Faculty of Bioscience Engineering

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Carbon Footprint of milk produced in extensive and intensive dairy production systems in Peru and potential for mitigation through diet optimization

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Promotor: Prof. dr. ir. Veerle Fievez

Master's dissertation submitted in partial fulfillment of the requirements for the degree of
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Abstract

The impact of livestock on the environment is getting more attention due to the intensification of agricultural production processes (e.g. landless animal production) and increasing public awareness. Therefore the amounts of studies, investigating which factors have the largest environmental impact on agricultural systems, are increasing. Nevertheless, the amount of studies which investigate the environmental burden of agriculture in tropical regions, are rather limited. Therefore this study was performed whereby the environmental impact of milk produced in intensive dairy systems in Lima is compared to milk produced in grass based extensive dairy systems in the Mantaro Valley in Peru. One of the tools to calculate the environmental burden of an output is a Carbon Footprint (CFP) which is a specific life cycle assessment (LCA) related to climate change. Data were collected by interrogation of each farmer in either system through a questionnaire. Collected data is processed in a CFP model which quantified the emissions from CO_2, CH_4 and N_2O, based on a spreadsheet package using Microsoft Excel. The CFP model is expressed in kg CO_2-equivalents per ton FPCM which allows to estimate the environmental impact of milk production at farm level on a yearly basis, considering a cradle-to-farm gate approach. One farmer of each dairy system was investigated, whereby the results obtained by the CFP model are taken as representative of intensive dairy systems in Lima and grass based dairy systems in the valley of the Peruvian Highlands.

The results indicate that the intensive dairy system emits 9,0% more overall GHG emissions (CFP, expressed in CO_2-eq per ton FPCM) per year at farmlevel in comparison with the grass based extensive dairy system. Expressed per ton FPCM, CO_2-emissions and N_2O emissions are respectively 262,5% and 62,6% higher than in the extensive grass based system. Import of feed and the high share of concentrates in the diet are most dominant for the CO_2 emission in the intensive dairy system, while in case of N_2O-emissions large animals with high intake levels and the presence of a dry lot manure management system are mostly responsible. In the extensive system, due to low digestibility of the ration and low milk production (12,5 kg/cow/day), CH_4 emissions expressed per ton FPCM are 30,6% higher than in the intensive dairy system.

The best mitigation strategy in the intensive dairy system would be the change of a dry lot management system into a solid storage manure system. Although challenges in terms of eutrophication cannot be overlooked since in a dry lot storage manure management the liquid fraction can infiltrate in the soil which leads to possible nitrate leaching and NH_3 emissions. Therefore another strategy which could lower both CH_4 as well N_2O emissions is anaerobic digestion whereby fraction of nitrogen and phosphor can be transformed into dry fertilizer granules. This strategy could be an option for future innovation research. Second best mitigation strategy in the intensive dairy system was the substitution of soybean meal by sunflower meal. A decrease of concentrates in the ration according to NE and CP requirements had the least effect. In case of the extensive system improved animal genetics is the most effective mitigation strategy, while adding red clover to the ration as “cut and carry” instead of mixed pasture is second best. An improved pasture management, whereby effects on eutrophication and acidification should be considered, had the least effect in reduction of the CFP. A mitigation strategy on national level could be achieved by producing one fourth of the yearly milk production of Lima in the extensive grass based dairy farms in the valleys of the Andean highlands. Supporting small scale famers to increase their herd size would be a good start in reducing emissions at country level, when these systems would partially replace intensive systems around Lima.

Samenvatting

Impact van vee op het milieu krijgt steeds meer aandacht waardoor studies die deze belasting kwantificeren toenemen. De kwantitatieve milieu impact van vee in een tropisch klimaat is echter door weinig studies onderzocht. Daarom werd deze studie uitgevoerd waarin de milieu-impact van melk geproduceerd op intensive melkveebedrijven in Lima t.o.v. gras gebaseerde extensieve melkveebedrijven in de Mantaro vallei in Peru, wordt vergeleken. Een mogelijke manier om deze milieu-impact te berekenen was op basis van een Carbon FootPrint (CFP) die gedefinieerd word als een specifieke levens cyclus analyse gerelateerd aan klimaat verandering. Data werden in situ verzameld in beide productie systemen in Peru aan de hand van vragenlijsten en vervolgens verwerkt in een CFP model dat de emissies van CO_2, CH_4 en N_2O kwantificeert op basis van verschillende werkbladen in Microsoft Excel. De CFP is uitgedrukt in kg CO_2 - equivalenten per ton FPCM die het mogelijk maakt om de milieu-impact van de melkproductie op bedrijfsniveau op jaarbasis te schatten, volgens de grenzen van *cradle-to-farm gate*. Één boer in elk melkvee systeem werd doorgelicht, waarbij de door het CFP bekomen modelresultaten worden aanzien als representatief voor intensieve melkvee bedrijven in Lima en extensieve bedrijven in de vallei van de Peruaanse hooglanden.

De resultaten tonen dat het intensieve melkveesysteem een CFP heeft die 9,0% hoger ligt dan in het extensieve melkveesysteem, waarbij CO_2 en N_2O-emissies (uitgedrukt per kg CO_2-equivalenten per ton FPCM) respectievelijk 262,5% en 62,6% hoger zijn dan in het gras-gebaseerde extensieve system. Voor de CO_2-uitstoot in het intensieve melkvee systeem hebben de aanvoer van voedercomponenten en het hoge aandeel van krachtvoer in het rantsoen de grootste invloed, terwijl in het geval van de N_2O vooral de omvang van de dieren, gepaard met een hoge voederinname, en het dry lot mest systeem het meest doorslaggevend zijn. In het extensieve systeem zijn CH_4-emissie (uitgedrukt per kg CO_2-equivalenten per ton FPCM) 30,6% hoger dan in het intensieve systeem wat voornamelijk kan toegeschreven worden aan de lage verteerbaarheid van het rantsoen en de lage melkproductie (12,5 kg/koe/dag).

De beste mitigatiestrategie in het intensieve systeem is de verandering van het dry lot management systeem naar een vaste opslag van mest (CFP: -8,9%) al kan dit voor uitdagingen zorgen op gebied van eutrophicatie aangezien de vloeibare mest fractie in de bodem infiltreert. Daarom is de denkpiste naar anaerobe mestopslag een optie die in verder onderzoek kan onderzocht worden. De tweede beste strategie voor CFP reductie is de substitutie van sojameel door zonnebloem meel. Een verminderde gift van krachtvoer in het rantsoen conform de NE en CP behoeften van de koe had het minste effect. In het extensieve systeem had een verbeterde diergenetica het meeste invloed in het reduceren van emissies, terwijl het toevoegen van rode klaver in het rantsoen als "cut and carry" in plaats van gemengd grasland, als de op één na beste mitigatie strategie wordt beschouwd. Een verbeterd weilandbeheer (e.g. bemesting) had het minste effect. Een mitigatiestrategie op nationaal niveau (e.g. daling van de globale CFP) kan worden bekomen door een vierde van de jaarlijkse melkproductie in Lima te produceren in de extensieve melkvee systemen in de valleien van de Andes. Om dit te bewerkstelligen zou de ondersteuning van kleinschalige boeren een goede start zijn in het verminderen van de uitstoot op nationaal niveau, wanneer deze systemen een gedeeltelijke vervanging van intensieve systemen in Lima zouden zijn.

List of abbreviations

ADF	Acid detergent fiber
ADL	Acid detergent lignin
CA	Crude ash
CF	Crude fat
CFP	Carbon FootPrint
CP	Crude protein
CVB	Centraal Veevoeder Bureau
DDGS	Dried distillers grain with solubles
DE	Digestible energy
DIM	Days in milk
DM	Dry matter
DS	Dry season forage
ECM	Energy Corrected Milk
EF_3	Emmision factor for direct N_2O emission from manure managment
eq	Equivalent
EU	Europe
FAO	Food and Agriculture Organization of the United Nations
FPCM	Fat and Protein Corrected Milk
FU	Functional Unit
GHG	Green house gas
GM	Geneticly modified
GWP	Global Warming Potential
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organisation for Standardization
LCA	Life Cycle Assesment
LCI	Life Cyle Inventory analysis
LCIA	Life Cycle Impact Assessment
LUC	Land Use Change
MCF	Methane conversion factor
NDF	Non-detergent fiber
NE	Net energy
NEL	Net energy for lactation
NEM	Net energy for maintenance
NRC	Neutrient Requirements of dairy Cattle
OC	Optimized nutrient composition
RR	Roundup Ready seeds
RS	Rainy season forage
TMR	Total Mixed Ration
UNALM	Universidad Nacional Agraria La Molina
USA	United States of America
VEM	Voedereenheid melk
WHO	World Health Organization

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1. Introduction

The impact of livestock on the environment is getting more attention due to the intensification of agricultural production processes (e.g. landless animal production) and increasing public awareness [2, 3]. Therefore the amounts of studies, investigating which factors have the largest environmental impact on agricultural systems, are increasing. Nevertheless, the amount of studies which investigate the environmental burden of agriculture in tropical regions, are rather limited [4].

Therefore this study was performed whereby the environmental impact of milk produced in intensive dairy systems in Lima is compared to milk produced in grass based extensive dairy systems in the Mantaro Valley in Peru. One of the tools to calculate the environmental burden of an output is a Carbon Footprint (CFP) which is a specific life cycle assessment (LCA) related to climate change. A CFP quantifies the emission of greenhouse gases (CO_2, NH_4 and NO_2) along the entire life cycle of a product, in this case 1 kg fat-and-protein-corrected milk (FPCM). In the current thesis, the assessment was applied to one average intensive dairy system and one average extensive dairy farm.

In chapter "Literature review", intensive dairy farms in Lima and extensive dairy farms in the Valley of the Andean highlands are characterised followed by the goal and structure of a life cycle assessment. Afterwards previously performed LCA studies focusing on the quantification and reduction of the environmental burden due to milk production in intensive and grass based extensive dairy farms around the world are discussed. At the end, the ration of dairy cattle is profoundly elaborated together with the environmental impact of soy on the environment and which solutions could be handled.

"Material and Methods" include a detailed description of the calculation model used for calculating the environmental impact of milk in both dairy systems. Afterwards the obtained results are carried forward in the chapter "Results". In the discussion various mitigation strategies are implemented in the CFP model and the best strategies to lower the environmental burden in both dairy systems are presented. Finally, a general conclusion will end this master thesis.

2. Literature review

2.1. Introduction

In this literature review the difference between extensive and intensive dairy cattle systems in Peru will be discussed in terms of impact on the environment and the ration the livestock receives. A comparison will be made between formerly performed LCA studies around the world on the subject of intensive and extensive dairy systems. The impact of the ration on the environment will be discussed and feed alternatives will be proposed.

2.2. Difference between extensive and intensive dairy cattle systems in Peru

2.2.1 Lower slopes of the Andean Highland: Mantaro Valley

In the Andean valleys (e.g. Mantaro Valley) mixed livestock production systems are most dominant [5]. Because of daily milk sales [6] dairy husbandry provides a more regular income for small-scale farmers in comparison with crop production [7]. In the Peruvian highlands, the Criollo cattle was the most common cattle type. These were introduced from Spain in the 16th century and are adapted to low quality feeds and high altitude [8]. However, nowadays crossbreeding with Brown Swiss or Holstein-Friesian occurs frequently [9, 10]. The study of Piccand et al. showed that the Brown Swiss breed, within a grass-based and low concentrate system, had a lower milk performance than Holstein-Friesian ruminants when fed with the same diet [11]. Andean livestock is often raised on irrigated alfalfa, oats, and/or ryegrass-clover and conserved roughages [12, 13]. Although it's possible that modest amounts of concentrates are part of the diet [7].

To understand why irrigation of the feed is necessary, a description was given by the FAO about the Andean climate [7]. There are two basic Andean seasons, the rainy summer from October through April and the dry winter in the remaining months. The valley climate is moderate without extreme cold or heat [7]. Even though the annual precipitation around the Mantaro Valley reaches a multiannual average (years: 1960-2000) of approximately 750 mm/m^2, the possibilities are limited by the availability of irrigation water originating from the Mantaro river, during the dry season [14]. Due to the possibility of irrigation by the Mantaro river, valley bottoms (2.800–3.200 m) have better access to water than slope areas (3.200–3.500 m) [7]. The irrigation process is based on a gravitational, unfortified system [4].

2.2.2 The coastal region: Lima

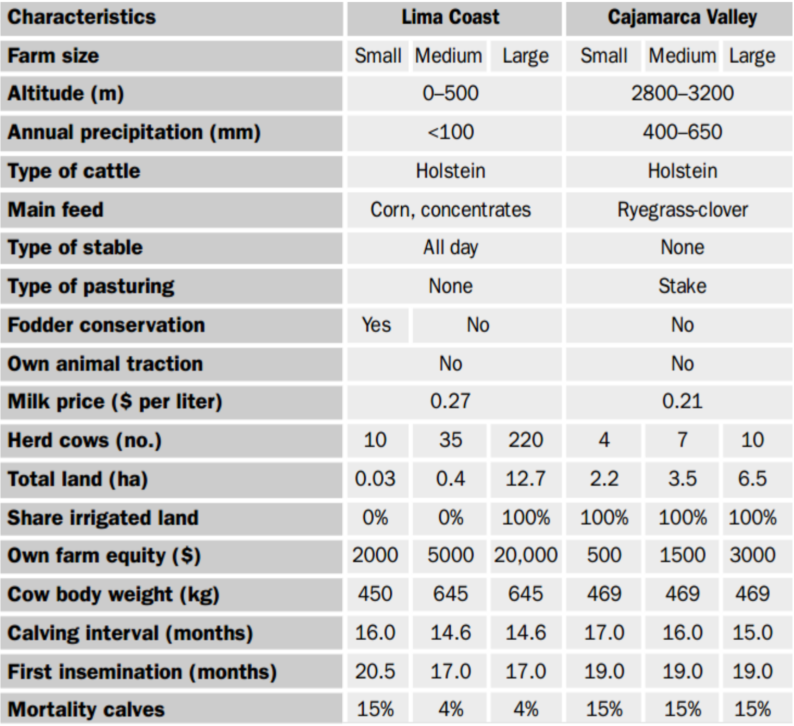
In 2009, one fifth of the milk production in Latin America was produced in Peru (1.878 thousand tons) from which 17% in the capital of Lima (Peru) [15]. The Peruvian population is estimated at 27.412.157 inhabitants, of whom 31% live in the capital [16]. The strong growth in urban demand for industrially processed dairy products has induced a rapid increase in milk production along the coastline, which has led to large intensive dairy production systems [5, 17]. Large farms are in the best position to withstand milk price reduction because of the economy of scale. Contracted specialists (e.g. accountants, nutritionists and veterinarians) replace family labor and stable-feeding allow high milk productivity [10, 17]. The economy of scale enables to negotiate with input providers for feed prices and quality [10].

Close to 90% of the dairy cattle in Lima is Holstein Friesian and was imported in the 90s from the USA and Europe [7]. Livestock is kept in a fenced dry lot [4]. These “cattle stables” are located on desert land, which is cheaper than irrigated land. These infertile acreages are no exceptions at the coastal area were the climate is characterized by a high humidity level, low annual rainfall and a mean temperature of 18,1 C° [7].

Since the dairy cattle are grouped by age and lactation stage, the quality and quantity of feed is adjusted to the animals’ specific nutrient requirements [10]. The diet in these intensive farms often consists of maize stover supplemented with a mix of concentrates of which ingredients are purchased weekly from specialized producers [10]. Often all rations are prepared on-farm. Every couple of months the manure is collected and sold to farmers nearby who produce crops [10]. Intensive dairy production systems have no actual limit of herd size, the number of cattle can rise up to 800 units or more [10].

In Table 2-1, Bernet et al. [10] give an overview of the differences in milk production systems at the coast of Lima and in the Cajamarca Valley. The valley of Cajamarca is situated in the northern part of the Andes (2.620 m) and is similar to the Mantaro Valley with respect to geography and climate (Appendix A), but also in terms of extensive dairy farms characteristics [7, 18].

Table 2-1: Differences between milk production systems at the Coast area and at the Cajamarca valley [10].



Characteristics	**Lima Coast**			**Cajamarca Valley**		
Farm size	Small	Medium	Large	Small	Medium	Large
Altitude (m)	0–500			2800–3200		
Annual precipitation (mm)	<100			400–650		
Type of cattle	Holstein			Holstein		
Main feed	Corn, concentrates			Ryegrass-clover		
Type of stable	All day			None		
Type of pasturing	None			Stake		
Fodder conservation	Yes	No		No		
Own animal traction	No			No		
Milk price ($ per liter)	0.27			0.21		
Herd cows (no.)	10	35	220	4	7	10
Total land (ha)	0.03	0.4	12.7	2.2	3.5	6.5
Share irrigated land	0%	0%	100%	100%	100%	100%
Own farm equity ($)	2000	5000	20,000	500	1500	3000
Cow body weight (kg)	450	645	645	469	469	469
Calving interval (months)	16.0	14.6	14.6	17.0	16.0	15.0
First insemination (months)	20.5	17.0	17.0	19.0	19.0	19.0
Mortality calves	15%	4%	4%	15%	15%	15%

2.3. Life cycle assessment (LCA)

2.3.1 Why a LCA?

Nutrient balances at farm level are used to assess the environmental impact of agricultural systems (e.g N-excess at farm level) [19]. But according to de Boer [20] nutrient balances at farm level have several problems because they only consider nutrient losses at the farm and exclude nutrient losses during production of farm inputs (e.g. concentrates, artificial fertiliser). A life cycle assessment (LCA) is a method that has the capacity to overcome these problems [3]. "By identifying where the environmental impacts and damages take place, the first step towards sustainable development could be made" [21].

2.3.2 What is a LCA?

A life cycle assessment (LCA) is a tool which monitors and therefore might help to identify and reduce the total environmental impact of products and production systems. At each stage in the life cycle of the product, used resources and emissions (to the environment) are determined [22]. The development, production and transport of raw materials, together with the processing and packaging of the product, the transport and use of the product by the consumer up to and including the process of waste disposal, are data which could be taken into account to perform a LCA [23]. Yan et al. [24] describes that animal scientists tend to use a process-based LCA. “A process-based LCA describes the production system as a series of activities that transforms inputs (e.g. raw materials and energy) into outputs (e.g. product and emissions” [24] .”Another approach called input-output LCA, which uses the economic transaction tables and national environmental accounts to determine the environmental impact triggered by final demand of milk production, is often less used due to data scarcity and higher uncertainty“ [24, 25].

The International Organization for Standardization (ISO) has developed two standards (ISO 14040:2006 and ISO 14044:2006) aiming at better **transparency** between different studies using the LCA-methodology. In a LCA *four phases can be differentiated* (Figure 2-1):

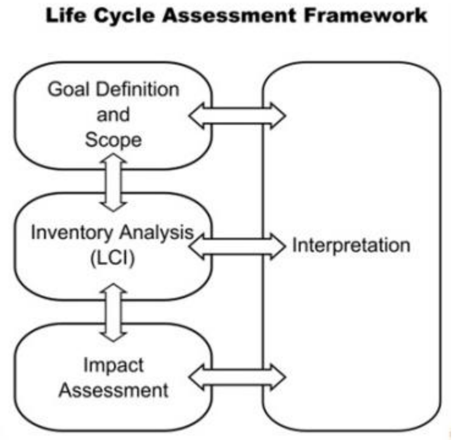


Figure 2-1: LCA frameworks as explained in the ISO Standards 14040 [27].

The first phase or the “***Goal and scope definition***” includes defining the production system that will be studied with the associated boundaries, data requirements and limitations, the reason the study is performed, in which context it is situated and the definition of the audience one wants to reach [22]. Ideally, the boundaries of a LCA-study include the environmental impact of a product over its entire life cycle, i.e. from “cradle to grave” [26]. Instead LCA studies of agricultural systems often assess the farm gate”-approach [20] which might include processes such as production of concentrates and roughage, heifer rearing and replacement of culled dairy cows, transport associated with production of purchased inputs, as shown in the study of Thomassen et al. [27].

A LCA is calculated using a Functional Unit (FU). “This functional unit defines what is being studied. All subsequent analyses should be expressed relative to that functional unit” [28]. In most LCA’s of agricultural products, the FU has been defined as the mass of the product leaving the farm gate (e.g. kg of fat and protein corrected milk (FPCM)) [29].

In the second phase or the ***”Life Cycle Inventory analysis (LCI)”*** a flow diagram is designed and data collected. At this stage, product allocation also should be defined. The result of the inventory analysis is the input for the impact assessment. When a LCA is applied in the agricultural sector economic allocation is mostly used. “The environmental impact of a production system or process is allocated to its multiple outputs based on their relative economic value. LCA results based on different allocation methods cannot be compared directly” [27].

In the third phase or “**L*ife Cycle Impact Assessment (LCIA*)**“, the results of the LCI will be further processed and interpreted. [30]

Finally the ***interpretation*** as fourth phase is to draw conclusions and to make recommendations for identified limitations [30]. When a LCA of a milk production system is calculated, environmental impact categories such as acidification, eutrophication, global warming, toxicity, and use of resources, can be included [20].

Acidification

Acidification as a consequence of air pollution has several impacts on the environment. The precipitation of SO_2 (industry), NO_x (cars) and ammonia (animal production) will lead to an ‘acid deposition’ with the consequence of a pH-drop in soil and water. This decreases the buffer capacity of the environment and gives rise to eutrophication [31]. The acidification potential is expressed in a **SO_2-equivalent factor** (kg SO_2-eq). This factor shows the total impact of the gasses SO_2, NO_x and NH_3 on the environment in terms of acidification.

In the Master thesis of Hofmans S. [32], different possibilities to calculate this factor are listed, which are summarized in Table 2-2.

Table 2-2: Different possibilities to calculate 1 kg SO_2-eq.

Formula	Reference
1 kg SO_2-eq = kg SO_2 + kg NO_x*0.7 + kg NH_3 *1.88	Heijungs et al. (1992) [35]
1 kg SO_2-eq = kg SO_2 *1.2 + kg NO_x*0.5 + kg NH_3 *1.6	Huijbregts(1999) [36]
1 kg SO_2-eq = kg SO_2 + kg NO_x*0.7 + kg NH_3 *1.89	Reinhardt (1997) [37]

Eutrophication:

“Eutrophication [33] is characterized by excessive plant and algal growth due to the increased availability of one or more limiting growth factors needed for photosynthesis, such as sunlight, carbon dioxide, and nutrient fertilizers (e.g. nitrates)“. The eutrophication potential is expressed in a **PO_4-equivalent factor** (kg PO_4-eq). This factor shows the total impact of the related gasses on the environment in terms of eutrophication. There are multiple equations possible to calculate this factor (Table 2-3) [32].

Table 2-3: Different possibilities to calculate 1 kg PO_4-eq.

Formula	Reference
1 kg PO_4-eq = kg PO_4 + g NOx*0.13 + kg NO_3*0.10 + kg NH_3*0.35	Heijungs et al. (1992) [35]
1 kg PO_4-eq = kg PO_4 + kg NOx*0.13 + kg N*0.42 + kg P*3.06	Guinée et al. 2002 [40]

Global warming

“Solar energy drives the weather and climate on earth, and heats the earth’s surface. In turn, the earth radiates energy back into space through ultraviolet radiation. Atmospheric greenhouse gasses (GHG) trap some of the outgoing energy and retain heat” [34]. Human activities, such as fossil fuel burning and deforestation are enforcing earth’s natural greenhouse effect by increasing the level of GHG in the atmosphere [34]. Furthermore, methane emission from ruminants has been identified as another non-negligible GHG source [35]. The global warming potential is expressed in CO_2-equivalent factors given by IPCC 2013 [36] or IPCC 2007 [37]. The formulas are presented in Table 2-4:

Table 2-4: Formula to calculate 1 kg CO_2-equivalents.

Formula	Reference
1 kg CO_2-eq = kg CO_2 + kg CH_4*34 + kg N_2O*298	IPCC 2013, [36]
1 kg CO_2-eq = kg CO_2 + kg CH_4*25 + kg N_2O*298	IPCC 2007, [37]

2.4. Results of formerly performed LCA studies related to intensive and extensive dairy systems

Often it's not possible to compare LCA studies because of the difference in approach of the LCA methodology (e.g. system boundaries, functional unit and allocation method). Therefore, it is advised [20, 38, 39] not to make numerical comparisons between different environmental studies using the LCA method. The quality of a LCA study depends of the available data and the assumptions that have been made. Hence, any conclusion has to be taken with caution [27].

In Table 2-5 an overview is given of the farm and LCA characteristics of 4 formerly performed LCA studies in 3 different countries.

Table 2-5: Overview of farm and LCA characteristics of 4 formerly performed LCA studies in 3 different countries and one LCA study performed at global level.

	Peru (Bartl et al. [4])		**Ireland (O' Brien et al. [40])**		**Canada (Mc Geough et al. [41])**	**World level (Gerber et al. [39])**
Farm	*Extensive*	*Intensive*	*Extensive*	*Intensive*	*Intensive*	*Extensive*
Grazing on pastures	*yes*	*no*	*yes*	not reported	*no*	*not reported*
Forage	*rye grass clover*	*fodder maize*	*yes*	grass/legume mixture	*corn silage, alfalfa hay*	*not reported*
Concentrates	no	yes	*yes**	yes	*yes*	*not reported*
Boundaries	cradle to farmgate		cradle to farmgate		cradle to farmgate	cradle to retail
Functional Unit	kg ECM[1]		kg FPCM[2]		kg FPCM[2]	kg FPCM[2]
Time period	1 year		1 year		6 years	not reported
Allocation	economic		economic		economic	overall protein mass
Emission Unit	kg CO_2-eq/kg ECM kg CO_2-eq/animal		kg CO_2-eq/kg FPCM		kg CO_2-eq/kg FPCM	kg CO_2-eq/kg FPCM kg CO_2-eq/animal
Characterisation factor GWP	kg CO2-eq, CH_4: **72** kg CO2-eq, N_2O: 289 (IPCC 2007)[37] 20-year time horizon		kg CO2-eq, CH_4: 21 kg CO2-eq, N_2O: 310 (IPCC 1996)[42] 100-year time horizon		kg CO2-eq, CH_4: 25 kg CO2-eq, N_2O: 298 (IPCC 2007)[37] 100-year time horizon	kg CO2-eq, CH_4: 25 kg CO2-eq, N_2O: 298 (IPCC 2007)[37] 100-year time horizon

*yes=Grass silage and concentrate were offered during periods when pasture growth was unable to meet the nutritional requirements of the herd; [1] Energy corrected milk, ECM (kg/day) = milk (kg/day) x [0.038 x fat (g/kg) + 0.024 x protein (g/kg) + 0.017 x lactose (g/kg)]/3.14 [4]; [2] Fat and protein corrected milk, FPCM (kg) = raw milk (kg) x (0,337+0,116 x fat content (%) + 0,06 x protein content (%))[43];

From Table 2-5 it is obvious that comparison of results across studies is impossible because of differences in FU, LCA boundaries and/or characterization of GWP. Therefore, the studies are discussed separately in the following paragraphs.

2.4.1 Peru

The cradle-to-farmgate LCA study performed by Bartl, et al. [4] evaluated the environmental impact of milk production of two smallholder systems in Peru. Extensive production systems in the Andean Highlands were compared with more intensive smallholder systems at the coast of Lima. The feed of the cows in the extensive system consisted of permanent pastures with ryegrass-clover (Table 2-5). At the coast dairy cows were fed fodder maize and purchased concentrate [4]. The milk production level of the cows was considered very low (2,57 kg milk/cow/day) in comparison with the livestock at the coast (19,54 kg milk/cow/day) which were fed fodder maize and concentrates. The functional unit of 1 kg Energy Corrected Milk (ECM) was used (Table 2-6) whereby 1 kg milk is adjusted to standard milk (4% fat; 3,2% protein and 4,8% lactose). The difference in duration of lactation between the two systems was resolved by recalculating the ECM yield to one year. Economic allocation was chosen in order to deal with the different life cycles of farm inputs and outputs (Table 2-5).

Table 2-6: Formulas to calculate ECM and FPCM.

Formula	Ref.
ECM (kg/day) = milk (kg/day) x [0,038 x fat (g/kg) + 0,024 x protein (g/kg) + 0,017 x lactose (g/kg)]/3.14	[4]
FPCM (kg) = raw milk (kg) x (0,337+0,116 x fat content (%) + 0,06 x protein content (%))	[43]

In the Andean Highlands, the extensive system consistently emits more than the intensive system when expressed per kg ECM (due to livestock emissions) (Table 2-8). Whereas extensive dairy farms emitted 85% less than intensive farming when expressed per animal (Table 2-8). The biggest impact of extensive systems on the environment was due to the enteric fermentation of livestock expressed in methane per kg ECM [4]. “Activities mainly responsible for acidification and eutrophication at the coast are the cultivation and processing of the forages and the concentrate ingredients” [4] (Table 2-9).

Solutions to lower the burden per kg ECM included an increase of the animal’s productivity or to lower the methane emission due to enteric fermentation (e.g. increased digestibility). To lower the environmental impact of intensive systems at the coast it was suggested to change the protein source of the concentrate (i.e. mainly soya) because the biggest impact on the global warming potential was due to the production of concentrates (Table 2-9).

2.4.2 Other countries

2.4.2.1 *Ireland*

O’ Brien et al. [40] have used an LCA model to compare the environmental impact of pasture-based dairy farms with confinement farms of Holstein-Friesian cows in Ireland. The chosen time period was one year and economic allocation has been applied. The emissions were expressed per kg FPCM (Table 2-6). The ration in the extensive system was grass-based while in the intensive system a total mixed ration was given based on concentrates (rather than on forages) what explains a part of the higher emissions per unit of milk (Table 2-8).

O'Brien et al. [40] suggested to reduce CH_4 and NH_3 emissions in the confinement system by storing manure under aerobic conditions. In the grass-based systems a mitigation strategy could be to prolong the time of the herd on the pastures in the grazing season [40]. Reducing the impact of concentrates with a high environmental impact would also lower the burden of the confinement systems on the environment (Table 2-9). Still attribution from enteric fermentation to GHG emissions was in both systems the most abundant (representing 46% for the grass-based and 36% for the TMR system in the global GHG emissions). Acidification and eutrophication was lower in the grass-based system when expressed per kg FPCM (Table 2-8).

2.4.2.2 ***Canada***

In the study of Mc Geough et al. [41] the total GHG-emissions of a non-grazing dairy production systems were calculated using the model "Holos" which is a software program that estimates whole-farm GHG emissions based on information entered for individual farms. It is based on IPCC methodologies, modified with Canadian farming practices [41]. The chosen time period was 6-years and all on- and off-farm processes that contributed to dairy production were taken into account (cradle to farmgate). Economic allocation was used and the emissions were expressed in CO_2-eq/kg FPCM (Table 2-8).

In Canada also pastoral based dairy farms are common. The GHG emissions in these systems were higher per kg FPCM. According to Mc Geough et al. this fact can have multiple reasons but the most abundant is the difference in ration and milk yield. The ration has an effect on the CH_4 emissions due to enteric fermentation. "Diets high in readily fermentable carbohydrates reduce enteric CH_4 production relative to that in high-fiber pastoral diets, due to their greater propionic acid production and lower pH in the rumen"[41]. Still, the highest contributor in total GHG emissions of the non-grazing dairy systems was the emission of CH_4 (56%)(Figure 2-2). The emissions of N_2O were also notable (40%) (Figure 2-2). This reflects the N-input which is used to fertilize feed crops [41]. According to Beauchemin et al. [44], this shows the importance of nutrient cycling and management in dairy systems.

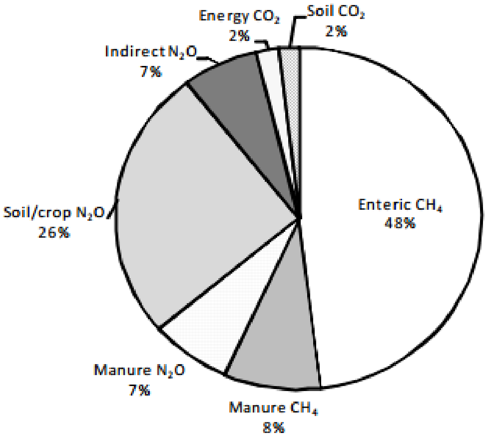


Figure 2-2: Results from the LCA of dairy production in Canada (Mc Geough et al., unpublished. From Beauchemin 2012), relative proportion of the various GHG emissions from the dairy production cycle (% CO_2-eq.) [41].

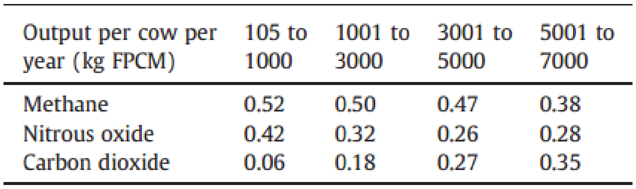
2.4.2.3 *Global*

The goal of Gerber et al. [39] was to investigate on a global scale if an increase in milk production of dairy cattle would lead to a decrease in the emissions of GHG and could be labeled as a mitigation strategy. Gerber et al. used the system boundaries of 'cradle to retail' and the chosen functional unit was CO_2-equivalents per kg FPCM at farm gate. This means that emissions related to processing and transport (post-farm processing) was integrated in the calculations. This study has not used the economic allocation method. The proportion of the overall protein mass found in each product (meat and milk) defined the allocation. "While improving animal productivity resulted in increased GHG emissions per animal, the high milk response rate resulted in a trend of decreasing net emissions per kilogram of milk [39]".

When GHG emissions were expressed <u>per animal</u>, the release of CH_4 and CO_2 increased at a higher milk production." This is due to the fact that a higher production is associated with larger animals with a higher feed intake and thus higher methane production [38]." Milk yield increase of a herd was associated with more sophisticated production systems which ask more inputs and fossil energy which higher the carbon dioxide emission. No conclusion could be taken for nitrous oxide because the result was not significant.

Emission expressed <u>per kg FPCM</u> showed other results (Table 2-7). CH_4 and N_2O will decrease with higher yields. In contrast CO_2 will increase. High producing animals need more concentrates which require fossil energy during production [39].

Table 2-7: Fraction of CH_4, N_2O and CO_2 in total GHG emissions (output/cow) [39].



Output per cow per year (kg FPCM)	105 to 1000	1001 to 3000	3001 to 5000	5001 to 7000
Methane	0.52	0.50	0.47	0.38
Nitrous oxide	0.42	0.32	0.26	0.28
Carbon dioxide	0.06	0.18	0.27	0.35

According to Gerber et al. [39] and Capper et al. [45] several reasons can be listed why emissions of GHG decreases per unit of milk produced. Enteric fermentation is known as having the largest share in emissions of GHG. The diet in intensive dairy production systems contains more concentrates and less roughage. This leads to a higher digestibility which contributes to a reducing enteric methane production.

As the production intensifies, an increasing proportion of feed energy is used for milk production. In this way emissions associated with animal maintenance are “spread” over a larger amount of milk. Another effect of intensification is the higher nitrogen use efficiency. Because the composition of the diet is optimized (e.g. protein/energy balance) proportionally lower amounts of nitrogen will be excreted in feces and urine. This reduces the N_2O emission per kg of milk.

As a conclusion Gerber et al. considered the increase of milk productivity as a mitigation strategy for dairy cows which produce currently less than 2000 kg milk per year [39]. Those production systems could lower their emissions to one fourth of their current emissions from 12 to 3 kg CO_2-eq/kg FPCM by increasing the milk production up to 2000 kg milk per year [39]. On the other hand, potential benefits of further increases in production rates of high producing dairy herds (e.g. > 6000 kg FPCM/year) are marginal as compared with low producing animals. On a global scale this means that it’s desirable to focus on dairy farms with low productivity (i.e. developing countries). In these systems reduction in methane could be obtained by improving the feed quality, genetics and animal health. In high productive systems more attention could be paid to the emissions related to the production of concentrates [39].

2.4.2.4 *Results of discussed studies*

Table 2-8: Acidification, eutrophication and global warming potential expressed in functional unit of 3 formerly performed studies.

	Peru (Bartl et al.[4])					**Ireland (O' Brien et al.[40])**				**Canada (Mc Geough et al.[41])**	
		Extensive	***Intensive***	***Ext<Int***	***Int <Ext***		***Extensive***	***Intensive***	***Ext<Int***		***Intensive***
Acidification	g SO_2-eq/kg ECM/year	14,1	7,6		47%	g SO_2-eq/kg FPCM	6,9	11,9	42%		
	g SO_2-eq/animal/year	2918	19174	85%							
Eutrophication	g PO_4-eq/kg ECM/year	15,5	4,8		69%	g PO_4-eq/kg FPCM	3,4	4,6	26%		
	g PO_4-eq/animal/year	3195	12296	74%							
Global warming potential	kg CO_2-eq/**ton** ECM/year	13780	3180		77%	kg CO_2-eq/**ton** FPCM	874	1027	15%	kg CO_2-eq/**ton** FPCM	920
	kg CO_2-eq/animal/year	2846	8066	65%							

Table 2-9: Summary of the possible bottlenecks and its solutions to lower the environmental burden of intensive and extensive dairy farms.

	Bottlenecks	**% total GHG emission***	**Solutions**	**Reference**
Intensive farm	Concentrate cultivation and processing		Increase locally produced high protein sources	Bartl et al. [4] O'brien et al. [46]
	Enteric fermentation	36%	choose low impact protein source	Bartl et al.[4] O'brien et al. [46]
	Manure storage	12%	Storing manure: e.g. solid storage, bio gas plant Increase frequency of manure removal	O'brien et al. [46]
	Elektricity and fertiliser production	14.5%		O'brien et al. [46]
	N-losses		Carefull diet formulation	O'brien et al. [46]
Extensive farm	Enteric fermentation	46%	Increase digestibility of the feed	Bartl et al.[4] Mc Geough et al.[47]
			Increase productivity by genetic improvements, fertiliser use, improved feed	Bartl et al. [4] Gerber et al. [45]

* Data from: O'Brien et al.

2.5. Ration of dairy cattle in extensive and intensive systems in Peru

Although livestock is mostly kept on pastures in the Peruvian highlands, also conserved roughages are important. According to Bartl et al. [12] who studied the nutritional value of common local forages in the central Peruvian highlands, the annual forages oat (*Avena sativa L.*) and barley (*Hordeum vulgare L.*) were the most common species, together with the perennial forages Italian ryegrass *(Lolium multiflorum)*, alfalfa (*Medicago Sativa L.)* and the common vetch (*Vicia Sativa L.*).

Information about the DM yield (kg/ha), CP (g/kg DM), NDF (g/kg DM), NE_L (MJ/kg DM), CP yield (kg/ha) and NE_L yield (MJ/ha) can be found in Appendix B (Table 7-1 and Table 7-2).

Bartl et al. has investigated the effect of diet type on the performance of two cattle breeds (Criollo and Brown Swiss) living on different heights in Peru. The diets represent the quality of typical highland dry-season forage (DS), highland rainy-season forage (RS) and a diet with optimized nutrient composition (OC) in Peru (Table 2-10) [12].

According to Table 2-10 the amount of crude protein (g/kg dry matter) was higher in the rainy season and in the optimized diet, while the NDF content decreased when the quality of the diet was enhanced. The net energy of the feed available for milk production (NE_L) is the highest in the optimized nutrient diet. This explains why the milk yield expanded with increasing feed quality [9].

Table 2-10: Description of possible diets with its chemical composition in the Peruvian Highland: dry-season forages (DS), rainy-season forages (RS) and a diet with optimized nutrient composition (OC) [9].

	Dry season diet (DS)	Rainy season diet (RS)	Optimized diet (OC)
Components	oat straw & maize stover	mixture of oat hay, alfalfa hay & maize stover	alfalfa hay & maize stover + concentrate*
Ratio	0.54 : 0.46	0.54:0.32:0.14	0.81:0.19 +concentrate*
DM (g/kg)	819	823	825
OM (g/kg)	935	923	899
CP (g/kg)	41,3	80,5	130,9
NDF (g/kg DM)	734	580	512
ADF (g/kg DM)	437	375	372
ADL (g/kg DM)	68,4	68	87,9
NEL (MJ/kg DM)	3,91	5,02	4,88

* Composition concentrate: maize, wheat middling, 130 g/kg total DMI and optimized in CP and NE requirements for cows of 454 kg BW producing 15 kg milk/day with a fat content of 40 g/kg milk.

When the diet existed of dry season feed an energy deficit occurred (Table 1-10). This was the result of a low dry matter intake combined with the low nutritional value of the feed. This deficit led to mobilization of body reserves. Cows fed with the rainy season or optimized diet did not experience a negative energy balance. For both cattle breeds the milk production increased when an optimized diet was given.

Bartl et al. [4] mentioned that dairy cattle at the coastal area of Peru is kept in fenced dry lots with a diet consisting of maize stover and concentrate mixes [4]. To have an idea of a possible ration presented to dairy cows in an intensive system in Peru the study of O'Brien et al. could be used, which described the ratio of livestock in a confinement system in Ireland [40]. In this system concentrates were essential in the ration of the herd where soybean meal dominated in terms of amount (g/kg DM) [40]. According to Bartl and al. [4] the cultivation and processing of concentrate compounds for livestock had an important share (11%) in the total emissions of GHG in the intensive coastal area of Peru.

Because of its high crude protein content, soy is often used in concentrate feed. Especially soybean meal (i.e. by-product of the oil industry) has gained interest in the animal feed industry because it's rather cheap. Argentina and Brazil are the largest producers and are expanding their cultivation area which has led to pressure on the ecosystem [46]. The impact of soy on the environment will be investigated in the following section.

2.6. Impact of soy on the environment

The FAO report of 2013 concluded that 266 million tons of soy was produced around the world in the former years, however the utilization of soy was less (Figure 2-3). They estimated that the world production will rise another 7% in the next year [1].

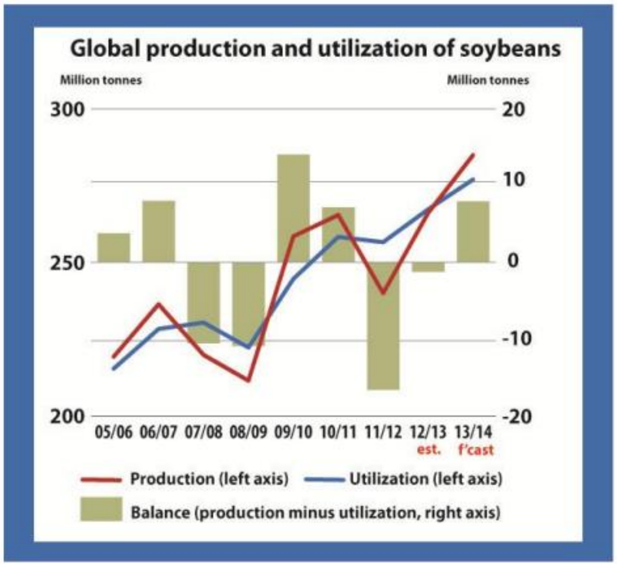


Figure 2-3: Global production and utilization of soybeans expressed in million tons [1].

The United States will be responsible for the largest share of this increase. Likewise other leading soybean-producing countries as Argentina, Brazil, India and China will have a share in the growth of global soy production [1].

In Table 2-11 countries which import soy to the EU are listed. Additionaly acreages needed in every country to fullfill the soybean meal and oil requirements of the EU 27 are presented. In total 10.566.377 hectares are needed and 27.621 000 tons are imported to the EU. The average yield of soybean in Brazil is 2,6 tons/ha which is slighlty lower as in the USA, according to Berkum et al. [47].

Table 2-11: Inventory of the acreage needed in the countries of origin to fulfill EU requirements [48].

Country of origin	Soybean equivalent, [1000T]	Acreage, [ha]
United States	2 102	781 256
Canada	463	182 290
Argentina	11 450	4 240 559
Brazil	12 789	4 995 608
Paraguay	585	263 553
Uruguay	53	26 319
Other countries	180	76 791
Total	27 622	10 566 376

In order to meet the demand, local cultivated crops and Amazon rainforest disappear to ensure enough surface for soy production. Originally more than 40% of the increased soybean area in Argentina was not cultivated and included forest and savannah [49, 50]. This land transformation leads to loss of biodiversity, land erosion and CO_2 releases. Also the chemicals used in soy production can pollute water and soil [51]. “The expansion of soy production is also a source of conflicts about land rights, violation of labor law, soil erosion, loss of health and local food security and employment in South America”[52].

Soybean producing countries were interested in genetic modified (GM) soybean plants and seeds because of the positive impact on farm income. This was accomplished by a combination of enhanced productivity and the facility of weed management. The transgenic Roundup Ready seeds (RR) are tolerant against the broad spectrum herbicide glyphosate [49, 53]. “In 2001 over 90% of the Argentine soybean area was cultivated with RR seeds”[54]. The RR soybean cultivation became a powerful competitor to other types of land use [49]. According to Qaim et al. [54] glyphosate has a low danger for the environment because there are no residues after decomposing. Likewise the international classification of pesticides (WHO 1988) has situated glyphosate in the lowest class of toxicity. Additionally Qaim et al. referred to the abandonment of herbicides belonging to toxicity classes II and III because of the GM technology [54].

On the other hand the absolute use of glyphosate in Argentina has more than doubled in 4 years (45 million kg in 2004, up to 20 million in 2000) (Figure 2-4). Although the toxicity of Glyphosate is believed to have a low danger [50], Cummins warns about some new formulations of glyphosate which have negative effects on both health and environment [55].

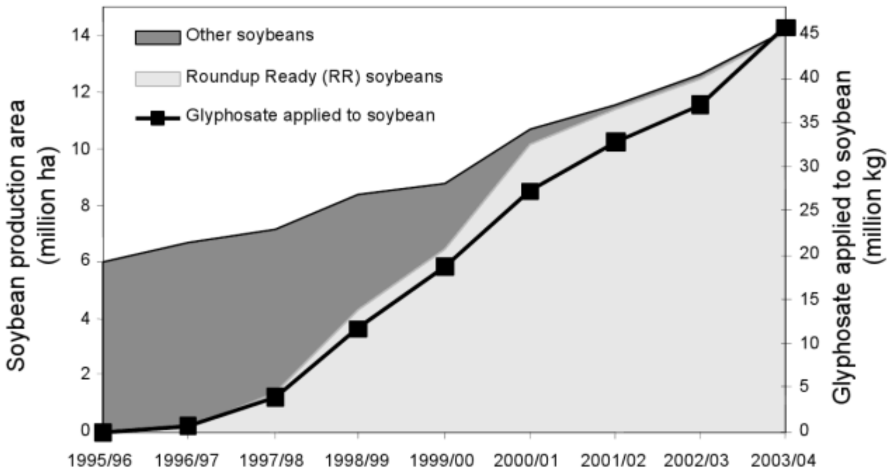


Figure 2-4: Soybean production area (million ha) and Glyphosate utilization (million kg active ingredient) in Argentina from 1996 to 2004 [50].

According to the summarized studies it can be concluded that soy has an important social and environmental impact. Up to one fourth of concentrates in animal feed consist of soybean meal [48], hence, potential replacement of this feedstuff should be considered.

2.6.1 Alternatives with similar nutritional value and low environmental impact

In the following section, different alternatives for soybean meal will be discussed. In Table 2-12 the chemical composition, nutritive value and environmental impact are listed for soybean meal and it's different alternatives [56]. The CFP, expressed in kg CO_2-equivalents per kg feed, includes cultivation inputs, machine use, processing, feed mill, additives and transport. According to data of FeedPrint [56] DDGS has a rather low CP value (261 g/kg DM, Table 2-12) while CVB [57] assigns a value of 486 g/kg DM as CP content. "The value of DDGS depends on the quality of grain, the course of fermentation and the proportion of distillers grains and soluble, and the course of drying" [58]. Therefore conclusions about the chemical composition of DDGS has to be taken with caution.

Table 2-12: Summary of chemical composition nutritive values and CFP of soybean meal and possible replacers [56].

	DM (g/kg feed)	CP (g/kg feed)	VEM$^{(1)}$ (VEM/ kg feed)	Total CFP (kg CO_2-eq/kg feed)
Soybean meal	**874**	**453**	**1013**	**575**
Possible substitutes				
Lupine	901	343	1138	788
Pea	867	221	1025	728
Fishmeal	919	641	*	1347
Cottonseed meal	892	350	767	711
DDGS	901	261	1079	718
Sunflower seed meal	890	330	736	510

(1) VEM = voedereenheid melk (Belgian-Dutch Energy evaluation system, 1 VEM=6,9 kJ NE_L); (2) DDGS = Distiller`s Dried Grains with Solubles; * not expressed in VEM: 14,5 MJ/kg DM; **Total CFP includes emissions due cultivation inputs, machine use, processing, feedmill, additives and transport.

2.6.1.1 *Lupine and/or pea*

The information resource portal for lupines [59] declare that the legume lupine can fix atmospheric nitrogen up to 200 kg/ha. Due to this quality together with the deep root system it has a high tolerance on infertile and dry soils and it has the possibility to develop in both dry and subtropical climates [59]. In Peru the average annual production of lupine grain has risen from 1.330 tons in the sixties to 9.540 tons in 2005 [59]. Froidmont et al. [60] have performed an experiment in which soybean meal is replaced by lupine or a 1:1 mixture of pea/lupine (Appendix C, Table 7-3). Pea on its own was not suitable to replace even 75% of soybean meal in the ration due to its low CP content [60]. Froidmont et al. [60] conclude that a total soybean meal substitution by lupine seeds without any loss of milk production, is possible (Appendix C, Table 7-4). According to data of FeedPrint, [56] both pea and lupine have a higher CFP than soybean meal (Table 2-12). Therefore other alternatives with a lower environmental impact have to be investigated.

2.6.1.2 *Fish meal*

One of Peru's biggest export products is fish meal and fish oil derived from pelagic fish (e.g. anchovy) [61]. The entire Peruvian national production is intended for a third of the worldwide supply (2 billion dollars fishmeal/oil) [61]. In the study of Abu et al. [62] soybean meal was replaced by fishmeal in different proportions. No effect on the milk yield or feed intake was observed although milk composition changed when soybean meal was replaced by fishmeal. Unfortunately fishmeal is no alternative due to the more than double total CFP (Table 2-12) [56] and the pressure on fish stock [61].

2.6.1.3 *Cottonseed meal and sunflower meal*

"Cottonseed meal is the product obtained by finely grinding the flakes which remain after removal of most of the oil from cottonseed by a solvent extraction process"[63]. Dehulled sunflower seed passes through the same process (i.e. solvent extraction) as cottonseed to obtain sunflower meal [63]. When cottonseed meal or sunflower meal was added to dairy cows fed with a basal ration of good quality irrigated pasture, Etheridge et al., [64] concluded that no difference in the milk yield among the different diets was significant. In order to make a comparison the intake was fixed on 1 kg CP/day. Cows fed with cottonseed meal noted a higher fat percentage in the milk. Appendix C, Table 7-5 shows the different milk yield, milk fat and milk protein contents when the CP-content intake was fixed on 1 kg a day for each feed component. Vincent et al., [65] confirmed that sunflower seed meal (as a protein supplement) had an equal feeding value for milk production as soybean meal when 300 g protein of sunflower meal (760 g feed component) was supplemented instead of the same amount of protein as soybean meal (500 g feed component). In terms of environmental burden, cotton seed meal has more impact (i.e. CFP) as soybean meal and is therefore no option (Table 2-12). The best alternative in terms of CFP would be sunflower meal compared with other soy replacing alternatives (Table 2-12).

2.6.1.4 *DDGS*

"Dried distillers grain is a by-product of bioethanol production and with the addition of solubles it is known as DDGS [58]" In the study performed by Szulc et al. [58], 26 Holstein-Friesian cows in early lactation (2nd and 3th month) received a total mixed ration of corn silage, alfalfa silage, grains and compound concentrates according to their milk production level. Additionally the cows received 1 kg soybean meal and 1 kg rapeseed meal whereas 0,5 kg of soybean meal was replaced by 1 kg DDGS. The control group received 1kg of soybean meal and 1 kg of rapeseed meal. As a result an increase of 2,4 kg of milk a day was noted in the first month whereas in the second there was no increase in milk yield. Overall there was a slight reduction in milk fat but an increase in milk protein [58]. The study of Szulc et al. [58] concluded that 50% of soybean meal could be successfully replaced by double amount of DDGS.

Benchaar et al. [66] performed an *in vivo experiment* which investigated the methane production of Holstein-Friesian cows (with rumen cannulas) on an increased amount of DDGS in the diet (up to 30% of the diet in expense of soybean meal and corn). Benchaar et al. [66] concluded that with maximum exchange of DDGS in the ration, methane emissions will linearly decrease (up to 4 %). The down side of the rise in DDGS in the ration is the lower efficiency of N utilization which declined by increasing DDGS [66]. Table 2-12 shows that the CFP of DDGS is higher than soybean meal, while the CFP of sunflower meal is the only proposed alternative which has a lower CFP.

2.7. Conclusion of the literature review

In this literature review the difference between extensive and intensive dairy cattle systems in Peru was discussed in terms of impact on the environment and the ration the livestock receives.

In the Andean valleys small mixed livestock production systems are most dominant [5]. Crossbreeding between the Brown Swiss and Holstein-Friesian breed is common [9, 10]. The ration in the Andean valley exists of irrigated alfalfa, oats and ryegrass clover [12, 13]. A modest supplement of concentrates is possible [7]. At the coastal region of Peru (Lima) large intensive dairy farms are most common [5, 17]. Livestock is kept in fenced dry lots [4] and receive a ration according to their specific nutrient requirements. Often corn stover or maize silage is supplemented with a mix of concentrates [10].

A comparison was made between formerly performed LCA studies around the world on the subject of intensive vs. extensive dairy systems with exception of the study performed by Gerber et al. which focused on a mitigation strategy on a global scale [39]. Often it's not possible to compare LCA studies because of the different approach and methodology (e.g. system boundaries, functional unit and allocation method) [20, 38, 39]. The bottlenecks for intensive dairy farms in terms of environmental impact are enteric fermentation (36% of total GHG emission), the cultivation, processing and transport of inputs (e.g. concentrates), manure storage (12% of total GHG emission) and the use of electricity and fertilizer production (14,5% of total GHG emissions) (Table 2-9) [46]. Solutions to reduce these impacts are proposed by Bartl et al. [4] by using alternative protein sources to replace soybean meal in concentrates which are locally cultivated with attention to their environmental burden. O' Brien et al. [40] also mentioned the importance of manure storage and processing (e.g. bio gas plant). A careful diet formulation would help to reduce N-losses as well. In extensive dairy systems, enteric fermentation had the largest share in terms of total GHG emissions. In order to reduce this impact an increase in digestibility of the feed [4, 41], improved genetics [39] and a higher milk yield [39] was proposed by Bartl et al. [4], Gerber et al. [39] and Mc Geough et al. [41].

Because of the previously mentioned impact of the cultivation and processing of concentrates the share of soybean meal and its environmental burden was investigated. Land transformation, water pollution and social conflicts were few of the effects of the expansion of the soybean cultivation area [51, 52]. Soy alternatives potentially include lupine, fishmeal, cottonseed meal, sunflower meal and DDGS which should not impair milk production difference in milk production [58, 60, 62, 64] when appropriately formulated. Regarding environmental impact, sunflower meal is the best soy alternative due to its low CFP (Table 2-12).

3. Material en methods

3.1. Collection of information in Peru

3.1.1 Selecting participating farmers

Sample collection and questionnaires were performed between August 14 and September 20, 2013 (end of the dry season). In order to collect information and feed samples of extensive and intensive dairy farmers, different locations with a high density of each dairy system were selected. The experience and knowledge of the different regions by staff members of UNALM (Universidad Nacional Agraria La Molina) helped us to select potential participating farmers. UNALM was the base from which preparatory work and excursions to farmers were prepared. The university is situated in the capital of Peru, Lima. The number of farmers who wanted to cooperate enlarged as the study evolved. The main selection criteria of farmers were on one hand the dairy management system the farmer applied and on the other hand the farmers' interest to participate. Each farmer in either system was interrogated trough a questionnaire which was made in advance (Appendix D). The questionnaire was written in Spanish and based on the questionnaire used by Nina Bienz [67]. Different topics included in the questionnaire: general information about the farm (e.g. amount of hectares, name of the farmer, location of the farm, etc.), characteristics of the herd (e.g. average milk production per year, calve weight, herd structure, etc.), ration of the herd (lactating cows, dry cows and calves), manure management, use of fertilizers and pesticides, irrigation and cultivation of forages. The questionnaires were obtained 'on site' (i.e. the farmers property) and personally completed and discussed with the farmer. In order to have a proper understanding of the farmers' response, a student of UNALM helped by writing down and translating the answers of the farmers'.

3.1.2 Location of the extensive and the intensive dairy farms

For the extensive dairy farms two districts from the Mantaro valley, in the department of Junín, were selected. In the two districts Apata (province of Jauja) and Matahuasi (province of Concepcion), 13 farms were sampled and farmers interrogated (Figure 3-1).

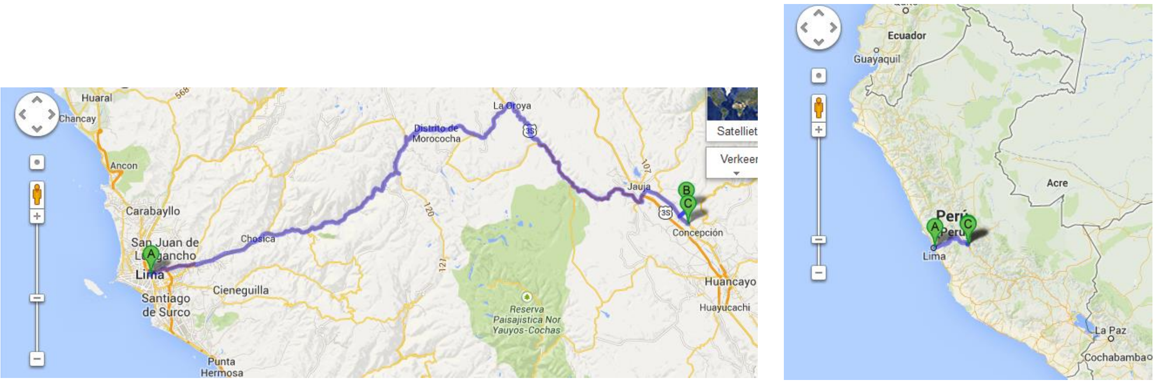


Figure 3-1: Map which shows the distance between the Capital Lima (A) and the districts Apata (B) and Matahuasi (C).

Sampling of the 13 intensive dairy farms took place in two provinces of the department of Lima, Cañete and Huaral (Figure 3-2).

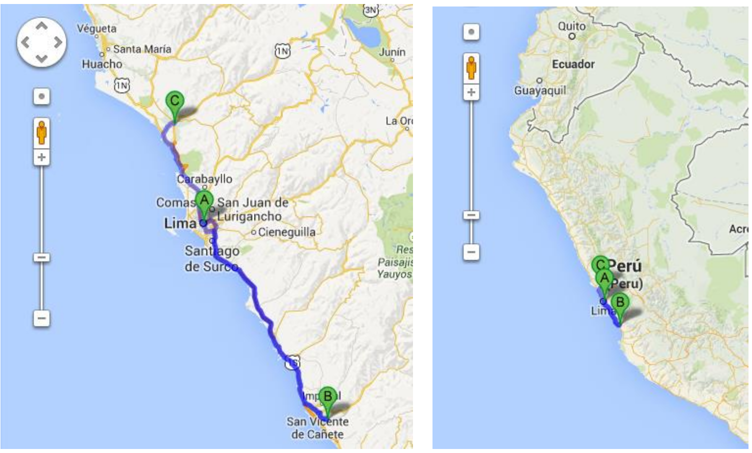


Figure 3-2: Map which shows the distance between the Capital Lima (A) and the districts Cañete (B) and Huaral (C)

3.2. Collection and preparation of feed samples

In order to propose dietary mitigation strategies feed samples of the different rations of the herd were collected. Diets most often consisted of different roughages and concentrates. All feed samples were collected separately in plastic bags. In the Mantaro Valley feed samples were sundried. Afterwards, at UNALM these feed samples were pre-dried in a little convection oven for 3 hours at 70 C° in paper bags. Feed samples which were collected at dairy farms in the department of Lima were dried in the convection oven together with the pre-dried roughages of the Mantaro valley for 24 hours at 70 C°. Due to a misunderstanding, information about the weight of the fresh samples got lost, preventing the calculation of the effective moisture content. After grinding the material trough a 1 mm screen, each feed sample was packed in a plastic bag, ready for transport to Belgium.

3.3. Proximate analysis of feed samples

The feed samples which were taken from the participating dairy farms were imported in Belgium and underwent a proximate analysis in the Laboratory of Animal production situated in Melle. All feed samples were assayed once. Analysis included crude ash (CA), crude protein (CP), ether extract (crude fat), non-detergent fibre (NDF), acid-detergent fibre (ADF) and acid-detergent lignin (ADL).

3.3.1 Dry matter (DM), organic matter (OM) and crude ash

Dry matter remains when water is evaporated by high temperature combustion. “Feed values and nutrient requirements for ruminants are expressed on a dry matter basis to compensate for the large variation in moisture content of feeds commonly fed to cattle [68]”. Crude ash is the inorganic leftover when the feed is incinerated at high temperature. The followed protocol is written down in the official journal of the European commission [69].

3.3.2 *C*rude protein (CP)

In order to obtain the crude protein content of the feed, the Kjeldahl method is applied [70]: “A sample is digested at high temperature in presence of the sulphuric acid with two catalysts. The organic nitrogen is converted to ammonium hydrogen sulphate which is then liberated by adding concentrated NaOH solution, evaporated by steam distillation and collected in a boric acid solution. Finally, the ammonium hydroxide concentration is determined by titration with a hydrochloride acid solution of known concentration and is equivalent with the nitrogen content. This N amount is calculated back to protein content by multiplying with 6,25 [70]”.

3.3.3 Ether extract

After a weak hydrolysis, fat is extracted with diethyl ether. After evaporation of the solvent, fat is gravimetrically determined, following the Soxhlet method [70]”.

3.3.4 Non-detergent fibre (NDF), Acid detergent fibre (ADF) and acid-detergent lignin (ADL)

NDF includes the amount of cellulose, hemicellulose and lignin. In order to separate the hemicellulose, the ADF technique is applied followed by ADL to reveal the lignin content of the feed. “NDF was analysed with sodium sulphite but without a heat-stable amylase and expressed exclusive of residual ash. Acid detergent fibre (ADF) was determined by sequential analysis of the residual NDF and expressed exclusive of residual ash [71]". The remaining material after the ADF method is used for the determination of lignin (ADL).

3.4. Carbon Foot Print (CFP) of milk

3.4.1 General characteristics of a CFP

A Carbon Footprint (CFP) is a specific life cycle assessment (LCA) which is related to climate change. A CFP quantifies the emission of greenhouse gases (CO_2, NH_4 and NO_2) along the entire life cycle of a product, in this case 1 kg fat-and-protein-corrected milk (FPCM) [22]. This 1 kg FPCM is called the functional unit. A CFP model is chosen instead of an LCA model because of lacking data to perform the necessary research of the impact of eutrophication and acidification on the environment. In this current thesis, the assessment was applied to one average intensive dairy system and one average extensive dairy farm.

Development of a CFP is an iterative process, which requires decisions to be made based on data which need to be collected, respecting feasibility to collect these data at farm level. Furthermore, some assumptions needed to be made during the process of the CFP model development. The model as it is described in the Materials and Methods section is the result of this iterative process and could be used as a basis for data collection to extend the project to a larger number of farms from both production areas.

A detailed description of processes and applied methods included in the calculation, is provided below. The work of Meul et al. [72], who conceptualized a LCA model as a spreadsheet package using Microsoft Excel was used as a starting point for the current model development. They used detailed farm data, which were generally retrieved from farm accountancies of Flemish farms [72]. The CFP model which is expressed in kg CO_2-equivalents allows to estimate the environmental impact of milk production at farm level on a yearly basis, considering a cradle-to-farm gate approach, i.e. including all processes of the milk production cycle up to the moment that raw milk leaves the farm [72]. Production of applied medicine and minerals fed to dairy cows are not included in the CFP because of their small environmental impact [40]. In the current case study, no accountancy data were available and the model uses detailed farm data retrieved by interrogation of participating farmers in the selected region. Allocation between produced milk and meat at different dairy farms is not known. Because there was no indication for differences between both systems in terms of meat vs. milk output the same value for allocation was taken for both systems, which was based on the intensive dairy farm in the study of Bartl et al. [4] (96 milk : 4 meat). No environmental impact is allocated to exported manure [72]. Due to lack of complete data, the CFP of used inputs for cultivation, processing and transport of home grown and purchased crops (mineral fertilizers, pesticides, diesel, electricity, feed mill, etc.) was estimated using the program FeedPrint (Appendix G, Table 7-11). Whereas economic allocation in the production of feed ingredients and their co-products was automatically applied.

3.4.2 Life cycle inventory

The CFP model is implemented as a spread sheet package in Microsoft Excel. In Figure 3-3 an overview is given from the structure of the CFP model. The first 4 subjects (Preparation) will calculate intermediate solutions which are integrated in the general information sheet. The emissions of the different processes at farm gate level (Processes) will be calculated separately and listed in an overall summary. The purpose of the different sheets, together with the applied calculations, will be discussed in the following sections.

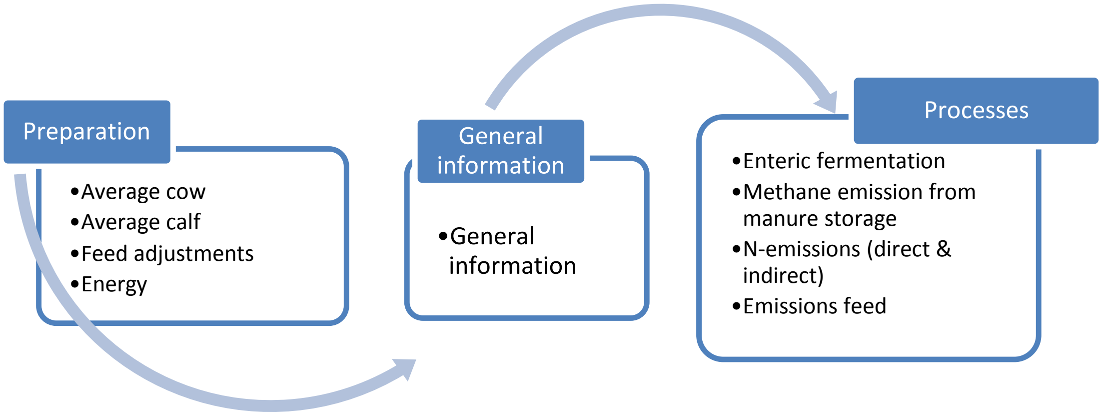


Figure 3-3: Structure of the CFP model: Preparation, base and different processes wherefore each subject covers a excel work sheet.

3.4.2.1 *Preparation*

Thanks to the predefined Spanish questionnaire detailed information was obtained about each dairy farm (e.g. structure of the herd, total milk production and average milk production per cow, weight of a new born calve). Additional information concerning grazing management and the time per year the herd spent on pasture was also provided by the farmer.

In the “Preparation” section, 4 subjects calculate intermediate solutions which are needed in the general information sheet (Figure 3-3). All data and calculations of each subject are presented separately below. First a detailed description of the difference in breed, calf mortality and calving rate of heifers in both systems, is presented. This information is needed to calculate all 4 subjects.

Key figures of the total dairy herd

On all surveyed dairy farms male calves were sold. Female calves and heifers were kept as replacement herd. In order to calculate the net energy for maintenance, the average weight of the dairy herd and calves (until 24 months) is needed. Different data are used for the different dairy systems (intensive vs. extensive). In the coastal area the Holstein breed is most common. Therefore the weight of the calf at birth and after 2 years (i.e. birth: 45 kg, 24 months: 620 kg, adult: 680 kg) is taken from Previvet [73]. This is similar as the ones proposed by the Holstein Association USA [74]. In the Mantaro valley the local Criollo breed is often mixed with Brown Swiss and Holstein cows. Therefore data is taken from Bartl et al. [75] for the weight of a calf at birth and as an adult (i.e. birth: 30 kg, adult: 420 kg).

One of the parameters that are needed to calculate the net energy for growth, is growth per day of calves and growth per day of the dairy herd. Growth per day of the dairy herd is set on the value zero due to lack of data and the small contribution of NE growth to the total NE requirements of the cow. Growth per day for calves until 2 years (730 days) is calculated according to Equation 3-1.

Equation 3-1: Calculation to become growth of calves until 2 years old in kg per day.

$$\text{Growth calves (kg/day)} = \frac{\text{weight calves (kg)}}{730\,\text{days}}$$

The net energy for pregnancy calculated in the “Feed adjustment” worksheet (see further) needs the total number of calvings a year and the calving rate by heifers. In order to calculate the total number of calvings a year, calf mortality has to be known. For the extensive dairy systems data for calf mortality is taken from Bartl et al. [75] were two possibilities for the percentage of calf mortality were given depending the farmers’ income by selling milk. Therefore an average has been taken between the number of the two scenarios (i.e. calf mortality of 15,35 %).

After consulting data from the questionnaire completed by the intensive dairy farm “Piamonte” the calf mortality rate was set on a yearly average of 8.54%. Due to lack of data this outcome was used for the intensive dairy farm which was implemented in the CFP model. The calving rate of heifers was also received from data of the “Piamonte farm” which was set on 32%. Lack of data of the valley forced us to use the same value for this farming system.

Average cow

In order to know the average feed intake of an average cow during one year, the sheet “Average cow” was implemented. It is not preferable to work with fixed numbers of lactating and dry cows because of the variation in the herd over a year. Therefore the proportion of time a cow is in a lactating or dry stage as well as the primiparous or multiparous status of the cow is taken into account (Equation 3-2). The number of months an average cow is in lactation, the length of the dry period and calving interval is known due to the answers given by farmers as a response on the questionnaire. The percentage of primiparous animals in the herd is calculated trough the number of primparous animals divided by the number of animals present in the total herd multiplied by 100 (i.e. replacement rate). The multiparous animals are calculated as 100% minus the replacement rate.

Equation 3-2: Proportion of time an average cow is in lactation or dry stage, taken into account the distribution of primiparous and multiparous cows in the herd.

$$\%\ \text{time lactating} = \frac{\text{number of months in lactation}}{\text{calving interval}}$$

$$\%\ \text{time dry multiparous} = \frac{\text{number of months dry}}{\text{calving interval}}$$

$$\%\ \text{time dry primiparous} = \%\ \text{time dry multiparous}$$

If a concentrate mixture is part of the ration, the formula of the compounds of the concentrate of the different production groups of the herd has to be known. The next step is to calculate the total ration (per feed component) consumed within the different groups of the herd according lactation stage (early, mid and late lactating animals, dry cows) per day.

In order to calculate the total daily supply of fresh feed of an average cow, the share of feed intake per feed component by each of the subgroups (lactating animals' multiparous, dry cows' multiparous, lactating animals primiparous, dry cows primiparous) is calculated separately (Equation 3-3) and summed at the end per feed component (Equation 3-4). The fixed values used in Equation 3-3 refer to the time (%) dairy cows are separated in different groups according their lactation stage. Lactating animals are divided for 33% of the time in the "early lactation" group (Early: 0-100 DIM), 49% of time in the "mid lactation" group (mid: 100-250 DIM) and 18% of the time in the final stage of their lactation (late: 250-305 DIM).

Equation 3-3: intake of feed component x for different subgroups within the herd (multiparous, lactating animals; multiparous dry animals; primiparous, dry animals; primiparous lactating animals).

$$\boxed{\begin{aligned}
&SLAM_{feedcompx} = \%time\,lactating * \%\,multiparous * EG * 33\% + MG * 49\% + LG * 18\% \\
&SDAM_{feedcompx} = \%time\,dry\,multiparous * \%multiparous * DG \\
&SLAP_{feedcompx} = \%\;time\;lactating * \%\,primiparous * EG * 33\% + MG * 49\% + LG * 18\% \\
&SDAP_{feedcompx} = \%time\,dry\,primiparous * \%\;primiparous * DG
\end{aligned}}$$

With: $SLAM_{feedcomp\,x}$(kg fresh/day) = daily amount of a feed component x consumed by multiparous lactating animals

$SDAM_{feedcomp\,x}$(kg fresh/day) = daily amount of a feed component x consumed by multiparous dry animals

$SLAP_{feedcomp\,x}$ (kg fresh/day) = daily amount of a component x consumed by primiparous lactating animals

$SDAP_{feedcomp\,x}$(kg fresh/day) = daily amount of a component x consumed by primiparous dry animals

HG (kg fresh/day) = daily amount of a feed component x consumed by early lactating animals

MG (kg fresh/day) = daily amount of a feed component x consumed by mid lactating animals

LG (kg fresh/day) = daily amount of a feed component x consumed by late lactating animals

DG (kg fresh/day) = daily amount of a feed component x consumed by dry animals

Equation 3-4: calculation of total amount of component x consumed by an average cow (kg fresh).

$$\boxed{TAF_{feedcompx}(kg\,/\,day\,/\,cow) = SLAM_{feedcompx} + SDAM_{feedcompx} + SLAP_{feedcompx} + SDAP_{feedcompx}}$$

With: $SLAM_{feedcomp\,x}$(kg fresh/day) = daily amount of a feed component x consumed by multiparous lactating animals

$SDAM_{feedcomp\,x}$(kg fresh/day) = daily amount of a feed component x consumed by multiparous dry animals

$SLAP_{feedcomp\,x}$ (kg fresh/day) = daily amount of a feed component x consumed by primiparous lactating animals

$SDAP_{feedcomp\,x}$(kg fresh/day) = daily amount of a feed component x consumed by primiparous dry animals

$TAF_{feedcomp\,x}$ (kg fresh/day) = total daily amount of a feed component x consumed by an average cow

Average calf

Intensive dairy system

Due to lack of data an average calf (0-2 year) in each intensive dairy system receives the same ration. In order to calculate the ration of an average calf, different amounts of feed for different stages of age and a fixed formula of concentrates, were taken into account based on personal communication with UNALM (Table 7-6, appendix E). The amount of feed varies between the age of 0-3 months, 3-12 months and between 1 and 2 year old heifers (i.e. older female calves ready to give birth). The total intake of concentrates by heifers was set on 3, 5 kg. The intake of roughage by heifers was calculated in the same way as done for the cows (i.e. according NE and CP requirements). These calculations will be explained in the section “feed adjustments”. The total feed intake (kg DM/day) for an average calf is calculated in Equation 3-5.

Equation 3-5: Feed intake (kg/day) for an average cow.

$$\text{Feedintake}\left(\frac{kg\,DM}{day}\right)=\sum_{1}^{n}\left(\frac{3}{24}\,feedcomp_{xi}\,(A)+\frac{9}{24}\,feedcomp_{xi}\,(B)+\frac{12}{24}\,feedcomp_{xi}\,(C)\right)$$

With: Feed intake (kg DM/day) = amount of kg DM an average calf could ingest per day

Feedcomp$_{xi}$ (A) (kg DM/day) = amount of component x a calf receives between the age of 0 and 3 months

Feedcomp$_{xi}$ (B) (kg DM/day) = amount of component x a calf receives between the age of 3 and 12 months

Feedcomp$_{xi}$ (C) (kg DM/day) = amount of component x a calf receives between the age of 12 and 14 months

Extensive dairy system

In order to calculate the ration of an average calf (0-2 year), information of different interrogated farmers was combined due to incomplete data of individual farms. The amount of feed and the feed components varied along the age of the calf. The calf received milk in decreasing amount until the age of 3 months, gradually supplemented with a milk replacement mix. Afterwards, wheat bran was supplied in increasing amounts according to the age of the calf. The intake of roughages was calculated according to the approach described in the next section “Feed adjustments”.

Feed adjustments

In the section “Average cow”, the feed intake of an average cow expressed in kg fresh matter per day was calculated. The amount of concentrates an average cow receives will not be changed because it is assumed that these values are known correctly by the farmer. In the intensive dairy systems, farmers often could not display exact data on roughage intake. Therefore it is possible that feed supply of roughages, calculated in sheet “Average cow”, is overestimated. Moreover, in case of the extensive dairy system it was not possible to gather exact data of intake by grazing on the mixed pastures or of the oat straw ingested in the stable. Therefore feed adjustments are made based on the principle to fulfil the daily net energy (NE) and crude protein (CP) requirements of the cows according to the IPCC guidelines (Appendix H, Table 7-12) for milk production and maintenance, respecting the ratio of the different roughage compounds as indicated by the farmer.

Roughage intake estimated from NE and CP requirements for dairy cows

First, the calculation of the importance of each roughage in the ration (Importance$_{roughagex}$) is based on kg fresh matter of each roughage, indicated by the farmer, in this way the original ratio of the roughages in the ration remains the same as indicated by the farmer. In case of the extensive dairy system the intake of certain roughages is estimated by the farmer (i.e. corn stover and fresh maize) while in case of others (i.e. pastures and oat straw) no data were available. In order to have a realistic distribution of the average intake of each roughage the "Importance$_{roughagex}$" is estimated for the roughages from which no proposed intake was available. This estimation is based on the importance of each roughage in the ration taken into account the original ratio of roughages (indicated by the farmer) and/or according time cows were exposed to the roughage source (e.g. grazing). Also the palatability is roughly estimated and taken into account (e.g. intake in total ration of irrigated pasture will be higher than intake of corn stover).

Equation 3-6: Ratio of intake of roughage $x_{i.}$

$$\text{Importance}_{Roughagex_i}(\%) = \frac{\text{supply}_{roughage\, x_i}}{\sum_{1}^{n} \text{supply}_{roughages\, x_i}} * 100$$

With: Importance $_{Roughage\ xi}$ (%) = share of the supply of roughage x_i on the total supply of all roughages together

supply $_{roughage\ xi}$ (kg fresh/day) = supply of roughage x_i by an average cow

Secondly the total intake in kg DM is estimated according to NE and CP requirements. Starting with the estimation of the ration requirements of an average cow in CP [76] and NE following the IPCC [37] Tier 2 approach. Afterwards the amount of CP and NE fulfilled by the concentrates in the ration are subtracted from the NE and CP requirements of the cow. The remaining NE and CP needs to be filled trough NE and CP of roughages.

The total NE content of the roughages in the ration will be calculated taken into account their importance in the ration (Importance $_{Roughage\ xi}$) and the NE content of each feed component (Table 7-7, Appendix E) (Equation 3-7).

Equation 3-7: Total net energy of roughages (MJ/day) in the ration according their proportion.

$$NE_{Roughages}\left(\frac{MJ}{day}\right) = \sum_{i=1}^{n}\left(\text{Importance}_{Roughagex_i}(\%) * NE_{Roughagex_i}\left(\frac{MJ}{day}\right)\right)$$

With: NE Roughages (MJ/day) = Total NE content in roughages according their proportion in the ration.

Importance roughagexi (%) = Share of the intake of roughage xi on the total intake of all roughages together

NE $_{Roughagexi}$ (MJ/day) = NE content of each roughage compound x_i (Table 7-7, Appendix E).

The amount of kg DM needed to fulfil the NE requirements are calculated in Equation 3-8.

Equation 3-8: Total intake in kg DM of roughages to fulfill the net energy requirements.

$$Intake_{NE\,req}\left(kg\ DM\right)=\frac{\left(NE_{tot\,req}\left(MJ/day\right)-NE_{conc}\left(MJ/day\right)\right)}{NE_{Roughages}\left(MJ/day\right)}$$

With: Intake $_{NE\ req}$ (kg DM) = total amount of kg DM of roughages to fulfil net energy requirements of the cow

NE $_{tot\ req}$ (MJ/day) = Total net energy requirements of the cow

NE $_{conc}$ (MJ/day)= Net energy requirements fulfilled by concentrates

NE $_{Roughages}$ (MJ/day) = total amount of NE in the roughages according their proportion in the ration.

Exactly the same methodology is used to know the intake level of roughages according to CP requirements. As last step the lowest total intake of roughages (kg DM) will be chosen and fulfilled with mixed pastures in the extensive dairy system and with urea in the intensive dairy system in order to meet both daily requirements of NE and CP of an average cow. Because urea has no energy content the ration in the intensive system has no excess in NE, while in the extensive system the ration will have an excess in NE due to the extra amount of mixed pastures added to the ration in order to fulfil the daily requirements in CP.

Roughage intake estimated from NE requirements for calves

Also for the ration of an average calf, adjustment of roughage intake is made. The same methodology as described for the feed adjustments of an average cow is used.

Digestible energy of the feed

Digestible energy (DE%) of the total ration of the dairy cows and calves (expressed relatively with respect to the gross energy (GE) content of the ration), was based on the net energy (NE%) data of each feed component. Table 7-7 (Appendix E) which is based on NRC guidelines and personal communication with staff from UNALM gives an overview of the net energy of different feed components (Mcal/kg DM). The gross energy (MJ/kg DM) of each feedstuff is calculated using the outcomes of the ‘proximate’ analysis whereby the share of the carbohydrates is estimated by subtracting ash, CP and CF content (decimal digits) of the total components (Equation 3-9).

Equation 3-9: Calculation of the gross energy (GE) in MJ/kg DM of component x_i In the ration.

$$GE_{Component xi}(MJ/kg\ DM)=\frac{CP\%}{100}*24,5+\frac{CF\%}{100}*39+(1-\frac{\text{ash}\%}{100}-\frac{\text{CP}\%}{100}-\frac{\text{CF}\%}{100})^{(1)}*17,5$$

$^{(1)}$ share of carbohydrates in the sample

After the conversion of NE (Mcal/kg DM) to NE (MJ/kg DM) by multiplying with factor 4,18 MJ/Mcal the ration of NE (MJ/kg DM) to GE (MJ/kg DM) leads to NE%. Through the ratio of net energy available in diet for maintenance (NE_M) to digestible energy consumed (REM)(eq. 10.14 IPCC 2006, [37]) the DE% can be found when the NE% is known using the mathematical program Maple.

3.4.2.2 *General information*

The worksheet "General information" is divided in two different subsections. All data and calculations of each topic are presented separately. This worksheet forms the basis of the CFP model (Figure 3-3).

Home grown and purchased roughages, concentrates and by-products

The results of the worksheet "Average cow" and "Average calf" are integrated in this section together with the adjustments (kg DM of roughages) of the worksheet "feed adjustments". The total amount of roughage intake and concentrate intake is summarised in this subsection (Equation 3-10).

Equation 3-10: Total amount of feed for cow or calves (kg DM/day/ total amount of animals).

$$TAFK\ (kg\ DM\ /\ day\ /\ dairy\ herd) = \sum_{1}^{n} TAK_{feedcompxi} (kg\ fresh\ /\ day\ /\ cow) * DM_{feedcompxi} (g\ /\ kg) * LADC$$

$$TAFC\ (kg\ DM\ /\ day\ /\ all\ calves) = \sum_{1}^{n} TAC_{feedcompxi} (kg\ DM\ /\ day\ /\ calf) * CAH$$

With:

TAFK (kg DM/day/dairy herd) = total amount of feed component x_i consumed per day by lactating and dry cows.

TAFC (kg DM/day/dairy herd) = total amount of feed component xi consumed per day by all calves.

LADC = number of lactating and dry cows (primiparous and multiparous)

CAH = number of calves and heifers

$DM_{feedcompxi}$ = Dry matter content for each feed component xi taken from (Table 7-7, Appendix E)

Nitrogen content of feed

In order to calculate the dietary N intake by the dairy cows and calves, the nitrogen content of the ration is calculated in kg N per kg DM (Equation 3-11), based on the CP analysis of the sampled ration components.

Equation 3-11: Calculation of kg nitrogen per kg dry matter in the ration of the dairy herd, or in the ration of the calves.

$$kg\ N\ per\ kg\ DM_{ration\ dairyherd} = \frac{\sum (kg\ N\ per\ kg\ DM_{feedcompx} * total\ kg\ DM_{feedcompx})}{total\ kg\ DM_{ration\ dairy\ herd}}$$

$$kg\ N\ per\ kg\ DM_{ration\ calves} = \frac{\sum (kg\ N\ per\ kg\ DM_{feedcompx} * total\ kg\ DM_{feedcompx})}{total\ kg\ DM_{ration\ calves}}$$

Milk production

The total yearly milk production of each dairy herd was given by the participating farmer. The milk composition (% fat and protein), which was necessary to calculate kg FPCM, was determined by a student-colleague using milk samples taken on every farm. For more details about the collection of the milk samples as well as the analysis of the milk components, the master thesis of Van Coppenholle H. [77] can be consulted. The amount of kg FPCM is important in the "Summary" where the environmental impact is expressed per ton FPCM. The calculations to convert milk production in kg FPCM can be found in Equation 3-12.

Equation 3-12: Formula to convert milk production (l/year) to kg fat-protein-corrected milk (FPCM) [78].

$$kg\ FPCM = (0{,}337 + (0{,}116 * \%\ protein) + (0{,}06 * \%\ fat)) * milkproduction(l / year)$$

3.4.2.3 ***Processes***

Different processes responsible for environmental burden which occur on-farm and off-farm are presented separately. First the animal feed digestion or enteric fermentation is presented followed by the manure storage and its mode of application. As mentioned before the overall nutrient surplus at farm level is not included in the CFP model. Next, the direct nitrogen emissions from manure storage and grazing are given as well as the indirect emissions due to leaching and volatilisation of nitrogen. The last process that is presented include emissions due to feed production which comprises the cultivation of home grown roughages and emissions due to the cultivation and transport of purchased concentrates, by-products and roughages. In the case of the surveyed extensive and intensive dairy farms, no animals were sold except for the young male calves.

Enteric fermentation

The enteric fermentation (Equation 3-13) is estimated from the gross energy intake by the animals according to IPCC Tier 2 approach and the use of the methane emission factor (Equation 3-14) to incorporate differences in feed digestibility between farms [72].

"Gross energy intake was estimated for lactating cows and replacement animals using yearly average numbers of animals in each category and included an estimation of net energy requirements according to the IPCC Tier 2 approach"[72]. The calculation of the digestibility of the ration of dairy cows and calves is described in the previous section "Digestible energy of the feed".

Equation 3-13: Calculation of the emission of kg methane at farm level per year due to enteric fermentation [37].

$$EF = \left[\frac{\left[GE_{DC} * \frac{Y_{m\,DC}}{100} * 365 * DC\right]}{55.65}\right] + \left[\frac{\left[GE_{C} * \frac{Y_{m\,C}}{100} * 365 * C\right]}{55.65}\right]$$

With: EF = Emission of kg methane at farm level per year

GE_{DC} = gross daily energy intake of dairy cows, MJ/herd/year

Ym_{DC} = methane conversion factor, percentage of gross energy in feed converted to methane

DC = number of dairy cows

GE_C = gross daily energy intake of calves, MJ/herd/year

Ym_C = methane conversion factor, percentage of gross energy in feed converted to methane

C = number of dairy cows

55.65 = energy content of methane (MJ/kg CH_4)

Equation 3-14: Calculation of methane emission factor whereby DE% = DE (MJ/kg DM) / GE (MJ/kg DM) [79].

$$Y_m = 9.57 * 0.05 * digestibility\ rate\,(DE\%)$$

Methane emissions from manure storage and grazing

Methane emission due to manure storage and manure excretion on pastures is estimated in Equation 3-15 according to IPCC Tier 2 guidelines. Methane conversion factors for each manure management system S within a specific climate region k ($MCF_{(S,K)}$) with temperate annual temperatures were retrieved from IPCC guidelines [37].

Equation 3-15: Annual methane emission factor of manure management at farm level per year [37].

$$EF_{(T)} = \left(VS_{(T)} * 365\right) * \left[B_{o(T)} * 0.67 \frac{kg}{m^3} * \sum_{S,K} \frac{MCF_{S,K}}{100} * MS_{(T,S,K)} \right] * LS_T$$

With:

$EF_{(T)}$ = annual CH_4 emission factor for livestock category T, kg CH_4/animal/year

$VS_{(T)}$ = daily volatile solids excreted for livestock category T, kg DM/animal/year

365 = basis for calculating annual VS production/day/year

$Bo_{(T)}$ = maximum methane producing capacity for manure produced by livestock category T, m3 CH_4/kg of VS excreted

0,67 = conversion factor from m^3 CH_4 to kilogram CH_4

$MCF_{(S,K)}$ = methane conversion factors for each manure management system S within climate region k,%

$MS_{(T,S,K)}$ = fraction of livestock category T's manure handles using manure management system S in climate region k, dimensionless

LS_T = number of animals in livestock category T

In the intensive dairy farms, calves until 6 months were housed on straw bedding which follows the manure management system of solid storage (MCF= 4%). From the age of 6 months all animals were kept on dry lots (MCF=1,5%). In the extensive dairy farms, information concerning the time per year spent on pasture by calves and dairy cows was used to calculate the fraction of manure in each manure management system ($MS_{(T,S,K)}$) [72]. Calves under the age of 6 months are mostly kept on straw bedding but in certain extensive dairy farms the calves are not separated from the mother. The dairy herd stays on pastures (MCF = 1,5%) for 7 hours a day. By night and during milking the herd is kept in stables on sandy or concrete floors. In the extensive dairy system implemented in the CFP model, collected manure is sundried and stored for several months (MCF= 4%).

Direct nitrogen emissions from manure storage and grazing

"Nitrogen excreted by animals was estimated as the difference between the total N intake – calculated as the dietary DM intake and the N content of the diet – and the amount of N retained by the animals in milk production and weight gain (according to IPCC [37]). For each farm, information concerning time per year spent on pasture by calves and dairy cows was used to calculate the fraction of manure in each manure management system (i.e. on pasture, on straw bedding or on dry lot)"[72].

Direct nitrous oxide emissions were estimated using IPCC Tier 2 approach [72] (Equation 3-16). Emission factors (EF_3) were 0,02 kg N_2O-N per kg N excreted on pasture; 0,005 kg N_2O-N per kg N excreted for solid manure and 0,02 kg N_2O-N per kg N excreted on a dry lot, according to IPCC [37].

Equation 3-16: Direct N_2O emissions from manure management kg N_2O/year.

$$N_2O_D = \left[\sum_S \left(\sum_T N_{(T)} * Nex_{(T)} * MS_{(T,S)} \right) * EF_{3(S)} \right] * \frac{44}{28}$$

With: N_2O_D = direct N_2O emission from manure management, kg N_2O/year

$N_{(T)}$ = number of head of livestock species/category T in the farm

$Nex_{(T)}$ = annual average N excretion per head of species/ category T, kg N/animal/year

$MS_{(T,S)}$ = fraction of total annual nitrogen excretion for each livestock species/category T that is managed in manure management system S, dimensionless

$EF_{3(S)}$ = emission factor for direct N_2O emission from manure management system S, kg N_2O-N/kg N in manure management system S

S = manure management system

T = category of livestock

44/28 = conversion of (N_2O-N) emissions to N_2O emissions

Indirect N_2O emissions after volatilization and leaching

Indirect N_2O-emissions due to volatilization and leaching of nitrogen according the manure management system are estimated using IPCC methodology [37]. Due to lack of data, Tier 2 approach (Equation 3-17 and 3-18) is used in combination with Tier 1 in order to obtain nitrogen loss due to volatilization ($N_{volatilisation}$) and leaching ($N_{leaching}$).

Equation 3-17: Indirect N_2O emission due to volatilization of N from manure management (kg N_2O/year).

$$N_2O_{vol} = (N_{volatilisation} * EF_4) * \frac{44}{28}$$

With: N_20_{vol} = indirect N_2O emissions due to volatilization of N from manure management, kg N_2O/ year
EF_4 = emission factor for N_2O emissions from atmospheric deposition of nitrogen on soils and water surfaces kg N_2O-N (0.01 = default value in kg N_2O-N)
$N_{volatilization}$ = amount of manure nitrogen that is lost due to volatilsation of NH_3 and NO_X, kg N/year

Equation 3-18: Indirect N_2O emission due to leaching of N from manure management (kg N_2O/year).

$$N_2O_{leach} = (N_{leaching} * EF5) * \frac{44}{28}$$

With: N_20_{vol} = indirect N_2O emissions due to leaching and run-off from manure management, kg N_2O/ year

EF_5 = emission factor for N_2O emissions from nitrogen leaching and run-off kg N_2O-N

(0.0075 = default value in kg N_2O-N)

$N_{leaching}$ = amount of manure nitrogen that leached from manure management systems, kg N/year

Emissions due to feed production

The goal of this section is to calculate the total CFP of the production of roughages (purchased and homegrown) and purchased concentrates taken into account the intake of the dairy herd.

First the ration of the dairy herd is listed in kg DM according to previous calculations in the "Average cow" and "Adjustments feed" sheet. The FeedPrint tool is used to obtain the total contribution of CFP (expressed in kg CO_2-equivalents/kg feed) of each component of the ration and the share of transport (%) in the total CFP. In this way the CFP of cultivation inputs, machine use, feed mill and processing can be obtained without the inclusion of transport. Because the emissions due to transport in FeedPrint are based on data from the Netherlands. In order to estimate the transport cost of the roughages and concentrates the Origin of feedstuffs in the diet of both farming systems was assigned based on information obtained from staff of UNALM (Appendix G, Table 7-10).

After assigning a distance between Lima and certain importing countries or areas as USA (9400 km), Paraguay (3664 km), Bolivia (1872 km) and Concepcion (Mantaro valley, Peru, 278 km) by Google Maps and the information of CFP of each type of transport (road, railway, ocean, river) by Meul et al. [80], the total transport cost in terms of CO_2-emissions was estimated. The distance between Lima and Argentina was not obtained by Google Maps due to the outcome which was higher than in case of Lima-USA. Therefore data from Bartl et al. was used for Lima-Argentina (e.g. 7495 km [4])

The estimated transport cost for each component of the ration (Equation 3-19) was summed with remaining CFP (without transport cost) calculated by FeedPrint. The total CFP of a feed component$_{xi}$ in the ration is estimated in Equation 3-20.

In order to have an idea about the impact on land use change (LUC) of the ration, the FeedPrint tool is used to calculate the LUC of each feed component of the ration of the dairy herd.

Equation 3-19: Calculation of the CFP of a component $_{xi}$ in the ration (kg CO_{2}-eq/kg feed) taken into account the distance between place of cultivation and area of intake together with the type of transport used for this transport.

$$\text{Transport}_{P\,compxi} = \sum_{i=1}^{n} (\text{Distance}_{compxi} * \text{Type of transport}_{compxi})$$

With: Transport P $_{compxi}$ (kg CO_2-eq/kg feed) = CFP of component$_{xi}$ due to transport between cultivation and intake

Distance $_{compxi}$ (kilometre) = Distance of component$_{xi}$ between place of cultivation and place of intake

Type of transport $_{compxi}$ (kg CO_2-eq/kilometre) = Type of transport used to overcome the distance

Equation 3-20: Calculation of the total CFP of each component$_{xi}$ in the ration.

$$\text{CFP}_{\text{compxi}} = \left[\left(\text{Total CFP}_{\text{Fcompxi}} - \text{Transport}_{\text{Fcompxi}}\right) + \text{Transport}_{\text{P compxi}}\right] * \text{Intake dairy herd}$$

With: CFP $_{\text{compxi}}$ (kg CO_2-eq/farm level/day) = Total CFP of component$_{xi}$ at farm level

Total CFP F $_{\text{comp xi}}$ (kg CO_2-eq/kg feed) = Total CFP of component$_{xi}$ calculated by FeedPrint

Transport F $_{\text{comp xi}}$ (kg CO_2-eq/kilometre) = CFP of component$_{xi}$ due to transport calculated by FeedPrint

Transport P $_{\text{compxi}}$ (kg CO_2-eq/kilometre) = CFP of component$_{xi}$ due to transport between place of cultivation and place of intake

Intake dairy herd $_{\text{compxi}}$ (kg DM/dairy herd/day) = Intake of feed component$_{xi}$ by dairy cows and calves

3.4.2.4 *Summary*

In the excel worksheet “Summary” the emissions of the different processes are summarised (Figure 3-3). The different processes are expressed in their corresponding emissions (g CO_2, g CH_4 and g N_2O) and in overall kg CO_2-equivalents per animal per day which allows to compare the emissions of different processes and to compile emissions of different sources. The same output expressed in kg CO_2-equivalents at farm level per year can be found in Appendix F Table 7-8. The total CFP for each dairy farm is expressed in kg CO_2-eq per kg FPCM at farm level. The overall land use change (LUC) for the total ration can also be found in the summarised table expressed in kg CO_2-eq per kg FPCM at farm level in this Excel sheet.

4. Results

4.1. Farm characteristics

4.1.1 Characteristics of extensive dairy farms in Mantaro Valley

The extensive dairy farms in the Mantaro Valley are characterized by family farming with a low input management system. The herd size is often small (between 6-35 adult cows)(Table 4-1). But exceptions with 70 cows or more occur (e.g. IVITA which was in ownership of the university UNALM and had a herd number of 160 cows). The herd is kept on pastures for on average of 5 to 6 hours a day. The pastures are not permanent and are reseeded every 3 years. The cultivated pastures consist of 40% Italian ryegrass (Lolium multiflorum), 40% red clover (*Trifolium pratense)* and 20% alfalfa (*Medicago sativa*). When the herd is not on the pastures, it is housed in stables (e.g. during two-daily milkings, overnight). The pavement of the stables often exists of concrete or sand. The replacement herd is kept on straw bedding (i.e. until 6 months). Part of the land is cultivated and used for the production of roughages. Most common roughages in the Mantaro valley area are maize (*Zea mays*), alfalfa, oats (*Avena sativa*) and the common vetch (*Vicia sativa*). Maize is cultivated in the wet season while oat is seeded in the dry season (Table 4-2). All land in the valley is irrigated by the Mantaro River. Depending on the farmers judgement, extra roughages are given to the herd as “cut and carry”. This is variable throughout the year while corn stover is rather a dominant roughage in the dry season. When the mixed pasture is cut, several farmers fertilise with urea. Others use calcium ammonium nitrate. Triple superphosphate is used by the big dairy farm which is under university ownership. Pesticides are not used by the interrogated farmers. There is no uniform practice in terms of manure use. Some farmers spread the manure daily on the field while others prefer to keep the sun dried manure during several months in order to fertilise the mixed pastures 3 times a year (Table 4-1).

Table 4-1: Comparison of the characteristics of intensive dairy farms in the region of Lima and extensive dairy farms of the Mantaro valley (Peru).

	Intensive dairy farm	Extensive dairy farm
Location	Lima (Cañete, Huaral)	Mantaro Valley (Apata, Matahuasi)
Dairy herd size	200-700 lactating cows	6-35 lactating cows
Herd structure	Different groups (~lact. stage)	1 group
Management system	Dry lot	Pasture based
Roughages	Imported (MS***, maize)	Home grown (Maize, oat) Pasture association**
Concentrates	Yes (fixed, balanced formula)	Yes (limited)
Manure	Collected + sold	Daily spread on pastures or collected for several months (sundried)
Milking	Machine	Machine or by hand
Breed	Pure Holstein	Mix of local breeds, BS*, Holstein
Average weight (kg)	650	370

* BS: Brown Swiss, ** 40% Italian ryegrass, 20% alfalfa, 20% red clover,*** Maize silage

Table 4-2: Average feed cultivation in the Mantaro Valley according to interrogated dairy farmers.

	Rainy season*						Dry season**					
Feed cultivation	N	D	J	F	M	A	M	J	J	A	S	O
Maize	x	x	x	x	x	x						
Oat / Common vetch							x	x	x	x	x	x
Mixed pasture (40% Italian ryegrass, 20% alfalfa, 20% red clover)	x	x	x	x	x	x	x	x	x	x	x	x

*Rainy season: November- April; ** Dry season: March - October

4.1.2 Characteristics of intensive dairy farms in Lima

Dairy farms in provinces Cañete and Huaral in the department of Lima are characterised by a very large herd number (i.e. 230-700). The management structure often exists of one or two managers which give orders to employees who all have different tasks at the dairy farm. Mostly, there is a close relationship with a veterinarian who inspects the dairy herd on a regular basis. The dairy herd is housed in fenced dry lots and often separated according to their lactating stage. “Early” (i.e. 0-100 DIM) is the group which produces the most volume of milk, these are the animals in the first days of their lactation. Further, a

“Mid” (i.e. 100-250 DIM) and “Late” (250-305 DIM) producing group is associated with progressive lactation stages. Heifers are also kept in dry lot systems and grouped according to age. Calves are housed either in a dry lot or on straw. A nutritionist composes the ration of the dairy herd. All feed is imported and there is no possibility of the dairy herd to graze on pastures. Roughages often exist of maize silage and fresh or dry corn stalks depending the season. Roughages are supplemented with concentrates in a fixed formula depending on the lactating group. All farmers use milking machines and own large cooling tanks. Manure is collected after several weeks and sold to farmers located remotely from the dry Lima area.

4.2. Proximate analysis of feed samples

The feed samples which were taken from the participating dairy farms in Lima and the Mantaro Valley were imported in Belgium and underwent a proximate analysis in order to have an idea of the chemical composition of each feed sample (Table 4-3 and Table 4-4). The results of the proximate analysis were compared with values from Table 7-7 (Appendix E) which is based on NRC and personal communication with prof. Carlos Gomez from UNALM. This comparison was applied to assess the most appropriate NE-values (Mcal/kg DM) based on NRC tables. In this way digestible energy (DE%) of the ration of the dairy herd and calves could be estimated, which is required within the LCA calculation. Due to logistic problems the effective dry matter of the samples is not known.

Table 4-3: Summary of the proximate composition of different feeds in intensive dairy farms in the region of Lima (Peru) (%DM).

Intensive dairy farm	%ash	%CF[1]	%CP[1]	% NDF[1]	% ADF[1]	%hem[1]	%ligni[1]	%cell[1]
Maize silage	7,8	3,0	7,6	69,4	39,2	30,2	4,5	25,3
Corn stover	7,7	1,6	4,3	64,2	47,0	17,2	6,3	31,3
Conc. mix, E*	8,8	9,2	22,2	28,8	9,4	19,3	2,0	5,7
Conc. mix, M*	7,6	8,7	20,8	25,7	9,0	16,6	1,8	5,6
Conc. mix, L*	8,9	7,7	18,0	34,6	14,7	20,0	2,5	8,4
Artichoke (by-product)	6,7	2,7	14,5	69,8	51,4	18,4	5,8	25,2

*Mixture of concentrates: E = early lactation (i.e. 0-100 DIM), M = mid lactation (i.e. 100-250 DIM), L= late lactation (i.e. 250-305 DIM);[1] CF = Crude fat, CP = Crude protein, NDF = Non detergent fibre, ADF= acid detergent fibre , hem= hemicellulose, ligni= lignin, cell= cellulose.

According to Table 4-3 maize silage has a comparable CF content (3,0% vs. 3,2%) and NDF value (69% vs. 69%) but a lower CP (7,6% vs. 9%) with the values from NRC tables (Table 6-7, Appendix E). In the case of corn stover the CF was comparable (1,6% vs. 1,3%) and the CP slightly lower than in Table 6-7 (Appendix E) (4,3% vs. 5,9%). On certain dairy farms there is no difference in ration of the "mid" and "late" lactating group. Animals which reach the dry period (i.e. 60 days prior to calving) also receive a different ration. There is a clear decrease in CF and CP along the three groups (i.e. Conc. mix E/M/L: CF: 9,2%; 8,7%; 7,7% and CP: 22,2%; 20,8%; 18,0%). An increasing NDF-value could be expected from the "early" to the "late" lactation group. This will be mainly provoked by an increasing proportion of roughages in the diet with progressive lactation stage. Additionally the concentrate distributed towards end of the lactation contains higher amounts of CF as compared with the concentrate of the "early" and "mid" lactating group. The chemical composition of the artichoke by-product sampled within the frame of this thesis differed from the values obtained from UNALM collaborators (Table 7-7, Appendix E) in terms of CP content (14,5% vs. 17,1%) and CF content (2,7% vs. 1,8%).

Table 4-4: Summary of the proximate composition of different feeds in extensive dairy farms in the region of Mantaro Valley (Peru) (%DM).

Extensive dairy farm	%ash	%CF[1]	%CP[1]	% NDF[1]	% ADF[1]	%hem[1]	%ligni[1]	%cell[1]
Maize silage	7,5	2,4	7,8	63,3	37,5	25,7	5,4	30,7
Corn stover	6,9	2,3	4,8	69,6	44,1	25,5	7,6	36,7
Conc. Mix[2]	7,6	5,9	19,4	38,2	13,6	24,6	3,9	9,4
Wheat bran	7,3	5,6	16,4	48,2	19,9	28,3	5,5	13,0
Pasture assoc.	11,5	4,6	17,7	39,1	24,0	15,1	4,4	18,5
Oat straw	5,8	1,9	3,7	63,9	38,3	25,6	6,8	30,8
Oat silage	10,8	2,8	9,8	61,2	40,5	20,7	8,5	28,2

[1] CF = Crude fat, CP = Crude protein, NDF = Non detergent fibre, ADF= detergent fibre , hem= hemicellulose, ligni= lignin, cell= cellulose. [2] Mixture of concentrates.

Maize silage in the Mantaro valley has a slightly lower CF (2,4% vs. 3,0%) and NDF (63,3% vs. 69,4%) but a comparable CP content (7,8% vs. 7,6%) than silage used in Lima. Corn stover in the valley has a higher CF (2,3% vs. 1,6%) and CP content (4,8% vs. 4,3%) than in Lima.

The concentrate mixture consists of several feed components with a high share of wheat bran. The higher CP content can be explained because of the soybean meal which is added to the concentrate mix. The mixed pasture contains more CP (17,7% vs. 16,5%) and CF (4,6% vs. 3,8%) than average in Table 7-7 (Appendix E). Oat straw has much lower values for CF (1,9% vs. 2,8%) and CP (3,7% vs. 9,8%) in comparison with oat silage.

4.3. Results of the CFP model of milk

In this section the CFP results of a single model of an intensive dairy farm and one model, extensive dairy farm are presented and calculated following the structure of the CFP model (see outline Material and methods). First the characteristics of these specific farms are introduced (Table 4-5). Afterwards the results of the most important calculations on the different worksheets are shown in the subsection "4.3.2. General information". At the end of the section the results in terms of emissions of each process will be shown in subsection "4.3.3. Emissions from the different processes". In "4.4. Summary" the total CFP emission per ton FPCM, expressed in kg CO_2-equivalents, is presented.

Table 4-5:Farm characteristics of an Intensive dairy farm (Don Mateo) in Lima and an extensive dairy farm (Jufra) in the Mantaro valley (Peru).

	Intensive dairy farm	Extensive dairy farm
Location	Lima (Cañete)	Mantaro Valley (Matahuasi)
Dairy herd size	236	6
Herd structure	1 group	1 group
Management system	100% dry lot	33,3% pasture; 66,67% daily spread
Roughages	Imported (MS*,corn stover)	Home grown (Maize, oat) Pasture association**
Concentrates	Yes (balanced formula)	Yes (limited)
Manure	Collected + sold	Collected + sun dried
Milking	Machine	Elementary machine
Breed	Pure Holstein	Mix of local breeds, BS*, Holstein
Average weight adult cow (kg)	660	370
Weight at birth (kg)	45	35
Milk production (litre/cow/year)	7888	4430
Milk production (litre/cow/day)	21,6	12,2

* BS: Brown Swiss, ** 40% Italian ryegrass, 20% alfalfa, 20% red clover,*** Maize silage

4.3.1 Results of the preparatory work sheets

4.3.1.1 *Average cow and feed adjustments*

Farmer Don Mateo of the intensive dairy system did not divide the herd according to lactation stage. There was only one group of lactating animals and one group of dry animals. Both groups had a separate concentrate formula and also the amount of roughages and concentrates were different. In the case of the extensive system, the farmer Jufra only gives a limited amount of concentrates to the lactating cows. In Table 4-6 the ration is listed, for an average cow expressed in kg fresh matter per day. The ration of each dairy system is based on information gathered trough questionnaires addressed directly to the farmer.

Table 4-6: The ration of an average cow (kg fresh/day) at an intensive (Don Mateo) dairy farm in Lima and an extensive (Jufra) dairy farm in the Mantaro Valley (Peru) are based on farmers questionnaires. Between brackets: the kg DM of each feed component/average cow/day.

	Intensive dairy farm (Don Mateo, Lima)	**Extensive dairy farm (Jufra, Mantaro Valley)**
Average cow	**total kg fresh/average cow/day**	**total kg fresh/average cow/day**
Mixed pastures	No	Yes
Maize silage	42,4 (10,6)	
Corn stover	1,7 (1,5)	5,0 (4,3)
Fresh maize plant (without corn cob)		5,0 (1,4)
Components of the concentrate		
Wheat bran	1,3 (1,2)	1,3 (1,2)
Maize	3,8 (3,3)	0,1 (0,1)
Soybean meal	2,0 (1,8)	0,1 (0,1)
Soya flour	1,0 (0,9)	0,1 (0,1)
Cotton seed cake	1,0 (0,9)	
Barley		0,1 (0,1)
Molasses sugarcane	0,4 (0,3)	
REST	0,6 (0,5)	
Total # concentrates	**10,1 (8,9)**	**1,8 (1,6)**
Total # roughages	**44,1 (12,1)**	**10,0 (5,7)**
Total	**54,2 (20,8)**	**11,8 (7,2)**

Farmer Don Mateo of the intensive dairy system could not display exact data on roughage intake, because distribution of feed was not registered based on weight due to lack of a feeding wagon. Therefore it is possible that Table 4-6 shows an over- or underestimation of feed supply to the dairy herd. In this case based on requirements of the dairy herd on milk production an overestimation of feed supply is most plausible. In case of the extensive dairy system it was not possible to gather exact data of intake by grazing on the mixed pastures or of the oat straw ingested in the stable. In Table 4-7 a feed adjustment is made based on the net energy and crude protein requirements of the cows based on registered milk production in both systems with respecting the original ratio of different roughage components proposed by the farmer.

Table 4-7: Feed intake of roughages after adjustment for NE-requirements for the intensive dairy farm of Don Mateo in Lima and the extensive dairy farm of Jufra in the Mantaro Valley (Peru).

	Intensive dairy farm (Don Mateo, Lima)		Extensive dairy farm (Jufra, Mantaro Valley)	
Average cow	**Total kg DM/average cow/day**	**Ratio of the final amount of roughages (%)**	**Total kg DM/average cow/day**	**Ratio of the final amount of roughages (%)**
Maize silage	9,4*	96		
Corn stover	0,4*	4	2,0*	16
Fresh maize plant**			2,0*	16
Pasture			7,4	59
Oat hay			1,0	8
Total # adjusted roughages	**9,8**		**14,1**	

** Without corn cob

An average cow in the intensive system receives less roughages (-30,5%, Table 4-7) than in case of the extensive system where an average cow receives 14,1 kg DM of roughages whereof 52,5% exists of pastures (Table 4-7). In contrast to the low-roughage gift the proportion of concentrate is much higher at the intensive system of Don Mateo were an average cow receives 5,6 times more concentrates than in the extensive system (Table 4-6).

4.3.1.2 *Average calf*

In Table 4-8 the ration of an average calf is listed in the extensive and intensive dairy farm. An average calf is covering the age from 0 to 2 years old. The rations of heifers are included in the calculations of the "average calf" because their age is estimated between 1 and 2 year.

Table 4-8: The ration of an average calve (kg DM/day) at an intensive (Don Mateo) dairy farm in Lima and an extensive (Jufra) dairy farm in the Mantaro Valley (Peru). Between brackets: the kg fresh matter of roughages/average calf/day.

Average calf (0-2 yr)	**Intensive dairy farm (Don Mateo, Lima) Total kg DM/average calf/day**	**Extensive dairy farm (Jufra, Mantaro Valley) Total kg DM/average calf/day**
Maize silage	3,1 (8,7)	
Corn stover	2,2 (3,6)	2,0 (2,3)
Fresh maize		
Mixed pasture		1,6 (6,9)
Oat hay		0,4 (0,4)
Wheat bran	1,8	0,5
Maize	0,2	
Cottonseed pulp	0,1	
milk	0,1	0,1
Concentrate milk replac. Mix.		0,1
REST	0,1	
Total # concentrates	**2,2**	**0,7**
Total # roughages	**5,3 (12,3)**	**4,0 (9,6)**
Total	**7,5**	**4,7**

Methane emissions is linked to total manure production which reflects the total intake. The total intake of an average calf is 32,5% lower in the case of the extensive system (Table 4-8) which is in accordance to the lower average weight of the calves (Table 4-5). The lower intake of concentrates in the extensive system (-68,2%) was expected in comparison with the rather high intake of concentrates in the intensive dairy system.

4.3.2 General information

The net energy (NE%) and the digestibility (DE%) of the ration for the dairy cow and calves is listed in Table 4-9.

Table 4-9: The net energy and digestible energy of the intensive (Don Mateo) dairy farm in Lima and an extensive (Jufra) dairy farm in the Mantaro Valley (Peru). Both DE(%) and NE(%) are presented proportional to the gross energy (GE) content, i.e. NE%= (J/kg DM)/GE (MJ/ kg DM, DE%= DE (MJ/kg DM)/GE (MJ/ kg DM).

	Intensive dairy farm (Don Mateo, Lima)		Extensive dairy farm (Jufra, Mantaro Valley)	
Average cow or calf (0-2 yr)	**Total kg DM/average cow-calf/day**		**Total kg DM/average cow-calf/day**	
	NE%	**DE%**	**NE%**	**DE%**
Maize silage	35,4	67,2		
Corn stover	27,4	56,5	26,7	56,1
Fresh maize*			34,1	67,3
Mixed pasture			36,0	68,6
Oat hay			32,9	64,3
Wheat bran		71,4	37,6	71,4
Corn		71,8[2]		
Cottonseed pulp		72,1[2]		
milk		90,0		90,0[1]
Concentrate milk replac. Mix.				80,0[1]
Concentrate mix	39,1	72,8	39,3	73,1
DE% dairy cows ration	69,5		66,8	
DE% calves ration	68,6		63,6	

Black: roughages for calves and dairy cows, Green: concentrate for dairy cows, Purple: concentrate components for calves. DE (%) calculated based on NE (%) unless stated otherwise. [1]source: NIR Belgium, [2] source: feedipedia.com, * without corn cobs.

The digestibility of the ration of the dairy cows in the intensive system is 4,0% higher than the digestibility of the ration in the extensive system (Table 4-9). The low digestibility of the ration of the calves in case of the extensive system can be explained by the large amount of corn stover which is low in digestible energy (Table 4-9).

The nitrogen content per kg DM in the ration of dairy herd and calves for both dairy management systems is listed in Table 4-10. In case of the intensive system the dairy cows receive much more nitrogen (+31,7%) in the diet than in case of the extensive dairy system.

Table 4-10: Nitrogen content per kg DM in ration of dairy cows and calves of the intensive (Don Mateo) dairy farm in Lima and of the extensive (Jufra) dairy farm in the Mantaro Valley (Peru).

	Intensive dairy farm (Don Mateo, Lima)		Extensive dairy farm (Jufra, Mantaro Valley)	
Average cow or calf	**Total kg DM/average cow-calf/day**		**Total kg DM/average cow-calf/day**	
	g N per kg DM (cow)	g N per kg DM (calf)	g N per kg DM (cow)	g N per kg DM (calf)
Maize silage	12,9	12,9		
Corn stover	7,2	7,2	13,3	13,3
Fresh maize			10,6	
Mixed pasture			23,4	23,4
Oat hay			6,3	6,3
Wheat bran		33,1		33,1
Corn		17,1		
Cottonseed pulp		33,1		
milk		42,9		42,3
Conc. milk replac. Mix.				38,7
Concentrate mix	41,8		32,7	
Total kg N/kg DM ration	**26,2**	**18,7**	**19,9**	**19,0**

4.3.3 Emissions from different processes

The emission of each process of the intensive and extensive dairy farm is listed in order to have an idea where improvements can be implemented. Table 4-11 gives an overview of the emissions expressed per animal per day. It's only possible to compare emissions of different origin (g CO_2, g CH_4 and g N_2O) when they are expressed per kg CO_2-equivalents (Table 4-11). In Appendix F, Table 7-8 the emissions of each process *at farm level* of both intensive and extensive system are summarised.

Table 4-11: Comparison in terms of emissions for the intensive dairy farm of Don Mateo in Lima and the extensive dairy farm of Jufra in the Mantaro Valley (Peru). GWP: CH_4 = 25 according to IPCC 2007 guidelines.

	Intensive dairy farm (Don Mateo, Lima)			Extensive dairy farm (Jufra, Mantaro Valley)		
Environmental-impact/animal/ day	g CO_2	g CH_4	g N_2O	g CO_2	g CH_4	g N_2O
Enteric fermentation		507			380	
Methane from manure and pastures		20			17	
N_2O direct			13			4,1
N_2O indirect volatilisation			1,4			1,2
N_2O indirect leaching			0,0026			0,0012
Emissions roughage production	961			138		
Emissions concentrate production	4953			806		
Total (Expressed per g green house gas/animal/day)	**5914**	**527**	**15**	**944**	**398**	**5,3**

Expressed per kg CO2-eq/animal/day	**5,9**	**13,2**	**4,4**	**0,9**	**9,9**	**1,6**

4.3.3.1 *Methane emission from enteric fermentation and manure management*

When the *enteric fermentation* was expressed in g CH_4 per cow per day the emissions were higher in the intensive farm than in the extensive farm (507 g CH_4/cow/day vs. 380 g CH_4/cow/day, Table 4-11).

In the case of the extensive system, *methane emission from manure storage and grazing* is comparable with the emissions of the intensive system (17 g CH_4 vs. 20 g CH_4, Table 4-11) due to the high methane conversion factor for solid storage in the extensive system (MCF= 4%) as in comparison with a dry lot management system (MCF = 1,5%) in the intensive system. The high MCF is softened by the lower intake of gross energy by the extensive kept dairy herd which is linked to the total manure production. Since pastures have the same MCF-factor as a dry lot system this difference in management practice cannot explain differences in emissions from manure systems.

In the intensive system of Don Mateo CH_4 emission from animals and manure is 33,3% higher than in the extensive system of Jufra, when expressed per kg CO_2-equivalents per animal per day (Table 4-11).

4.3.3.2 *N_2O direct & indirect*

The high emissions of direct N_2O in the intensive system (13 g N_2O/cow/day vs. 4,1 g N_2O/cow/day, Table 4-11) are linked to the emission factor (EF_3) which differs for each manure management system. In the case of animals which are housed in a dry lot system the emission factor is 4 times higher (EF_3= 0,02) than in case of solid storage (EF_3 = 0,005). The EF_3 of pastures is the same as for a dry lot system.

Furthermore N_2O emissions are related to N-intake which largely determines N excretion. (Table 4-12).

Table 4-12: N-intake, N-retention and N-excretion expressed in kg/cow/day for an intensive and extensive dairy farm.

	Intensive dairy farm	Extensive dairy farm
kg N-excretion/cow/day	0,363	0,207
kg N-intake/cow/day	0,475	0,270
kg N-retention/cow/day	0,112	0,062

The N-intake in the extensive dairy system is low in comparison with the intensive farm system (0,270 vs. 0,475 Table 4-12). This is mostly related to the lower total intake as a consequence of low milk production. Secondly, the lower N-content in the ration of the herd (Table 4-10) and the N-retention which is based on milk production and the average weight of the cow is much lower than in the intensive system (0,062 vs. 0,112). Together with the most dominant manure management system "solid storage", which has a 4 times lower EF_3 factor (= 0,005) in comparison with a dry lot, direct N_2O emissions are very low. Indirect N_2O-emissions due to volatilisation are comparable in both systems due to the high volatilisation emission factor assigned to solid storage ($Frac_{vol}$ = 30%) in the extensive system which is softened by the lower N-excretion, while in the intensive dairy farm large N-excretion and a lower emission factor ($Frac_{vol}$ = 20%) leads to a comparable outcome.

The nitrous oxide emissions from the intensive system of Don Mateo is 2,75 times higher than in the extensive system of Jufra, when expressed per kg CO_2-equivalents per animal per day (Table 4-11).

4.3.3.3 *Emissions due to feed production*

In the intensive dairy system all feed is imported (Table 4-5). Therefore, the *emissions due to feed production,* were very high in comparison with the extensive dairy farm (5914 g CO_2/cow/day vs. 944 g CO_2/cow/day) where roughages are home-grown (Table 4-5) and less concentrates are given (Table 4-8). The concentrates like corn, cottonseed meal, soybean meal and soy flour which are largely imported from other countries have a large share in the CO_2 emissions. The lack of pastures has an important share in the high kg CO_2 emissions of feed.

In case of the extensive system the concentrates (e.g. wheat bran) are assumed to be cultivated in fertile valley areas (e.g. Mantaro Valley) and transported to Lima for processing which takes the largest share of the CFP of the feed. Afterwards concentrates are packed and distributed through the country and hence to Mantaro Valley. The use of pastures which have a low CFP in terms of kg CO_2 are most determining in the low amount of total kg CO_2 of the ration.

The intensive system of Don Mateo has carbon dioxide emission which is 6,6 times higher than in the extensive system of Jufra, when expressed per kg CO_2-equivalents per animal per day (Table 4-11).

4.4. Summary

Table 4-13 gives an overview of all emissions expressed per ton FPCM for the intensive dairy farm of Don Mateo and the extensive farm of Jufra.

Table 4-13: Environmental-impact per ton FPCM of the emissions related to the intensive dairy farm of Don Mateo in Lima and the extensive farm of Jufra in the Mantaro Valley (Peru). The economic allocation is set at 96% milk : 4% meat for both farms. GWP: CH_4 = 25 according to IPCC 2007 guidelines.

Environmental-impact per ton FPCM	Intensive dairy farm (Don Mateo, Lima)			Extensive dairy farm (Jufra, Mantaro Valley)		
Dairy cows	236			6		
Milk production (liter/animal/day)	21,5			14,5		
Milkproduction (ton FPCM/dairy herd/year)	1872			27		
	kg CO_2	kg CH_4	kg N_2O	kg CO_2	kg CH_4	kg N_2O
Total GHG (kg) per ton milk	261	23	0,65	72	30	0,40
Total per ton milk in kg CO_2-eq	**261**	**582**	**195**	**72**	**760**	**120**
	CFP (kg CO_2-eq/ton FPCM)		**1038**	**CFP (kg CO_2-eq/ton FPCM)**		**952**
	LUC (kg CO_2-eq)		**98**	**LUC (kg CO_2-eq)**		**30**

If **the CO_2- emissions** are expressed per ton FPCM (in kg CO_2-equivalents), the emissions are much higher than in the extensive system (+262,5%, Table 4-13) . As mentioned before this is due to fact that, at one hand all feed is imported and at the other hand, there is no access to pastures.

Although the **CH_4-emissions** (in kg CO_2-equivalents) in the intensive system were higher when the emissions were expressed per animal per day (Table 4-11), when it is expressed per ton of FPCM at farm level the extensive system has the highest value (+30,6%, Table 4-13) particularly due to the lower milk production in the extensive dairy system. Methane emissions have an enteric as well as manure origin. Enteric methane emission per unit of milk produced are somewhat higher in the extensive system, related to the dietary digestibility, whereas differences in methane from manure are mainly related to manure management practices (solid storage in case of extensive systems).

The **N_2O-emmisions** expressed per ton FPCM are much higher in the case of the intensive system (+62,5%, Table 4-13) due to the previous mentioned higher N-excretion and the emission factors linked with the dry lot management system.

*As a **summarized result** the **carbon footprint** of the intensive system of Don Mateo is 9,0% (Table 4-13) higher than in the extensive dairy system of Jufra.*

5. Discussion

5.1. Introduction

The intensive dairy system of Don Mateo has a carbon footprint (CFP) at farmlevel of 1038 (expressed in kg CO_2-eq/ton FPCM) which is 9,0% higher than the CFP of the extensive dairy system of Jufra (952 kg CO_2-eq/ton FPCM) (Table 4-13).

There has to be mentioned that comparison of LCA-results from various studies only should be considered with great caution because of differences in methodology (FU, Characterization factor for GWP, allocation method, emission unit, time period, etc.) and assumptions [20, 27, 38, 41]. Still some careful comparisons are made with previously performed LCA studies on either grass based or/and intensive dairy systems (Table 2-5) to assess whether the CFP outcome for both systems is realistic.

The study performed by O'Brien et al. [40] obtained comparable outcomes in terms of CFP in the intensive dairy systems (1027 kg CO_2-eq/ton FPCM) while the emissions for grass based dairy systems in Ireland were lower (874 kg CO2-eq/ton FPCM). Although there has to be mentioned that the characterisation of the GWP factor was based on IPCC 1996 (Table 2-5). The lower GWP factor for methane (21 vs. 25) could explain the lower CFP in the extensive system in comparison with the outcome of this study since methane is the most dominant emission in an extensive dairy system. O'Brien accomplished a difference of 15,5% in CFP between both systems which is higher than our result (9,0%).

Mc Geough et al. [41] who performed an LCA of an intensive dairy farm in Canada have calculated a comparable CFP-value of 1079 kg CO_2-eq/ton FPCM (Table 2-5). This outcome is comparable with European milk production systems (De Vries et al. [26], 1040 kg CO2-eq/ton ECM).

Although the LCA study performed by Bartl et al. [4] partly focused on the same area, intensive dairy farms in Lima and extensive dairy farms at the slope area of the Andean highlands in Peru, the outcome is not comparable with our study. The difference in GWP factors (based on a 20-year time horizon, Table 2-5) partly explains for one part the very high CFP in both systems (13780 kg CO_2-eq/ton ECM for the extensive system and 3180 kg CO2-eq/ton ECM for the intensive system). Even when the LCA results were converted to a 100-year time horizon, as applied in the current study, still rather high emissions occurred (5420 kg CO_2-eq/ton ECM for the extensive system and 1740 kg CO2-eq/ton ECM for the coastal intensive system). The extremely high CFP in the extensive dairy system calculated by Bartl et al. [4] in comparison with our study could be allocated to the very low milk production level of the cows in the extensive dairy system at the slopes (i.e. 2,57 kg milk), differences in breed (e.g. Criollo, low average weight (330 kg), low GE intake) and feed (e.g. natural pastures with low digestibility). Also the allocation between meat and milk caused a large difference between the extensive and intensive dairy system in the study of Bartl et al. (64:36 vs. 96:4) in comparison with our study were the allocation ratio is fixed on 96:4 for both systems since there was no indication for differences in terms of meat vs. milk output.

In the performed CFP model (Table 4-13) the intensive dairy system achieved considerably higher **CO_2-emissions** (+262,5%) and **N_2O-emmisions** (+62,5%) expressed in kg CO_2-eq per ton FPCM at farm level than in the extensive dairy system. The most important impact in case of the CO_2- emissions in the intensive system is the import of the majority of the concentrate components, which leads to a high transport cost in terms of CO_2-emissions. High N-excretion and emission factors linked to the dry lot manure storage also led to higher N_2O-emmisions in the intensive dairy of Don Mateo.

In terms of environmental impact due to **CH_4-emissions,** the extensive dairy farm of Jufra has the highest emissions when expressed in kg CO_2-eq per ton of FPCM at farm level (+30,6%, Table 4-13) mainly due to the lower milk production (Table 4-5) and lower digestibility of the ration in comparison with the intensive dairy system (Table 4-9).

The highest methane emission is associated with the intensive system, when expressed per animal per day (Table 4-11). This could be explained by the moderate digestibility of the ration despite the large amount of (imported) concentrates in the intensive dairy system (Table 4-9) and particularly due to the greater amounts of gross energy (GE) intake. The GE-intake is based on the net energy (NE) requirements of the cow, which in turn is determined by the average weight of an adult cow and the average milk production. In the extensive system the average weight of an adult cow is much lower due do the difference in breed (Table 4-5) which leads, together with the low level of milk production (i.e. 12,5 litres milk/cow/day), to a lower total feed intake which in turn is linked with lower manure production. This softens the emissions linked with manure management since solid storage has a high methane conversion factor (MCF=4%) in comparison with a dry lot management (MCF =1,5%).

In the performed CFP model (Table 4-13) the GWP factors are based on guidelines of IPCC 2007 on a 100-year time horizon, in order to “compare” with formerly performed LCA-studies. Although new guidelines (IPCC 2013) advise to increase the importance of methane (GWP_{CH4}: 34 instead of 25) with respect to the total environmental burden of CO_2, CH_4 and N_2O. This adaption in the calculation of the overall CFP will have a major effect: $CFP_{\text{Intensive dairy farm}}$ increases with 20,1% and the $CFP_{\text{extensive dairy farm}}$ increases with 28,8% (Table 5-1). The implementation of this adjustment leads to a comparable CFP between both systems due to the greater share of methane (expressed in CO_2-eq/ ton FPCM) in the extensive dairy system.

Table 5-1: Environmental-impact per ton FPCM of the emissions related to the intensive dairy farm of Don Mateo in Lima and the extensive farm of Jufra in the Mantaro Valley (Peru). The economic allocation is set at 96% milk : 4% meat for both farms. GWP: CH_4 = 34 according to IPCC 2013 guidelines.

Environmental-impact per ton FPCM	**Intensive dairy farm (Don Mateo, Lima)**			**Extensive dairy farm (Jufra, Mantaro Valley)**		
Dairy cows	236			6		
Milk production (liter/animal/day)	21,5			14,5		
Milkproduction (ton FPCM/dairy herd/year)	1872			27		
	kg CO_2	kg CH_4	kg N_2O	kg CO_2	kg CH_4	kg N_2O
Total GHG (kg) per ton milk	261	23	0,65	72	30	0,40
Total per ton milk in kg CO_2-eq	261	**791**	195	72	**1033**	120
	CFP **(kg CO_2-eq/ton FPCM)**		**1247**	**CFP** **(kg CO_2-eq/ton FPCM)**		**1226**
	LUC (kg CO_2-eq)		98	LUC (kg CO_2-eq)		30

In the next section mitigation strategies will be discussed for both dairy systems and at country level. The goal of a mitigation strategy is to assess the potential to optimize management in each of the systems (intensive and extensive) trough modified or alternative feeding and management strategies.

5.2. Mitigation strategies

5.2.1 Introduction

Based on the proposed results, “hotspots”, as the most important contributors to the overall emissions in both dairy systems (intensive and extensive), are identified. In order to lower the environmental impact of these bottlenecks adjustments are proposed through mitigation strategies (Table 5-1). Parameters for this adjustment are integrated into the CFP-model. Thus, the potential of this adjustment can be evaluated.

It has to be mentioned that only two dairy farms were investigated, whereby the results obtained by the CFP model are taken as representative of intensive dairy systems in Lima and grass based dairy systems in the valley of Peruvian highlands.

Since the intensive dairy farm has a much higher CFP in comparison with the extensive dairy system a third way of lowering the greenhouse gas emissions is proposed at a more global level (country level) in which part of the milk production is moved from the region of Lima to Andean Highlands (Table 5-2). In case of the intensive dairy farms **CO_2** and **N_2O-emmisions** are particularly emphasized for mitigation while in the extensive system the focus lays on decreasing **CH_4-emissions.** On country level, it is attempted to produce milk as much as possible in milk production systems with a **lower CFP.**

Table 5-2: Possible mitigation strategies to lower the carbon footprint (CFP) caused by enteric fermentation, feed production and direct N_2O emissions for intensive (Lima) and extensive dairy systems (Mantaro Valley) and at country level (Peru).

	Intensive dairy farm (Don Mateo, Lima)	**Extensive dairy farm (Jufra, Mantaro Valley)**	**Country level**
Enteric fermentation (kg CH_4/ farm level)		▪ Digestibility ↑ (e.g. appropriate fertilisation management on the irrigated pastures, cut & carry of red clover) ▪ Improve animal genetics => milk production ↑	
Emissions due to feed (kg CO_2/ farm level)	▪ Less import of feed components ▪ Replacement of soy in the ration		▪ Higher proportion of Peruvian milk produced in extensive dairy systems in highlands at the expense of intensive dairies in Lima
Direct & indirect N_2O emissions (kg N_2O/ farm level)	▪ Alternative for dry lot manure management (EF3 ↓) (e.g. solid storage)		

In the following subsections the various mitigation strategies proposed (Table 5-2) for both an intensive and extensive dairy system are assessed quantitatively. The results from each mitigation strategy are then compared.

5.2.2 Potential mitigation strategies for intensive dairy farms

5.2.2.1 *Description of the strategies*

In the case of Don Mateo, maize silage and corn stover are the dominant roughage components in the ration. Due to the large CO_2-cost of transport, the on-farm cultivation of maize, could lower the environmental impact. Secondly, a decrease of concentrates (-15,7%, Table 5-3) in the ration will lower the environmental burden because a lower volume of feed has to be imported on the farm. However, reduction of the amount of concentrates without loss in milk production will require an increase in intake of (highly digestible) roughages (Table 5-3). This is only possible when total intake of the cows still can be increased and higher amounts of such high digestible forages are available. Because the CP-content of the ration has to remain the same another formula as suggested by the farmer is applied whereby the amount of maize in the ration is decreased and whereas soybean meal and flour are increased (maize: 31% vs 37,5%, soybean meal: 24% vs. 20% and soy flour: 12,5% vs. 10%).

Table 5-3: Amount of concentrates and roughages in the ration at the intensive dairy farm of Don Mateo (Lima, Peru) before and after the ration adjustments (directed at lowering the concentrate intake) according to net energy and crude protein requirements.

	Original ration	**Ration after adjustments**
Intensive dairy farm (Don Mateo, Lima)	**total kg DM/average cow/day**	**total kg DM/average cow/day**
Maize silage	9,4	10,6
Corn stover	0,4	1,0
Components of the conc.		
Wheat bran	1,2	1,0
Maize	3,3	2,4
Soybean meal	1,8	1,9
Soya flour	0,9	1,0
Cotton seed cake	0,9	0,8
Molasses sugarcane	0,3	0,3
REST (without urea)	0,4	0,4
urea	0,1	0,1
Total # roughages	**9,8**	**11,6**
Total # concentrates	**8,9**	**7,8**
Total	**18,6**	**19,4**

The environmental impact of soybean meal was investigated by Hall [51] and the Dutch Soy Coalition [52] which stated that the expansion of the soybean cultivation leads to land transformation, water pollution and social conflicts. In the original ration soy accounts for 30,3% in the concentrate mix when expressed per kg DM (Table 4-6). Therefore a third mitigation strategy is proposed which decreases soy in the ration of the dairy herd by substitution of soybean meal by an alternative feed component with the same nutritional value and a lower environmental impact.

Soy alternatives which do not impair milk production potentially include DDGS [58], cottonseed meal [64], sunflower meal [64] and lupine [60] when appropriately formulated. In terms of CFP, based on data from FeedPrint [56], sunflower meal is the best soy alternative. In order to investigate these alternatives the net energy (NE), crude protein (CP), carbon footprint (CFP) and land use change (LUC) of soybean meal and its possible substitutes are summarised in Table 5-4.

Based on NE, lupine and DDGS are comparable with soybean meal but have a high CFP and would not be an improvement in terms of environmental impact. It is preferable to take an alternative which has a rather low CFP. Therefore sunflower meal is a good alternative but it has a high LUC which is not taken into account in the current overall CFP.

Table 5-4: Comparison of soybean meal and its possible substitutes in net energy (NE = Mcal/kg), crude protein (CP,% of DM), the CFP (kg $CO_{2\text{-eq}}$/kg feed) and LUC ((kg $CO_{2\text{-eq}}$/kg feed).

Concentrate component	NE (Mcal/kg)*	CP (%)*	CFP (kg CO_2-eq/kg feed)[2]	LUC (kg CO_2-eq/kg feed)[1]
Soybean meal	2,10	49,9	0,671	0,394
DDGS	2,05	32,4	0,818	0
Sunflowerseed meal	1,55	40,5	0,397	0,425
Lupins[1]	1,90	34,3	0,661	0,850

*Data based on NRC Tables and communication with prof. Carlos Gomez from UNALM [81].
[1]Data from FeedPrint (Table 7-11, Appendix G); [2]Calculated in CFP model

According to IPCC 2006 [37], is "solid storage" defined as a manure management system (> 20% DM) whereby manure is stacked in unconfined piles due to presence of sufficient amount of bedding material or loss of moisture by evaporation. If "solid storage" would be implemented instead of the commonly used dry lots, direct nitrous-oxide emissions would decrease due to the low EF_3 factor of the solid storage system. Although there has to be mentioned that indirect N_2O emission due to volatilization will increase.

5.2.2.2 *Bottlenecks*

In Table 5-5 bottlenecks of the proposed mitigation strategies for the intensive dairy system of Don Mateo are summarised.

Table 5-5: Bottlenecks for the proposed mitigation strategies for the intensive dairy farm of Don Mateo in Lima (Peru).

	Intensive dairy farm (Don Mateo, Lima)
Home grown roughages	▪ Lima = low annual precipitation => shortage of water
Solid manure storage system	▪ Trade off between decreased N_2O and increased CH_4 emissions

Although irrigation is possible in certain areas in the department of Lima, from an environmental point of view it would be irresponsible to propose home grown roughages as a possible mitigation strategy to lower environmental burden due to the shortage of water (low annual precipitation) and the infertile soil.

A side effect of solid storage, as a manure management system, is the increase in methane emission as the methane emission factor (MCF_{ST}= 4%) is higher than in a dry lot (MCF_{dl} =1,5%).

5.2.2.3 ***Sensitivity analysis: Impact of the mitigation strategies on the system's CFP***

All mitigation strategies, except for the home grown roughages have been integrated in the CFP model and the results in terms of greenhouse gas emissions are summarised in Figure 5-1.

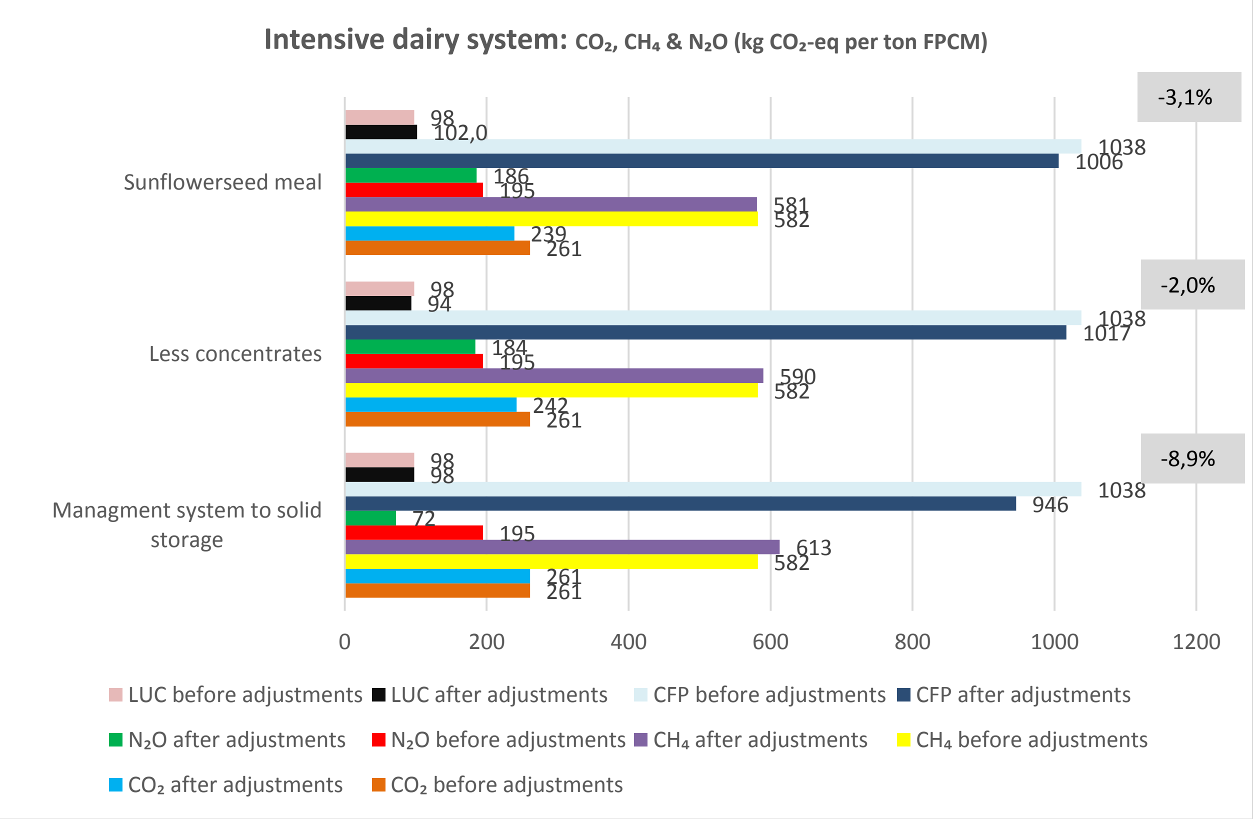


Figure 5-1: The overall CFP, LUC and greenhouse gas emissions (expressed in kg CO_2-eq/ ton FPCM) of various mitigation strategies after implementation in the CFP model of the intensive dairy system of Don Mateo.

In terms of lowering the emissions due to CO_2 the best mitigation strategy would be the potential replacement of soybean meal by sunflower seed meal in the concentrate mixture of the cows (-8,4%). Second best would be lowering the concentrates in the ration of the herd (-7,3%, Figure 5-1). A change in management system from a "dry lot" system to a "solid storage" has no net effect on CO_2-emissions but whereas N_2O emissions decreased (-63,1%) and CH4 emissions increased (5,1%).

The best mitigation strategy in order to lower the overall CFP (expressed per kg CO_2 per ton FPCM) for the intensive dairy system of Don Mateo can be found in Figure 5-1: the change of the dry lot management manure system into solid storage. This mitigation strategy leads to a decrease of CFP (expressed in kg CO_2 per ton FPCM) with 8,9% and obviously has no effect on land use change (LUC) whereas the use of less concentrates (with higher share of compounds with high LUC) and sunflower seed meal as a substitute for soybean meal both provide a higher LUC than in the original model, which is not preferable.

Bartl et al. [4] and O'Brien et al. [40], propose the use of less concentrates or the use of concentrates with a low environmental impact as a mitigation strategy for the intensive dairy systems at the coastal area of Peru. Especially a changed concentrate composition in which soybean meal is substituted by local ingredients was proposed as the most preferred option by Bartl et al. [4]. Since soybean meal as a mitigation strategy is replaced by sunflower seed meal which is produced in Peru and not imported from Argentina (i.e. soybean meal) it is a successful mitigation strategy in terms of lowering the CO_2-emissions due to transport. Unfortunately, it is not preferable to take sunflower meal as a substitute for soybean meal due to its disappointing results in terms of LUC.

Most studies with a focus on mitigations strategies for intensive dairy systems proposed a change in manure management in terms of manure storage and removal (O'Brien et al.[40], Bracquené et al. [82] , Gerber et al. [83]). Although it has to be mentioned that in these strategies the manure management system was based on liquid manure or manure storage in pit below confined animals which was changed to solid storage. Management modification from liquid to solid manure storage results in an opposite trade off, i.e. lower methane emissions due to lower methane conversion factor (MCF) and increase of N_2O [83], resulting in a net decrease in CFP of 2,3%.

Despite the opposite result in this study (decrease in N_2O, increase of CH_4) a same mindset is applied. The methane conversion factor (MCF) in case of a solid storage is higher than a dry lot but is lowest or even negligible during liquid storage (4% vs. 1,5% vs. 27%) whereas the emission factor for direct N_2O emission in solid storage is lower than a dry lot and higher or comparable with liquid storage (0,005 vs. 0,02 vs. 0 – 0,005). Therefore the overall CFP is decreased (-8,9%) but due to the decrease/increase of the opposite emissions as in case of Gerber et al. [83]. Preliminary studies which investigate the change in manure management from dry lot to solid storage are not found. Since the obtained results are positive (lowering the CFP) it could be a subject in future investigations. Although challenges in terms of eutrophication cannot be overlooked since in a dry lot storage manure management the liquid fraction can infiltrate in the soil which leads to possible nitrate leaching and NH_3 emissions. Therefore another strategy which could lower both methane as well nitrous oxide emission proposed by Gerber et al. [83], is anaerobic digestion. A realistic yet futuristic option could be the installation of a bio gas plant of which the reaming N and P fraction could be dried to a granular fertilizer. This strategy could be an option for future innovation research.

5.2.3 Potential mitigation strategies for extensive dairy systems

5.2.3.1 *Description of the strategies*

Digestible energy (DE% = DE (MJ/kg DM) / GE (MJ/kg DM) of the ration in the extensive system could be increased by applying a more appropriate fertilisation management on the irrigated pastures which leads to the possibility to faster rotate on younger, more digestible pastures. In this way more yields will be obtained which allows an increased number of cuts of younger forage with a higher CP content [84]. The mixture of Italian ryegrass and red clover at the extensive dairy farm of Jufra has a CP content of 13,4%. In order to have an idea of the fertiliser use in the Mantaro Valley and the corresponding yield, data from Bartl et al. [4] are used: 33 kg N/ha achieves a yield of 14,8 ton DM/ha. The yield proposed by Bartl et al. [4] is comparable to Belgian values (12 and 17 ton DM/ha, [85, 86]) despite the very low fertilization. Information obtained by the questionnaire of the large extensive dairy farm IVITA, shows the use of 150 kg urea/ha and 120 kg/ha super phosphate each two years. These fertilization data seems more realistic when compared with data measured by ILVO [86], which achieved a yield of 11,2 ton/ha in a Italian ryegrass/red clover mixture with a fertilisation of 108 kg/ha.

The relatively low digestible energy (68,6%) and CP content (13,4%) of the mixed pasture in the extensive system could be improved when compared with Belgian standards (DE = 70% and CP = 14%-25% [87]). Given the favourable climate conditions and continuous irrigation opportunities in the valley, the extensive system can pursue a similar nutritional quality of the mixed pastures as in the Netherlands. This will lower the enteric fermentation by adaptation of the nutritional quality of the mixed pasture obtaining a higher digestible energy (70%) and CP (18%). The mitigation strategy to obtain an increased digestible energy of the mixed pasture by an increased and appropriate fertilisation management is implemented in the CFP model whereby cultivation inputs are estimated by FeedPrint (e.g. fertilisation according to Dutch standards), a CP content of 18% is achieved and the digestible energy of the mixed pasture is increased from 68,6% to 70%.

The increase in the ration of pure red clover which has a higher digestible energy (DE_{clover}=70,9%) content than the mixed pasture ($DE_{Mix.Pastures}$ = 68,6%)(e.g. trough "cut and carry") could higher the digestibility of the ration. Therefore a modified ration formulated according to NE and CP requirements of the cow could consist of 16,3% fresh maize, 16,3% corn stover, 8,2% oat straw, 53% pastures and 7,8% red clover and would result in a CFP reduction due to the increase in overall digestible energy of the ration (DE_{ration} = 66,8% => 67,2%). The latter modification only required the replacement of 1 kg DM/day of mixed pasture by red clover in the diet of an average cow (Figure 5-2). In the previous method there was no change in intake of corn stover and fresh maize. Although a decrease in corn stover would higher the digestibility of the ration, it is no option to reduce this roughage fraction and allow increased intake trough grazing given the limited carrying capacity of the pastures. Moreover, from an economic point of view, farmers have major interest in corn stover as these are available at low price. More concentrates to increase the digestibility of the ration suffers of the trade-off between reduced enteric emissions and elevated CO_2-emissions associated with transport and hence does not result in an overall decrease in the CFP.

An increase in milk production due to improved animal genetics could be another possibility in order to lower the methane emissions per ton FPCM. At this moment the average production of a cow in the extensive dairy system from Jufra is set on 4430 litre a year (12,2 l/day, Table 3-5). As certain farmers (Mesias and Rodriguez) in the Mantaro Valley reach milk yields up to 15 litres/cow with the same amount of concentrates (1,6 kg) due to the use of Holstein cows, the same could be achieved in case of Jufra. Therefore an increase in daily milk production up to 15 litres could be considered as a realistic goal after genetic improvement of the dairy herd (4430 litres/year to 5475 litres/year). Obviously the total net energy (+11,4%) and CP requirements (+12,8%) will increase due to the higher milk production. Avoiding increased intake of concentrates can only be compensated by intake of extra roughages (i.e. mixed pasture intake + 1,5 kg DM).

5.2.3.2 *Bottlenecks*

In Table 5-6, a summary is given of the possible bottleneck for the proposed mitigation strategies in the previous section.

Table 5-6: Summary of possible bottlenecks which can have a negative effect on mitigation strategies

	Extensive dairy farm
digestibility ration ↑ trough improved management of cultivated pastures	▪ Possible negative effect on the nutrient balance of the farm (eutrophication/acidification)

Increased mineral fertilisation on pastures could deregulate the nutrient balance of the farm. This effect is not taken into account in the CFP model. Hence no conclusion could be made about the overall environmental impact of increased fertilisation of the mixed pastures. The mitigation strategies of increased fertilisation, higher amount of red clover in the ration by “cut and carry” and the increase of milk production by improved genetics has been implemented in the CFP model of which results are presented in the next sub section.

5.2.3.3 *Sensitivity analysis: Impact of the mitigation strategies on the system's CFP*

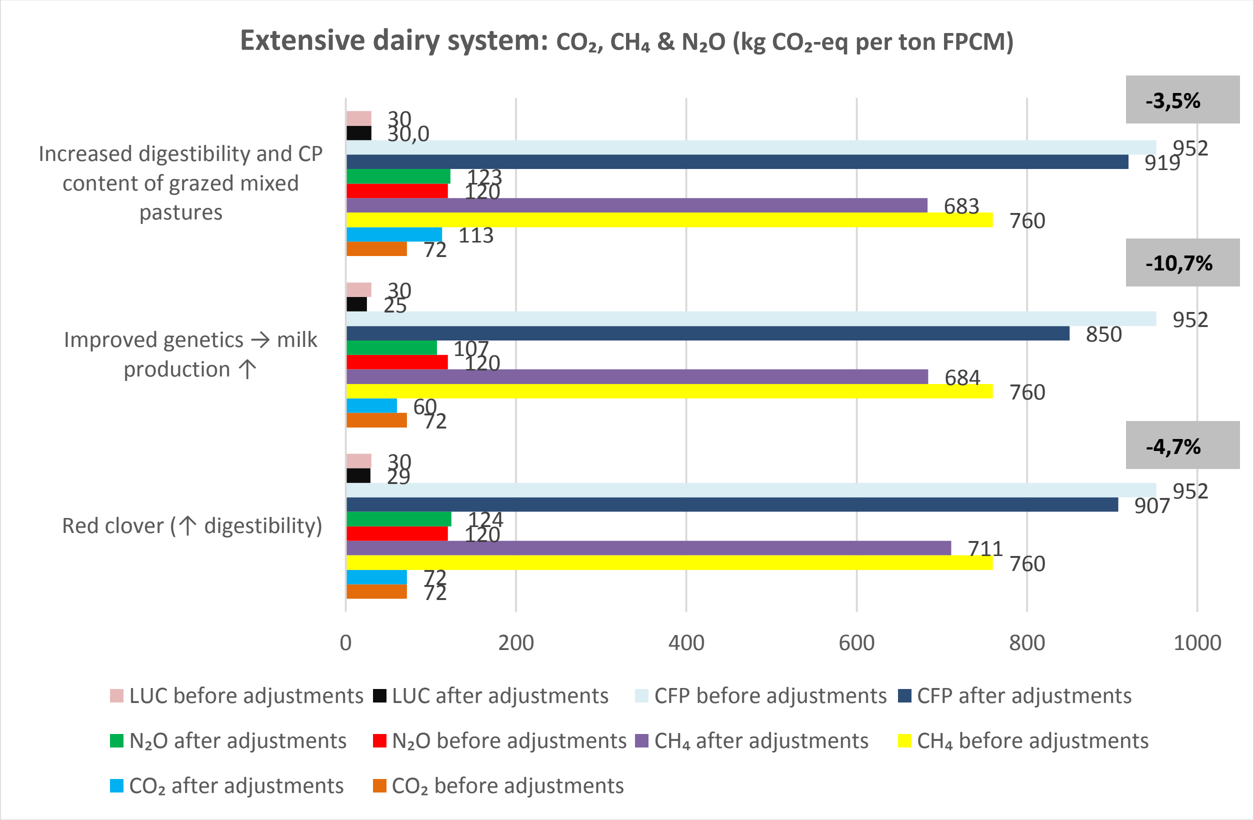


Figure 5-2: The overall CFP, LUC and greenhouse gas emissions (expressed in kg CO_2-eq/ ton FPCM) of various mitigation strategies after implementation in the CFP model of the extensive dairy system of Jufra.

An increase of the milk production (12,2 liter/day => 15 liter/day) shows an important decrease in the overall greenhouse gas budget (CO_2, CH_4, N_2O) because it is expressed per ton FPCM (Figure 5-2). Increasing the yearly milk production from 26.577 to 32.850 litre/cow due to improved genetics could be considered as the best mitigation strategy (-10,7%, Figure 5-2). The increase in digestibility of the ration from 66,8% to 67,2% through a higher inclusion rate of red clover will lead to a decrease of 6,9% in methane emissions (Figure 5-2) and a decrease in CFP of 4,7%. An increase in digestibility of the ration (66,8% to 70%) and increase in CP content of the mixed pasture (13,4% to 18%) due to an improvement pasture management will lead to a moderate decrease in CFP (-3,5%) due to increased CO_2 emissions, associated with pasture cultivation.

Although numerous studies [4, 40] cite that improving milk production and increased digestibility of the ration would lower the environmental impact (e.g. methane emissions) in grass based dairy systems, no further quantitative information was provided on how to achieve this goal and which reduction it would realize.

Gerber et al. [83] concluded that due to improvement of feed digestibility in extensive Indian dairy farms, 30% of GHG gasses could be decreased. Although this reduction is mainly attributed to the reduction of animals in the dairy herd: milk yield increases and the same milk production can be achieved with 10% fewer animals.

According to another study of Gerber et al. [88] the most relevant mitigation option for smallholders in mixed crop-livestock systems in developing countries is to increase individual animal productivity. This could be achieved by providing better feeds (e.g. leguminous fodder) and genetically improvements. In this way, CH_4 emissions will be reduced at farm level and per unit of animal product. A logical consequence is a reduction of animals because farmers in smallholder systems have no interest in having a large herd as long they not produce for commercial goals.

In another study of Gerber et al. [79] a quantitative approach was followed in order to reduce the GHG gasses emitted by an extensive dairy farm. The digestibility of the feed was increased by 10% (original average digestibility of the ration was 56%) which reduced GHG emissions by 14,8%. Although they mentioned that in practice, quality of feed is interrelated with milk production. Therefore, when the effect of changes in feed quality and milk production are combined (both increase of 10%), they assume a decrease of GHG emissions with 19,2% in the extensive system.

5.2.4 Potential mitigation strategies at country level

5.2.4.1 *Description of the strategies*

Lowering the amount of intensively farmed dairy cattle in the region of Lima and increasing the dairy herd in the extensive dairy systems in valley area of the highlands could be an effective mitigation strategy on country level because an extensive dairy farm has a lower CFP than an intensively kept dairy (Table 4-13).

5.2.4.2 *Bottlenecks*

According to prof. Carlos Gomez from UNALM only 25% of the current milk production in Lima could be produced in the Mantaro valley due to limitations of the carrying capacity of the pasture based system

(Table 5-7). Another bottleneck is the location of milk consumers whereas the largest share is located around the capital of Lima (e.g. high population density) which inevitably would lead to transport costs.

Table 5-7: Summary of possible bottlenecks which can have a negative effect on the proposed mitigation strategy.

	Country level
Higher proportion of Peruvian milk produced in extensive dairy systems in highlands at the expense on intensive dairies in Lima	▪ Max. 25% of milk production in Lima could be produced in the Mantaro Valley (limited carrying capacity of the pasture based system) ▪ Distance ↑ to milk consumer

5.2.4.3 *Recommendation at country level*

According to El Ministerio de Agricultura y Riego del Peru [89] 1.700 000 tons of milk was produced in 2009 within 3 mean production areas: Arequipa (24,4%), Cajamarca Valley (17,8%) and Lima (17,5%). Management systems in Arequipa are slightly more intensive according to the ration of the dairy herd (e.g. irrigated mixed pastures, corn, alfalfa) as compared with Cajamarca Valley (e.g. mixed pastures) but less intensive as compared with the dairy systems in Lima (large stables, mainly concentrates in the ration) [17].

If one fourth of the yearly milk production in Lima (i.e. 0,25* 0,175 *1700 000 tons = 74375 tons) could be produced in the extensive grass based dairy farms in the valleys of the Andean highlands, 4,4% of the yearly total milk production would be produced at a lower CFP (Table 4-13), which obviously would lower the CFP on country level. Although it also has to be mentioned that 25% of the total milk consumption in Peru is imported and produced at an unknown CFP [90]. The national deficit in dairy products demonstrates the difficulties to compensate for growing domestic demand [89]. Supporting small scale famers to increase their herd size would be a good start in reducing emissions at the country level, when these systems would partially replace intensive systems around Lima. However socio-economic factors (e.g. high sales prices of certain crops) have large effects on extensive dairy systems since they have the flexibility to respond on changes in market orientation by cultivating cash-crops. This lowers the importance of milk production while in the intensive dairy systems, milk levels remains stable due to lack of flexibility to respond on the market. Therefore, more security is achieved to produce a certain volume of milk at national level when intensive dairy farms provide milk.

6. Conclusion

In this dissertation a detailed CFP has been developed for two dairy farms which are considered representative for intensive farming systems in the neighbourhood of Lima and grass-based, more extensive systems in the Mantaro Valley in Peru.

The overall environmental impact expressed as a **CFP in kg CO_2-equivalents** shows that the intensive system of Don Mateo (area of Lima) has led to a higher environmental burden (1038 vs. 952; +9,0%) than the extensive dairy system of Jufra (Mantaro Valley).

Especially the higher **CO_2-emissions** expressed *per ton FPCM* (in kg CO_2-equivalents) (+262,5%) due to off-farm production of all feed components, the lack of access to pastures or home-grown forages and the large share of imported (from abroad) ration compounds largely contributed to the high CO_2- emissions of the intensive dairy system.

The most dominant emission for both dairy systems was **methane**. When *expressed in g CH_4 per cow per day* the emissions of **enteric fermentation** were higher in the intensive farm than in the extensive farm (507 g CH_4 vs. 380 g CH_4; +33,4%) as digestibility of the diet in the intensive system was only slightly higher than in the grass-based system and GE-intake was higher particularly due to increased milk yields. Moreover, in the extensive system the average weight of a cow is lower due to differences in breeds between both systems, resulting in lower intakes for maintenance in the Mantaro Valley. This could explain the rather low emission due to enteric fermentation despite the low digestibility of the feed.

The **methane emissions from manure** and its application contributed the most to the CFP of the intensive dairy system (20 g CH_4 vs. 17 g CH_4; +17,6%) although the emissions of the extensive system came close due to the high methane conversion factor for solid storage (MCF= 4%) as compared in a dry lot management system (MCF = 1,5%). The lower intake of gross energy in the extensive system which is linked to the total manure production softens the impact of the methane conversion factor of solid storage. Since pastures have the same MCF-factor as a dry lot system this difference in management practice cannot explain differences in emissions from manure systems. However when **CH_4-emissions** (in kg CO_2-equivalents) were expressed *per ton of FPCM at farm level* the extensive system had the highest value (+30,6 %) due to the lower milk production in the extensive dairy system.

The **N_2O-emmisions** expressed *per ton FPCM* are much higher in the case of the intensive system (+62,5 %). When nitrous oxide is expressed per kg CO_2-equivalents *per animal per day* again the intensive system of Don Mateo has led to an emission which is 6,5 times higher than in the extensive system of Jufra. The low value in the extensive dairy could be explained by the calculation of N-retention which is based on milk production and the average weight of the cow (lower than in the intensive system (0,062 vs. 0,112). Together with the most dominant manure management system “solid storage”, which has a 4 times lower EF_3 factor (= 0,005) in comparison with a dry lot, direct N_2O emissions are very low.

Proposed mitigation strategies which will lower the overall CFP are named from highest impact to lowest impact taking into account the possible physical and climatologic barriers (e.g. shortage of water, desert area) and trade-offs towards other environmental compartments (e.g. disturbed nutrient balance).

In the intensive system the best mitigation strategy would be the change of a dry lot management system into a solid storage manure system (CFP: -8,9%). Although challenges in terms of eutrophication cannot be overlooked since the liquid fraction in solid storage manure system can infiltrate in the soil which leads to possible nitrate leaching and NH_3 emissions. Therefore another strategy which could lower both methane as well nitrous oxide emission is anaerobic digestion in a bio gas plant whereby fraction of nitrogen and phosphor can be transformed into dry fertilizer granules. This strategy could be an option for future innovation research.

Second best would be the substitution of soybean meal by sunflower meal (CFP: - 3,5%) whereas the least decrease of CFP (-2,0%) is measured when the ration is adjusted to less concentrates, according to net energy and crude protein requirements of the cow needed to obtain the same milk production level.

In the case of the extensive system, improved animal genetics (e.g. Holstein), which would lead to an increased milk production, is the most effective mitigation strategy (CFP: -10,7%). Adding 1 kg red clover as “cut and carry” instead of mixed pasture will enlarge the digestibility of the ration (66,8% to 67,2%) without increasing the CO_2 emissions. This strategy is the second best and corresponds to a decrease in CFP of 4,7%. Improving pasture management to enlarge the CP content (13,4% to 18%) increases the digestibility of the ration and will lower the CFP with 3,5% but effects on eutrophication and acidification should be considered.

If one fourth of the yearly milk production in Lima (i.e. 17,5% of the Peruvian production or 297.500 tons) would be produced in the extensive grass based dairy farms in the valleys of the Andean highlands, 4,4% (i.e. 74375 tons) of the yearly total milk production would be produced at a lower CFP, which obviously would lower the CFP on country level. Although it has to be mentioned that currently already 25% of the total milk consumption in Peru relies on imported milk which might illustrate challenges to increase national production levels. Supporting small scale famers to increase their herd size would be a good start in reducing emissions at the country level, when these systems would partially replace intensive systems around Lima.

7. Appendix

7.1. Appendix A: The climate similarity of the Cajamarca Valley and the Mantaro Valley

The Cajamarca valley has a temperate climate with a mean temperature of 15,1 C° and a rainfall of 726 mm/m². This region is well known for the production of dairy cattle [7]. In figure 7-1, Fuentes et al. shows both valleys show a high similarity in the case of geography and climate [18].

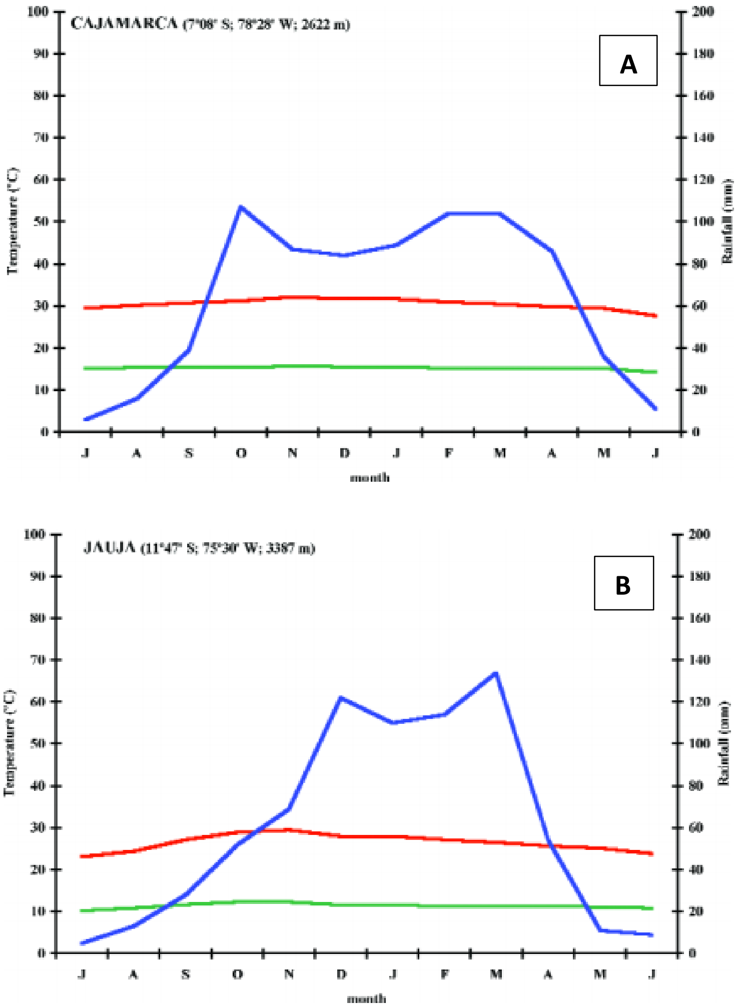
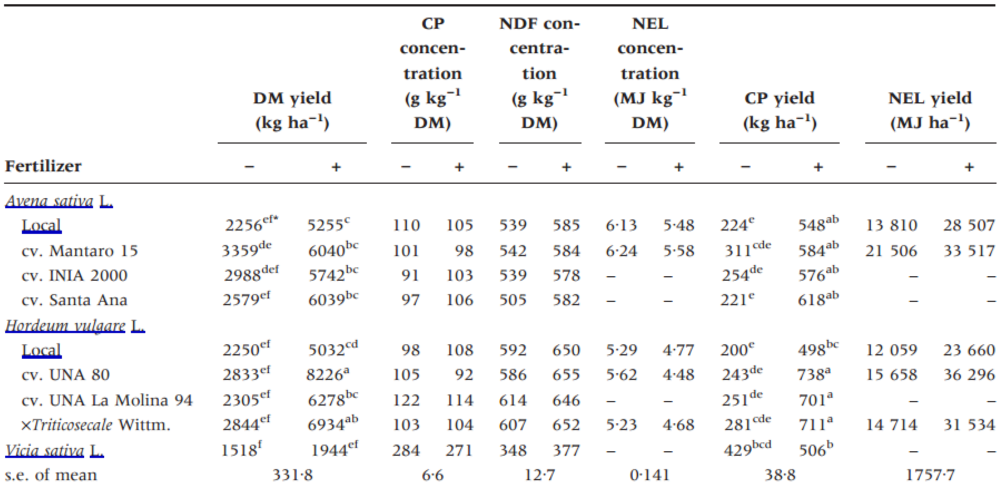


Figure 7-1: Climagram of Cajamarca (A) and Mantaro Valley (B).

7.2. Appendix B: Information about the nutritional value of common local forages in the central Peruvian highlands

In Table 7-1 information is given about the dry matter yield, neutral fiber concentrations and the crude protein content of the annual forage species. Source: Bartl et al. [12].

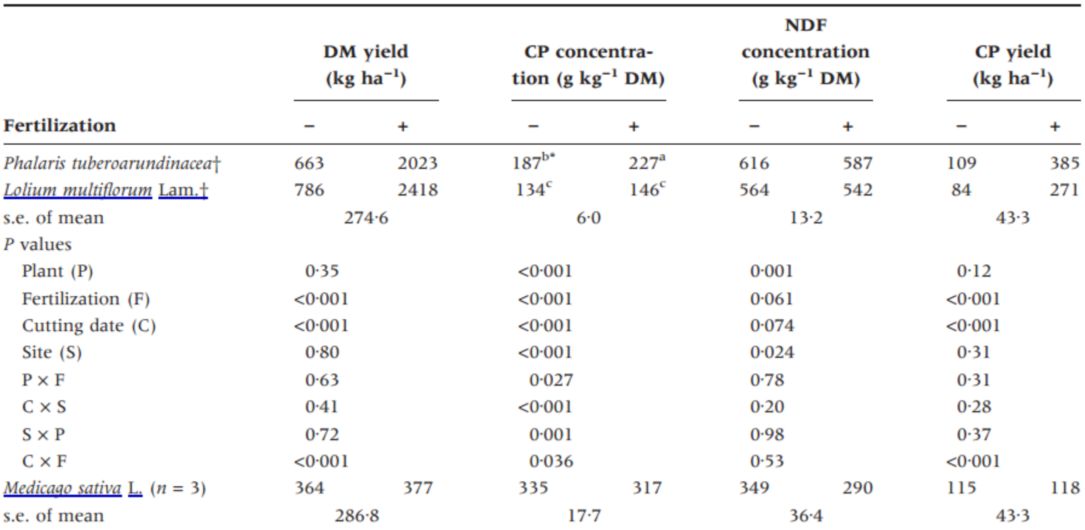
Table 7-1: Summary of the chemical composition of annual forage species in the Peruvian highlands. Two fertilizer treatments: not fertilized (-) or fertilized with N;P;K mainly applied at sowing (+) [12].



	DM yield (kg ha^{-1})		CP concentration (g kg^{-1} DM)		NDF concentration (g kg^{-1} DM)		NEL concentration (MJ kg^{-1} DM)		CP yield (kg ha^{-1})		NEL yield (MJ ha^{-1})	
Fertilizer	–	+	–	+	–	+	–	+	–	+	–	+
Avena sativa L.												
Local	2256^{ef*}	5255^{c}	110	105	539	585	6·13	5·48	224^{e}	548^{ab}	13 810	28 507
cv. Mantaro 15	3359de	6040^{bc}	101	98	542	584	6·24	5·58	311^{cde}	584^{ab}	21 506	33 517
cv. INIA 2000	2988^{def}	5742^{bc}	91	103	539	578	–	–	254de	576^{ab}	–	–
cv. Santa Ana	2579^{ef}	6039^{bc}	97	106	505	582	–	–	221^{e}	618^{ab}	–	–
Hordeum vulgare L.												
Local	2250^{ef}	5032^{cd}	98	108	592	650	5·29	4·77	200^{e}	498^{bc}	12 059	23 660
cv. UNA 80	2833^{ef}	8226^{a}	105	92	586	655	5·62	4·48	243de	738^{a}	15 658	36 296
cv. UNA La Molina 94	2305^{ef}	6278^{bc}	122	114	614	646	–	–	251de	701^{a}	–	–
×*Triticosecale* Wittm.	2844^{ef}	6934^{ab}	103	104	607	652	5·23	4·68	281^{cde}	711^{a}	14 714	31 534
Vicia sativa L.	1518^{f}	1944^{ef}	284	271	348	377	–	–	429^{bcd}	506^{b}	–	–
s.e. of mean	331·8		6·6		12·7		0·141		38·8		1757·7	

In Table 7-2 information is given about the dry matter yield, neutral fiber concentrations and the crude protein content of the perennial forage species. Source: Bartl et al. [12].

Table 7-2: Summary of the chemical composition of perennial forage species in the Peruvian highlands. Two fertilizer treatments: not fertilized (-) or fertilized with N;P;K mainly applied at sowing (+) [12].



	DM yield (kg ha^{-1})		CP concentration (g kg^{-1} DM)		NDF concentration (g kg^{-1} DM)		CP yield (kg ha^{-1})	
Fertilization	–	+	–	+	–	+	–	+
Phalaris tuberoarundinacea†	663	2023	187^{b*}	227^{a}	616	587	109	385
Lolium multiflorum Lam.†	786	2418	134^{c}	146^{c}	564	542	84	271
s.e. of mean	274·6		6·0		13·2		43·3	
P values								
Plant (P)	0·35		<0·001		0·001		0·12	
Fertilization (F)	<0·001		<0·001		0·061		<0·001	
Cutting date (C)	<0·001		<0·001		0·074		<0·001	
Site (S)	0·80		<0·001		0·024		0·31	
P × F	0·63		0·027		0·78		0·31	
C × S	0·41		<0·001		0·20		0·28	
S × P	0·72		0·001		0·98		0·37	
C × F	<0·001		0·036		0·53		<0·001	
Medicago sativa L. (*n* = 3)	364	377	335	317	349	290	115	118
s.e. of mean	286·8		17·7		36·4		43·3	

7.3. Appendix C: Nutritional values and chemical composition of different dietary protein sources which possibly could replace soybean meal in a dairy ration

Table 7-3: Summary of the chemical composition and nutritive values of soybean meal and his possible alternatives when the same value of crude protein is ingested [60].

	Dietary protein source				
	Soybean meal	Lupin	Lupin/Pea	SEM[4]	*P*
Ingestion					
DM (kg·d^{-1})	21.5^{a}	23.7^{b}	24.8^{c}	0.046	0.001
OM (kg·d^{-1})	20.0^{a}	22.2^{b}	23.3^{c}	0.040	0.001
CP (kg·d^{-1})	4.209^{a}	4.485^{b}	4.295^{c}	0.166	0.001
Crude fibre (kg·d^{-1})	3.123^{a}	3.653^{b}	3.535^{c}	0.012	0.001
VEM[1] (VEM·d^{-1})	21385^{a}	24782^{b}	25790^{c}	37.73	0.001
DVE[2] (g·d^{-1})	2156^{a}	2022^{b}	2111^{c}	2.706	0.001
OEB[3] (g·d^{-1})	566^{a}	869^{b}	783^{c}	2.217	0.001
Digestibility					
DM (%)	65.8^{a}	70.8^{b}	67.8^{c}	0.294	0.001
OM (%)	67.8^{a}	72.3^{b}	69.5^{a}	0.284	0.001
CP (%)	71.7^{a}	74.3^{b}	68.9^{c}	0.262	0.001
Crude fibre (%)	46.4^{a}	53.3^{b}	48.5^{a}	0.583	0.001

$^{a, b, c}$ Within a row, means lacking a common superscript letter differ ($P < 0.05$).

According to the Dutch system [36, 37]: [1] Net Energy, [2] Digestible protein in the small intestine, [3] Degradable N / Fermentable energy balance in the rumen.

[4] Standard error of the mean.

Table 7-4: Effect of three different dietary protein sources on milk production, N-efficiency and live weight variation [60].

	Dietary protein source				
	Soybean meal	Lupin	Lupin/Pea	SEM[3]	*P*
Milk production factors					
Production (L·d^{-1})	34.2^{a}	35.7^{b}	34.7^{a}	0.15	0.001
Standard production[1] (L·d^{-1})	31.8	31.8	31.4	0.18	0.616
Fat (%)	3.52^{a}	3.21^{b}	3.34^{ab}	0.03	0.001
Protein (%)	3.18	3.16	3.18	0.01	0.602
Fat (g·d^{-1})	1186	1121	1127	11.89	0.077
Protein (g·d^{-1})	1081^{a}	1124^{b}	1100^{ab}	4.96	0.004
Urea (mg·L^{-1})	403^{ab}	416^{a}	372^{b}	5.07	0.004
N efficiency[2] (%)	25.74	25.05	25.57	0.12	0.062
Live weight variation (kg)	–15.3	+2.3	–10.04	3.59	0.230

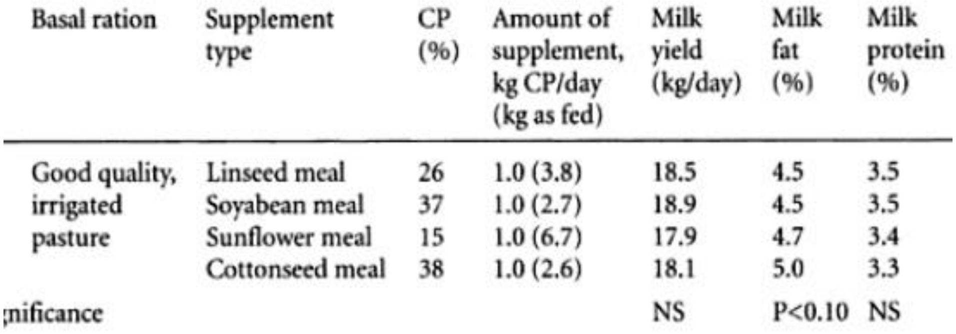
$^{a, b}$ Within a row, means lacking a common superscript letter differ ($P < 0.05$).

[1] Standard milk production (L) = [0.337 + (0.116 × % Fat) + (0.06 × % Protein)] × Production (L).

[2] Dietary N efficiency (%) = [Milk protein (g·d^{-1}) / Protein ingested (g·d^{-1})] × 100.

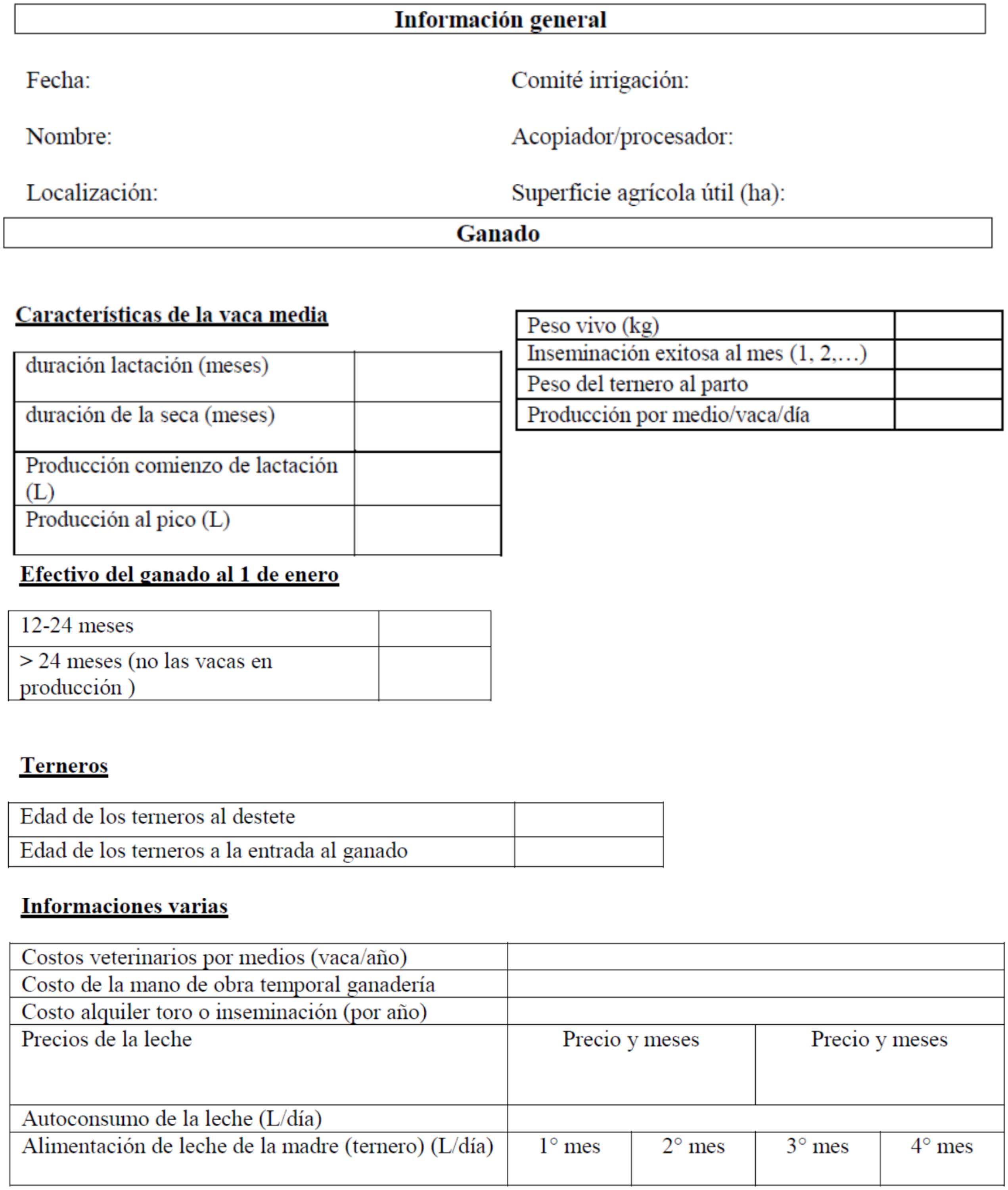
[3] Standard error of the mean.

Table 7-5:Comparison of different protein meals for dairy cows grazing pasture [64].



Basal ration	Supplement type	CP (%)	Amount of supplement, kg CP/day (kg as fed)	Milk yield (kg/day)	Milk fat (%)	Milk protein (%)
Good quality, irrigated pasture	Linseed meal	26	1.0 (3.8)	18.5	4.5	3.5
	Soyabean meal	37	1.0 (2.7)	18.9	4.5	3.5
	Sunflower meal	15	1.0 (6.7)	17.9	4.7	3.4
	Cottonseed meal	38	1.0 (2.6)	18.1	5.0	3.3
nificance				NS	P<0.10	NS

7.4. Appendix D: Predefined Spanish questionnaire



Información general

Fecha:

Comité irrigación:

Nombre:

Acopiador/procesador:

Localización:

Superficie agrícola útil (ha):

Ganado

Características de la vaca media

duración lactación (meses)	
duración de la seca (meses)	
Producción comienzo de lactación (L)	
Producción al pico (L)	

Peso vivo (kg)	
Inseminación exitosa al mes (1, 2,…)	
Peso del ternero al parto	
Producción por medio/vaca/día	

Efectivo del ganado al 1 de enero

12-24 meses	
> 24 meses (no las vacas en producción)	

Terneros

Edad de los terneros al destete	
Edad de los terneros a la entrada al ganado	

Informaciones varias

Costos veterinarios por medios (vaca/año)				
Costo de la mano de obra temporal ganadería				
Costo alquiler toro o inseminación (por año)				
Precios de la leche	Precio y meses		Precio y meses	
Autoconsumo de la leche (L/día)				
Alimentación de leche de la madre (ternero) (L/día)	1° mes	2° mes	3° mes	4° mes

Raciones de las vacas en producción (kg MV/vaca/día)

Alimentos	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SET	OCT	NOV	DIC

Raciones de base de los otros animales

Alimentos/ concentrados	ENE	FEB	MAR	ABR	MAY	JUN	JUL	AGO	SET	OCT	NOV	DIC

Cultivos forrajeros

Cultivo:				**Stock:** sí / no			**Nivel del stock: (kg)**			**Mes:**		
Superficie (ha)												
Rendimiento (t/ha/año)												
	J	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Nivel de producción (%)												

Recursos de la explotación

Compras de recursos alimentarios no producidos sobre la explotación

Concentrados y tubérculos	Forrajes
Sal mineral (kg/año por el ganado)	

Fertilizantes comprados

Situaciones de cultivos

Cultivo	
% de pajas cosechadas	
Fertilizantes (cantidad/ha)	
Pesticidas, herbicidas (cantidad/ha)	
Semilla (cantidad/ha)	
Mecanización (carburante, alquileres, preparación del suelo, etc.)	
Mano de obra temporal	
Alquileres de tierras	

Informaciones varias

Nombre de fosa de purín	
Capacidad de almacenamiento de la fosa (t de estiércol fresco)	
Estiércol en la fosa	
Limpia(s) de la fosa por año	
Parque por ganado sin techo (sí o no)	
Parque/edificio con techo (sí o no)	

7.5. Appendix E: Characteristics of the feed ration of the dairy herd and calves in Peru

Table 7-6: Ration of calves in an intensive dairy farm in Peru based on personal communication with prof Carlos Gomez from UNALM.

	Nacimiento al destete (0-3 meses)		Destete a 1 año (3 - 12 meses)	
	%	**kg/día**	**%**	**kg/día**
Subproducto de trigo (wheat bran)	**58**	0,29	**83**	0,83
Maíz	**25**	0,13	**10**	0,1
Pasta de algodón	**15**	0,08	**5**	0,05
Vitaminas y minerales	**1**	0,005	**1**	0,01
Sal	**1**	0,005	**1**	0,01
Sub Total	**100**	**0,5**	**100**	**1**

Maíz chala				20
Total				**21**
Consumo de Maize silage (kg/día)		**0,45**		**6,5**

Table 7-7: Chemical composition and net energy (NE) of possible feed components in the ration of dairy cattle [81].

	NE (net energy) Mcal/kg DM	% DM	ASH (%DM)	Crude Fat (%DM)	Crude Protein (%DM)	NDF (%DM)	ADF (%DM)	Crude fiber (% DM)	ADL = lignin (%DM)
avena hay / dry avena	1,35	90	8,3	3,3	14	62	39	32	6
avena silage	1,35	25	8,3	3,3	14	62	39	32	6
fresh avena	1,35	25	8,3	3,3	14	62	39	32	6
mais silage	1,47	25,0	4,3	3,2	9	69	30,8	29	3,5
dry mais / corn stover	1,1	85,0	7,2	1,3	5,9	76	39	34,4	
fresh mais	1,47	28,0	4,3	3,2	9	69	30,8	29	3,5
fresh alfalfa	1,42	25	9,2	3,8	20	40	29	22	7
association pasture, slopes	1,49	23	12	3,8	16,5	53,7	35,6	20	3,3
natural pasture	1,1	30	7,2	1,3	5,9	76	39	34,4	
artichoke biomass	1,26	23,0	10,7	2	6	54,4		29	
artichoke (byproduct)	1,40	14,0	6,8	1,8	17,1	55,9	41,4	25	11,5
nutrients in concentrates:									
maiz	2,00	88,1	1,5	4,2	9,4	9,5	3,4	2,4	0,9
Torta de Soya	2,10	89,1	6,6	1,6	49,9	14,9	10	4,5	0,7
Harina Integral de Soya	2,30	92,0	5,0	19	42	22,1	14,7	8,1	3,1
harina de pescado	2,20	92,0	16,0	4,6	71,2	0	0	0	0
Afrecho/Subproducto de trigo	1,67	89,5	5,0	4,5	18,5	36,7	12,1	11	4,2
Pasta de algodón	1,70	90,0	6,7	2,3	39,8	32	20,9	12	7,6
pepa algodón	1,94	90,1	4,2	19,3	23,5	50,3	40,1	19	12,9
DDGS	2,05	89,4	5,0	10,4	32,4	41,4	16,9	7,2	4,3
melaza	1,76	74,3	13,3	0	5,8	0	0	0	0
torta de girasol	1,55	90	7,6	2	40,5	36,9	23,4	20,4	5,6
repaso de maiz	1,95	88,0	2,1	3,9	9,5	10	3	4	1
orujo de cerveceria	1,71	21,8	4,9	5,2	28,4	47,1	23,1	18	4,7

7.6. Appendix F: Additional information of emissions on dairy farms and their bottlenecks

Table 7-8: Summary of the emissions of the different processes which take place at an intensive (Don Mateo) and extensive dairy farm (Jufra) at farm level. GWP: CH_4 = 25 according to IPCC 2007 guidelines.

	Intensive dairy farm (Don Mateo, Lima)			Extensive dairy farm (Jufra, Mantaro Valley)		
Environmental-impact/farm level/year	kg CO_2	kg CH_4	kg N_2O	kg CO_2	kg CH_4	kg N_2O
Enteric fermentation		43695			833	
Methane from manure and pastures		1690			38	
N_2O direct			1151			9,1
N_2O indirect volatilisation			124			2,5
N_2O indirect leaching			0,22			0,0026
Emissions roughage production	82797			303		
Emissions concentrate production	426665			1765		
Total (Expressed per g green house gas/farmlevel/year)	509462	45385	1275	**2068**	**871**	**11,6**

Expressed per kg CO2-eq/animal/day	**5,9**	**13,2**	**4,4**	**0,9**	**9,9**	**1,6**

7.7. Appendix G: Additional information for the calculation of the emissions due to feed

Table 7-9: Summary of origin of different components used in the ration of the dairy herd together with type of transport they are imported or divided in Peru. Also the place where the Peruvian feed components are cultivated is mentioned.

Feed component	Origin of feed	Type of transport	Place of cultivation
corn	ARGENTINA 84%	boat	
	PARAGUAY 10%	truck	
	PERU 6%	truck	fertile grond, Mantarro valley
Soybean meal	Bolivia 50%	truck	
	Paraguay 26%	truck	
	ARGENTINA16%	boat	
	USA 8 %	boat	
soybean flour	Bolivia 50%	truck	
	Paraguay 26%	truck	
	ARGENTINA16%	boat	
	USA 6%	boat	
fishmeal	PERU	truck	ocean, close to LIMA
wheat bran	PERU	truck	fertile grond, Mantarro valley + processing LIMA
grains (barley)	PERU	truck	fertile grond, Mantarro valley
cottonseed meal	PERU	truck	by product, industrie, LIMA
whole cotton seed	PERU	truck	fertile grond, Mantarro valley + processing LIMA
DDGS	USA	boat	
molasses sugarcane	PERU	truck	by product, industrie, LIMA
sunflower meal	PERU	truck	by product, industrie, LIMA
whole mais plant	PERU	truck	fertile grond, Mantarro valley
artichoke	PERU	truck	by product, industrie, LIMA
Corn*	PERU	truck	fertile grond, Mantarro valley + processing LIMA
Wet brewers' Grain	PERU	truck	by product, industrie, LIMA
Calf concentrates	PERU	truck	inudstrial product, LIMA

Table 7-10: Used data from FeedPrint in order to calculate the emissions of feed production or estimate the LUC of each feed component [56].

Feed component	Total CFP** (kg CO2-eq/kg feed)	% CFP due to transport	LUC (kg CO2-eq/kg feed)
Concentrate			
Corn	0,506	14%	0,149
Soybean meal	0,575	31%	0,394
Soybean flour	0,363	41%	0,212
Barley	0,421	16%	0,163
Fishmeal	0,310	24%	0,000
Wheat bran	0,310	10%	0,055
Cotton seed meal	0,711	20%	0,314
Whole cotton seed	0,927	18%	0,440
DDGS	0,718	1%	0,000
Molasses sugarcane	0,308	79%	0,027
Sunflower meal	0,510	31%	0,425
Concentrate milk replacement mix	0,670	19%	0,414
Wet brewers grain	0,001	100%	0,000
Roughages			
Whole mais plant[1]	0,046	0%	0,026
Maize silage	0,046	0%	0,026
Corn stover[2]	0,000	0%	0,026
Fresh maize plant[2] **(without cob)**	0,000	0%	0,026
Pasture	0,087*	0%	0,026
Oat straw	0,226[3]	0%	0,026

** The total CFP for a feed component includes cultivation, processing, machine use, feed mill and transport.*Pasture in the Netherlands receives large amount of fertilizer (max 345 kg N/ha clay [91]). Therefore we assume in the Mantaro valley 10 times less CFP due to the lower fertilization (33 kg N/ha[4]); [1] No data available from FeedPrint, therefore estimated as the same CFP as in case of Maize silage. [2] Not data available from FeedPrint 90% of the input goes to the corn, 10% goes into the corn stover or fresh maize plant. This amount of CFP will be comparable as a byproduct (e.g. wet brewers grain), Therefore total CFP is zero. [3]Oat straw has high total CFP according to FeedPrint. Assumed oat straw do not need more inputs as maize silage.

7.8. Appendix H: Additional information for worksheet “Feed adjustments”

Table 7-11: Overview of the formulas needed to calculate the NE and CP requirements of a cow [37].

Calculation of NE requirements based on IPCC 2006 [37]	Calculation of CP requirements based on lecture notes “Animal nutrition” [76]
Equation 7-1: Daily net energy required for maintenance for cattle $NE_M = Cf_i * (weight)^{0,75}$ **Equation 7-2: Daily net energy requirement for activity for cattle** $NE_a = C_a * NE_M$ **Equation 7-3:Daily net energy requirement for growth for cattle** $NE_g = 22.02 * \left(\frac{BW}{C * MW} \right)^{0.75} * WG^{1.097}$ **Equation 7-4: Daily net energy requirement for lactation for dairy cattle** $NE_L = Milk * (1.47 + 0.40 * Fat)$ **Equation 7-5: Daily net energy requirement for pregnancy for cattle** $NE_P = C_{pregnancy} * NE_M$ **Equation 7-6: Total daily net energy requirement for cattle** $NE_{Tot} = NE_M + NE_a + NE_g + NE_L + \left(NE_P * \left(\frac{calv_T - calv_H}{dairy cows} \right) \right)$ With: NE_M = net energy required by the animal for maintenance (MJ/day) Cf_i = a fixed coefficient which varies for each animal category (cattle = 0,386) Weight = live-weight of animal, kg NE_a = net energy for animal activity MJ/day C_a= coefficient corresponding to animal’s feeding situation (Pasture/dry lot = 0,17) NE_g= net energy needed for growth, MJ/day BW= the average live body weight (BW) of the animals in the population, kg C = a coefficient with a value of 0.8 for females MW= the mature live body weight of an adult female in moderate body condition, kg WG = the average daily weight gain of the animals in the population, kg/day NE_L = net energy for lactation, MJ/day Milk= amount of milk produced, kg of milk/day Fat = fat content of milk, % by weight NEP = net energy for pregnancy, MJ/day $C_{pregnancy}$ = pregnancy coefficient (cattle = 0.1) NE_{Tot} = Total daily net energy requirements for catlle $Calv_T$ = number of calvings in total $Calv_H$=number of calvings of heifers Dairy cows = number of dairy cows	**Equation 7-7: Daily crude protein requirement for maintenance for cattle** $CP_M = \frac{7.45\, g\, CP}{BW^{0.75}}$ **Equation 7-8: Daily crude protein requirement for lactation for cattle** $CP_L = \frac{83\, g\, CP}{kg\, milk}$ With: CP_M = Daily crude protein requirement for maintenance for cattle(g/cow/day) BW= the average live body weight (BW) of the animals in the population, kg CP_L = Daily crude protein requirement for lactation for cattle (g/cow/day) kg milk = kg FPCM (fat and protein corrected milk)

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