Does intensification of grassland and forage use lead to efficient, profitable and sustainable ecosystems?

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Abstract. The increasing demand for safe and nutritional dairy and beef products in our globalizing world, together with the needs to increase resource use efficiency and to protect biodiversity, provide strong incentives for intensification of grassland and forage use. This paper addresses the question in the title. Firstly, we present some notions about 'intensification of agricultural production'. Secondly, we discuss the intensification of grassland-based dairy production in The Netherlands (NL), Chile and New Zealand (NZ). Finally, we arrive at some conclusions. External driving forces and 'the law of the optimum' provide strong incentives for intensification, *i.e.*, for increasing the output per unit surface area and labour. The three country cases illustrate that intensification of grassland use is a global phenomenon, with winners and losers. Winners are farmers who are able to achieve a high return on investments. Losers are small farmers, who drop-out of business, unless they broaden the income-basis. The relationship between intensification and environmental impact is complex. Within certain ranges, intensification leads to increased emissions of nutrients and greenhouse gases to air and water per unit surface area, but to decreased emissions when expressed per unit of produce. The sustainability of a grassland-based ecosystem is ultimately defined by the societal appreciation of that system and by biophysical and socio-economic constraints. In conclusion, intensification may lead to more efficient and profitable, and thereby more sustainable grassland ecosystems, if the systems of departure are extensively managed, under-utilized, low-productive, over-exploited and/or unregulated systems, and the target systems meets societal demands.

Keywords: Dairy farms, GHG emissions, nitrogen, resource use, technological progress, yield gap.

Introduction

Global food security and environmental sustainability are major scientific and political issues (*e.g.*, Smil 2000; Sachs 2008). Food production will have to increase by more than 50% to be able to feed the expected 20 to 40% additional people in the world by 2050 (Bruinsma 2009; Parry and Hawkesford 2010). The shifts in human diets towards more animal-derived food and the increasing demand for bio-energy production add to the challenges of food security. At the same time, the need to curb the negative side-effects of food production on the environment is becoming increasingly evident, because the contribution of current food production systems to biodiversity loss, climate change, land degradation, water pollution are large and increasing in many areas (Steinfeld *et al.* 2006; 2010; Galloway *et al.* 2008). Evidently, to ensure global food security with environmentally sound practices, it is required that food production and resource use efficiency are increased simultaneously (Tilman *et al.* 2002; Godfray *et al.* 2010). And if we want to reduce the total environmental footprint of grassland and forage use, the rate of resource use efficiency will need to increase at a faster pace than the rate of production increases.

The question in the title of this paper relates to the mighty topics of food security and environmental sustainability. The title was suggested by the organizers of the 22nd International Grassland Congress, along with the invitation to address the question in maximal 16 pages. Our shortest answer to the question 'Does intensification of grassland and forage use lead to efficient, profitable and sustainable ecosystems?' is 'yes, but not necessarily'. Of course, if we see the trend lines in production of main commodities during the last five decades (Smil 2000; Evenson and Gollin 2003), we can be rather optimistic, but at the same time, there has been a massive exodus of farm labour, remaining malnutrition is overwhelming, emissions of greenhouse gases (GHG) and other unwanted emissions have gone up (*e.g.* Steinfeld *et al.* 2006), and there are clear examples of our inability to manage ecosystems properly (*e.g.*, Diamond 2005). Another reason for our nuanced answer is the huge area and huge diversity of grasslands in the world. Grasslands in the wider sense are among the largest ecosystems in the world, with an estimated area of 52 million km^2, equivalent to 40% of the global terrestrial area (Suttie *et al.* 2005). Most of the world's grasslands are on poor quality land and are highly vulnerable. A third reason is the versatile meaning of the verb and adjectives in the title. Both, intensification, efficient, profitable, and sustainable are often perceived differently by different persons, and for meaningful discussions therefore need to be defined in operational terms. There is a common notion that these terms are more easily defined in relative terms (from less to more and vice versa) than in absolute terms. Another notion is that these terms are highly contextual; the meaning and rating greatly differ between systems, regions and also between individual farm(er)s. Here, we define these terms briefly as: intensification is 'increasing marketable output per unit surface area and per unit labour', efficient is 'high marketable output per unit of input', profitable is 'monetary value of output exceeds total costs of inputs', and sustainable is 'a combination of economically profitable, socially acceptable and environmentally sound, for now and later' (*e.g.*, De Wit 1993; Cassman 1999; Garnett and Godfrey, 2012). A fourth reason for our nuanced answer relates to the difficulty of defining 'ecosystems' (*e.g*., Sagoff, 2003). We distinguish natural ecosystems and agro-ecosystems. Both are controlled by external (*e.g.* climate) and internal (*e.g.* soil and plant characteristics) factors, but influence by human activities is dominant in the case of agro-ecosystems.

In this paper we explore biophysical, socio-economic and environmental drivers of and constraints to intensification of grassland and forage use and discuss how these drivers/constraints affect the development of agro-ecosystems. We focus on grassland-based dairy production in three countries across three continents, *i.e*., The Netherlands (NL), Chile and New Zealand (NZ). First, we present some general notions about intensification of agricultural production. Next, we present empirical data about intensification of grassland-based dairy production in NL, Chile and NZ. We close by providing a more definite answer to the general question of this paper.

Intensification of grassland and forage use; some conceptual notions

Intensification of agricultural production in general and of grassland and forage use in particular is a complex process, with driving forces, side-effects and bio-physical, socio-economic and environmental constraints. Intensification is a result of technological progress, which is fuelled by developments in technology, markets, and/or policy (Fig. 1). These developments provide tools for technological progress, including improvements in knowledge, management, mechanization and in herbage and animal breeds. Commonly, there is also a change in non-factor inputs like fertilizers, concentrate feed, herbicides, veterinary assistance, contractor assistance, *etc.* Technological progress leads to changes in the utilization of grassland and forage use, which subsequently leads to higher yields per ha and per unit labour, but also to changes in various emissions. The resulting changes in productivity, efficiency and farm income may subsequently lead to changes in farm structure and in the price ratio of outputs and inputs, which may provide new impulses to intensification. Hence, intensification of grassland and forage use involves a chain of processes. The outcome is often region and farm specific, because of intrinsic differences between regions and between farms.

Yields of grassland are ultimately constrained by yield defining, yield limiting and yield reducing factors (Fig. 2). In practice, there are large gaps between potential yield, water and nutrient limited yield, and actual yield (*e.g.*, Lobell *et al.* 2009; Mueller *et al.* 2012). These gaps basically provide the incentive and justification for the intensification of grassland and forage use. The potential yield depends on the genetic traits of the crop and climatic conditions. Intensification of grassland narrows the gap between potential and actual yields. Evans (1993) defines potential crop yield as the yield of a cultivar when grown in environments to which it is adapted, with nutrients and water non-limiting and with pest, diseases, weeds, lodging and stresses effectively controlled. Soil features are also listed as possible yield limiting factors in Figure 2, because soil depth, slope, texture, and hydrology may limit yield, next to water and nutrients. It has been suggested that intensification of cereal production is possible until actual yields are on average 70 to 80% of the potential yield (Cassman 1999). Grassland and forage crops have a relatively high yield potential, due to the long growing period, existing root system, and whole-crop harvest (*e.g.*, Evan 1993; Murphy 2005; Glover *et al.* 2010), but growth and regrowth cycles are very sensitive to management, and hence to yield (*e.g.* Slewinski, 2012). However, there is little quantitative information about the gap between potential and actual dry matter yields of grassland in

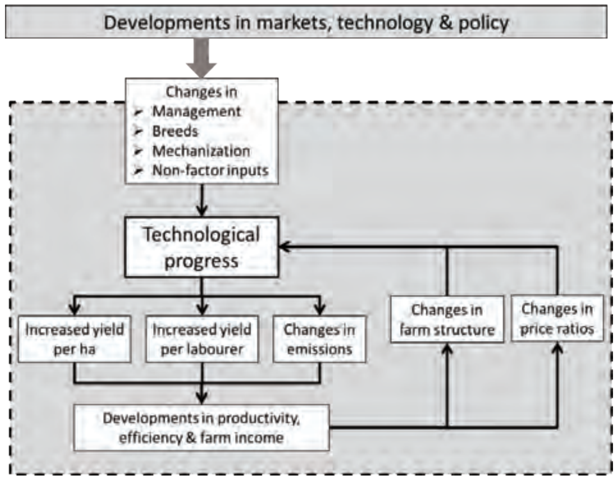

Figure 1. Concept of the intensification of grassland and forage use, as used in this paper. External driving forces are on top. Arrows represent influences and/or incentives; boxes represent processes or results.

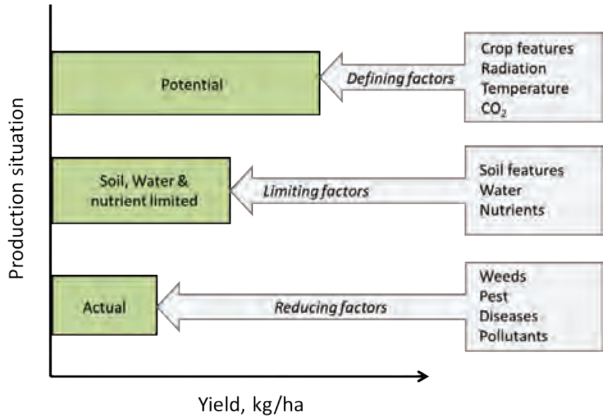

Figure 2. Yields of grassland and crop land are the results of interactions between yield defining factors, yield limiting factors and yield reducing factors. After Van Ittersum and Rabbinge (1997).

practice. Herbage is an intermediate product, used to feed ruminants and to produce milk and beef. As a consequence, there is no statistical information about grassland yields.

The production ecological concept of yield defining, limiting and reducing factors for grassland and crop land in Figure 2 also holds for animal production systems. Here, yield defining factors are animal species/breed/sex, while yield limiting factors are the availability and quality of feed and water. Main yield reducing factors are diseases, animal well-being and pollutants (Van de Ven *et al.* 2003). There is a lot of information about differences between regions and farms in actual yields of dairy and beef production systems, but there is not much information about the gap between potential and actual yields in practice. Yield potential is difficult to measure, but simulation models can provide reasonable estimates of functional yield potentials in a given environment, based on physiological relationships that govern plant and animal development and growth (*e.g.* Cassman 1999).

Animal production depends in practice mainly on animal species and breed, feed quality, and herd management. Within a system, maximal animal productivity is constraint by the limits of the system. Intensification of animal production may then involve a change in system, as indicated in Figure 3. Higher yielding systems are often more complex and require more management skill and non-factor inputs such as energy, fertilizers, feed and veterinary assistance. Figure 3 shows that animal protein output per unit of surface area may differ four orders of magnitude between systems. While animal production in pastoral systems and grassland-based beef production largely depend on the primary production of the grassland, animal production in feedlots completely depends on purchased animal feed. This holds to some extent also for intensively managed grassland-based dairy production systems; these systems import fertilizers to boost herbage production, and import supplementary feed to boost milk and beef production. The shift in system is also a result of technological progress, through changes in farm structure (see also Fig. 1).

All systems depend on natural resources such as plant and animal traits, photosynthetic radiation, CO_2, water and nutrients, as shown in Figure 2. Also, the law of diminishing returns holds for all systems, although yields may differ by 4 to 5 orders of magnitude between systems. Evidently, the decrease in marginal returns with an increase in resource input, as predicted by the law of diminishing returns, is compensated by the benefits of other technological changes when the system is changed (De Wit 1993). Resources are used more efficiently with increasing yield level, due to further optimization of production conditions according to ‘the law of the optimum’ (De Wit 1993). Evidently, this is a strong internal driving force for intensification. It is not only the quest for more food by the growing global population that drives intensification of agricultural production, it is also the need to lower production costs and resources use, and to increase farm income, which drive intensification, and which ultimately leads to more efficient utilization of resources. With the intensification of animal production along the trajectories discussed in Figure 3, an increasing number of inputs gradually lose their variable character (De Wit 1993).

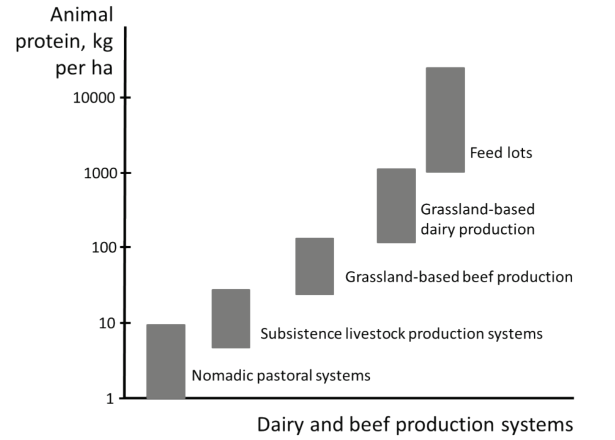

Figure 3.Comparison of animal protein production levels of various beef and dairy production systems. Developed for the purpose of this paper, based on Smil (2000). Note logarithmic scale of Y-axis.

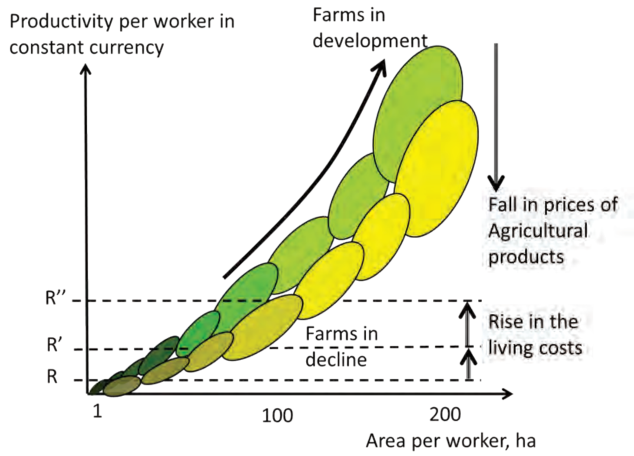

Figure 4.Comparison of productivity per worker for various farming systems in the world. Subsistence farms and small farms are situated in the lower left corner, highly mechanized large farms in the upper right corner. Over time, the productivity per worker expressed in constant currency drops down, due to fall in the prices of agricultural products, visualized by a change from green-coloured to yellow-coloured farming systems. At the bottom, farms are in decline, because the cost of living goes up from R to R’ and R’’, *i.e.*, the point of marginalization moves upward (after Mazoyer and Roudart 2006).

In their ‘History of World Agriculture’, Mazoyer and Roudart (2006) argue that in a globalizing world: (1) modern farms in the western world compete on the world market with small subsistence farms elsewhere; (2) the productivity per ha and per unit labour increases due to technical progress, but much more in the western world than in the developing world; (3) prices for agricultural commodities decrease due to technical progress and increased competition; (4) cost of living increase due to higher standards and inflation; and (5) farmers with low productivity drop out, while new, higher productive farms develop further on the other side of the spectrum. These lines of thoughts are visualized in Figure 4; it basically conveys the message that intensification, up-scaling and increasing labour productivity is the only way to stay in

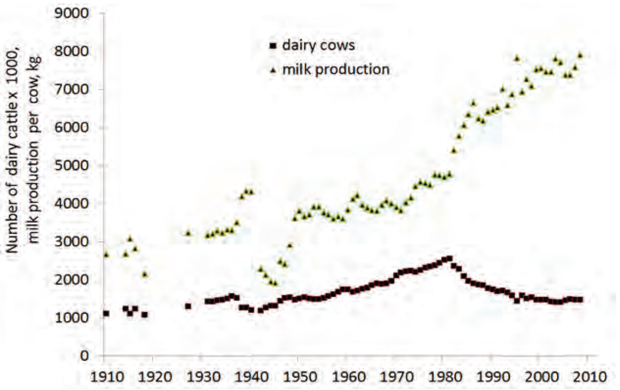

Figure 5. Number of dairy cows and milk yield per cow in The Netherlands between 1910-2010.

production in a globalizing world. Of course, this is a too simple a statement, as there is also a third axis not shown in Figure 4, the axis of creating 'added value' and additional income sources. Production and marketing of 'farmer-made cheese', landscape maintenance, tourist housing, and care for less-favoured and disabled people may provide additional income sources for the farmer, especially in rich and densely populated countries (Van der Ploeg 2009). However, this trajectory is not further discussed here.

Possible side-effects of intensification relate to increased resource use and increased emissions of unwanted substances per unit of surface area. Dairy (and beef) production systems are major emitters of the green-house gases (GHG) methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2). Emissions of CH_4 (mainly from ruminants) account roughly for half of the total GHG emissions from dairy production, when expressed in CO_2-equivalents, and N_2O (from soils and manure management) and CO_2 (from energy combustion and soils) account both roughly for 25% of the total GHG emissions from dairy production (FAO, 2010). Emissions expressed in mass per unit surface area generally increase with intensification of production, but this picture is often reversed when emissions are expressed per unit of produce. For example, Van Groenigen *et al.* (2009) showed that yield-scaled N_2O emissions are lowest near optimal N fertilization levels, where crop yields are near maximum attainable yields.

Both, suboptimal and over optimal N fertilization leads to higher N_2O emissions per unit of crop produced. The same is often true for nitrate (NO_3^-) leaching from pastures and ammonia (NH_3) emissions from animal manures. However, losses of N via NO_3^- leaching and NH_3 emissions from dairy production systems also depend on climate, soil type and management, making the relationship with intensification of grassland and forage use often complex and diffuse.

Methane (CH_4) emissions from dairy production are related to feed intake; on average between 4 and 7% of the gross energy intake is lost as CH_4. Increasing the quality of feed, especially roughage, and increasing milk production per cow can reduce enteric CH_4 production per unit of milk and/or beef. Emissions of CH_4 decrease on average by 0.4 to 0.5 g/kg milk when milk yield per cow increases 1 kg. Hence, intensification through increasing milk yield per cow lowers CH_4 emissions per kg of milk produced (Casey and Holden 2005; Flysjö 2012). Similarly, energy use related CO_2 emissions tend to go up with intensification of grassland and forage use, due to greater use of resources and mechanization. However, emissions per unit of forage or milk produced may not go up necessarily with an increase in intensification of grassland and forage use; it very much depends on the specific system and labour availability.

The sustainability of intensive production systems is also constrained by its social acceptability. Consumers will have to buy the products, and the society, including pressure groups and political systems, should not reject these systems or aspects of these systems. Social acceptability may differ greatly between countries. For example, while genetically modified soybean and maize in animal feed, and use of recombinant bovine somatotropin (rbST) in dairy production are common in the Americas, they are not accepted in Europe. Also, changing notions about animal welfare increasingly force farmers in Europe to adjust stables and promote grazing instead of zero-grazing.

Summarizing, intensification of grassland-based dairy and beef production has strong external and internal drivers. It is a global and non-linear process, which leads to the evolution of systems and often to exodus of smallholders in less competitive areas. Relationships between intensification of grassland and forage use and agronomic and environmental performances are complicated by the effects of climate, soil type, and management. Intensification of production seems the only sustainable way forward to feed the growing human population. The question is then where and how far to intensify production. Below, we discuss three case-studies, *i.e.*, NL, Chile and NZ, to further illustrate the concepts and constraints described above.

Intensification of grassland and forage use in The Netherlands

Approximately half of the agricultural area (2 million ha) in The Netherlands (NL) is grassland, used mainly for dairy production. The development of grassland utilization for dairy production in NL is strongly related to its geographical situation and to the European Union with its Common Agricultural Policy, which both have boosted agricultural production. Total milk production has increased from about 2.5 billion kg in 1900 to about 11.5 billion in 1985. Thereafter, milk production stabilized at about that level due to the milk quota regulation. Milk yield per cow increased from 2500 kg in 1900 to 5500 in 1985 and to 8000 in 2010 (Fig. 5), while milk fat+protein content increased from 6% in 1900 to 8% in 2000s. Milk yield per unit surface area increased from 2000 kg in 1900 to 12000 kg/ha in 2010 (Bieleman, 2008), but with a large variation between farms (range 8000 to 25000 kg/ha).

The strongest intensification occurred between 1960 and 1985 thereafter the utilization of grassland and forage use has been constrained by milk quota. The number of farms with dairy cattle decreased from 192,600 in 1910 to 29,500 in 2000. Mean number of dairy cows per farm increased in this period from 5 to >50 per farm, and labour input decreased from 330 to <45 men-hours per cow (Bieleman 2008). The main tools for intensification of grassland and forage use were subsequently: (1) improved grazing and mowing management; (2) soil drainage; (3) fertilization; (4) reseeding grassland by high-yielding varieties; (5) increased selection and breeding for high yielding-dairy cows; (6) feed supplementation; (7) replacement of rye and some grassland by forage maize; (8) improved herd and disease management; (9) precision feeding, in part through stall-feeding and zero-grazing; (10) milking robots and switching from two to three milkings per day; and (11) up-scaling.

Grassland yields have increased less than milk yield. However, there is not much empirical information about changes in mean harvested forage in practice. Estimates suggest that mean harvested yield through grazing and mowing (for hay and silage) was about 4000 to 5000 kg/ha/year in early 1900, about 6000 to 7000 in the 1970s, and on average about 10000 kg/ha/year in 2000s' (Oenema *et al.* 2012). Variations between farms and between years are large. Differences between farms in the utilization of grassland are related to the milk yield per ha, and hence to the demand for herbage, but also to soil type and grassland management. Differences between years are mainly related to differences in rainfall and earliness of the spring.

Recorded herbage yields are higher in field experiments than on farms. Vellinga and Andre (1999) summarized the results of fertilization experiments in NL carried out between 1934 to 1994. The data set had 4700 records with a peak in the period 1960-1975. Mean dry matter yield, not limited by nutrients, was ~15,000 kg per ha per year, but with a significant year-effect. They concluded that grassland renovation, drainage, soil fertility, and grassland management have increased mean dry matter yield, N use efficiency and apparent N recovery in herbage. The proportion of clover in swards decreased over time, as a consequence of increased N fertilizer use.

Though potential herbage yield, as defined in Figure 2, has been estimated at ~20,000 kg/ha/year (Van Ittersum and Rabbinge 1997) mean 'attainable herbage yield' as obtained in well-managed field experiments is about 15,000 kg/ha/year. This would suggest that farmers on average utilise realise on average 60-70% of the attainable herbage yield. Hence, the scope for further intensification of grassland use is rather modest. A further intensification may have to come from the conversion of the C3-species grasslands into forage land cropped with C4 maize. Most dairy farms on sand and clay soils currently have about 30% of the area in forage maize. Mean dry matter yield of silage maize averages 15,000 kg/ha/year, but with significant annual and regional variations due to differences in rainfall, spring temperature, and wetness in autumn. Further conversion of grassland into crop land for forage maize production is constraint by governmental regulations and also by practical limitations.

Developments in performances over time of two groups of dairy farms between 1999 and 2004 are compared in Table 1. The 16 dairy pilot farms of Cows & Opportunities were guided to lower nitrogen (N) losses and to be ahead of the reference group (Doornewaard *et al.* 2007). Both the pilot group and the reference group decreased the N surplus; as expected the N surplus was lower for the pilot group than the reference groups. Also the NUE increased significantly on the pilot farms. Both groups increased farm area considerably between 1999 and 2004; investments in land and buildings were larger for the pilot farms. Fertilizer costs were only a small percentage of the total allocated costs (<10%) and non-allocated costs (<3%). A significant fraction of contractor costs is related to low-emission slurry spreading, which ranged between 2.5 and 3.5 €/m^3 in 2010, depending on the contractor and transport distance. Also, the costs of milk quota are high.

Ten years later, in 2012, farm surface area, number of dairy cows per farm and milk yield per cow have increased considerable. Cost of feed, fertilizers, and energy roughly doubled and in 2008/2009 even tripled. Fluctuations in the prices of milk, feed, fertilizers and energy have increased strongly during the last ten years, which requires strategic planning of investments and savings. Many dairy farmers have anticipated that the milk quota system will be abolished by 2015 and have enlarged the farm area and buildings, and hence made investments. The investments have also increased the price of land, which ranged from 75,000 euro/ha for good quality land to 30,000 euro/ha for lower quality land in 2010 (LEI/CBS, 2012). The high purchase and rent prices for land has been a strong driver for the intensification of grassland and forage use in NL over time. The increasing size of dairy farms has also provoked a strong societal debate about so-called 'mega-stables' (Breeman *et al.* 2013); these farms with more than 300 dairy cows are criticized for deteriorating the livelihood of the country side.

Summarizing, grassland-based dairy farming is a competitive agricultural sector in NL. Intensification of grassland and forage use occurred steadily throughout the 20th century, but herbage yields now seems to plateau due to biophysical and environmental (regulations) constraints, although there is a considerable variation between farms. Milk yield per cow continues to increase at a mean rate of 84 kg/cow/year. Productivity per unit of labour also continues to increase through mechanization, milking robots and increasing the farm surface area, while the number of dairy farms decreases by 2-4% per year. Losses of N via NH_3 volatilization and NO_3^- leaching, in mass per kg of milk produced, have decreased by roughly 50% and GHG emissions by about 30%, due to the implementation of strict governmental measures. As a result, the eco-efficiency of dairy production in NL is one of the highest in EU-27 (Lesschen *et al.* 2011*)*. However, profitability is under pressure due to increasing cost. Hence, the main challenge is to drastically lower the cost of milk production and to further increase productivity per unit of labourer, so as to prepare for the convergence of milk prices in Europe with those on the world market. This provides incentives for smart intensification.

Intensification of grassland and forage use in Chile

Chile extends from the Atacama Desert in the north to Patagonian rangeland in the south (4300 km). The central part of Chile is dominated by a Mediterranean climate with a mean rainfall of 300-1000 mm. Further south the country is dominated by a temperate climate with 1.300 and 2.500 mm/year.

Chile had 3.6 million cattle for beef and dairy production in 2006 (INE, 2007). Dairy production is mainly

Table 1. Comparison of two groups of dairy farms in technical and economic performances between 1999 and 2004. The 16 dairy farms of Cows & Opportunities were guided to lower N surpluses, farms of the reference group (about 500 farms) not. (Doornewaard *et al.* 2007).

Resources and performance indicators	Cows & Opportunities		Reference group	
	1999	2004	1999	2004
Area, ha	41	52	42	51
Dairy cows	76	97	75	92
Milk yield, t/ha	15.6	15.2	15.4	15.1
Milk yield, t/cow	8.1	7.9	8.1	8.0
Milk fat & protein, g/kg	78.4	79.6	78.6	79.4
Young stock, number per cow	0.8	0.64	0.83	0.71
Concentrates, kg/cow	2098	2256	2079	2004
N surplus, kg/ha	275	165	333	212
P surplus	15	3	10	5
Economic results, €/100 kg milk				
Revenues milk	33.5	33.4	33.0	33.2
Revenues cattle	4.2	5.8	4.1	4.7
Total allocated costs	9.0	10.1	8.9	10.0
Concentrates	*4.5*	*5.4*	*4.6*	*5.4*
Veterinary assistance	*1.1*	*1.0*	*0.8*	*0.9*
Fertilizers	*0.5*	*0.7*	*0.7*	*0.9*
Total non-allocated costs	40.4	41.1	40.7	39.7
Labor	*12.8*	*11.9*	*13.5*	*13.4*
Contractors	*2.3*	*3.3*	*1.9*	*2.4*
Machines	*4.7*	*5.5*	*4.8*	*5.5*
Land & buildings	*9.5*	*10.3*	*9.3*	*9.3*
Milk quota	*7.9*	*7.0*	*8.1*	*6.6*
Energy and water	*1.0*	*1.2*	*0.8*	*1,1*
General costs	*2.2*	*1.9*	*2.3*	*1.5*
Net operating result	-11.7	-12.0	-12.5	-11.8

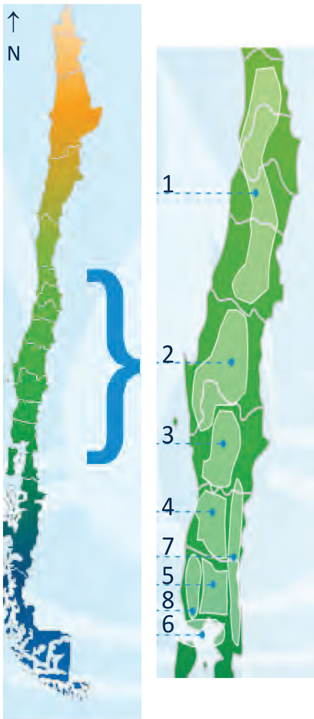

Figure 6. Distribution of dairy production zones in Chile (Consorcio Lechero 2012).

found between 32°-42°S and beef production further south between 40 to 56°S. Eight dairy production zones are distinguished (Fig. 6). More than 4 million ha of grasslands are used for beef production and another 1.5 million ha for 474.000 dairy cows (FIA 2008; INE 2007). Intensive dairy systems are found in the central part of Chile (Table 2), while grazing systems dominate in southern Chili (FIA, 2008). Yet, 72% of the dairy cows, and 66% of the total milk production comes from the southern zones (FIA 2008).

Chilean dairy production significantly increased from about 2002, in response to the development of the export sector, which has grown by 23% during the period 1998-2007. Currently, 15% of the national production is exported (FIA 2008), and the milk price paid to farmers is highly correlated to that of the world market. This price has increased on average by 7.5% per year (Fig. 7). It is expected that the intensification of the dairy sector will continue during next decade, as milk production in Chile is not constrained by milk quotas or environmental legislation yet. The current internal economic and political stability and the potential for intensive grassland-based dairy production, has also attracted foreign capital, and these foreign direct investments have also contributed to the development of the dairy sector, especially the processing industry.

Holstein Friesian dairy cows are found on the more intensive systems. These animals have higher demands in terms of feed quality and management than the local, rustic breeds. As a result, dairy systems in the Central part of the country (zone 1) are more vulnerable to changes in weather, crop yields, milk prices than the grassland-based dairy systems further south, also because of the large percentage of purchased feeds (Table 2). The cost of milk production is 30-40% higher in the intensive systems in zone 1 than in the grassland-based systems further south.

Intensification of dairy production has been made possible through increased pasture productivity, *i.e.*, through reseeding and fertilizer applications (Alfaro and Salazar 2005; Alfaro *et al.* 2008; Núñez *et al.* 2010), and increased grazing efficiency (Table 3). Also, use of supplementary crops (*e.g.*, turnip), to overcome temporary herbage shortages during dry periods has been helpful.

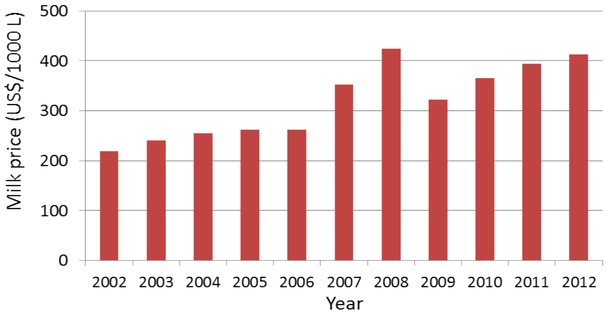

Figure 7. Mean milk price (US$/1000 L) per year paid to farmers in the last decade (Odepa 2012).

Table 2. Characteristics of dairy systems (with Holstein Frisians) in zones 1 and 5 in 2009-2011 (Consorcio Lechero, 2012).

Characteristics	Zone 1 Central Chile	Zone 5 Southern Chile
Milkings (no./day)	3	2
Production (L/ha)	16,481	8,232
Production (L/cow/day)	33	19
Grazing regime	Zero-grazing	57% grazing
Herbage in diet (%)	59	71
Purchased feed (%)	58	21
Feed cost (US$/L)	0.18	0.13

Intensification of beef production has been achieved through fertilizer applications and a switch from continuous to rotational grazing, which allowed higher stocking rates (Alfaro *et al.* 2008). Application of fertilizer P to pastures on the dominant (~90%) low-P volcanic soils has greatly contributed to increased pasture productivity (Escudey *et al.* 2001). These fertiliser applications and the increased amounts of manure P (in part through the import of animal feed) has increased Olsen P in the soil (0-10 cm depth), especially in areas with intensive systems. The increase in soil P, in combination with tactical fertilizer N applications, has increased pasture yields. Current pasture production in intensively managed dairy systems has been estimated at 50 to 80% of the attainable dry matter yield, as established in field experiments (15 to 18 t/ha/year; Araya *et al.* 2012). This suggests that further intensification in pasture production and use is still possible. Although direct P losses have been estimated to be low (<80 g P/ha) (Alfaro and Salazar 2007), there is an increasing risk of surface water pollution when high P inputs continue.

Intensification of pasture production has resulted in higher stocking and manure production rates (Table 3). Most of the cattle excrements are dropped on pastures during grazing. Slurries collected during confinement are temporarily stored in open ponds and then applied to pastures. Because of the relatively short housing period and the N losses during storage, slurry-N application rates are only in the range of ~40 kg/ha/year or less (Alfaro *et al.* 2008). Total ammonia (NH_3) volatilization losses from urea fertilizers and cattle slurry are in the range of 20 to 50% of the amounts of N applied (Salazar *et al.* 2012a). These high losses have economic impacts to farmers and environmental impacts to nearby pristine forest and lake ecosystems, but these impacts are not well quantified yet. Measured nitrate-N leaching losses (10-90 kg/ha/year; Alfaro *et al.* 2009; Núñez *et al.* 2010; Salazar *et al.* 2012a) and N_2O-N emissions (<0.2 kg/ha/year; Vistoso *et al.* 2012) are relatively low in comparison to those of similar systems in other regions of the world. This may be related to the physicochemical characteristics of the volcanic soils and the relatively young age of the pastures. Also, the N surplus in Chilean dairy and beef systems is still lower than that reported for dairy and beef systems in New Zealand and Western Europe. On most farms, a considerable proportion of the farm (10 up to 40%) is still woodland or shrub land, which contributes to the landscape diversity, carbon sequestration, and acts as buffer to larger natural areas (FIA 2008).

The further intensification of dairy and beef production may have serious environmental and social impacts. Chile is renowned for its biodiversity, beautiful landscapes and pristine air and water quality, especially in the south. These natural resources are being used in part by other economic sectors (aquaculture, tourism). Currently, there is a fragile balance between intensification of dairy and beef production and maintaining the high natural values of the current lake, forest and shrub ecosystems. The experiences gained elsewhere are considered highly relevant, as they may help to identify specific management practices and environmental regulations. They also allow benchmarking when analyzing the cost-benefit relationship of further intensification. International experience clearly indicates that there are limits to intensification, as the cost associated to the mitigation of negative effects are far higher than the economic benefit of intensification. These experiences also suggest that, from farmers' perspective, it is more beneficial to improve management practices than to decrease production. This does require education of farmers and extension services, as well as the development of farm specific tools, technology and best management practices.

Intensification of grassland and forage use in New Zealand

New Zealand has a predominately temperate climate, with warm humid summers and mild winters in the North and cooler summers and cold winters in the South. Average temperatures range from around 25°C (summer) and between 10-15°C (winter) in the north, to 15-20°C (summer) and 0-5°C (winter) in the south. Annual rainfall ranges from 1500-2000 mm (north) and from 900-1200 mm (south).

Grassland-based animal production is the backbone of the economy of New Zealand (NZ) and grazed pastures dominate the landscape. About a quarter of NZ's land area is high-yielding grassland, while another 30% is covered by low-productive grassland (Fig. 8). The high-yielding grasslands are typically ryegrass/white clover based and are intensively grazed year-round by predominantly dairy cattle, sheep and beef cattle. The low cost clover-based systems and the temperate climate that enables cattle to graze all year round are the key factors of the competitiveness of the NZ dairy industry.

The low producing grasslands are grazed by predominantly sheep and beef cattle. In the past decades there has been little change in areas of both the high and low producing grasslands (Fig. 8). In contrast, livestock numbers have changed considerably, with sheep numbers

Table 3. Characteristics of traditional and intensive grassland-based dairy production systems in Chili. Information derived from Alfaro and Salazar (2005); Alfaro *et al.* (2008); FIA (2008); Núñez *et al.* (2010).

Indicator	Traditional dairy system	Intensive dairy system
Grazing efficiency (%)	50%	70%
Average stocking rate (AU/ha)	1.0	2.3
Pasture yield (t/ha/year)	7-10	14-16
P soil status (Olsen P, 0-10 cm, mg/kg)	10-15	>30
N fertilizer (kg/ha/year)	45-90	150-250
P fertilizer (kg/ha/year)	35	85-100
N surplus (kg/ha/year)	0-50	15-120
P surplus (kg/ha)	-45-10	88-134

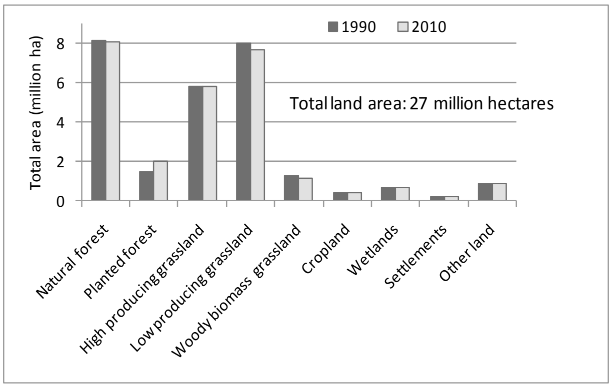

Figure 8. Land use in New Zealand in 1990 and 2010. Source: MfE (2012).

more than halved since the early 1980s, and dairy cow numbers more than doubled (Table 4).

Although sheep numbers halved between 1981 and 2009, sheep production reduced by less than a quarter, which reflects the significant increase in per-animal production over time. Similarly, beef production increased despite a reduction in beef cattle numbers. The largest increase in productivity has been in the dairy industry with milk production almost tripling, while animal numbers doubled. Also, the total area of land under dairying as well as cow numbers per hectare increased (by 6.3% and 6.7%, respectively between 2002 and 2009). All these factors combined resulted in an increase in milk output per area of land of 12% between 2002 and 2009.

The expansion and intensification of the dairy sector has resulted in increasing concerns of the ensuing pressures on soil and water resources. As a result, there has been significant focus on research to develop management practices for minimising the environmental footprint of dairy farms (*e.g.* de Klein *et al.* 2010; Monaghan *et al.* 2007). One of these research initiatives was the 'Best Practice Dairying Catchments project' that was established in 2001 to integrate environmentally sustainable practices into dairy farming (Monaghan *et al.* 2008). Detailed farm and land management surveys were conducted in five catchments in 2001, 2003, 2006 and 2009 to gather information on farm productivity levels, fertiliser use, purchased feed, farm effluent, irrigation, and soil management practices. The results typically show significant increases in milk production, stocking rate and N losses per ha over time (Table 5; Monaghan *et al.* 2008; de Klein and Monaghan 2011). Although N leaching and N_2O emissions per unit of milk produced decreased over time, thus indicating the farms became more efficient, the rates of efficiency gain were lower than the rate of production increase. As a result, total N leaching and N_2O emissions increased significantly. Simulation studies indicate that increasing milk production from 14.5 to 19.1 t/ha/yr would double total N leaching losses and would increase total N_2O emissions by 45%, while N losses per unit of product would increase by 58 and 10%, respectively (de Klein and Monaghan 2011).

The adoption of emission mitigation measures such as nitrification inhibitors, restricted grazing and low-protein supplementary feed can offset some but not all of the intensification-induced environmental losses (Beukes *et al.* 2011; de Klein and Monaghan 2011). In addition, these options often come at a cost. The most cost-efficient way of achieving the dual goals of increased productivity and reduced environmental losses is to focus the management first and foremost on practices that achieve 'more for less', *i.e.* more milk per animal or per unit of dry matter intake, and more dry matter per unit of N input, rather than focusing on mitigation of N losses.

Discussion and synthesis

There is an increasing demand for safe and nutritional dairy and beef products in our globalizing world, and the dairy and beef sectors are responding to this demand (*e.g.*, Bruinsma 2009; Steinfeld *et al.* 2010). As most dairy and beef production is grassland-based, the production of grassland will have to increase as well. This then raises the question 'Does intensification of grassland and forage use lead to efficient, profitable and sustainable ecosystems?' We tried to find answers to this question by analysing conceptual notions of 'intensification of grassland production', and by discussing country cases, *i.e*., the intensification of grassland-based dairy production in NL, Chile and NZ. In this chapter, we try to provide more definite answers.

External driving forces (*e.g.* Fig. 1 and 4) and internal driving forces (De Wit 1993; Fig. 2) both provide incentives for intensification, *i.e*., for increasing the output per unit surface area and labour. The three country cases (NL, Chile and NZ) suggest indeed that intensification is a global phenomenon, constrained by men-made limits (*e.g.* milk quota, fertilization limits) and by biophysical and socio-economic limits. Technological progress and systems changes provide opportunities to almost continuously increase the production per unit surface area and per unit labour (Fig. 3 and 4). Therefore, the relevant question is not 'intensification or extensification?' but 'where and how far to intensify production?' and 'under which conditions?' Unfortunately, there is no universally applicable and commonly accepted definition of 'intensive grassland production and forage use' because the biophysical and socio-economic conditions for grassland production show large spatial variations. Instead, operational and case-specific definitions have to be provided.

Evidently, there are winners and losers in the so-called 'rat race' of intensification. The winners are farmers who

Table 4. Changes in livestock numbers and livestock production in New Zealand (MfE 2012; FAO 2012).

Year	Livestock numbers (million)			Livestock production (Tg; 1 Tg=10^9 kg=10^{12} g)		
	Sheep	Beef	Dairy	Sheep meat	Beef meat	Milk
1981	70	5.1	2.9	626	499	6684
1990	58	4.6	3.4	542	481	7509
2002	40	4.5	5.2	523	578	13866
2009	32	4.1	5.9	478	639	16483
Change 1981 - 2009	-54%	-20%	+103%	-24%	+28%	+147%

Table 5. Changes in farm characteristics of dairy farms in the Waikakahi catchment in New Zealand between 2001 and 2009, relative to 2001 (after de Klein & Monaghan 2011).

Farm characteristics	Changes relative to 2011 (%)		
	2003	2006	2009
Milk production per ha	11	30	39
Stocking rate per ha	9	22	21
N fertiliser per ha	-7	16	15
N leaching/unit of product	-12	-1	-7
Total N leaching loss	-2	29	30
N_2O loss/unit of product	1	-3	-17
Total N_2O loss	6	27	21

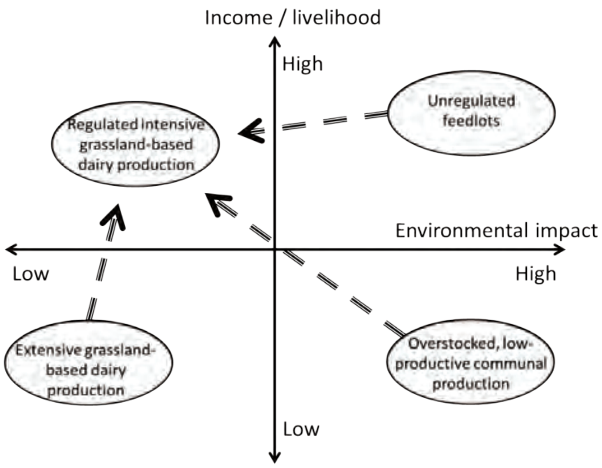

Figure 9. Pathways to increase the sustainability of dairy production (after McDermott *et al.* 2010).

are able to achieve a high return on investments, and thereby out-compete farmers with a low return on investment. Winners can have different strategies, ranging from minimizing costs to maximizing milk yield per cow or ha, and these strategies are applied in all three countries. Both in NL, Chile and NZ, milk production per farm may range from <8 to >16 t/ha/year. Currently, the percentage of relative intensive farms (milk yield >~16 t/ha/year) is larger in NL than in Chile and NZ, but the rate of intensification is much higher now in Chile and NZ than in NL, mainly because intensification in NL started already in the 1960s, but was halted by the introduction of the milk quota systems in 1984 and by strict nutrient management regulations from the 1990s.

Losers are small farmers, who drop-out of business everywhere in the world, and the environment. Small farmers tend to stay in business as long as possible by minimizing costs and in some cases by broadening the income-bases through providing services to other farmers and other people (*e.g.*, Van der Ploeg 2009). The environment, *i.e*., air, water, natural ecosystems, often is also a 'loser' of intensification, though not necessarily as all three country cases illustrate. The relationship between intensification of grassland and forage use and its environmental impact is complex, as it is influenced by site-specific conditions, the type of system and the management. In the three country cases, we focused on the nutrients N and P and the greenhouse gases CH_4 and N_2O, mainly because of the current governmental awareness. Intensification of grassland and forage use often leads to increased emissions of N, P, CH_4 and N_2O per unit surface area and to decreased emissions per unit of produce. The rate of increase per unit surface area and of the decrease per unit of produce greatly depends on the system and the management. Hence, optimal ranges of intensification of grassland and forage use can be defined with both, minimal emissions per unit of surface area and per unit of produce. These ranges depend on site-specific conditions, system and management, and on societal demands.

For NL, optimal milk yield currently seems to range between 12 and 25 t/ha/year. Farms at the lower end of this range are self-sufficient in forage (using restricted grazing systems) can accommodate the produced manure on own farm land, and can meet the current targets for NH_3 and GHG emissions to air and for N and P losses to water. Farms at the upper part of the range will have a zero-grazing, low-emission housing system, import a large fraction of the required forage and export a large fraction of the manure produced to other farms within the region (the latter often at high economic cost). The current optimal size ranges between ~80 to 300 dairy cows per farm, although there are few dairy farms with >1000 cows. Though large high-tech stables and 'agro-production parks' are technically highly efficient (*e.g.*, Smeets, 2009), public opinion is heavily against these so-called 'mega-stables', especially near villages and urban areas, because of issues related to odour, noise, landscape, animal welfare, antibiotics, hormones, and zoonosis (Breeman *et al.* 2013). Mega-stables are not well-defined, but in the public perception have more than ~300 dairy cows, or an equivalent number of goat, pigs and chicken. The public aversion against high-tech, zero-grazing mega-stables in NL illustrates the importance of societal limits to intensification of grassland and forage use, as well as the need for public debate about 'intensification of production'.

Yes, intensification leads to more efficient and profitable, and thereby to more sustainable grassland ecosystems, if the reference systems are extensively managed, under-utilized, low-productive, over-exploited and/or unregulated systems (Fig. 9). For grassland with high potential production, the future likely is *intensive* grassland-based dairy and beef production systems, but with regulations. Intensive systems require more knowledge and energy, and are likely more leaky. Producers and society will have to prepare for that. Changes in systems or management practices should focus on 'more for less' first and then on the mitigation of emissions. Governments, with the help of consumers, producers, processing industry and public pressure groups, will have to set realistic targets and limits for the intensification of grassland and forage use. So far, there is a lack of well-defined and accepted targets and limits for the intensification of grassland and forage use, as a function of site-specific conditions, system and management.

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