 2004
Daily NE from compound feed	$NE_L CFeed$	MJ/d	= $\Sigma(CFI \times CFeedNE_L)$	
Daily NE from forages	$NE_L For$	MJ/d	= $NE_L tot – NE_L CFeed$	
Dry Matter Intake	DMI	kg/d	= $NE_L For / ForNE_L + CFI$	

[1] Chemical composition of each compound feed was that declared in the feed label.

[2] Chemical composition of hays was achieved from a data base with analysis of more than 1800 of samples collected in the Province of Trento (Pecile, unpublished)

Table 6: Nitrogen balance for a cow kept on farm, excluding periods in highland pastures, and expressed on annual basis[1],[2].

Parameter	Acronym	Unit	Computation	Reference / source of data
N balance of cows				
Crude Protein of compound feeds	CP_feed	kg/kg	= CP content of compound feeds	Farm data; Sauvant *et al.*, 2004
Crude Protein of diet	CP_diet	kg/kg	= Σ(Feed × CP_feed)	
N intake	N_int	kg/year	= DMI × CP_diet /6.25 × 365	
N secreted or retained	N_ret	kg/year	= N_milk + N_preg + N_growth	
N secreted in milk	N_milk	kg/year	= MY × prot / 6.38 × 365	
N retained for pregnancy	N_preg	kg/year	= (BW_calf × PBWc /6.25)/CI × 365	
Body protein content of calf	PBWc	kg	= BW_calf × 0.22	-
Body protein content of reformed cow	PBW	kg	= (-0.01134 × $BCS_{5scores}$ + 0.1764) × CowBW	
Body protein content of cow at 1st calving	$PBW1^{st}$	kg	= (-0.01134 × 3 + 0.1764) ×$CowBW1^{st}$	
Body protein change	Δ protein	kg	= PBW – $PBW1^{st}$	
Daily retention of body protein	N_growth	kg/year	= (Δ protein / 6.25)/(LacN × CI) × 365	
N excreted	N_exc	kg/year	= N_int – N_ret	
Nitrogen balance of replacement				
Nitrogen intake	N_int_r	kg/year	See cows procedure	
N retained	N_ret_r	kg/year	= N_preg_r + N_grow_r	
N retained for pregnancy	N_preg_r	kg/year	= ($BW1^{st}$×0.062)×(0.22/6.25)/(AFC×30) ×365	
N for grow	N_grow_r	kg/year	= ($PBW1^{st}$ – PBWc)/6.25) /(AFC×30)×365	
N excreted	N_exc_r	kg/year	= N_int_r - N_ret_r	

[1] DMI = dry matter intake; MY= milk yield; Prot= milk crude protein; LacN= Lactations number; CI= calving interval; CowBW= cow body weight at maturity; $cowBW1^{st}$= CowBW at first calving; AFC= age at first calving. See previous tables for their computations.

[2] The procedure followed for P balance was similar to that described in this table: P intake was computed from DMI and the P contents of each feed ingredients or compounds feeds, P secretion in milk was computed assuming a 0.9% as P content of milk, P for growth was computed assuming 5.9 g/kg body gain, P retained for pregnancy was assumed to be 5.9 g/kg BW of the newborn calf, P excretion was computed as P intake minus P secreted in milk or retained in body tissues.

Table 7: Computations to determine methane emission from enteric and manure management.

Pollutant	Equation	Reference
Enteric fermentation		
CH_4 (g/h/d)	$= -64 + 26 \times DMI - 0.61 \times (DMI - 12.5)^2 + 0.25 \times OMD \times 10 - 66.4 \times EE / 100 \times DMI - 45 \times (NFC / (NDF + NFC))$ DMI = dry matter intake, kg/head/day; OMD = organic matter digestibility of diet, %; EE = fat of diet, %; NFC = non fiber carbohydrate, %; NDF = neutral detergent fiber.	Ramin and Huhtanen, 2013
Manure management		
CH_4 (kg/year)	$= (VS) \times (Bo_{(T)} \times 0.67\ (kg / m^3) \times \sum (MCF_{S,k} / 100) \times MS_{(S,k)}$	IPCC (2006)
	$VS = (GE_{DIET} \times (1 - DE / 100) + (UE \times GE)) \times ((1 - ASH) / GE_{DM})$	Tier 1-2
	GE_{DIET}: Gross Energy, MJ/day; DE: diet digestibility, %; UE: urinary energy fraction; ASH: ash content of manure; ASH = 0.08; GE_{DM}: Gross Energy per kg of DM, MJ/kg DM; $Bo_{(T)}$ = 0.24 m^3 CH4 / kg of VS excreted; maximum methane producing capacity for manure produced by livestock category T; $MCF_{S,k}$: methane conversion factor for manure management system; MCF_{manure} = 0.02, MCF_{slurry} = from 0.069 to 0.142 (factor in function of the temperature and altitude); $MS_{(S,k)}$: fraction of livestock category handled using manure management S.	

Table 8: Computation of N_2O emission from farm and crop production.

Pollutant	Equation	Reference
Manure management		
N_2O direct (kg/year)	$= (Head \times Nex \times MS_{(T,S)}) \times EF_S) \times 44 / 28$ Head: number of animal per each category; Nex: N excreted, kg/head/year; $MS_{(T,S)}$: fraction of total annual nitrogen excretion for each livestock category T that is managed in manure management system S; EFs : emission factor for manure management system; EF slurry = 0.005; EF solid manure = 0.005.	IPCC, 2006 Tier2
$N_{volatilization\_MMS}$, kg/year	$= ((Head \times Nex \times MS_{(T,S)}) \times (Frac_{GasMS} / 100))_{(T,S)}$	IPCC, 2006
	Head: number of animal per each category; Nex: N excreted, kg/head/year; $Frac_{GasMS}$ slurry: 0.40; $MS_{(T,S)}$: fraction of total annual nitrogen excretion for each livestock category T that is managed in manure management system S; $Frac_{GasMS}$ manure: 0.30.	Tier2
$N_2O_{(G)}$ indirect due to volatilization, kg/year	$= N_{volatilization\_MMS} \times EF \times 44 / 28$	IPCC, 2006
	EF = 0.01 kg N-N_2O / (kg N-NH_3 vol + kg N-NO_x vol)	Tier2
N_{MMS_Avb} (N available for soils)	$= (head \times Nex \times MS_{(T,S)})\times(1- Frac_{LossMS} / 100) + (head \times MS_{(T,S)}\ N_{beddingMS})$	IPCC, 2006
	Head: number of animal per each category; Nex: N excreted, kg/head/year; $MS_{(T,S)}$: fraction of total annual nitrogen excretion for each livestock category T that is managed in manure management system S; $Frac_{LossMS}$ = 0.40; $N_{beddingMS}$ = 7 kg N/head/year.	Tier2
Crop production		
N_2O direct (kg/year)	$= (F_{SN} + F_{ON} + F_{CR}) \times EF \times 44 / 28$ F_{SN} = annual amount of synthetic fertiliser N applied to soils, kg N/year; F_{ON} = annual amount of animal manure, kg N/year; F_{CR} = annual amount of N in crop residues, kg N/year; EF = 0.01 kg N-N_2O / kg N applied.	IPCC, 2006 Tier2
$N_2O_{(ATD)}$ indirect (kg/year) from atmospheric deposit.	$= (F_{SN} \times Frac_{GASF} + F_{ON} \times Frac_{GASM}) \times EF_4 \times 44 / 28$	IPCC, 2006
	$Frac_{GASF}$ = 0.1; $Frac_{GASM}$ = 0.2; EF_4 = 0.01 kg N– N_2O / (kg NH_3–N + NO_x–N volatilised); emission factor for N_2O emissions from atmospheric deposition of N on soils and water surfaces.	Tier2
$N_2O_{(L)}$ indirect (kg/year) from leaching and runoff of N	$= ((F_{SN} + F_{ON} + F_{CR}) \times Frac_{LEACH-(H)} \times EF_5) \times 44 / 28$	IPCC, 2006
	F_{SN} = annual amount of synthetic fertiliser N applied to soils, kg N/year; F_{ON} = annual amount of animal manure, kg N/year; F_{CR} = annual amount of N in crop residues, kg N/year; $Frac_{LEACH-(H)}$ = 0.30; EF_5 = 0.0075 kg N_2O –N / (kg N leaching/runoff).	Tier2
N_2O total annual	$= N_2O$ direct $+ N_2O_{(ATD)} + N_2O_{(L)}$	

Table 9: Computation of substances causing acidification.

Pollutant	Equation	Reference
NH_3 farm (kg/year)	$= (N_{volatilization\_MMS} - N_2O_{(G)} \times 28/44) \times 17/14$	IPCC, 2006
SO_2-eq from NH_3 farm (kg/year)	$= NH_3$ farm × 1.88	
NH_3 field (kg/year)	$= (F_{SN} \times 0.1 + F_{ON} \times 0.2) \times 17/14$	
SO_2-eq from NH_3 field (kg/year)	$= NH_3$ field × 1.88	
SO_2-eq straw (kg/year)	= kg straw × 0.010289	
SO_2-eq fuel (kg/year)	$= 0.000016 \times kg_{fuel} + 0.000013 \times kg_{fuel} \times 1.88 + 0.03337 \times kg_{fuel} \times 0.7$ Emission per kg of fuel: - SO_2 0.000016 - NH_3 0.000013 - NO_x 0.03337 Emission factor: - $SO_2 = 1\ SO_2$ - $NH_3 = 1.88\ SO_2$ - $NO_x = 0.7\ SO_2$	Guineè *et al.*, 2002
Acidification (kg SO_2-eq/year)	$= SO_2$ farm + SO_2 field + SO_2 straw + SO_2 fuel	

Table 10: Computation of substances causing eutrophication.

Pollutant	Equation	Reference
PO_4 leaching from NO_3	$= (F_{SN} + F_{ON}) \times 0.3 \times EP_{NO3}$	
	$EP_{NO3} = 0.42$; eutrophication potential from NO_3	Guineè *et al.*, 2002
P (kg) leaching	P leach cropping = 0.07 kg/ha/y P leach grassland = 0.06 kg/ha/y	Nemecek and Kagi, 2007
P (kg) run-off	= P run-off lost × [1 + 0.2/80 × mineral P_2O_5 (kg) + 0.4/80 × manure P_2O_5 (kg) + 0.7/80] Cropping P run-off lost = 0.175 kg P/(ha×year); Grassland P run-off lost = 0.150 kg P/(ha×year)	Nemecek and Kagi, 2007
P (kg/year) from NH_3 volatized	$= (NH_3$ farm + NH_3 field$) \times EP_{NH3}$	
	$EP_{NH3} = 0.35$; eutrophication potential from NH_3	Guineè *et al.*, 2002
Eutrophication (kg PO_4-eq/year)	$= PO_4$ leaching NO_3 + PO_4 leaching + PO_4 run-off + PO_4 from NO_3	

Table 11: impact categories with related units, contributing elements and characterization factors.

Impact category	**Unit**	**Contributing elements**	**Characterization factors**	**References**
Climate change	kg CO_2-equivalents	CO_2	1	IPCC, 2006
		CH_4	25	
		N_2O	298	
Acidification	kg SO_2-equivalents	SO_2	1	Heijungs *et al.*,1992
		NH_3	1.88	
		NO_x	0.7	
Eutrophication	kg PO_4^{3-}-equivalents	PO_4^{3-}	1	Guinèe *et al.*, 2002
		P	3.06	
		P_20_5	1.34	
		N	0.42	
		NH_3	0.35	

Table 12: Descriptive statistics of the main traits of the 38 controlled farms.

	Mean	DS	Min	Max
Cows and replacements:				
Total cows, n	49.4	33.0	17.0	165.2
Lactating cows, n	42.0	28.8	13.9	143.0
Dry cows, n	7.4	4.6	2.1	22.2
Culled cow per year, n	17.8	13.0	5.4	68.9
Replacement calves and heifers, n	28.4	19.4	6.2	88.9
Replacement rate per year, %	0.34	0.06	0.22	0.49
Age and time intervals:				
Age at first calving, mo	32.4	4.4	26.1	48.6
Age of all cows, mo	55.2	7.3	43.4	72.1
Calving interval, d	424.8	41.7	369.5	542.7
Days open, d	146.7	51.8	81.9	378.8
Average days in milk, d	183.4	22.9	144.6	238.6
Dry period, d	69.8	12.5	49.6	111.4
Milk production:				
Lactation number, n	2.6	0.4	1.7	3.4
Milk yield per cow, kg/d	23.0	6.5	11.2	39.5
Milk yield per farm, t/year	375.0	315.3	49.6	1,284.0
Protein, %	3.48	0.16	3.08	3.88
Fat, %	3.84	0.21	3.39	4.37
Body weight and condition of cattle:				
Body weight of replacement, kg	274.7	15.4	244.8	299.3
Body weight at first calving, kg	514.4	30.7	454.7	563.5
Body weight of all cows, kg	627.3	37.4	554.5	687.2
BCS of all cows, score	2.92	0.12	2.57	3.19
Average daily gain of replacement, kg/d	0.502	0.078	0.311	0.636
Average daily gain of cows, kg/d	0.106	0.021	0.064	0.155

Table 13: Chemical composition and energy content of the feed most frequently used in cows and replacement feeding.

Feed	DM %	CP %	Phosphorus %	NDF %	ADF %	EE %	Starch %	CPdig %CP	NE_L MJ/kg
Grass hay	88	11.0	0.27	61.0	40.0	2.6	0.0	65.0	4.54
Alfalfa hay	88	18.0	0.30	47.0	35.0	2.6	0.0	62.0	5.08
Straw	88	5.0	0.08	85.0	54.0	1.8	0.0	10.0	3.16
Grass silage	33	13.0	0.31	55.0	35.0	2.8	0.0	73.0	5.61
Corn silage	35	8.5	0.25	50.0	30.0	3.1	28.0	75.0	6.47
Sugar beet pulps	88	10.0	0.11	40.0	20.0	0.6	0.0	71.0	7.34
Corn meal	88	10.0	0.26	11.8	2.9	4.2	72.8	66.0	9.43
Barley	88	12.0	0.37	19.9	6.9	2.1	59.3	66.0	8.08
Cereal mix	88	12.0	0.40	14.0	3.8	1.9	68.7	66.0	8.76
Soybean meal	88	49.0	0.70	14.0	8.4	1.9	0.0	80.0	8.79
Fat	88	0.0	0.00	0.0	0.0	100.0	0.0	0.0	26.11
Compound feeds:									
- Mean	87	21.8	0.70	18.7	8.8	5.2	37.3	n.d.	8.60
- Min	86	6.1	0.10	7.1	1.9	1.0	3.8	n.d.	5.22
- Max	90	48.3	2.29	52.9	23.1	37.9	74.2	n.d.	13.19

Table 14: Average diet characteristics, nitrogen and phosphorus balance and methane emissions of dairy cows.

	Mean	DS	Min	Max
Diet				
Dry matter intake, kg/head/d	16.3	2.2	12.1	19.8
Crude protein, % DM	14.5	1.7	11.2	17.4
Phosphorus, % DM	0.40	0.08	0.29	0.64
NDF, % DM	42.0	5.8	31.5	55.5
ADF, % DM	26.6	4.1	19.6	36.0
EE, % DM	3.27	0.58	2.52	5.16
Starch, % DM	15.35	5.80	3.31	29.47
Non fiber carbohydrate, % DM	32.3	5.4	20.9	44.2
Organic matter digestibility, % DM	70.1	6.2	56.7	86.4
Gross Energy, MJ/kg	18.1	0.9	16.7	20.2
Net Energy, MJ/kg	6.14	0.67	4.67	7.74
Nitrogen balance, kg/head/y				
Intake	138.4	28.7	80.8	191.1
Excreted in milk	45.8	13.9	20.9	75.8
Retained for pregnancy	1.2	0.1	0.9	1.4
Retained for growth	0.9	0.2	0.6	1.3
Excreted in feces and urine	90.5	17.3	54.8	127.6
Phosphorus balance, kg/head/y				
Intake	24.0	6.6	13.6	41.5
Excreted in milk	7.52	2.15	3.68	12.98
Retained for growth	0.23	0.05	0.14	0.33
Retained for pregnancy	0.20	0.02	0.15	0.24
Excreted in feces and urine	16.08	5.25	8.78	32.30
Enteric methane emissions according to, kg/head/y				
Ramin and Huhtanen, 2013	122.2	12.4	98.5	144.4
Kirchgessner *et al.*, 1995	148.6	17.8	114.3	193.8
Moraes *et al.*, 2013	112.8	14.5	83.7	136.6
IPCC, 2006	116.5	18.4	84.5	148.2
Tagliapietra (unpublished)	134.9	20.1	90.0	165.3

Table 15: Average diet characteristics, nitrogen and phosphorus balance and methane emissions of replacement calves and heifers.

	Mean	DS	Min	Max
Diet				
Dry matter intake, kg/head/d	5.6	0.67	4.44	6.85
Crude protein, % DM	12.6	1.5	10.4	15.9
Phosphorus, % DM	0.34	0.08	0.27	0.58
NDF, % DM	53.3	7.0	34.5	61.0
ADF, % DM	34.1	5.1	20.9	40.0
EE, % DM	2.96	0.41	2.56	4.02
Starch, % DM	7.32	8.09	0.00	31.01
Non fiber carbohydrate, % DM	23.3	6.25	17.4	43.4
Organic matter digestibility, % DM	63.5	5.6	56.3	77.0
Gross Energy, MJ/h/d	18.60	0.17	17.81	18.83
Net Energy, MJ/h/d	5.36	0.65	4.54	6.86
Nitrogen balance, kg/head/y				
Intake	40.6	5.2	27.1	53.3
Retained for pregnancy	0.43	0.07	0.27	0.54
Retained for growth	3.94	0.61	2.46	5.00
Excreted	36.3	5.0	22.5	46.6
Phosphorus balance, kg/head/y				
Intake	6.79	1.30	4.83	10.99
Retained	1.37	0.22	0.85	1.74
Excreted	5.42	1.28	3.36	9.67
Enteric methane emissions according to, kg/head/y				
Ramin and Huhtanen, 2013	48.4	3.6	41.7	55.8
Kirchgessner *et al.*, 1995	78.3	13.9	50.3	101.8
Moraes *et al.*, 2013	43.8	5.2	34.3	53.3
IPCC, 2006	40.7	5.0	32.7	50.4
Tagliapietra (unpublished)	40.5	2.9	35.6	46.0

Table 16: Annual emission of impact category per FPCM.

	Mean	DS	Min	Max
Climate change (kg CO_2 eq. per kg FPCM)				
- On farm	0.99	0.37	0.57	2.18
- Off farm	0.47	0.33	0.09	1.50
- Total	1.46	0.58	0.83	3.42
Acidification (g SO_2 eq. per kg FPCM)				
- On farm	23.43	7.46	14.19	41.72
- Off farm	3.75	2.20	0.64	10.31
- Total	27.18	8.34	17.23	49.74
Eutrophication (g PO_4^{3-}eq. per kg FPCM)				
- On farm	5.56	1.81	3.34	10.31
- Off farm	2.36	1.16	0.51	6.03
- Total	7.91	2.31	5.30	14.62

Table 17: Comparison of the main ecological indices between farms grouped according to stall system and feeding technic.

Variable	R^2	Stall		Feeding		Interaction stall × feeding				RMSE	F-*value*		
						Traditional		TMR			Stall	Feeding	Stall × feeding
		Tied	Free	Traditional	TMR	Tied	Free	Tied	Free				
Farms, n		13	25	19	19	9	10	4	15				
Milk, kg/d	0.391	19.8	24.6	19.4	24.8	17.3	21.7	22.3	27.4	5.26	12.2***	9.6**	0.1
N excreted, kg/cow/year	0.429	82.7	96.4	82.1	96.9	71.8	92.5	93.5	100.3	13.5	16.4***	7.2**	2.0
P excreted, kg/cow/year	0.155	16.4	16.6	14.7	18.3	12.9	16.6	19.9	16.7	4.96	0.8	1.8	3.6
CH_4 emissions[1], kg/cow/year	0.593	115.2	126.5	114.4	127.3	107.3	121.5	123.1	131.6	22.4	30.1***	18.6***	0.9
CO_2 eq. per kg FPCM													
on farm, kg/kg	0.158	1.07	0.95	1.13	0.89	1.17	1.08	0.96	0.83	0.35	2.2	4.2*	0.1
off farm, kg/kg	0.198	0.54	0.39	0.54	0.40	0.73	0.35	0.36	0.43	0.31	4.1*	0.3	4.0
total, kg/kg	0.196	1.61	1.35	1.67	1.29	1.90	1.44	1.32	1.26	0.54	4.5*	2.8	1.0
SO_2 eq. per kg FPCM													
on farm, g/kg	0.131	22.8	24.1	25.8	21.0	24.4	27.2	21.2	20.9	7.25	0.1	4.8*	0.4
off farm, g/kg	0.150	4.27	3.27	4.22	3.32	5.25	3.18	3.28	3.36	2.12	3.5	0.5	2.0
total, g/kg	0.124	27.1	27.3	30.0	24.4	29.7	30.4	24.5	24.2	8.14	0.2	4.6*	0.1
PO_4^{3-} eq. per kg FPCM													
on farm, g/kg	0.121	5.51	5.64	6.15	5.00	5.95	6.35	5.08	4.93	1.77	0.1	4.4*	0.2
off farm, g/kg	0.115	2.38	2.20	2.55	2.03	2.99	2.11	1.76	2.30	1.13	1.0	0.5	2.9
total, g/kg	0.123	7.89	7.84	8.70	7.03	8.94	8.46	6.85	7.22	2.25	0.6	3.9	0.3

[1](Ramin and Huhtanen, 2013)

Table 18: Descriptive statistics of annual emission of impact category with allocation.

	Mean	**DS**	**Min**	**Max**
CO_2 eq. per kg FPCM				
on farm, kg/kg	0.72	0.16	0.50	1.12
off farm, kg/kg	0.34	0.19	0.06	0.89
total, kg/kg	1.06	0.23	0.69	1.85
SO_2 eq. per kg FPCM				
on farm, g/kg	17.23	4.01	11.96	28.99
off farm, g/kg	2.74	1.31	0.44	6.03
total, g/kg	19.97	4.10	13.79	30.62
PO_4^{3-}eq. per kg FPCM				
on farm, g/kg	4.08	0.96	2.84	6.30
off farm, g/kg	1.74	0.74	0.35	3.98
total, g/kg	5.82	1.07	4.04	8.50
CO_2 eq. per kg beef				
on farm, kg/kg	5.71	2.12	3.27	12.60
off farm, kg/kg	2.73	1.90	0.51	8.66
total, kg/kg	8.45	3.32	4.80	19.71
SO_2 eq. per kg beef				
on farm, g/kg	135.21	43.04	81.88	240.77
off farm, g/kg	21.65	12.69	3.71	59.53
total, g/kg	156.86	48.11	99.47	287.07
PO_4^{3-}eq. per kg beef				
on farm, g/kg	32.08	10.44	19.28	59.50
off farm, g/kg	13.59	6.67	2.94	34.81
total, g/kg	45.68	13.31	30.57	84.39

Table 19: Comparison of the main ecological indices between farms grouped according to stall system and feeding technic with allocation to milk and beef production.

Variable	R^2	Stall		Feeding		Interaction stall × feeding				RMSE	F-*value*		
						Traditional		TMR			Stall	Feeding	Stall × feeding
		Tied	Free	Traditional	TMR	Tied	Free	Tied	Free				
CO_2 eq. per kg FPCM													
on farm, kg/kg	0.155	0.72	0.73	0.77	0.68	0.72	0.81	0.71	0.65	0.2	0.1	4.7*	1.5
off farm, kg/kg	0.106	0.36	0.31	0.35	0.32	0.43	0.27	0.28	0.35	0.2	1.0	0.1	3.0
total, kg/kg	0.072	1.07	1.04	1.12	1.00	1.15	1.08	0.99	1.01	0.2	0.7	1.7	0.3
SO_2 eq. per kg FPCM													
on farm, g/kg	0.263	15.52	18.56	17.90	16.18	15.28	20.51	15.75	16.61	3.6	5.0*	4.3*	2.8
off farm, g/kg	0.040	2.86	2.59	2.80	2.64	3.16	2.45	2.56	2.72	1.3	0.6	0.1	0.8
total, g/kg	0.206	18.37	21.15	20.70	18.82	18.44	22.96	18.31	19.33	3.8	3.4	3.9	1.6
PO_4^{3-} eq. per kg FPCM													
on farm, g/kg	0.195	3.76	4.35	4.25	3.85	3.73	4.77	3.78	3.92	0.9	2.8	3.5	1.9
off farm, g/kg	0.050	1.60	1.74	1.72	1.62	1.82	1.61	1.37	1.87	0.7	0.1	0.1	1.7
total, g/kg	0.133	5.36	6.08	5.97	5.47	5.56	6.39	5.16	5.78	1.0	2.8	2.4	0.1
CO_2 eq. per kg beef													
on farm, kg/kg	0.158	6.16	5.51	6.51	5.16	6.76	6.26	5.56	4.76	2.0	2.2	4.2	0.0
off farm, kg/kg	0.198	3.14	2.27	3.11	2.29	4.19	2.04	2.08	2.50	1.8	4.1*	0.3	4.0
total, kg/kg	0.196	9.29	7.78	9.62	7.45	10.94	8.29	7.65	7.26	3.1	4.5*	2.8	1.0
SO_2 eq. per kg beef													
on farm, g/kg	0.132	131.65	138.85	149.07	121.43	140.97	157.17	122.32	120.53	41.8	0.1	4.8*	0.4
off farm, g/kg	0.150	24.64	18.86	24.33	19.17	30.32	18.35	18.96	19.38	12.2	3.5	0.5	2.0
total, g/kg	0.124	156.29	157.72	173.41	140.60	171.30	175.52	141.28	139.91	47.0	0.2	4.6*	0.0
PO_4^{3-} eq. per kg beef													
on farm, g/kg	0.121	31.81	32.54	35.49	28.86	34.33	36.65	29.30	28.43	10.2	0.1	4.2*	0.2
off farm, g/kg	0.115	13.74	12.71	14.71	11.73	17.26	12.17	10.21	13.25	6.5	1.0	0.5	2.9
total, g/kg	0.123	45.55	45.25	50.20	40.60	51.58	48.82	39.51	41.68	13.0	0.6	3.9	0.3

Appendix

Appendix 1: Questionnaire.

DAFNAE UNIVERSITY OF PADOVA — DEPARTMENT OF AGRONOMY FOOD NATURAL RESOURCES ANIMALS ENVIRONMENT

Provincia di Trento
COWPLUS PROJECT
WP1: Ambiente
Questionario GHG

UNIVERSITÀ DEGLI STUDI DI PADOVA

Intervistatore:________________ Data:___/___2013 Intervistato:________________ N:___

Azienda:________________ CUAA:________ Caseificio:________________ ☐ TNG ☐ DOP ☐ ALIM

Malga Manze_______________ ***Malga Vacche:*** _______________

Animali e alimenti:		Vacche in latte	Asciutte	Vitelli lattanti	Manzette	Manze
Capi presenti	N	_____	_____	_____	_____	_____
di cui in malga	N	_____	_____	_____	_____	_____
Monticazione	Data o d	___/___2012	___/___2012	___/___2012	___/___2012	___/___2012
Smonticazione	Data	___/___2012	___/___2012	___/___2012	___/___2012	___/___2012
Mangime malga:__________	kg/d	_____	_____	_____	_____	_____
Pascolo aziendale	capi N	_____	_____	_____	_____	_____
Periodo	mesi	_____	_____	_____	_____	_____
Unifeed,		SI - NO	SI - NO	SI - NO	SI - NO	SI - NO
Autoalimentatore		SI - NO	SI - NO			
Fieno polifita, ______% aziendale	kg/d	____ ____	_____	_____	_____	_____
Medica	kg/d	____ ____	_____	_____	_____	_____
Paglia in mangiatoia, kg/d		____ ____	_____	_____	_____	_____
Mangime (cart.) __________	kg/d	____ ____	_____	_____	_____	_____
Mangime (cart.) __________	kg/d	____ ____	_____	_____	_____	_____
Mangime (cart.) __________	kg/d	____ ____	_____	_____	_____	_____
Silomais, kg/d	__%az.	____ ____	_____	_____	_____	_____
Siloerba, kg/d	__%az	____ ____	_____	_____	_____	_____
Nucleo (cart.) __________	kg/d	____ ____	_____	_____	_____	_____
________________	kg/d	____ ____	_____	_____	_____	_____
________________	kg/d	____ ____	_____	_____	_____	_____

Informazioni sugli animali:

Manze acquistate, N/anno	_____	Primipare Presenti, N	_____	Vacche fec. Col BB, %	_____
Vitelli nati, N/anno	_____	Venduti scolostrati, N a	_____	Venduti svezzati, N a	_____
Vitelloni ingrassati, N/anno	_____	Manze ingrassate, N a	_____	__________N	_____
Durata allattamento, d	_____	Latte in polvere, hg/d	_____	Latte di vacca, kg/d	_____

Informazioni sulla stalla:

	Anno	Capi	Animali	Lunga	Larga	Tipo	Ventilatori	Luce notte	Rasch.	Lettiera
Stalla principale	____	____	Va As Ma Vi	__m	__m	Fi-LiCu-LiLe	N__kW__	SI - NO	__kW	Pag-Seg __kg/capo/d
Stalla 2 ______	____	____	Va As Ma Vi	__m	__m	Fi-LiCu-LiLe	N__kW__	SI - NO	__kW	Pag-Seg __kg/capo/d
Stalla 3 ______	____	____	Va As Ma Vi	__m	__m	Fi-LiCu-LiLe	N__kW__	SI - NO	__kW	Pag-Seg __kg/capo/d

Informazioni sull'energia elettrica (bolletta):

Consumo (acq.+prod), kWh/anno _____ Casa inclusa SI - NO Fotovoltaico SI - NO Superficie, m² _____

Scambio sul posto, kWp _____ Autoconsumo, kWh/anno _____ Vendita diretta, kWp _____ Venduti, kWh/anno _____

Informazioni sul biogas: SI - NO Digestore, volume, mc _____ Potenza prodotta, kW _____ Biomasse __________

Informazioni sui combustibili (UMA):

Gasolio, L/anno_____ Benzina, L/anno _____ GPL, L/anno _____ Olio, L/anno _____

Pannelli solari acqua calda: SI - NO Numero pannelli: _____ Boiler acqua, L: _____ Recupero cal. latte: SI - NO

Informazioni sulle colture:

	Prato	Mais	___	___
Superficie (ha)	___	___	___	___
Liquame (m³/ha/anno)	___	___	___	___
Letame (q/ha/anno)	___	___	___	___
Fertilizzante 1_____________kg/ha	___	___	___	___
Fertilizzante 2_____________kg/ha	___	___	___	___
Fertilizzante 3_____________kg/ha	___	___	___	___
Irrigazione (tipo__________), m³/ha	___	___	___	___
Diserbanti totali, kg/ha	___	___	___	___
Anticrittogamici totali, kg/ha	___	___	___	___
Produzione media, q/ha	___	___	___	___
Sostanza secca (%)	___	___	___	___

Informazioni su stoccaggio foraggi:

	Fienile	Siloerba	Trincea silomais
Sciolto - Balloni	Sc-Ba	Sc-Ba	
Lunghezza,	__ m	__ m	__ m
Larghezza	__ m	__ m	__ m
Altezza	__ m	__ m	__ m
Volume	__ m³	__ m³	__ m³
Riempimento max	__ %	__ %	__ %
Tagli, N	___	___	
Essiccazione	SI-NO		
Ventilatore	___kW		
Aria calda	SI-NO		
Elettricità, Gas, Gasolio	E-GPL-G		

Informazioni sui macchinari (C.T.=operazioni fatte da contoterzisti)

Macchinari	C.T.	Marca – tipo – portato – trainato - massa	Potenza	Utilizzo (ore/anno)	Anno
Trattore	_	____________________	___	___	___
Trattore	_	____________________	___	___	___
Trattore	_	____________________	___	___	___
Trattore	_	____________________	___	___	___
Carro Unifeed	_	____________________	___	___	___
Barra falciante	_	____________________	___	___	___
Falciatrice	_	____________________	___	___	___
Spandivoltafieno	_	____________________	___	___	___
Giroranghinatore	_	____________________	___	___	___
Rotoimballatrice	_	____________________	___	___	___
Autocaricante	_	____________________	___	___	___
Erpice	_	____________________	___	___	___
Botte spandi liquame	_	____________________	___	___	___
Spargi letame	_	____________________	___	___	___
Rimorchio	_	____________________	___	___	___
Aratro	_	____________________	___	___	___
Fresa	_	____________________	___	___	___
Spandi concime	_	____________________	___	___	___
Botte diserbo	_	____________________	___	___	___
___________	_	____________________	___	___	___
___________	_	____________________	___	___	___
___________	_	____________________	___	___	___

Info su stoccaggio deiezioni:

	Vasca liquami	Platea letame
Presenza	SI-NO	SI-NO
Coperta	SI-NO	SI-NO
Lunghezza,	__ m	__ m
Larghezza	__ m	__ m
Altezza	__ m	__ m
Volume	__ m³	__ m³
Riempim. max	__ %	__ %

	Numero	Potenza
Raschiatori	___	___
Vulcano	___	___
Pompe liquami	___	___
Separatore	___	___
Pala	___	___
Aerazione	___	___
Nastro palette	___	___

Detergenti ________________

Plastiche ________________

Note:____

General Conclusions

In the last decades the livestock sector in mountain areas experienced a relevant evolution. The number of traditional, small and low productive farms has been drastically decreased, while a trend towards modern farms, oriented to high production and less labor has been remarked. These changes, however, have economic, social and environmental consequences that need to be quantified. Environmental issues are becoming increasingly important to the public and play a central role in formulating strategies to support agriculture. Scientific knowledge should be assembled, since it provides a major component of the evidence required for societies to make sensible policy decisions.

This Doctoral thesis is part of this general framework. More precisely, the relationship between productive aspects and environmental sustainability of dairy farming systems in mountain areas has been studied.

The results of the thesis provide interesting insights on various aspects of the sustainability of cattle farms of the mountain, highlighting the strong relationship between the dairy cows and temporary summer farms, considering a general view of the system of management. A special focus on the response of different breed on transhumance to temporary summer farms in terms of production, body condition and milk quality has been given.

The PhD thesis consists of three main parts. In particular, the first experimental contribution clearly shows that smaller dairy farms of traditional management are more related to the transhumance to temporary summer farms and the lower productivity can be offset by higher environmental services that could be paid by the CAP measures. The quality of services provided could be further assessed in the future, and it would be desirable to identify indicators to be used for the differentiation of environmental payments for mountainous farms.

The second part discusses the effect of transhumance of lactating cows on temporary summer farms on milk yield, quality and body condition score it shows that there is a very significant effect of pastures on reduced production, on the variation of the milk quality and the condition of the animals. It emerges the use of local and dual-purpose breeds for mountain farms, since it is those that show less difficulty in adapting to the pasture environmental conditions, with some ability to maintain their productivity during the summer pasture period. The management has shown to be very diverse, often characterized by high levels of compound feed to support production. The choice of breeds adapted to mountain pastures can limit the use of compound feed, encouraging better use of forage resources of pasture without causing high changes in terms of milk production and quality.

In the third contribution the Life Cycle Assessment (LCA) approach was used to evaluate the environmental footprint of dairy farms of Trento Province. The sampling farms, representative of the mountainous area, have been useful to test and validate an operational tool that can be further used for evaluations in a larger scale.

For future research, it might be interesting to investigate the role of fossil input, external to the dairy farms, compared to the organic inputs for determining the different environmental impacts. In fact, the mountain systems are characterized by a low use of external inputs and high multi-functionality and, for assessing the overall sustainability of these systems, these aspects must be taken into account.