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GHG Emissions from Intensive and Extensive Dairy Production in Drylands: case studies from Inner Mongolia, China

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Abstract

This study compares GHG emissions from nine extensively and intensively managed dairy producers in a dryland area of Inner Mongolia, China. These included zero-grazing enterprises reliant on off-farm feed inputs; seasonal grazing enterprises with off-farm feed inputs; and year-round grazing enterprises with limited off-farm inputs. GHG emissions were estimated using recall survey questionnaires and default values for emission factors from the published literature. Given limitations on the inventory survey methods used, the estimated emissions per farm and per kg milk can only be considered rough approximations. The main results are:

- Average emissions across the 9 farm enterprises were 14.32 kg CO_2e per kg milk produced, with a range from 2.53 kg CO_2e per kg milk to 57.6 kg CO_2e per kg milk. Excluding two farms with the highest emissions, emissions for the other 7 farms averaged 6.9 kg CO_2e per kg milk. For the two highest emitters, the average was 39.5 kg CO_2e per kg milk.
- The highest emissions per unit milk produced were estimated for two farm enterprises that adopt broadly traditional, extensive grazing practices with no or limited external inputs. Estimated average milk yields per cow for these enterprises were significant lower than other enterprises.
- Milk yields per cow and GHG emissions per ha land used emerge as key determinants of the GHG emissions per kg milk produced.
- On-farm emissions were the majority of emissions for 5 of the 9 farm enterprises studied. Enteric fermentation is a major source of emissions, all of which occurs on-farm. The allocation of other emissions to on-farm or off-farm sources is primarily driven by fodder procurement strategies.
- Land use related emissions (primarily N_2O emissions) were a major source of on-farm emissions for 7 of the 9 farms studied.
- Emissions embodied in imported feeds accounted for the majority of off-farm emissions for all but one farm enterprise.

The study finds that land use is critical to GHG emissions in the dairy production process. While the results of the LCA point to the mitigation potential of intensifying dairy production, it does not follow that all cattle raising in the drylands should intensify. Most extensive grazing systems produce multiple products, not just milk. Indigenous cattle breeds are often less specialized in milk production, but are good multipurpose breeds adapted to dryland conditions. In some contexts, intensification of dairy production will drive conversion of dryland rangelands to crop lands, a process which incurs large emissions of GHGs. Dairy development and GHG mitigation strategies in the drylands should consider the dairy sector mitigation options in relation to the economics of production systems (e.g. considering financial and opportunity costs of adopting intensifying practices), and also in relation to the costs and benefits of alternative land uses.

keywords

GHG emissions; milk production; Life Cycle Analysis; drylands; climate change mitigation

Contents

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1. Introduction

1.1 Dairy production and emissions of greenhouse gases

Agriculture and land use together contribute around 31% of global greenhouse gas (GHG) emissions. Within agriculture, methane (CH_4) and nitrous oxide (N_2O) are the main GHGs emitted, while CO_2 is the main emission from land use and land use change. Agriculture accounts for 51% of global CH_4 emissions, a large proportion of which is due to enteric fermentation by ruminants. Fertilizer use in crop production and animal manure management account for a substantial proportion of global N_2O emissions from agriculture. Steinfeld et al (2006: 112) estimate that livestock account for 18% of total anthropogenic emissions, of which two thirds are from extensive production systems and one third from intensive systems. Dairy production is a source of several GHGs:

- CO_2 from land use and land conversion involved in both grazing and feed production as well as CO_2 emissions from fuel and energy used in production, processing and transport;
- CH_4 from enteric fermentation and manure management; and
- N_2O and ammonia from manure management and fertilizer use in feed production.

Although there is no reliable estimate of the specific contribution of the global dairy sector to livestock related emissions, it is likely to be significant, and is projected to grow as demand for dairy products grows worldwide. Steinfeld et al (2006) suggest that globally dairy cattle contribute around 18% of total livestock methane emissions from enteric fermentation and manure management, and 11% of livestock nitrous oxide emissions from manure management.

Driven by increasing demand from both developed and developing country populations, the livestock sector is one of the fastest growing agricultural sectors in many developing countries. Emissions from livestock production are therefore projected to increase (for an introductory review, see Steinfeld et al, 2006: Ch. 2). One question is whether this future demand should best be met from increased support to new intensive production, or from support to extensive production in pastoral areas where dairy production has traditionally taken place anyway? Livestock (including dairy) production and grazing systems have multiple values, social, economic and environmental impacts. The GHG implications of different production systems are just one perspective on the relative benefits of different systems.

In many dryland areas across the globe, intensive dairy production is being promoted. As urban demand for dairy products increase, there are perceived economic advantages to intensive production in peri-urban settings. This economic advantage is also partly supported by government subsidies to peri-urban dairy enterprises. By comparison, there are rarely strong government investments and subsidies for dairy production in extensively managed pastoral areas. This is probably due to the perception that total milk yields in extensive systems are low, that milk collection costs are higher, and that investment in pastoral areas is less efficient. Food safety and hygiene concerns may also support concentrated collection of milk over collection from dispersed sources. Extensive dairy producers are often blamed for causing degradation of vegetation and desertification and, as a consequence, face increasing regulatory constraints on grazing activities. Pastoral areas, and extensive production within pastoral areas, are therefore commonly perceived to have less comparative advantage in and to be less desirable sources of milk and other dairy products than intensively managed producer enterprises in peri-urban areas.

With increasing concern over the GHG emissions from agricultural practices, there is potential for future regulation to emerge governing the GHG emissions of different tradable agricultural products. Initial concern has focused on the emissions due to transportation from remote areas, but it has been shown that this concern is often not justified (Brenton et al 2009). Life cycle analysis of both beef and dairy production mostly find that the majority of emissions occur in the upstream feed production process and in on-farm production processes, not in the downstream transport of the livestock products produced (see sources cited in Garnett 2009).

There have been no comparisons of GHG emissions from dairy production in extensive and intensive production systems in dryland areas. The purpose of this study is to provide a comparison of GHG emissions from dairy production in extensive and intensive managed production systems in a dryland context. Case studies from nine dairy producers in dryland areas of Inner Mongolia, China, are presented and analyzed. The comparison is given in terms of GHG emissions (kg CO_2e)[1] per kg of raw marketable milk produced.

1.2 Dairy production in Inner Mongolia

Dryland areas differ greatly in the livestock types providing milk as well as in the production management practices employed. Within the same area, a variety of management practices are often employed by different households and enterprises. Even without accounting for differences in grazing management practice, internationally accepted enteric fermentation emission factors for dairy cattle in different parts of the developing world vary by as much as 29% (Steinfeld et al 2006). Therefore, it is not possible for a small scale study to represent GHG emissions across

[1] CO_2e (carbon dioxide equivalent units) are a way to express the global warming potential of different greenhouse gases. 1 kg of methane (CH_4) is equivalent to 25 kg CO_2; 1 kg of nitrous oxide (N_2O) is equivalent to 296 kg of CO_2.

the drylands as a whole. The production practices and GHG emissions from these case studies in Inner Mongolia, China, also reflect the impacts of rangeland management and dairy sector development policies implemented in that region, which are certain to differ in many respects from policies elsewhere.

Across North China, in recent years, restoration of grasslands has mainly been pursued through programmes supporting fencing of degraded grasslands to exclude livestock from grazing, and afforestation of degraded areas. In several provinces, resettlement of agricultural and pastoral populations has been promoted in order to move these populations away from degraded and vulnerable lands. Since 1999, Inner Mongolia has implemented a large scale programme known as 'fencing and relocation' (Chinese: *weifeng zhuanyi*), in which areas with extensive amounts of degraded grazing and arable lands are fenced off from use, and the local populations moved to new villages in peri-urban areas, where it is intended that they can generate livelihoods from alternative sources. In many areas that the population has moved in to, government has provided support for zero-grazing dairy production as one of those alternative income sources.

Promotion of zero-graze dairy production has also been driven by provincial government support for dairy sector development in general. From 1996 to 2007 the volume of milk production in China grew by more than five times, to a total of more than 35 million tonnes per year. Currently, Inner Mongolia produces about 25% of China's total milk yield. Decisions about the form of future producer support – whether support is given to extensive dairy producers or intensive producers – have implications for both dairy sector development and for land use policy in Inner Mongolia's drylands.

A comparison of GHG emissions from extensive and intensive dairy producers in Inner Mongolia is also highly relevant to China's national climate change mitigation policy. China is the world's largest emitter of GHGs. A study by McKinsey & Co (2009) highlighted that grassland management in China provides the most significant mitigation potential within China's agriculture sector (up to 80 million tonnes CO_2e up to 2030), and that it can be implemented at low cost and on the basis of existing technologies. The management practices considered in that study included reduced grazing intensity, irrigation of grasslands and cultivation of pasture. In general, implementation of these policies would support intensification of livestock production in dryland areas. Intensification, however, requires greater inputs of feed from agricultural sources. Development and climate change mitigation policies in the livestock and dairy sectors have implications for land use and mitigation policies in the agricultural sector as a whole. GHG mitigation policies and practices should avoid perverse outcomes and account for 'leakage' due to increased emissions outside the target area or sub-sector. The impacts on GHG emissions of intensification in the dairy sub-sector, therefore, cannot be considered without examination of implications for emissions from land use decisions in other sub-sectors.

2. Research Objective

The goal of this study is to compare GHG emissions between dairy producers across a gradient of intensive and extensive production practices in the drylands of Inner Mongolia, China. A further sub-goal has been to pilot methods for data elicitation and analysis where detailed production data are unavailable from the production units under study. Thus the concluding sections pay particular attention to reflection on the shortcomings in the methods used in this study.

3. Methodology

There is a growing body of research on GHG emissions from livestock production. The general approach for study of any particular product and for comparison between production units or production systems is Life Cycle Analysis (LCA). LCA is a method for assessing the integrated environmental impacts of production processes, and can be applied to accounting for environmental impacts in the production of inputs to the process of interest, the process itself, as well as environmental impacts of subsequent processing and transport processes. If different production units are to be compared, the analysis should account for environmental impacts in terms of comparable product outputs, and apply the same boundaries in defining the units to be compared. There are no strict or widely accepted standards yet for LCA of milk production. General standards for the conduct of LCAs have been produced (e.g. ISO 2006, BSI 2008), and a list of case studies reporting application of LCA to dairy production is provided in Annex 2. Reportedly, FAO is currently preparing guidelines for the conduct of lifecycle analysis of livestock products (P. Gerber, pers. comm.), which will shortly be available on the FAO's LEAD website (http://www.fao.org/agriculture/lead/en/). The following sections describe the methods used in this study, including description of the nine dairy producers sampled; the system boundaries defined for the life cycle analysis of each enterprise and for comparison between enterprises; the management activity data obtained and the sources of default values used for estimation of emissions.

3.1 Sampling of dairy producers

In the conduct of this study, nine dairy production units were investigated in Inner Mongolia, China. To represent intensive, zero-grazing dairy production in a peri-urban, dryland setting, four households in Xincang Village, Duolun County, were interviewed. To represent dairy production with seasonal grazing, we interviewed two households and one company in the vicinity of Maodeng Livestock Farm, Xilongol City. Two households with dual purpose herds under year-round grazing were also interviewed in Xilingol. Within each area, dairy producers were sampled opportunistically and purposively in order cover the maximum possible range of different production patterns in the region. Figure 1 shows the location of the two study areas. The following sub-sections summarize in a narrative fashion the characteristics of the producers interviewed, and Table 1 compares each farm on the basis of selected characteristics.

3.1.1 Peri-urban zero grazing producers

Duolun County, located in the southeast of Inner Mongolia, is an agro-pastoral area. Elevation in the county varies between 1150 – 1800 meters above sea level. Annual average precipitation is around 400 mm. The county has a land area of about 387,000 ha, of which 94% is agricultural land (including grassland). Of the agricultural land, 14% is arable land, 18% forested, and 67% grassland. Until the beginning of the present century, desertification was a pressing problem in the county, often attributed to conversion of grassland to arable land in earlier years. In the last 10 years, more than 30,000 ha of arable land has been abandoned, and returned to grassland or afforested.

Xincang Village is 1 km from Duolun county town. A large dairy corporation has a collection and primary processing plant on the other side of town. Xincang was constructed in 2002 to house people resettled from areas suffering from land degradation. It has around 400 households. Residents moved from several different parts of Inner Mongolia to this village. Most came from agricultural areas. In general, in their home area, households took part in the Sloped Farmland Conversion Programme (Chinese: *tuigeng huanlin*) in which they planted trees on former arable land and government gave a subsidy of 2400 RMB per ha per year for a period of 8 years (subsequently extended for another 8 years). The converted land cannot be used for any other land use. When resettled to Xincang, each person was allocated 0.1 ha of marginal arable land. Many households use this for silage corn production, but yields are mostly low because although there are irrigation wells, the electricity wires to run the pumps were stolen some years ago, so most fields are unirrigated. With limited and low productivity arable land, most feed is purchased from off-farm sources. For most households, dairy production provides only part of their income. Being located in a peri-urban setting, wage labour, transport services and urban employment also provide important income sources in addition to the subsidies from land conversion that the households receive.

In order to support development of livelihoods for the new migrants, local government supported the construction of a milking station in Xincang, and assisted many households to access loans to purchase Holstein Friesian cows. Thus, the model of intensive production studied involves individual households in the same community raising their own cows, and with dairy processing companies purchasing from the village milk station. Yili Corporation has a large dairy plant located near the county town. Artificial insemination services are provided by the county animal husbandry bureau. In 2008, the government also gave a small subsidy (100 RMB ≈ 14.7 USD) to households for each dairy cow raised, but this subsidy was not available in 2009. Villagers reported that a future subsidy may be provided for each pure-bred calf born. Xincang now has more than 300 households raising dairy cows. In 2008, the 'melamine milk' scandal in China brought about many changes and shocks to the dairy industry. When households were interviewed in July 2009, the village milking station was in operation but the price was very low, so many households were unwilling to sell. Households processed the milk into other storable dairy products for their own consumption instead of selling. Prices since late 2008 have been very low, and several households have recently sold off their stock.

Four households were interviewed. They were selected to represent households with relatively large herds and households with smaller herds, as well as households that produce their own silage corn and households that do not. Milk and silage corn yields also differ among the households. Overall, the households interviewed represent a broad spectrum of the range of productivity in the village.

Farm 1: Average size herd, low yield silage corn fields, low milk yields: This household has five members, including an elderly member, two adults and two school children. They have ten cows, and also earn income from wage labour. They estimate dairy income accounts for about 60% of household income. They have been raising cows since 2002, when they bought their first cow with a loan. The household has 0.5 ha of unirrigated arable land which they use to grow silage corn. Other feeds (hay, corn kernels and composite feed) are bought off-farm. About one third of cattle dung is used for household energy, and two thirds used as agricultural input.

Farm 2: Large size herd, no arable land, low milk yields: This household has five members, all of whom are able-bodied labour. Half of the family income comes from wage labour, a quarter from land conversion subsidies and a quarter from milk sales. The family moved from another province only three years ago, and was not allocated any arable land in Xincang village. They began raising cows only after their move to Xincang, and now have 23 cows, of which 13 are currently lactating cows. Hay and feed meal concentrate are the only forages fed. A small amount of cattle dung is used for household energy needs, as the household mostly uses coal instead. Most dung is sold for use as manure by nearby farmers.

Farm 3: Average size herd, low yield silage corn fields, low milk yields: This household has four members, of whom two are school children. They have been raising cows for four years. They now have nine cattle, of which five are currently lactating. With limited labour resources, the household subsists off land conversion subsidies and milk sales. The household has 0.4 ha of unirrigated arable land. Hay, silaged corn stalks, corn kernels and cobs, and feed meal concentrate are fed. About half of the cattle dung produced is used for household energy, and half used for manure.

Farm 4: Small herd, high silage corn yields, high milk yields: Before moving to Xincang, this household had been a worker on a state-owned livestock farm and has experience of raising cows. With five able bodied members, their main income is from wage labour and transport services, and milk sales only account for about 20% of household income. They have six cows, of which two are currently lactating. They have 0.5 ha of irrigated land used for growing silage corn. In addition to feed meal concentrate, they feed protein cakes bought from the rape seed oil factory in the county town. The household's energy needs are met from coal, so cattle dung is used as an agricultural input on-farm and the remainder is sold for use as manure by nearby farmers.

3.1.2 Dairy production with seasonal or year-round grazing

Xilingol Municipality is one of Inner Mongolia's most well-known grassland and dairy production areas. Annual average precipitation is around 295 mm. Grassland vegetation is dominated by *Stipa grandis* and *Leymus chinensis*. The western part of the municipality is severely desertified. In the last ten years, large areas of arable land have been abandoned, and grassland conservation programmes have greatly improved vegetation cover in formerly degraded areas.

Maodeng Livestock Farm was established in the late 1950s as a state-run livestock farm. It has a land area of 585 sq km, with about 400 households and a population of 2000. In the 1990s, the user rights over some parts of the state farm were allocated to the farm workers, and livestock production became the responsibility of each household. The farm became a service provider to the households, and runs its own enterprises, including production and sale of hay, silage and tree saplings. In 2003, 'fencing and relocation' was also implemented on the farm. With support from local government, a Milk Production Zone containing a settlement of some 200 households and a milking station were constructed on the edge of the farm's property. About 200 households were also moved to an adjacent plot of land from neighboring Chaoke Township. Subsidized loans were provided for purchase of Holstein Fresian cows. Households raise their own cows, purchase silage and hay from the state farm, and feed concentrate from the privately-run milking station.

Farm 5: Large size herd, seasonal grazing, household based dairy production: This household moved to the Milk Production Zone in 2004, when it bought eight cows and calves, which have now developed to a herd of 23. Eight cows are currently lactating. The household has 67 ha of grassland which is far from their new residence and the milking station, so they use it to raise 80 sheep. Their cows graze on common property grassland for three months each year. They also buy hay, feed concentrate and silage maize. Most household income comes from wage labour around the

Maodeng Livestock Farm, and from sheep. Milk sales provide a small proportion of their income. The household uses cattle dung and coal for heating.

Farm 6: Medium size herd, seasonal grazing, household based dairy production: This household is a former staff of Maodeng Livestock Farm that moved to the farm's Milk Production Zone in 2004. They have 12 Holstein Fresian cows (six of which are lactating), and earn most of their income from milk sales. The household has 67 ha of grassland, and their cattle graze for two months each year. But since it is poor quality grassland, they hire machine operators to make hay which they sell, and then buy good quality hay from other sources. They also purchase silage maize from Maodeng Livestock Farm and feed concentrate from the milking station. The household uses cattle dung and coal for heating.

Farm 7: Intensive production enterprise with seasonal grazing: This dairy and beef cattle enterprise has 520 head of cattle, of which 250 are lactating cows. This enterprise is owned by a private company which has production bases all over Inner Mongolia producing grain and oil crops. The cattle farm is located next to Maodeng Livestock Farm's Milk Production Zone. It has its own milking station, produces its own sugar beet and prepares its own feed mix. It rents over 2300 ha of grassland from the livestock farm and buys silage maize from Maodeng Livestock Farm. Lactating cows are stall-raised, but all other cattle graze for 4.5 months each year. The farm sells milk directly to a major milk processing corporation, and receives a higher price for its milk compared to the price given to smallholders who sell through the milking station. Apart from milk, the enterprise also sells around 100 head of fattened two-year old beef cattle each year. Heating energy needs are met by burning around 100 tonnes of coal each year.

Farm 8: Small-scale extensive household dual purpose production: This household is located about 1 km from the Milk Production Zone in Maodeng Livestock Farm. It does not belong to the farm, but to neighboring Chaoke Township. The household raises cattle in a traditional way, with no off-farm feed inputs. The cattle raised are indigenous cattle breeds. The household has 220 ha of grassland and earns most of its income from sale of hay harvested by hired machine operators from its grasslands. Other income comes from sale of 8-9 month old calves. Milk is used for household consumption only. Heating energy comes from cattle dung and coal.

Farm 9: Large-scale extensive household dual purpose production: Three brothers have joined their grassland and livestock together to develop a large-scale, household-based, dual purpose cattle production enterprise. The main income is from sale of livestock. Milk is used to feed calves and develop the herd, and for household consumption. They do not sell milk because yields are low, and in the last year milk prices have also been low. The livestock raised are indigenous breeds and Simmental and Charolais cross-breeds with indigenous cattle. The brothers feel the indigenous and Charolais are well-adapted to the semi-arid environment. Pure Simmental are less well adapted until they have been cross-bred with indigenous cattle. Together, the three brothers have 400 ha of grassland, and also rent about 330 ha of grassland for hay making. They have their own tractor with fitments for hay making, and their own truck for transport. Heating energy comes from cattle dung and coal.

3.2 Definition of system boundaries

General guidelines on the definition of system boundaries are given in ISO (2006) and BSI (2008). Full life cycle analysis should include emissions from core production processes that occur on-farm, upstream processes that occur on and off-farm providing inputs into core milk production processes, and downstream processes that are necessary to the production, processing and sale of milk products.

In this study, we attempted to consider all on- and off-farm emissions in core and upstream processes. Upstream processes are processes resulting in inputs to core on-farm production processes. These include emissions embodied in inputs imported from off-farm. Since the 'melamine milk' scandal, milking stations have been wary of investigations, so we were unable to elicit data on downstream processes such as milking and product processing. The system boundary was therefore drawn at the farm gate, and excluded all downstream processes. Figure 2 shows how the boundaries were defined in this study.

All households and enterprises surveyed produce milk on-farm. Core processes documented include on-farm utilization of grasslands, production of feed crops, cattle raising activities, manure production and manure management on-farm, all of which are necessary to the production of milk. The sources of GHGs estimated in these processes are listed in Table 2. Following IPCC guidance for drylands (IPCC 2006 Vol 4 Ch 11: 11.2.2.3), nitrogen leaching was not accounted for because evapotranspiration is much higher than precipitation in the study areas. Emissions of all GHGs were converted to CO_2e units using IPCC values for Global Warming Potential (Table 7).

Emissions from on-farm upstream processes documented include the use of fertilizer, fuel and electricity in feed production on-farm; fuel used on-farm (e.g. diesel used in hay making and on-farm transport of feeds); and emissions from land use (soils). Emissions for off-farm upstream processes include the fertilizer, fuel and electricity used in the production of feed concentrates and other purchased fodder; land use (soils) emissions in forage and feed production; and emissions from fuel use in transport to the farm of imported forage and feeds.

Production of milk leads to co-products on-farm, the main one being manure, but also including live animals sold for meat (e.g. off-take of young calves), hides and other products. Emissions from manure application after export from the farm were not included in the system boundary. A portion of emissions from dung burning for household energy use was allocated to dairy production based on the estimated percentage contribution of dairy income to the household enterprise. Although the same occurs for coal energy used, this was not included in the study. Since the most intensive enterprises studied (Farm 7) burns coal for heating needs, this omission leads to a significant underestimation for this enterprise in particular. It is necessary to produce calves in order to produce milk, therefore, direct emissions (due to enteric fermentation) from calves before their sale was included, but emissions from weaned male livestock was excluded. Land use emissions were allocated to dairy production based on the percentage of female + calves in the herd. The method of allocation to dairy as opposed to other products may overestimate the emissions attributable to dairy production, especially for the dual purpose enterprises, because outputs of other products (e.g. hides, live animal sales etc) were not examined in detail.

Data on on-farm management activities and on imports of off-farm feeds and transport activities were elicited through interviews with producers. The main imported feeds are silage maize and feed concentrate. Additional interviews were held with the manager responsible for silage production on Maodeng Livestock Farm to estimate inputs and yields in silage production, and with a manager of a feed concentrate factory in nearby Hubei Province to estimate inputs into feed concentrate processing. Feed concentrate inputs include a range of agricultural products. As a substitute for calculating the emissions from production of all these products, we used published data on inputs and yields from winter wheat production in North China, correcting for the proportion of winter wheat which is an input into feed concentrate. Our estimate of emissions from feed concentrate production is therefore only an approximation.

Outputs of each production unit included milk, manure and GHG losses to the environment. Milking is done by machine for all but the two extensive year-round grazing households. Emissions occur from electricity and diesel used in milking, storage of milk and transport of the raw milk to processing enterprises, but data on these downstream processes were not collected. Emissions from transport of milk to processors and consumers are reportedly a concern in some other countries, but unless products are transported by air (Edwards-Jones et al 2008), other studies have mostly found that post-production transport is not a major part of total emissions of dairy products (see references cited in Garnett 2009).

Emissions from direct land use and from land use change induced by demand for feed should ideally be included in the LCA (Garnett 2009). The intensive peri-urban producers studied are located in an agro-pastoral eco-tone. It can be assumed that the arable land they use was at some point converted to arable land from grassland, a process which causes large loss of soil organic carbon (Guo and Gifford 2002). However, the land plots used were arable land prior to their use by the current dairy producers. Therefore, land use conversion involved in intensive production was not included in the system. Feed meal inputs were produced in agricultural areas where it is assumed that no land use change occurred. Since land use change driven by intensification of dairy production is reportedly an issue of concern in some other countries, the implications of excluding land use conversion are discussed in Section 5. Emissions from direct land use (i.e. soil respiration from mown or grazed grasslands and arable land used for fodder production) are difficult to quantify. In this study, we used values of CO_2, CH_4 and N_2O per ha based on published research from the study region. Research shows that in Xilongol, grazed and ungrazed grassland are both CO_2 sinks in wet years and sources in dry years. Since the stocking rates of the farms studied were quite low, and no long-term degradation process could be demonstrated, we assume that grassland is neither a source nor a sink of CO_2. Grasslands and arable land are both CH_4 sinks in the region, but they are both also N_2O sources. Values for net CH_4 and N_2O fluxes were taken from the published literature.

Energy used by producer units can be a large contributor to total GHG emissions. Some part of household energy use should not be attributed to milk production related emissions because it is not a necessary activity in the production of milk. In the study area, dung and coal are used for household and enterprise heating needs. Part of the emissions due to dung burning were attributed to milk production based on the reported percentage of the producer's income deriving from milk production. Emissions from coal combustion were not calculated. The commercial enterprise studied (Farm 7) uses coal to heat the milking shed and to warm employees' quarters, but other smallholder enterprises do not use coal directly in milk production. To avoid complications and issues of comparability between producer units, we decided to exclude GHG emissions from coal combustion from the study. This leads to an underestimation of the emissions from Farm 7, and an underestimation of total farm emissions from all the enterprises that burn coal, but the proportion of emissions attributable to dairy production would require much more detailed examination of energy use and farm incomes, and allocation of emissions to different production processes based on the resulting analysis.

In order to simplify the estimation process, buildings, equipment and facilities (e.g. concrete silage tanks) were excluded from analysis.

Downstream emissions occurring after the raising of cattle were excluded. Some zero-grazing peri-urban dairy producers sell dung to nearby farmers for use as an agricultural input. The emissions related to the application of this dung as manure was excluded, because it is beyond the boundary of the producer unit and not necessary to the production of milk. The initial storage of the dung before its sale was, however, attributed to the producer unit because its management on-farm results in emissions prior to sale.

3.3 Management activity data and estimation of emissions

This study did not involve the collection of primary data on GHG emissions, nor did we directly measure the key input or output parameters in the production units surveyed. The general approach adopted was to assign default values for emissions based on emission factors reported in existing publications and data on management activities provided through interviews by each dairy producer unit. Where available, values from studies in Inner Mongolia or North China were used. Where these were not available, values for China or East Asia from other authoritative sources (e.g. IPCC 2006) were used. Annex 2 gives a list of reference sources for emission factors.

Interviews were held with each dairy producer unit to understand and quantify management practices over the previous year (July 2008 – July 2009). The data collected included the following:

(1) Cattle herds (stocks and flows): Data collected included: (i) current cattle numbers and the age, sex, breed and status (dry, lactating, pregnant) of each; (ii) changes in herd composition over the past year due to births, sales, mortality and purchases and the month in which the event occurred. These data were used to calculate the total ‘residence time’ of each type of cattle in the dairy production unit over the past year. Total residence time of each type of cattle was used together with reported feed and forage use to calculate dung yields. Total residence time of each type of cattle was also used in estimation of on-farm emissions due to enteric fermentation.

(2) Milk production: Producers do not keep records of milk yields of their animals. Data from the milking stations could not be accessed because this is a trade secret. In general, cows have a high yield period directly after calving, after which the milk yields gradually decline. Yields vary for different ages of cow / sequence of parturition. Producers were asked for information on the age of each lactating cow and the daily maximum yield during the high yield period, and on the daily yield towards the end of the lactation period. This data was fitted to a yield curve from research conducted in the study region (Su Jianhua 2001, Shi Hongjun 2005, Zhang Huilin et al 2006), from which the total yield of all lactating cows in the previous year was estimated. Milk yields are expressed in kg, and consider only marketable milk (i.e. excluding milk fed to calves). Interviews confirm that producers in the intensive system do not consume milk unless it cannot be sold. For the two extensive dual purpose households, milk consumed on-farm was taken as a measure of marketable milk in order to facilitate comparison with the milk sold by other producers. Data on fat and protein content of milk is collected by the milking stations, but was not available because it is a trade secret. Therefore, we have not corrected milk yield data for this. The functional unit used is kg of raw milk.

(3) Feed rations: Interviews with producers collected data on the total feed ration (TFR) and structure of TFR fed to different ages and classes of cattle over the course of the year. TFR is expressed in kg dry matter. Detailed data on TFR can be used to calculate emissions of CH_4 due to enteric fermentation (the method of calculation is given in IPCC 2006 Vol 4 Ch 10). However, for simplicity, we used default values for enteric fermentation adjusted for the level of milk productivity of the cows in the herd. The default values were derived from IPCC (2006), and are shown in Table 3. In general, the herds studied were of two types: high yielding Holstein-Fresian (av. annual yield per cow: ca. 5,345 kg), and lower yielding indigenous cattle with other cross-breeds (av. annual yield per cow: ca 1,688 kg). Enteric fermentation from the higher yielding cows was estimated using the average emission factor for Western Europe and North America, while the lower yielding cows were estimated using the average emission factor for Asia.

(4) On-farm feed production: In the intensive, peri-urban system, some dairy producers have their own arable land on which they produce feed crops. Data was collected on arable land area, crop types, yields (kg DM), tillage practices, fertilization and manure use (type and kg applied) and fuel consumption (liters of diesel consumed) in the cultivation, harvesting and transport process. Default values for direct emissions from fertilizer use, manure application and direct emissions from fuel use were drawn from the published literature. Emissions from land use on-farm were estimated using default values drawn from the published literature on GHG fluxes in the study region. Table 4 shows the default values used and their sources. GHGs emitted in the process of producing the fertilizers used on-farm are accounted for as an off-farm emission. Some households have their own grassland which is used for hay-making, which was accounted for as an on-farm emission. Several households seasonally rent grassland from others for the specific purpose of hay making once a year. This is accounted for as a forage import, and the related land-use and fuel consumption emissions were counted as off-farm emissions.

(5) Off-farm feed production: Off-farm feed imports included hay, silage maize, and feed concentrate. Only one producer used small amounts of protein cakes procured from a nearby rape seed processing factory. Emissions from this minor feed source were omitted. Estimates of fuel use in hay making and transport were obtained from interviews with producers. Inputs per kg of silage were estimated on the basis of an interview with the manager of silage production at Maodeng Livestock Farm. Electricity and fuel inputs per kg feed concentrate processed were estimated on the basis of an interview with the manager of a feed concentrate factory near Beijing. Because feed concentrate has a variety of agricultural crops as their contents, we made a simplifying assumption that feed concentrate input production could be represented by winter wheat production in North China. Inputs into winter wheat production and emissions from land use were estimated using default values drawn from the published literature on GHG fluxes in the study region. Table 5 shows the default values used and their sources.

(6) Manure management: Data was collected from interviews on the uses of manure. For some uses (e.g. household energy use, manure applied to arable land), estimates of the amount of manure consumed (kg DM) could be obtained through interviews. In some cases, interviewees could only provide an estimate of the proportion of total dung production used for different purposes. Based on the data on forage and feed rations, and following methods described in Feng (2006), the volume of total dung production per cattle type was calculated. The proportions of dung allocated to different uses were then applied to the total dung production. In the case of dung burned for household energy consumption, a proportion of emissions from dung burning was allocated to the dairy process based on the proportion of income from milk sales. However, the two extensive producers do not sell their milk, so the value of the milk they produce was imputed the current market price, and a proportion of income due to milk production was imputed on this basis. Emissions from coal burning by households were not accounted for as an input in the milk production process. Farm 7 uses coal to warm the milking shed and staff quarters, so omitting this source will underestimate the total GHG emissions from this enterprise. Emissions from manure management were calculated using the method described in IPCC (2006 Vol 4 Ch 10), and using default values for dairy cows in Asia.

(7) Emissions from fuel and electricity use: Data on fuel use on-farm as well as in the import of off-farm feed and forage were collected through interviews, and where interviewees were unable to provide reliable estimates, data was collected on the distance traveled, and estimates made on the basis of standard fuel consumption values for a 10-tonne truck (i.e. assuming 20 liters diesel per 100 km traveled). GHG emissions were then estimated on the basis of emission factors reported in Audsley et al (2003). For emissions due to electricity use (e.g. in irrigation pumps for crops), the marginal operating emission factor for the North China grid was applied. Table 6 shows the emission factors used.

3.4 Calculation of GHG emissions per unit of milk yield

The GHG emissions considered due to the management activities described above include CO_2, CH_4 and N_2O. These were converted to CO_2 equivalent units (CO_2e) using Global Warming Potentials provided by IPCC (2007) (Table 7). Milk yield is expressed in kg raw milk.

4. Results

4.1 Descriptive data on dairy producers

Table 1 presents some indicators that enable a comparison of the characteristics of the dairy producers surveyed, the main forage and feed inputs, and estimated yields.

- The producers surveyed represent a variety of production patterns, from zero-grazing using mostly off-farm feed inputs (Farms 1-4) to seasonal grazing with off-farm feed inputs (Farms 5-7), and all year round grazing with no or limited off-farm feed inputs (Farms 8-9).
- The scale of production also varied. Individual smallholders had between six and 23 cows (average 14); a commercial operation had 360 cows, and a joint household enterprise had 130 cows.
- Total farm milk yields were estimated by a combination of numbers of cows, forage and feed intake, breed and age (number of parturitions) structure of the herd. With the exception of Farms 8 and 9, all other farm enterprises raised Holstein-Fresians. Farms 8 and 9 raised mixed herds of Charolais, Simmental and indigenous cows. Estimated annual milk yields per cow varied between farms depending on feed intake, herd structure and breed. The estimated yields per cow varied between 1,688 kg per year (Farms 8 and 9) to a maximum of almost 8,000 kg per year (Farm 4). The average estimated yield was 4,532 kg per cow per year. (This is much higher than the yields on which IPCC default values for Asia are based.)
- The different farming systems of the nine farm enterprises are reflected in different land uses in dairy production. Table 8 summarizes the land uses of each farm enterprise (including arable and grassland owned and grassland rented by the households, but not including the arable land used in producing silage or feed concentrate).

4.2 Total GHG emissions by farm and GHG emissions per kg milk

Figure 3 shows the total GHG emissions per farm enterprise (kg CO_2e). For seven of the nine farm enterprises, total emissions per farm enterprise ranged between 277,000 kg CO_2e to 486,000 kg CO_2e per year. For two of the farms – a large scale dual purpose enterprise with 500 head of cattle (Farm 7) and a dual purpose joint household enterprise with 250 head of cattle (Farm 9) – total emissions were 4.11 million and 2.22 million kg CO_2e respectively. Exclusion of emissions from coal-based energy use underestimates total emissions for all farms, and for Farm 7 in particular.

Figure 4 shows the GHG emissions (kg CO_2e) per kg of milk produced in each production unit studied. Average emissions across the nine farm enterprises were 14.32 kg CO_2e per kg milk produced. There is a wide range of emissions per kg milk, from a low of 2.53 kg CO_2e per kg milk to a high of 57.6 kg CO_2e per kg milk. Among households sharing a roughly common general pattern of production, there is a wide difference in per kg milk emissions. For example, Farms 1-4 which are all zero-graze smallholder enterprises, per kg milk emissions range between 2.53 to 14.37 kg CO_2e. Farms 5 and 6 (3.95 and 7.57 kg CO_2e) are both seasonal grazing smallholders, and Farms 8 and 9 (22 and 57.6 kg CO_2e) are both dual purpose year-round grazing enterprises with traditional breeds. The highest emissions per unit milk produced are both year-round grazing enterprises with no or limited external inputs, i.e. more traditional pastoralist household and joint household enterprises. For the other 7 farms, the average per kg milk emission is 6.9 kg CO_2e. For the two high emission farms, the average is 39.5 kg CO_2e. The pattern of emissions among farm enterprises is different from the pattern of total emissions per farm (Figure 3). Farm 7 (the large-scale dual purpose enterprise) has the largest total farm emissions, but the second lowest per kg milk emissions. Farm 1 (a zero-grazing household enterprise) has the third lowest total farm emissions, but has the third highest per kg milk emissions. Farm 8, a dual purpose household enterprise with year-round grazing, has relatively low total emissions, but the highest per kg milk emissions. Because milk from the extensive dual purpose enterprises (Farms 8 and 9) is not marketed, and because other livestock products are also derived from the cows in these farms, the allocation rules adopted in this study may overestimate the proportion of emissions attributable to milk production for these two farms.

The estimated annual milk yields per cow and total annual milk yields per farm enterprise are key factors determining per kg milk emissions. Figure 5 shows that there is a general inverse relationship between GHG emissions per kg milk and the average milk yields per cow. That is, more productive cows tend to lead to lower GHG emissions per kg milk. There is also a general positive correlation between GHG emissions per kg milk and GHG emissions per ha of on-farm land use (Figure 6). That is, as GHG emissions per unit of land use fall, GHG emissions per unit of milk also tend to fall. As the analysis of the composition of farm emissions below shows, fodder procurement strategies and their implications for land use are a key determinant of emission levels.

The range of estimated emissions per kg milk produced is generally significantly higher than for other estimates in dryland areas (van Kernebeek and Gerber 2008 estimate 1.63 kg for a farm in Ropar, India) and higher than in most European studies (0.69 – 1.3 kg CO_2e per kg, various studies cited in de Boer 2003; 1.4 – 1.5 kg CO_2e per kg for a conventional and an organic farm in the Netherlands cited in Thomassen et al 2008).[2]

4.3 GHG emissions by source

GHG emissions in the system as defined above can be divided into on-farm and off-farm emissions. Figure 7 shows the percentage of emissions for each farm due to on-farm and off-farm sources. On-farm emissions accounted for less than half of total emissions for four of the nine farm enterprises. These farms included three of the four zero-grazing households (Farms 1-3), and one of the seasonal grazing smallholder enterprises (Farm 6), which depend to a large extent on imported feeds. Farm 8 is a traditional year-round grazing household that imports no off-farm inputs, and all its emissions were on farm. Farm 4 is a zero-grazing smallholder producer that is able to meet all fodder needs from its own cropland and grasslands from which it makes hay. 96% of its emissions were from on-farm sources. The percentage of total emissions due to off-farm emissions were the highest for 3 of the 4 zero-grazing smallholders (Farms 1-3). These households have limited cropland for silage production, and must meet all other fodder needs by importing forage and feed from off-farm sources.

4.3.1 Composition of on-farm emissions

Figure 8 shows the composition of on-farm emissions for each farm enterprise surveyed. Land use emissions (excluding feed production) accounted for more than 70% of on-farm emissions for six of the nine farm enterprises. Enteric fermentation was the second biggest on-farm emission source for all of these farms. Two farms had no on-farm land use emissions, and enteric fermentation accounted for more than 80% of both these farm enterprises' on-farm emissions. Emissions due to manure management (i.e. storage and burning) were a relatively small proportion of estimated emissions for all farm enterprises, averaging 3.7% of on-farm emissions (min. 0.9%, max 9.7%).

Among land use related emissions, emissions in the on-farm feed production process were limited for all farms because of the very small areas of arable land involved. The main contributors to on-farm land use emissions were emissions from grassland, whether it is used for grazing or for hay making. This is because in this dryland area of Inner Mongolia, although grassland is a net sink for methane, it is a net source of N_2O emissions, and N_2O has a very high Global Warming Potential. In the assumptions used in the estimation of land use emissions, we conservatively assumed that both grasslands and arable land are neither a CO_2 source nor a sink. The exact size of CH_4 and N_2O fluxes is a matter requiring more research. The figures used in this study were relatively conservative, but there are also literature reports of much higher emissions of CO_2, CH_4 and N_2O from land use.

[2] Note, however, that most of these studies calculated kg CO2e per kg of energy corrected milk or per kg of fat and protein corrected milk.

The exclusion of on-farm use of coal-based energy in this study underestimates the contribution of energy sources to on-farm emissions. Farm 7 in particular uses 100 tonnes of coal per year for heating of milking sheds and workers' quarters, so the exclusion of this emission source from this study greatly underestimates the contribution of this emission source to on-farm emissions in this enterprise.

4.3.2 Off-farm emissions

Figure 9 shows the composition of off-farm emissions. One farm enterprise (Farm 8) had no off-farm emissions. For all other farm enterprises, more than 85% of off-farm emissions were the emissions embodied in feeds imported to the farm. The majority of feeds imported were silage, hay and feed concentrate. This suggests, then, that land constrained dairy producer enterprises in the region are increasing feed resources by importing feeds from off-farm sources, but that this also implies that they are 'exporting' their dairy emissions to feed and forage suppliers. The emissions from fuel consumption in the process of importing feeds were in general not a significant source of emissions. Other studies have also found that post-production transport of dairy products is not a major contributor to emissions (see Garnett 2009).

4.3.3 Emissions in off-farm feed production

Emissions embodied in feeds imported to the farm enterprises were the main source of off-farm emissions. In terms of GHG emissions per kg feed, hay had the highest emission (1.9 kg CO_2e per kg hay), with feed concentrate (0.15 kg CO_2e per kg) and maize silage (0.08 kg CO_2e per kg) having much lower emissions per kg produced. Figure 10 shows the estimated composition of emission for the three main types of feed imported from off-farm sources. Emissions from hay are mainly from land use (again, mainly due to N_2O emissions despite haylands being a methane sink), while much higher yields per ha of silage and wheat mean that net CH_4 and N_2O emissions directly from soils account for a limited proportion of silage and feed concentrate emissions. For agricultural feed sources, direct emissions from fertilizers and embodied emissions from fertilizer production were a major component of unit feed emissions (36% for silage and 67% for feed concentrate). Silage and wheat produced in the drylands of the study area are produced with irrigation which uses electricity powered pumps, and electricity is a major input into feed concentrate processing. The North China electricity grid is coal-based, which has a relatively high emission factor.

The inclusion of land use, fertilizer and electricity emissions from off-farm feed production in the emissions of the dairy producing farm enterprises studied is a question of the definition of system boundaries. It may be argued that this is inappropriate, since these emissions should be accounted for in the emissions of the feed producing enterprises, not of the feed consuming enterprises. If emissions from hay, silage and feed production off-farm are not included in the emissions of the nine dairy enterprises studied, then total farm emissions fall on average by 31% (range: 0%

- 87%), and GHG emissions per kg milk produced average 10.3 kg CO_2e per kg milk (range: 0.8 – 57.6 kg CO_2e / kg milk). Enteric fermentation and on-farm land use remain by far the major sources of emissions (Figure 11).

5. Evaluation and Analysis

5.1 Evaluation of methods

At best, this study provides only rough indications of the level and composition of GHG emissions from the dairy producing enterprises studied. There were shortcomings both with the method for inventorying on-farm dairy input, management and output parameters, as well as with the methods used to allocate and calculate estimated emissions.

5.1.1 Sampling, system boundaries and allocation of emissions

The survey covered a range of dairy producer units with different farming systems. Some enterprises surveyed depend to a large degree on imported feeds. With limited on-farm feed resources, these imported feeds are necessary to dairy production. It was therefore decided to include the emissions created in the feed production process within the boundary of the dairy producing system, as has been done in several other LCAs of dairy production (e.g. van Kernebeek & Gerber 2008, Cederberg & Mattson 2000). Including emissions in the process of producing feeds off-farm reflects more fully the GHG implications of milk production in the region. But because different farms have different fodder procurement strategies, even with identical levels of consumption of hay or silage, the allocation of the related emissions to on- or off-farm sources varies between enterprises.

Most of the enterprises studied were household enterprises, and one was a fully commercial enterprise. All produced milk, but three were dual-purpose enterprises, producing milk, meat and other livestock products. Two of these do not sell milk, and therefore it was difficult to use the proportion of income from dairy production as a factor for attributing emissions from different on-farm sources to the dairy enterprise. This may lead to some overestimation of emissions attributed to milk production for these enterprises. Other allocation issues also arose. For example, all but one of the farm enterprises studied burn coal in winter for household heating. Some of this could be attributed to dairy production, but only in the case of the dual purpose commercial enterprise is it actually used to warm cow sheds and workers' quarters. With such complications, it was decided to exclude emissions from coal combustion altogether, though this leads to some underestimation of emissions for most of the farm enterprises studied and for the commercial enterprise (Farm 7) in particular. Future studies in drylands could attempt to categorize enterprise types in advance, and develop comparable protocols in advance of the field survey.

All enterprises also produce other products. Even those enterprises which raise only dairy cows also sell male calves. Dual purpose enterprises earn income from both milk and live animal (meat) sales. Therefore, emissions from various sources should be allocated to dairy only in proportion to the contribution of dairy production to use or demand for these emission sources. No data on other products were collected, and it was difficult therefore to perform this kind of allocation. Future studies could consider inventorying a wider range of livestock products and developing appropriate and workable rules for allocation of emissions to these different products. In multifunctional livestock systems in the drylands, this approach would be particularly relevant.

'Downstream' processes, such as milking, storage, transport and processing of milk were not included in this study, primarily because of the lack of access to data on management practices following the 'Melamine Milk' scandal in China in 2008. The exclusion of these processes in this study may not be significant because of the high degree of similarity in the processes used by all the commercial enterprises studied. In the study area, all smallholder dairy farms (Farms 1-6) take their cows to a nearby milking station where cows are milked using milking machines, and the milk stored on-site temporarily before collection and transport to a nearby processing factory. The commercial enterprise (Farm 7) has its own milking machines and temporary storage facilities, but the milk is also then collected and taken to the same nearby processing factory. Other studies have found that emissions from transport of milk are not a major emission source (see references cited in Garnett 2009). Unless the specifications of the milking and storage machines used or the energy sources used to power the machines are very different, the emissions from milking, storage, transportation and processing for Farms 1-7 should be similar. Farms 8 and 9 consume their own milk raw on-farm, and therefore do not incur emissions in these downstream processes prior to consumption. However, the comparison used in this study was between raw marketable milk (i.e. in theory milk from Farms 8 and 9 could be marketed instead of being consumed). If Farms 8 and 9 marketed their milk, we assume they would also use the same downstream processes and therefore also incur similar emissions in these processes. In other locations, intensive and extensive producers may be integrated into very different value chains and use very different processes subsequent to production of milk. In such cases, it would be very important to inventory the processes used and to compare emissions in 'downstream' processes between intensive and extensive enterprises and their respective value chains.

5.1.2 Inventory survey methods

Measured data on key input and output parameters was unavailable for the farm enterprises studied. The eight smallholder enterprises studied do not collect data on production inputs or milk yields. The commercial enterprise studied retains this data but it was not available to the researchers. Some relevant data exists at milking stations, but since the 'melamine milk' scandal of 2008, producers have been very wary of attempts to access such data. We therefore were only able to estimate input and output parameters by interviews that depended on respondent recall or estimation. Estimates of forage and feed use and dung production were cross-checked using rule of thumb figures, but they still remain only estimates. The values for these parameters are, however, within the plausible range for the region. High quality inventory data documenting the precise amounts of inputs, management parameters and outputs is required for accurate calculation of emissions from livestock enterprises. It is highly recommended that future studies select producers for which measured and recorded input and output data are available, or that research is undertaken to fill in data gaps on management parameters.

5. 2 Summary of results

Bearing in mind the methodological limitations described above, the study estimated total GHG emissions per farm enterprise and GHG emissions per kg milk produced for nine farm enterprises in two localities in the Inner Mongolian drylands. The main results are:

- Average emissions across the nine farm enterprises were 14.32 kg CO_2e per kg milk produced. There was a wide range of emissions per kg milk, from a low of 2.53 kg CO_2e per kg milk to a high of 57.6 kg CO_2e per kg milk. Excluding two farms with the highest emissions, emissions for the other seven enterprises averaged 6.9 kg CO_2e per kg milk. For the two highest emitters, the average was 39.5 kg CO_2e per kg milk.
- The highest emissions per unit milk produced were estimated for two farm enterprises that adopt broadly traditional, extensive grazing practices with no or limited external inputs. Estimated average milk yields per cow for these enterprises were lower than for all other enterprises.
- The productivity of cows is one determinant of per kg milk GHG emissions. In general, as per cow milk yields rise, per kg milk GHG emissions fall. Land use is another important influence of per kg milk emissions. In general, as GHG emissions per ha of land used falls, the per kg milk GHG emissions fall.
- On-farm emissions were the majority of emissions for five of the nine farm enterprises studied. Enteric fermentation is one major source of emissions, all of which occurs on-farm. The allocation of other emissions to on-farm or off-farm sources is primarily driven by fodder procurement strategies.
- Land use related emissions (primarily N_2O emissions) were a major source of on-farm emissions for seven of the nine farms studied.
- Emissions embodied in imported feeds accounted for the majority of off-farm emissions for all farm enterprises except Farm 8 which had no feed imports. Hay has a higher GHG emission per kg than silage or feed concentrate, primarily due

to N_2O emissions in land use. For silage and feed concentrate, fertilizer and electricity used in irrigation and processing accounts for significant proportions of emissions per kg feed produced.

- If emissions occurring during the production of imported feeds are excluded from the system boundary, enteric fermentation and on-farm land use are the main sources of GHG emissions.

In other milk LCA studies, land use has also been found to be a significant contributor to dairy emissions. In a study of one dairy farm in Ropar, India, which imported large amounts of feed, van Kernebeek and Gerber (2008) calculate that off-farm land use contributed almost 50% of total farm emissions. When on-farm land use was added, 57% of total farm emissions were derived from land use. N_2O was also found to be the main contributing GHG. N_2O was the main GHG linked to land use emissions in a study of two Swedish milk enterprises (Cederberg & Mattson 2000), and in a predominantly grazing system in New Zealand, Basset-Mens et al (n.d.) identify land use as a significant contributor to per kg milk GHG emissions.

It is interesting to note that this study found that within the nine sampled farm enterprises, higher average milk productivity per cow is generally associated with lower GHG emissions per kg milk; estimated average milk yields per cow (4350 kg per year) were much higher than the IPCC assumed yields for Asia; and average emissions per kg milk in this study were estimated to be much higher than have been reported in almost all other milk LCA studies. Deficiencies with the estimation method have been noted. However, there results seem to indicate that land use emissions in the dryland area studied are significantly higher than in other dairy producing areas. A review of GHG emissions associated with different land uses in dryland areas of the world would indicate whether the same high emissions per kg milk produced could also be expected in other dryland areas.

5.3 Possible mitigation actions

The findings of this study, as well as results and general prescriptions elsewhere, suggest the following actions can reduce on-farm GHG emissions per unit of milk production:

(1) Improving productivity of cow herds: A variety of livestock husbandry decisions and practices can increase total herd milk yields, including changes in herd structure (e.g. by increasing off-take of non-lactating cattle), increasing fodder supply and improving the quality of fodder (and thus also shortening the ‘dry’ period of each cow), raising specialized dairy breeds, improving insulation of warm sheds in winter, etc. Increasing intake of feed inputs is likely to have the largest impact because it reduces CH_4 emissions as well as increasing milk yields, and these benefits will probably outweigh the increased emissions from feed production.

(2) Changing management practices:

- In terms of feed management, improving the digestibility of feed which reduces methane emissions per cow, can be done by increasing imports of off-farm feeds;
- Land management: Research shows that winter grazing reduces greatly the level of CH_4 absorbed by grasslands. N_2O emissions of ungrazed grasslands are also much lower than of grazed grasslands. A shift to hay making with less grazing can reduce land use emissions from grasslands. In croplands, adoption of precision fertilization (measuring soil nutrient deficiencies before devising fertilization dosage) and more efficient irrigation can increase yields per kg CO_2e emitted from land use.

(3) Changing management of outputs:

- Substituting renewable energy sources for dung combustion can reduce emissions. Biogas is one option that integrates well with the management of dung, and technologies have been developed to make biogas work even in cold dryland areas.
- Dung management: Research shows that the manner in which dung is collected, piled and stored can reduce CH_4 and N_2O emissions from cow dung management. Lu et al (2007 and 2008) found that piling dung to 50 cm height emitted less than either piling to 25 cm height or adding 10 kg dung per day, and that covering dung heaps with maize stalks significantly reduces N_2O emissions.

The following actions can reduce off-farm emissions:

- Reduced tillage or no tillage: Wu et al (2007) show that in North China compared to conventional tillage, because of reduced inputs as well as benefits for soil carbon accumulation, reduced tillage reduces carbon emissions of winter wheat cultivation by 16.2 kg CO_2e per ha, and no-tillage reduces carbon emissions by 8.4 kg per ha.
- Improve fertilizer use efficiency: Research in Duolun county, Inner Mongolia (Zhang & Han 2008) shows that nitrogen fertilization of cropland is a major source of N_2O in the regional GHG budget. Precision fertilization (measuring soil nutrient deficiencies before deciding on fertilizer application doses) can increase the efficiency of fertilizer use.
- Improving water use efficiency: Electricity used in pumping water for crop irrigation accounted for about 20% of feed production emissions. Increasing the efficiency of water use in irrigation systems can reduce pumping requirements and electricity use (or diesel use where diesel pumps are used).

Before recommending specific changes in management practice, it is necessary to assess the direct financial costs and opportunity costs of adopting different practices. This study has not assessed whether adoption of the above mitigation actions would be economically feasible either in the absence of incentive payments or within the framework of support from carbon finance projects. Thus, while the suggestions listed above in general support increasing intensification of dairy production, it does not follow that all producer households should intensify, or that intensification is the best option for livestock production in dryland areas.

5.4 Implications for dryland dairy development

5.4.1 Dairy development, land use and GHG emissions in Inner Mongolia

Inner Mongolia provides 25% of China's raw milk, much of it sourced from smallholders. In the last ten years, a range of government policies aimed at restoring degraded environments and protecting vulnerable environments has resulted in relocation of large numbers of households to concentrated rural settlements and peri-urban villages. Other policies have promoted the development of a region-wide network of milk collection stations. Large dairy producers are only allowed to source milk from milking stations that monitor milk according to the regulations. This means that dairy producers selling to commercial sources are often not households engaging in traditional, extensive grazing (because herds are too far from milking stations), but are households or small enterprises that engage in zero-grazing, seasonal grazing or seasonal grazing of non-lactating livestock on grasslands near milking stations.

This transformation of settlements and the dairy sector has been accompanied by major changes in land use. Formerly vulnerable or degraded arable land and grasslands have been abandoned and allowed to recover without grazing. Milk production under the new settlement conditions means limited on-farm land use (e.g. under zero grazing), limited grazing during the grass growth season (which limits the risk of degrading grasslands by overgrazing), or a shift from grazing to hay making on grasslands. All these transformations can be expected in general to reduce the GHG emissions from land use in pastoral areas.

Grassland and hay yields are limited. Zero-grazing and seasonal grazing require the import of extra forage from other grasslands and of feed from agricultural sources. At a regional level, it is not clear whether demand for more feed crops increases land conversion in the grassland areas, increases the distance that feed crops are transported or whether it competes with food grain demand. Significant rates of land conversion have been documented for many parts of Inner Mongolia, but no study has attempted to link the drivers of land conversion to different sources of demand. So, if we assume that the producers of feed were crop producers before the development of the dairy sector, then it is plausible that increased feed can be provided to dairy producers without increasing GHG emissions from feed production. That is, the increased use of imported feeds can have a positive effect in reducing GHG emissions per unit of milk produced, especially when combined with other factors such as increased populations of dairy specialized cow breeds, artificial insemination services and improved access to milk stations. This study has also identified a range of generic actions that can further reduce GHG emissions in intensified dairy production systems in the region.

5.4.2 Implications for livestock production in other dryland areas

Do the findings of this study mean that pastoralists in other dryland areas should intensify? From a GHG emission and mitigation perspective, many aspects of intensification can reduce GHG emissions per unit of milk produced. However, intensification has several preconditions and assumptions. For example:

- Lactating cows would have to stay close to milking stations and refrigeration facilities in order for their milk to be sold commercially, so specialized milk production is not feasible for all households in the pastoral areas;
- Increased dependence on milk incomes and specialization in milk production can increase household risk (e.g. as the market collapse following the 'melamine milk' scandal showed);
- Maintaining indigenous breeds reduces risks due to extreme weather events (e.g. droughts), and reduces expenditures on veterinary medicines;
- This study has focused solely on quantifying GHG emissions per unit of milk produced. Dual purpose herds also produce meat, hides and other livestock products. Indigenous breeds are often more suitable for providing multifunctional services than specialized breeds.

Therefore, it should be stressed that dual purpose herds, indigenous breeds, and production strategies based on extensive grazing have their rationality in the dryland context, and – in the absence of payments for environmental services – it does not follow that all cattle raising households would be better off if they followed a GHG-minimizing development strategy.

As has been found in other dairy LCAs, this study found that land use contributes significantly to GHG emissions related to dairy production. Firstly, it should be noted that while there has been significant attention paid to the carbon sequestration potential of dryland ecosystems (see e.g. FAO 2004, Trumper et al 2008), N_2O emissions were estimated in this study to be much more significant than CO_2 emitted or sequestered by land use processes. Secondly, the study was undertaken in areas of Inner Mongolia that had previously undergone processes of land conversion and land degradation, but which are now undergoing a land rehabilitation process. Increased demand from off-farm sources for feeds is being met by imports from nearby agricultural areas. However, in many other contexts, conversion of rangelands to cropland is taking place on a significant scale, and this process has major implications for GHG fluxes.

According to global analysis by the World Resources Institute (White et al 2000), temperate grasslands, savannas and shrublands have experienced heavy conversion to agriculture. In temperate areas of the world, they estimate that more than 40% of historical grassland has now been converted to cropland. In tropical and subtropical grassland 15 percent has been converted to agriculture. The process of conversion removes native vegetation, increases soil erosion and changes soil water retention properties. Irrigated agriculture in dryland ecosystems has been associated with a range of land degradation processes (Safriel and Adeel 2005). In terms of GHG emissions, Guo and Gifford (2002) estimate that on average 59% of soil carbon stocks are lost (and therefore emitted as CO_2) after conversion of native grassland to cropland. Impacts of conversion on CH_4 and N_2O emissions are generally less severe (Del Grosso et al 2002). Where dairy intensification drives land conversion, and particularly where after conversion agricultural yields are low, costs may well outweigh benefits. Therefore, it may also be the case that extensive land use in dryland areas is the land use option with the least GHG emissions over a given accounting period. Accounting for the multiple outputs of livestock systems in drylands (e.g. meat, milk, wool, leather, environmental and cultural services – see Rodriguez 2008) would also give a different picture of the GHG emissions attributable to different products. Garnett (2009) rightly suggests, therefore, that the results of LCAs should be viewed from the perspective of (i) impacts of livestock production on land use and land use GHG emissions, (ii) opportunity costs of alternative land uses and (iii) social needs.

6. Conclusions

This study reported a comparison of GHG emissions from nine dairy producers in Inner Mongolia, China, broadly covering three types of dairy production: zero-grazing, seasonal grazing with off-farm feed inputs, and year-round grazing with limited off-farm feed inputs. There have been few other studies of GHG emissions in dairy production in developing country dryland contexts (but see Saxena 2002 and van Kernebeer and Gerber 2008). Production systems in other dryland areas are likely to differ in many respects from those studied here. The results of this study are therefore not directly transferable to milk production in other dryland areas. It is recommended that studies based on management activities common in the local context are undertaken.

Two key findings from this study are:

(i) GHG emissions from land use constitute a significant proportion of emissions in the dairy production process.

(ii) Intensification of dairy production by increasing imports of off-farm feeds, accompanied by increases in milk yields and improved on-farm management of emission sources, can reduce GHG emissions per kg of milk produced.

However, if intensification of dairy production leads to conversion of rangelands to agricultural production, this is likely to cause additional GHG emissions – as well as other land degradation problems – that may outweigh the benefits of reduced emissions per kg of milk produced.

Drynet is concerned to support CSOs working with communities to address land degradation and drought in dryland areas. Dryland dairy sector development and factors driving land use changes often involve local, and even national governments. The findings of this study are relevant not only to actors in the livestock and dairy sectors, but also to actors with influence on land use and agricultural irrigation policies, since these often drive conversion of and intensification of agriculture in dryland areas. Where relevant, the findings of this study should be communicated in the context of trends in land use changes in the region where the CSO works, and in the context of the concerns of stakeholders involved in these policy arenas.

At the international level, the findings of this study are relevant to ongoing discussions in both UNCCD and UNFCCC. Since land degradation processes most often involve emission of soil nutrients (e.g. carbon, nitrogen) into the atmosphere, there is a natural linkage between UNCCD and UNFCCC on the contributions of sustainable land management to climate change mitigation in ways that benefit local populations. Scientific advisors to UNCCD[3] have recently been stressing the need to focus less on land degradation itself, and more on the links between land use, ecosystem services and human well-being. The 'Dryland Development Paradigm' stresses that socio-economic and biophysical aspects of land management processes are integrated. Garnett (2009) also argues that the results of Life Cycle Analysis such as this study should be viewed from the wider perspectives on the biophysical, social and economic implications of land use changes associated with changing trends in GHG emissions. This study can provide an example of tradeoffs between multiple goals in dryland development.

The role of sustainable land management in implementation of the UNFCCC has been somewhat uncertain. Land use mitigation options other than afforestation / reforestation have been excluded from eligibility for support under the Clean Development Mechanism. This has primarily been due to the perceived risk that GHG emission reductions can be reversed (and therefore non-permanent) if land uses again change. However, if non-forestry land uses are to continue to be excluded from international agreements, then most of the world's dryland rangeland and agricultural areas will be unable to receive international support for mitigating climate change under the UNFCCC. Methane reduction actions are eligible under the CDM. But as this study has shown, GHG emission trends in the dairy sector are closely linked to drivers of GHG emissions in other sectors, notably agricultural land use. This study therefore provides an example of how different sub-sectors are linked and how these linkages drive GHG emissions in both sectors. This can form part of the basis of an argument for inclusion of a wider range of agricultural and land use based mitigation options in future international climate agreements and mechanisms (e.g. the CDM) so that emissions from dryland land use and livelihood systems can be more completely accounted for.

[3] See http://dsd-consortium.jrc.ec.europa.eu/php/index.php?action=view&id=150

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8. Annexes

Annex 1: Tables and Figures

Table 1: Characteristics of the farms surveyed

#	Location	Characterization	No. of cattle	No. of cows	No lactating cows	Total annual milk yield (kg)	Estimated av. milk yield per cow (kg)	Grazing?	Feed sources
1	Xincang, Duolun	Small scale hh zero-grazing	10	10	3	12,795	4,265	No	Grow silage; Buy hay, corn, feed
2	Xincang, Duolun	Small scale hh zero-grazing	23	23	13	54,403	4,185	No	Buy hay, feed
3	Xincang, Duolun	Small scale hh zero-grazing	9	9	5	27,615	5,523	No	Grow silage; Buy hay, corn, feed
4	Xincang, Duolun	Small scale hh zero-grazing	6	6	2	15,851	7,926	No	Grow silage Buy feed, protein cakes
5	Maodeng, Xilingol	Small scale hh seasonal grazing	23	23	8	42,435	5,304	3 months / year	Buy hay, feed, silage
6	Maodeng, Xilingol	Small scale hh seasonal grazing	12	12	6	26,042	4,340	2 months / year	Make hay; buy hay, silage & feed
7	Maodeng, Xilingol	Dairy / beef enterprise	520	360	250	1,467,750	5,871	Non-lactating cows graze 4.5 months / year	Grow turnip; make hay; buy silage
8	Chaoke, Xilingol	Small scale hh dual purpose production	15	15	5	8440	1,688	Year-round grazing	Make hay on-farm
9	Chaoke, Xilingol	Small scale hh dual purpose production	200	130	60	101,280	1,688	Year-round grazing	Make hay off-farm

Table 2: Emission sources and GHGs estimated in the study

Activity / source	CO_2	CH_4	N_2O
On-farm emissions			
Enteric fermentation		√	
Dung & manure mgt.			
- solid storage		√	√
- grassland deposit			√
- dung burning		√	√
Feed production & land use on-farm			
- direct emissions from fertilizer use	√		√
- fuel use	√	√	√
- electricity use	√		
- land use	√	√	√
Off-farm emissions			
Feed imports			
- fuel used in harvesting & transport	√	√	√
- electricity used	√		
- direct emissions from fertilizer use	√		√
- emissions embodied in fertilizers used off-farm	√		
Emissions embodied in fertilizers used on-farm	√		

Table 3: Default values for enteric fermentation used in this study

Producer unit	Av. milk yields per cow (kg)	Default value adopted (kg CH_4 per head per year)
Farms 1,2, 3, 5, 6	4,723	Cow: 108 Other: 57
Farm 4, 7	6,899	Cow: 122 Other: 55
Farms 8 and 9	1,688	Cow: 68 Other: 47

Source: IPCC 2006 Vol 4 Ch 10 Table 10.11

Table 4: Default values used to estimate emissions from on-farm forage & feed production

Emission source	Default value applied	Reference
Arable land use (silage production)	CO_2: 0 kg per ha CH_4: -1.1 kg per ha N_2O: 3.29 kg per ha	Various inconsistent Wang (2001), Ma (2006) Wang (2001), Ma (2006)
Grassland, grazed	CO_2: 0 kg per ha CH_4: -1.8 kg per ha N_2O: 7.2 kg per ha	Various inconsistent Ma (2006) Ma (2006)
Grassland, ungrazed	CO_2: 0 kg per ha CH_4: -2.3 kg per ha N_2O: 3.6 kg per ha	Various inconsistent Ma (2006) Ma (2006)

Table 5: Default values used to estimate emissions from off-farm forage & feed production

Emission source	Default value applied	Reference
Arable land use (silage production)	CO_2: 0 kg per ha CH_4: -1.1 kg per ha N_2O: 3.29 kg per ha	Various inconsistent Wang (2001), Ma (2006) Wang (2001), Ma (2006)
Arable land use (wheat production)	CO_2: 0 kg per ha CH_4: - 0.62 kg per ha N_2O: 0.0195 kg per ha	Various inconsistent Qi et al (2002) Ding et al (2007)
Electricity	CO_2e: 0.00095 kg per kwh	http://cdm.unfccc.int/ UserManagement/FileStorage/ FS_147407685

Table 6: Emission factors for fuel and electricity use used in this study

Source	Emission factor	Reference
Fuel consumption	CO_2: 2.961 kg CO_2 per l diesel CH_4: 0.0038 kg N_2O per l diesel N_2O: 0.0000067 kg N_2O per l diesel	Audsley et al. (2003)
Electricity consumption	CO_2e: 0.00095 kg per kwh	http://cdm.unfccc.int/ UserManagement/FileStorage/ FS_147407685

Table 7: Global Warming Potential used to convert GHGs to CO_2e

Methane (CH_4)	25
Nitrous oxide (N_2O)	296
Carbon dioxide (CO_2)	1

Table 8: Land use by dairy producing enterprises surveyed (ha)

	Farm 1	Farm 2	Farm 3	Farm 4	Farm 5	Farm 6	Farm 7	Farm 8	Farm 9
Crop land	0.5	0	0.4	0.5	0	0	20	0	0
Mown grassland	30	324	42	43	9	6.4	6.6	0	333
Grazed grassland	0	0	0	0	50	67	2333	220	400

Figure 1: Location of the case study sites in Inner Mongolia

Figure 2: System boundaries defined in this study.
Dashed lines define the boundary of on-farm emissions. Double lines define the boundaries of the system documented in this study. Boxes outside the double lines have not been documented in this study.

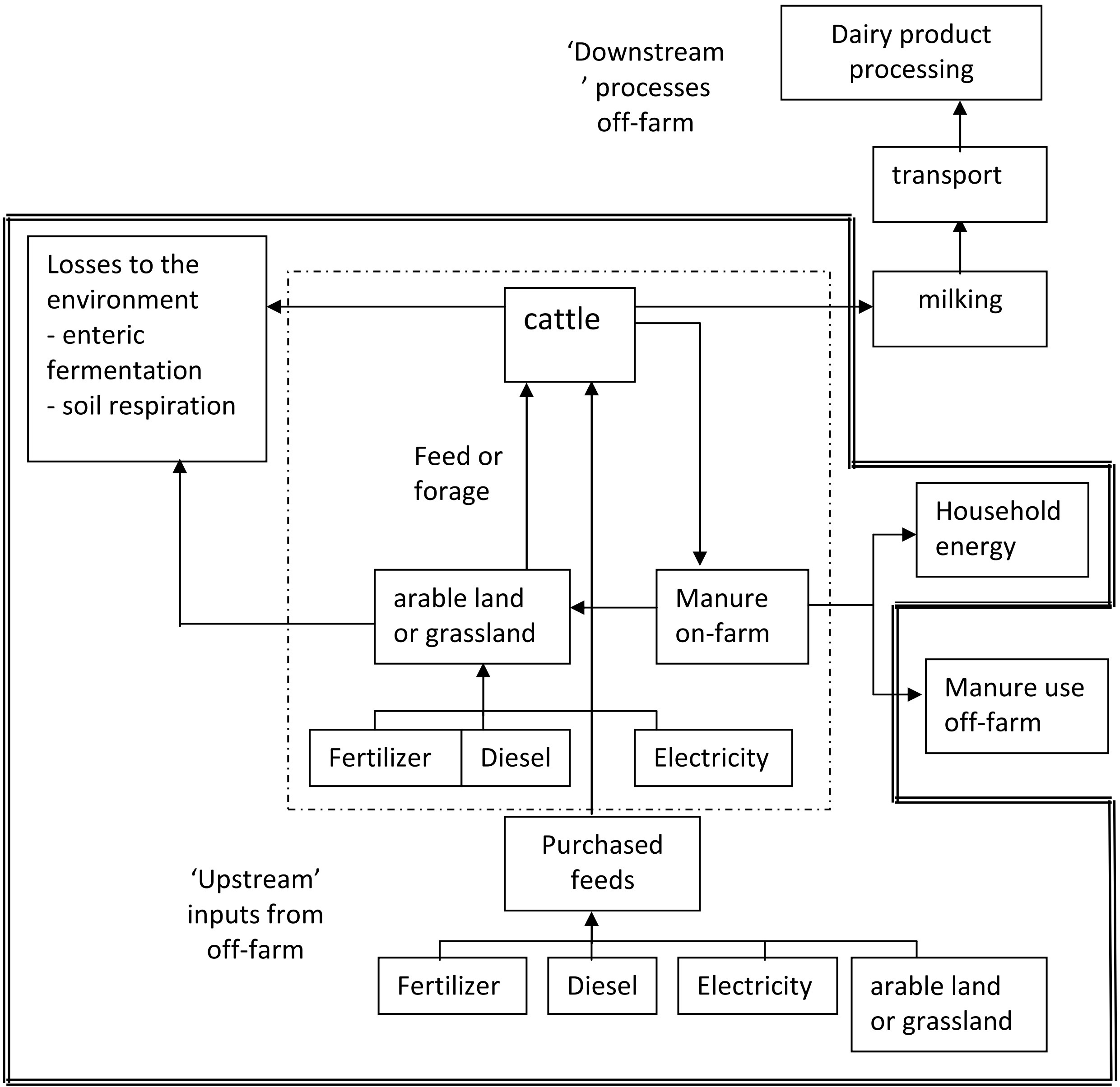


Figure 3: Total GHG emissions per farm (kg CO_2e)

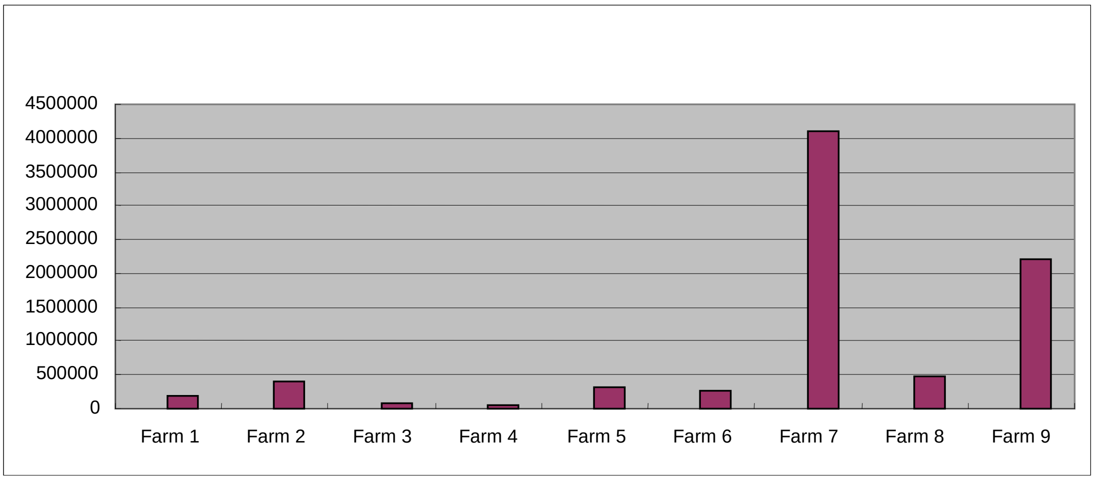


Figure 4: GHG emissions per kg milk (kg CO_2e)

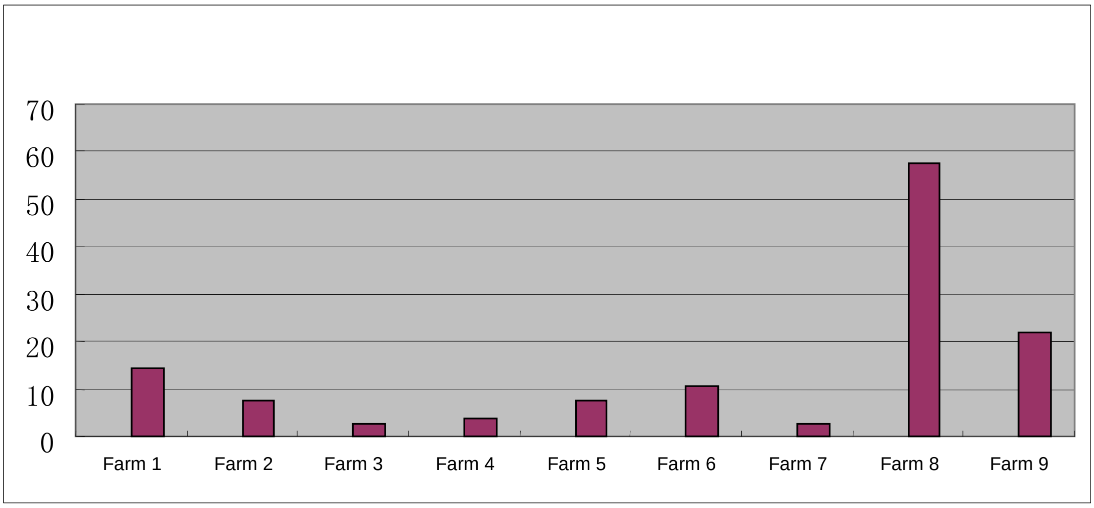


Figure 5: Relationship between emissions per kg milk and average milk yields per cow

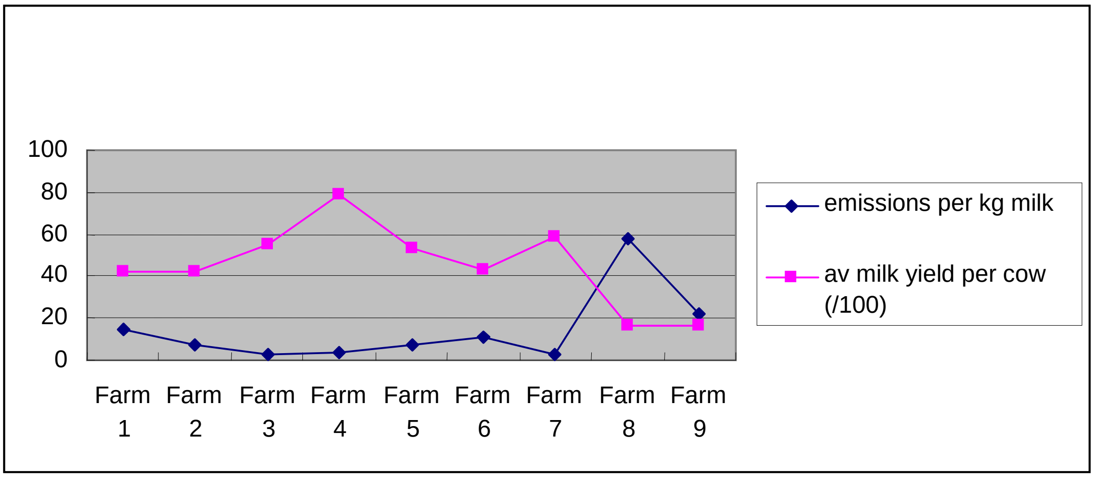


Figure 6: Relationship between per ha on-farm land use emissions and per kg milk emissions

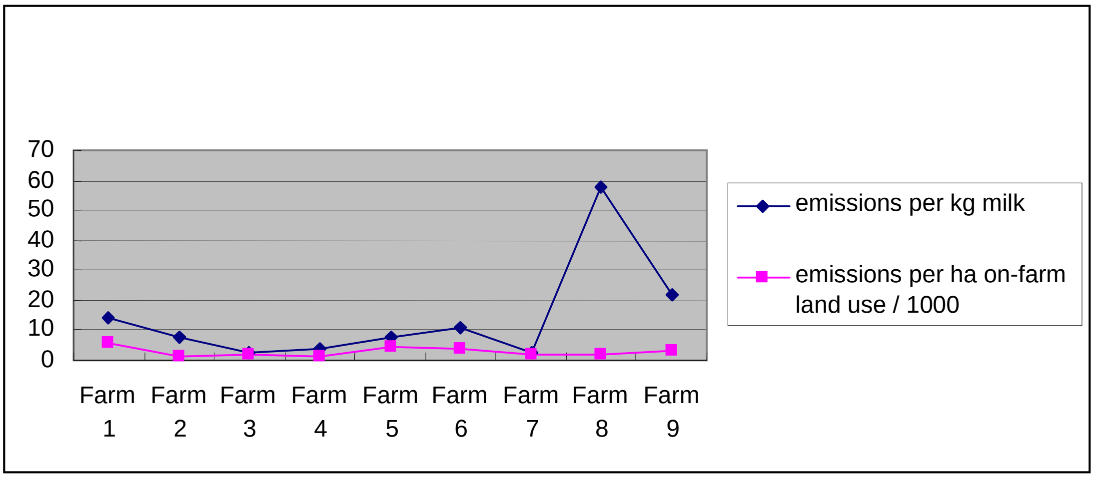


Figure 7: Percentage of on- and off-farm emissions

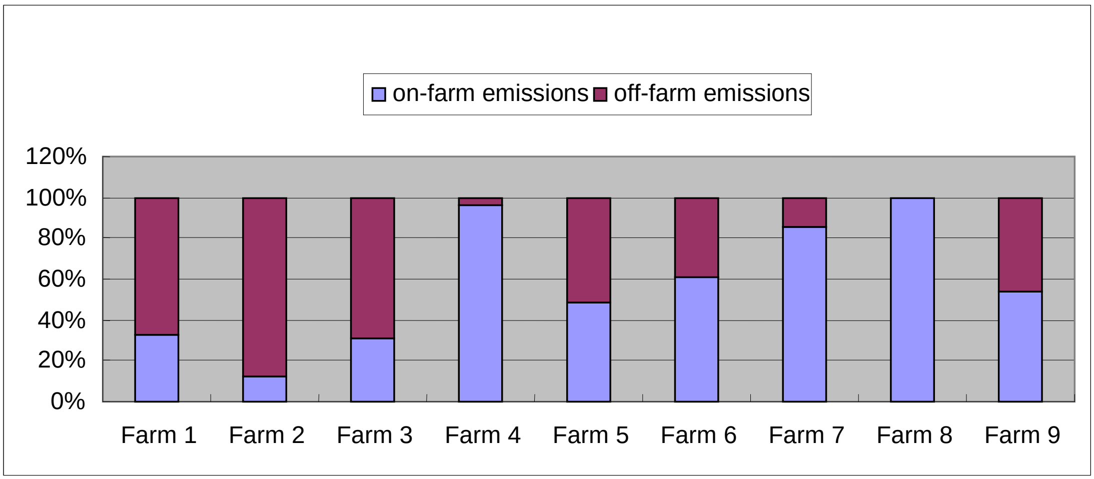


Figure 8: Composition of on-farm emissions (%)

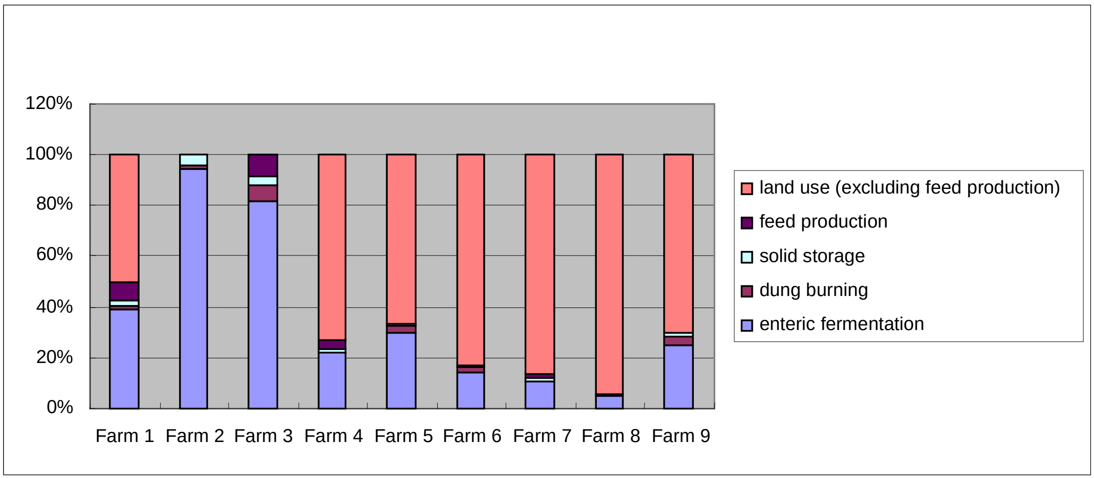


Figure 9: Composition of off-farm emissions (%)

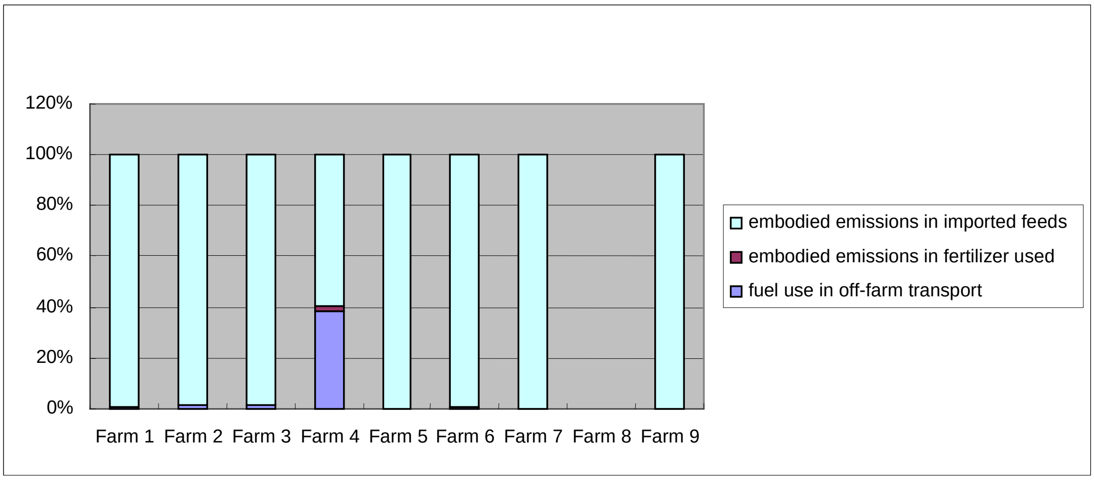


Figure 10: Composition of emissions embodied in off-farm feed sources (%)

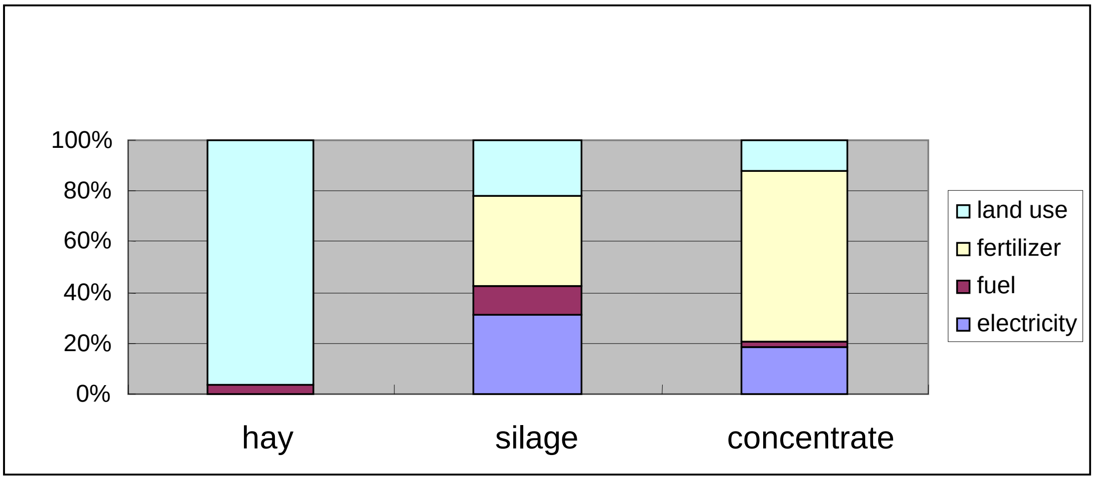
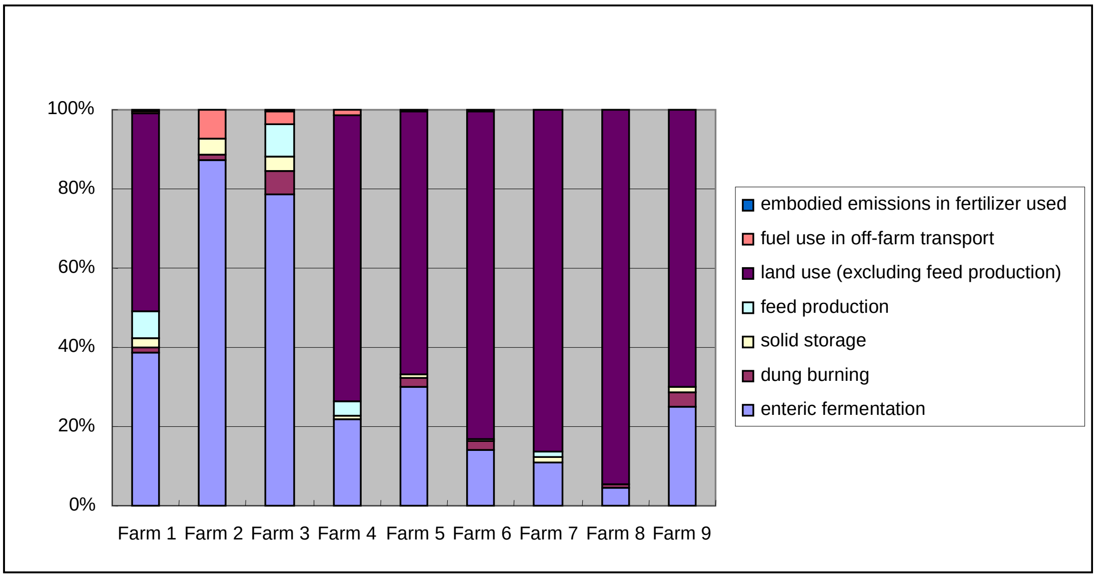


Figure 11: Composition of total farm emissions excluding embodied emissions in feed imports (%)



Annex 2: Reference sources for emission factors and relevant case studies

1. References sources for emission factors

IPCC 2006 Vol 4 Ch. 10 Emissions from Livestock and Manure Management
IPCC 2006 Vol 4 Ch. 11 N2O emissions from managed soils and CO2 emissions from Lime and Urea application
IPCC 2006 Vol 2 Ch. 2 Stationary combustion [for dung burning emission factors]
The above IPCC publications can be obtained from http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.html
Other useful reference sources include:
US EPA, 1995, http://www.epa.gov/ttn/chief/ap42/ [for chemical fertilizer emission factors]
Wood, S and A Cowie, 2004, 'A Review of Greenhouse Gas Emission Factors for Fertiliser Production', IEA Bioenergy Task 38 [for embodied emissions in fertilizers]

2. Relevant case studies

de Boer, I.J.M., 2003, 'Environmental impact assessment of conventional and organic milk production', in Livestock Production Science 80: 69–77

Basset-Mens, C., Ledgard, S. and A. Carran, n.d. , 'First Life Cycle Assessment of Milk Production from New Zealand Dairy Farm Systems', available at http://www.anzsee.org/anzsee2005papers/Basset-Mens_LCA_NZ_milk_production.pdf

Cederberg & Mattson 2000, , Life cycle assessment of milk production — a comparison of conventional and organic farming', in Journal of Cleaner Production 8: 49–60

van Kernebeek, H. and P. Gerber, 2008, 'Environmental Life Cycle Analysis of milk production in Ropar, India,' FAO: Rome

Thomassen, M.A., van Calker, K.J., Smits , M.C.J., Iepema, G.L. and I.J.M. de Boer, 2008, 'Life cycle assessment of conventional and organic milk production in the Netherlands', in Agricultural Systems 96: 95–107