A dairy system based on forages and grazing in temperate Mexico

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Subject headings: alfalfa, orchard grass, oats, annual ryegrass, maize silage, concentrates, nitrogen, irrigation, stocking rate, productivity, profitability.

Contents

PROPOSITIONS

1. Due to increased competition, the strategy of dairy farming in Mexico can only be sustainable on the basis of free trade world prices. *This thesis*

2. For Mexico the future of dairy farming does not lie in the tropics as was predicted. *This thesis*

3. In temperate Mexico, dairy farming based on forages and grazing enable a substantial reduction in feeding costs, provided high stocking rates are maintained. *This thesis*

4. The response of milk production per hectare to supplementation is affected more by changes in stocking rate than by changes in production per cow. *This thesis*

5. Farm research results should always be related to financial returns.

6. The number of bites taken per unit area can be used to describe the effects of herbage allowance on herbage intake and to analyse the interaction between daily intake per animal and intake per unit area. *This thesis*

7. Uneven distribution of incomes between and within nations hinders the development of sustainable agricultural systems.

8. The development of sustainable agriculture is more dependent on political than on technological measures.

9. There is no pure science and applied science, only science and the application of science. Mueller R. A. E. 1993. The product of science. In: M. J. Baker (Ed.). Grasslands for our world. SIR Publishing. Wellington, New Zealand, pp. 176-183.

10. Knowing in part may make a fine tale, but wisdom comes from seeing the whole. E. Young. Seven blind mice. Scholastic Inc. N York. 1992

11. *Navigare necesse est, vivere non est necesse*. Taken over from Carlos Quijano and three generations of Uruguayans stubbornly looking for freedom and justice.

Propositions belonging to the thesis

A dairy system based on forages and grazing in temperate Mexico

by Ricardo D. Amendola, Wageningen, The Netherlands, 27 February 2002.

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Abstract

Mexican dairy farmers will face in the near future the challenge of increased competition and the strategy to survive this at farm level will have to be based on competitive free trade world prices. This thesis describes the design of a dairy system based on forages and grazing to reduce production costs in temperate Mexico. This dairy system is based on a sequential cropping system of permanent pastures of alfalfa and orchard grass, winter annual pastures of oats and annual ryegrass and silage maize. Between May and October the cows graze on permanent pastures and between November and April they graze both types of pastures. Between October and April the cows also receive supplementary feeding with maize silage. The cows are supplementarily fed with moderate amounts of concentrates during the lactation. The responses of stocking rate and milk production per hectare to increasing levels supplementary feeding with maize silage and concentrates were studied in two experiments. In both experiments a high and uniform pasture utilisation was targeted irrespective of the level of supplementary feeding. Milk production per hectare was more closely affected by changes in stocking rate than by changes in production per cow. Supplementary feeding with maize silage up to 4.8 kg DM of silage cow^{-1} day^{-1} and 4 kg of concentrate cow^{-1} day^{-1} appeared to be economically feasible. The right economic decision could not have been based on the response in milk production per cow to supplementary feeding. The allowance - intake relationship for dairy cows grazing oats and annual ryegrass pastures is reported. The responses of herbage intake and composition of the ingested herbage to different levels of herbage allowance were used to identify the levels of stocking rate and height of residual herbage that maximised production per unit of area. The number of bites taken per unit of area appeared to be an adequate variable to interpret the responses to herbage allowance. The effects of nitrogen fertilisation and irrigation on herbage and nitrogen yield of oats and ryegrass pastures were evaluated in a cutting trial. Nitrogen fertilisation between 50 and 100 kg N ha^{-1} harvest^{-1} increased herbage production, reduced the cost of produced herbage and improved the efficiency of utilisation of irrigation water. Using a high level of irrigation reduced the efficiency of utilisation of irrigation water and the recovery of fertilizer-N. However, increasing the frequency of irrigation increased the efficiency of use of absorbed N. The results of two years of operation (1998 and 1999) of the Farmlet for Dairy Production Under Grazing of Chapingo University are reported. The average stocking rate was 2.6 cows ha^{-1}, the average production per cow was 6200 kg milk per lactation and the average productivity was 16 Mg milk ha^{-1} year^{-1}. Feeding costs in this dairy system were 43% lower than the average feeding costs in prevailing dairy systems. The net revenues (1273 US $ ha^{-1} year^{-1}) indicate that this dairy system is a feasible option. Based on these results, an improved pasture-crop rotation is proposed with a targeted productivity of 29 Mg milk ha^{-1} year^{-1}.

Cover: Het gras van de buren is altijd groener (Grazing cows at Chapingo),

Wil Lantinga-Nienhuis.

To María, Lucía, Julio and Belén; to the memory of my brother Pepe and Andrés Aguilar Santelises, two outstanding agronomists.

Institutional Acknowledgements

I received a sandwich fellowship from Wageningen Agricultural University. During the whole duration of the project I also received financial and institutional support from Universidad Autónoma Chapingo. I express my gratitude to both institutions.

Preface

I could say it all started when, after many years, I met Prof. 't Mannetje again at the International Rangeland Congress in 1995. Coming back to my alma mater, and being able to work again with Prof. L. t' Mannetje and Dr. E. A. Lantinga, was all the encouragement I needed to start my PhD studies at the age of 45. But life is a matter of love and passion. Thus I have to admit it also started back in the early 60's when, as a child, I concluded that farmers and their workers fulfill a truly essential duty: producing food for themselves and everyone else. Some standpoints being held in the current social debate make me think that nowadays not everyone agrees with my conclusion. Farmers are being blamed for damaging the environment. But farmers did not create agricultural systems that damage the environment; those systems have been created by the - further developing - uneven distribution of incomes between and within nations.

Designing an alternative production system might seem too ambitious to be the aim of a personal project. However, this was an institutional project of Chapingo University. Many people contributed to it, but naming everyone would make this preface extremely long. Nevertheless, it becomes inevitable to mention those whose participation made the whole project possible. Melitón Córdoba Alvarez, Luis M. Serrano Covarrubias, Rames Salcedo Baca, Manuel Cuca García and José Solís Ramirez, authorities of Chapingo University that lent me the required support. Marco A. Siordia Lara and José Cortés Arriola (a field-worker of the University and a M. Sc. student, respectively) supported me far more than I could expect during the very difficult early times of the project, when the farmlet had to be built from bare ground. The results here reported are the product of the work of M. Sc. students or our University. Working and learning together with José Cortés Arriola, Marco A. Martínez Castillo, Francisco Roman de la Cruz, Enrique Rivera Reyes, María Mercedes Flores Paredes and Feliciano Martínez Valenzuela has been one of the most rewarding experiences of my life. Moreover, many B. Sc. students of our University also contributed to these results. Antonio Mendoza Pedroza has been in charge of the daily operation of the farmlet since January 1998; he released me from responsibilities that hindered my involvement in research. Juan A. Burgueño Ferreira gave me advice and assistance whenever I required it. Mi reconocimiento y agradecimiento a todos.

The support and guidance of Prof. Dr. Ir. L. t' Mannetje and Dr. Ir. E. A. Lantinga were essential to the fulfilment of the objectives of this project. Leen, Egbert, Marieke en Wil, dankzij jullie vriendschap, weer thuis te zijn is heerlijk geweest. De gastvrijheid van Biologische Bedrijfsystemen zorgde voor een zeer plezierige werksfeer tijdens mijn verblijf in Wageningen. Daarom wil ik Prof Dr. Ir. A. H. C. van Bruggen en de medewerkers van de afdeling - in het bijzonder Wampie en Hennie - danken. Anne, Maya, Esther, Sander, Aitana en Santiago jullie zijn geweldige kamergenoten geweest.

Sander Essers en Kees van Maaswaal have been dearest friends since I started studying at the Landbouwhogeschool, no wonder they are today my paranimphs. My wife María and my daughter Lucía were patient and supporting - though Lucía still believes that the cows of the experimental farmlet rank above her in my affections. However, they were also rewarded, the year we spent together at Marieke's wonderful house in Bennekom is unforgetable. Since then, we three share the many reasons I have to be proudly -though not uncritically - Dutch.

Chapter 1

General introduction

Dairy production in Mexico had suffered a severe crisis of profitability during the 1980s. More than 70% of the milk is produced under temperate and semi-arid conditions in the Plateau and North of Mexico. Two dairy systems prevail in those regions: the intensive Specialised Dairy System and Semi-specialised Dairy System. Farms of the Specialised Dairy are large, the production is highly mechanised, the productivity is relatively high and farmers are well organised and highly integrated. Farms of the Semi-specialised dairy system are much smaller; rely to some extent on the use of unpaid family labour and the degrees of adoption of modern technology and of integration increase with the size of the farm. In both systems cows are permanently kept indoors, and the ration includes high proportions of concentrates. Production costs in these systems are high, leading to low margins. Feeding costs represent approximately 70% of those costs.

In Mexico, like in many other countries forages and grazing might offer a solution for the problem of high production costs. Dr R. De Lucía and M Sc J. C. Avendaño working in Chapingo University started pioneering by the beginning of the 1990s with a design of a dairy system based on grazing of alfalfa and orchard grass pastures (Avendaño *et al.*, 1991). However, when this system was adopted by farmers, many imperfections emerged which jeopardised its sustainability. The main problems faced by farmers were:

- low herbage availability during the winter,
- lack of options for the problem of poor persistence of pastures,
- too high rumen degradable protein content in the diet,
- high bloat-risks,
- too low productivity of cows,
- poor body condition and reproductive performance of cows,
- lack of estimates of the range of stocking rates leading to best performance of the system,
- lack of estimates of economically feasible levels of supplementary feeding.

Different problems were apparently related with each other. Too low productivity of cows, poor body condition and reproductive performance were related to excessively high stocking rates during the winter. The high content of rumen degradable protein of the diet made this problem even worse. Pastures lost persistence and had to be sown again after a few years. Sowing must take place in the autumn to avoid high levels of weed infestation. However, sowing in the autumn reduced even more the already low herbage availability during the winter. Events of bloat were frequent and to face the risk, longer rest periods and lower herbage allowances were applied. This kind of grazing management reduced the risks of bloat in one grazing cycle. But it also increased the proportion of alfalfa and hence the risks of bloat in the next grazing cycle. Due to the lower herbage allowances used the poor body condition of cows became even worse. The use of supplementary feeding could have helped to solve these problems, but no information was available on the economically feasible levels of supplementary feeding. Therefore, this alternative dairy system was obviously not sustainable.

In the late 1990s, we undertook the task of developing a sustainable dairy system at Chapingo University based on forages and grazing. We assumed that profitability is one of the most important components of sustainable agricultural systems. Therefore in this initial phase of design of the system, research was focused mainly on profitability. In doing so, we dangerously moved in a narrow edge between agricultural science and invention (Mueller, 1993). We accepted that risk because we agree with the statement by Nores and Vera (1993) that to remain viable and relevant, the grassland profession needs to transmit its research output in a manner that facilitates its use and makes its socioeconomic relevance explicit.

The problem was complex, and to face it, three forms of general-purpose heuristics -as briefly described by Mueller (1993)- were used: i) the progress principle, ii) means-ends analysis and iii) problem splitting. The general goal was to develop a sustainable dairy system widely applicable in the Plateau and North of Mexico. By applying the progress principle, we aimed with this project to design a first version of an economically feasible dairy system in a particular ecological and socio-economic environment (that of a small enterprise in the State of Mexico). The design of this alternative system to be evaluated found its roots in: i) dairy systems based on forages and grazing in other countries (Australia, Argentina and Uruguay), ii) the forages used in the Specialised Dairy System of Mexico, and iii) previous research carried out at Chapingo University. In doing so we used means-ends analysis. According to McCall and Sheath (1993), matching animal feed demand and the supply pattern of forage is essential in the development of intensive animal production systems based on grasslands. Therefore, the components of the system related to the availability of feed during the winter deserved priority in research. Research was conducted in order to find rather specific answers to specific questions on the use of supplementary feeding, grassland management and the use of nitrogen fertilisation and irrigation water. The experiments were intended to provide results that could be used in the further development of the design of the alternative system. That was our *sui generis* way of using problem splitting general-purpose heuristics.

Based on the results of Jiménez *et al.* (1986), Dr. R. De Lucía and M Sc J. C. Avendaño chose alfalfa and orchard grass as the mixture for the permanent pastures. In later experiments (Améndola *et al.* 1997, Marín *et al.* 1997a, 1997b; Paniagua, 1999) it was confirmed that at Chapingo alfalfa and orchard grass mixtures were superior to perennial ryegrass and white clover mixtures. A review of 17 experiments on grazing of alfalfa and orchard grass pastures carried out at Chapingo (Sanchez *et al.*, 1996) revealed that herbage accumulation rates of the pastures ranged between 72 kg DM ha^{-1} d^{-1} (between April and October) and 47 kg DM ha^{-1} d^{-1} (between November and March). The crude protein content of herbage on offer for the same periods was on average 23.5 % and 27.0 % respectively. Hardly any information was available on the persistence of these pastures. However, an experiment on third-year pastures composed of orchard grass mixed with different cultivars of alfalfa (Julián, 1996) revealed that net herbage production between November and March ranged between 16 and 24 kg DM ha^{-1} d^{-1}, and was therefore much lower than the average reported by Sánchez *et al.* (1996). The productivity of these third-year pastures during late autumn and winter was closely related with the proportion of alfalfa.

The Specialised Dairy System of the Plateau and North of Mexico is based on the use of cut- and carry-forages. That dairy system uses a crop rotation where alfalfa pastures are rotated with silage maize (during the summer) and oats or annual ryegrass (during the winter). Preliminary research carried out at Chapingo on grazing of the mixture of oats and annual ryegrass (Améndola *et al.*, 1995; Morales, 1995; Améndola and Morales, 1997; Dorantes, 1997) showed that:

- the mixture was able to produce 8000 to 10000 kg DM ha^{-1} in four grazing cycles carried out between the end of November and April, i.e. the period when the productivity of alfalfa and orchard grass pastures was low,
- the variety of oats was an important factor (Coker 234 was a variety well-suited for grazing),
- a 50%-50% proportion of the seed densities used in monocultures led to best results,
- fertilising with 50 kg nitrogen per ha after each grazing cycle led to higher yields than including legumes,
- in order to attain high herbage production during the winter sowing should take place in the beginning of the autumn.

The variety of maize V-107 is the highest yielding variety of forage maize available for temperate regions in the State of Mexico, yielding 26000 kg DM ha^{-1} under experimental conditions (Bravo, 1994). Muñoz (1997) sampled commercial crops of that variety during three years and found that average yields ranged between 11250 and 18030 kg DM ha^{-1}. However, Cortés (1995) reported a yield of 28876 kg DM with this variety in Chapingo. Between 1989 and 1991, commercial crops in the experimental field of Chapingo University yielded 19000±1098 kg DM ha^{-1}. The dry matter content of these commercial crops was on average 22.2% DM (unpublished results).

Based on all this information a pasture-crop rotation was proposed as a basis for the alternative dairy system. This rotation would include a phase of 4 years of alfalfa and orchard grass pastures. The pastures would be rotated with oats and ryegrass pastures during the winter and silage maize during the summer. The hypothetical feed availability expected with that rotation is depicted in Figure 1.

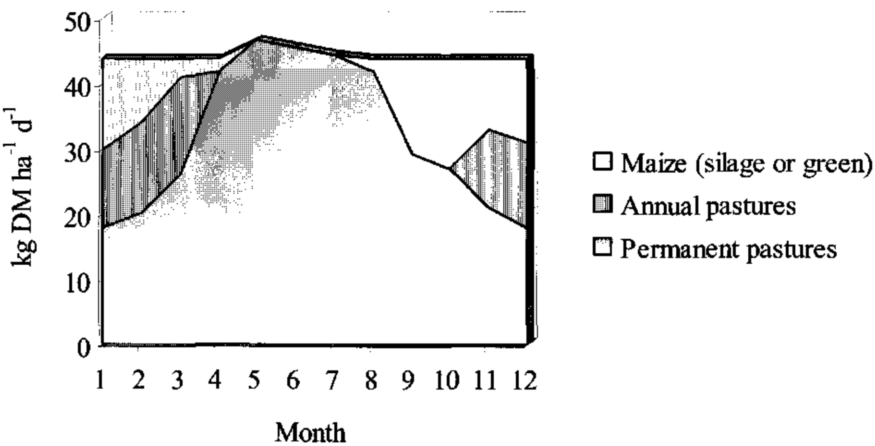

Figure 1. Hypothetical feed availability with the alternative pastures-crop rotation.

The questions to be answered for designing the first version of the alternative dairy system based on grazing of these pastures and supplementary feeding with maize silage were:

- How much silage can be supplementarily fed to cows and what are the responses to supplementary feeding in terms of stocking rate and productivity per unit of area?

- How are the responses to supplementary feeding with concentrates in terms of stocking rate and productivity per unit of area, and which levels of supplementary feeding with concentrates are economically feasible?
- How do annual pastures compare against permanent pastures during the winter?
- What are the effects of supplementary feeding with maize silage and concentrates on the content of rumen degradable protein in the diet?
- What levels of daily herbage allowance can be used once cows are supplementary fed, and which are the levels of stocking rate leading to highest performance of the system?
- What levels of nitrogen fertilisation have to be used in the winter annual pastures and how does nitrogen fertilisation interact with the level of irrigation water?
- How are the biophysical and economical results of the dairy system based on this pasture-crop rotation?

The situation of the international and the national dairy markets changed strongly during the 1990s. Nonetheless, there was no report available on the probable consequences of those changes for Mexican dairy farmers. Taking into account that these changes could have a huge effect on the probable adoption of the alternative dairy system, a review of that topic was deemed to be necessary.

Structure of the thesis

In Chapter 2, a review of dairy production in Mexico is presented. This constitutes a more detailed description of the main problems. The difficult task of previewing perspectives for the Mexican dairy sector receives special attention. The following four chapters report the results of experiments dealing with the specific questions: the use of supplementary feeding with maize silage (Chapter 3), daily herbage allowance on winter annual pastures (Chapter 4), the use of supplementary feeding with concentrates (Chapter 5), and the use of nitrogen fertilisation and irrigation water on winter annual pastures (Chapter 6). The alternative system was implemented in an experimental farmlet at Chapingo University. In Chapter 7, the biophysical and economical results of two years of operation of that farmlet are reported. In the General Discussion (Chapter 8), the consequences of the results are reviewed in terms of the efficiency of the dairy system. Factors affecting that efficiency are discussed. Based on that analysis an improved pasture-crop rotation is proposed and future research needs are outlined.

Chapter 2
Dairy production in Mexico

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Summary

A review of the dairy production sector in Mexico over the last 25 years was carried out. The main objective was to update the characterisation of the sector and the outlines of its perspectives. The Mexican dairy sector and its relationship with the world dairy market suffered major changes during the 1990s. Between 1985 and 1997 the price paid to Mexican dairy farmers was coupled to the international price of skim milk powder. The dairy systems of Mexico were exposed to a heavily subsidised world market and this exposure had a huge negative effect on the national dairy production. Around 1990, imported dairy products supplied on average more than 25% of the national demand. The per capita consumption of dairy products in Mexico is not expected to grow in the near future since the Programme of Social Supply is being reduced and dairy products might be unaffordable for a high proportion of the population. Since the beginning of the 1990s, world dairy production has been moving from high-cost countries to low-cost countries and international competition is becoming more intense. Production systems of the latter countries are based on year-round grazing of temperate and sub-tropical pastures. If - as expected - the dairy sector of Mexico becomes increasingly exposed to that competition, prices paid to farmers will approach the theoretical world milk price, which during the 1990s was lower than the prices paid to Mexican farmers. Feeding costs in the dairy systems of the Plateau and North of Mexico where 80% of the national milk production takes place are high, representing more than 90% of the theoretical world milk price during the 1990s. Taking into account the prospects on reduced growth of demand, increase of competition and reduction in the prices paid to farmers, those dairy systems should reduce feeding costs in order to remain competitive. In other parts of the world, grazing-based dairying with low use of concentrates is considered as a viable way to face the new context, in which the strategy at farm level must be based on competitive free trade world prices. The technological basis for dairy production based on forages and grazing of temperate pastures in Mexico is weak. If such a system appears to be a promising candidate for low-cost production, solutions should be found for the unbalanced feed supply throughout the year and the low persistence of the pastures. The use of supplementary feeding and the potential productivity and economical feasibility of the system should also be evaluated.

Introduction

During the 1980s and 1990s Mexico faced a severe deficit in milk production. The country was in that period the main importer of skim milk powder (SMP) in the world, buying on average 13% of the SMP traded (FAO, 2000d). For many years imported dairy products supplied on average more than 25% of the demand and national food security was jeopardised by the increase in dependence (Muñoz *et al*, 1995). The national milk production stagnated without net growth between 1985 and 1995 (FAO, 2000c; CEA, 2000b). Muñoz & Odermatt (1992) concluded that the economic feasibility of Mexican dairy farms was low and this lack of competitiveness led to the stagnation of the sector. In agreement with this conclusion, ITESM (1994) reported that during 1990 and 1991, average national production costs were US $ 0.28 per litre while the average price paid to farmers was US $ 0.29 per litre.

During the 1990s descriptions and diagnoses of the dairy production sector in Mexico were given in different reports. According to Muñoz *et al* (1995) and ITESM (1994), the Mexican dairy sector is composed of three main systems: i) specialized and large enterprises located in the northern and central regions under temperate or semi-arid climates (with irrigation), ii) small family-based (semi-specialized) enterprises mainly located in the central plateau and iii) tropical dual purpose (calf-milk) systems. In the specialized and family-based or semi-intensive systems cows are permanently housed and are fed with cut-and-carry forages and high amounts of concentrates. Both systems share their most important problem: high feeding costs leading to low margins. According to Perez *et al.* (1991) and ITESM (1994), feeding costs in those systems represent about 70% of production costs; the high use of concentrates being the main cause. Feeding in the tropical dual-purpose system is based on grazing of sown and native pastures and therefore feeding costs are much lower. Muñoz *et al* (1995) concluded that: i) the competitiveness of the specialized system was very low and adopting a dairy system based on grazing of temperate pastures could be the way to increase competitiveness, ii) production costs in the family-based or semi-intensive systems were high but were counteracted by intensive use of unpaid family labour, and iii) the competitiveness was expected to be highest in the tropics, particularly if the dual-purpose systems were changed into dairy systems.

However, during the 1990s the Mexican dairy sector and its relationship with the world dairy market suffered major changes. Updating the characterisations of the sector and the outlines of perspectives for the sector was necessary in order to provide a wide problem representation for dairy production based on forages and grazing in temperate Mexico. Therefore, a review of the dairy production in Mexico over the last 25 years was carried out.

Many of the factors that constitute the environment for dairy production are analysed in this review: i) the evolution of demand for dairy products, ii) dairy policies, including import of skim milk powder and definition of prices paid to farmers, iii) milk production of the different dairy systems including a brief description of these systems and their production costs, iv) the evolution of the world dairy market and v) changes in the national dairy market. Additionally, available technological options for dairy production based on grazing of temperate pastures were reviewed in order to identify research needs.

Demand for dairy products

The absolute demand for dairy products in Mexico grew at much higher relative rates than the world average (Figure 1a). However, until 1981 the growth rate was extremely high and rather constant, whilst afterwards it decreased and became erratic. The rate of increase in demand for dairy products depends on demographic growth and changes in the supply per capita. Changes in supply per capita are generally linked to more general changes in the nutritional pattern of the population. These changes are usually ascribed to migration of rural populations to urban areas and to fluctuations in consumer spending power.

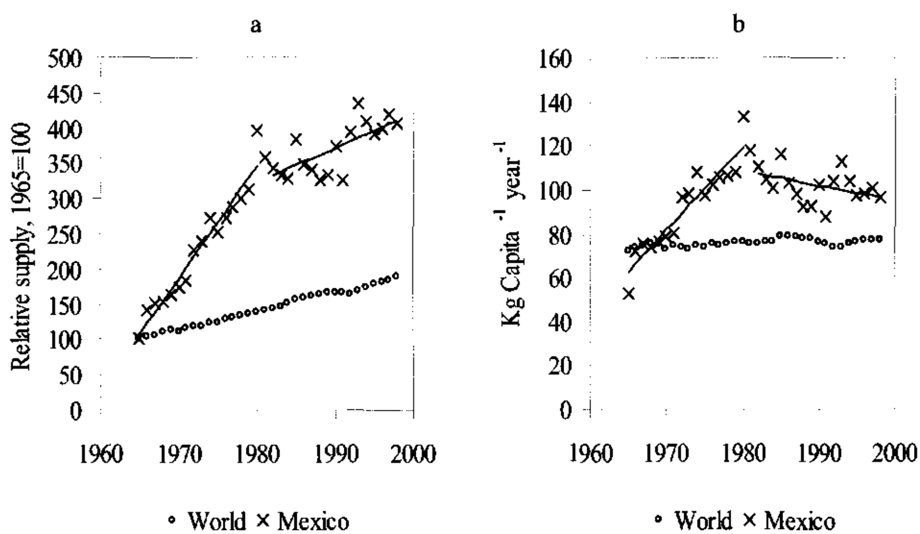

Figure 1. The supply of dairy products in Mexico and the world. Relative supply considering supply in 1965=100 (a), and per capita supply (b). Lines depict linear equations that minimise rest standard deviation. After FAO (2000a).

Demographic growth explains part of the increase in demand for dairy products. The population of Mexico grew at much higher relative rates than the world population (INEGI, 2000; FAO, 2000b). Demographic growth in Mexico is slowing down – according to INEGI (2000) annual relative growth rate of the population decreased from 3.3% in the 1970s to 2.1% in the 1990s - but the sharp change of slope in Figure 1a appears to be more closely related to fluctuations in per capita consumption (Figure 1b). Between 1965 and 1981 supply of dairy products per capita increased at an annual rate of 3.77 kg cap^{-1}, and afterwards it remained with no significant changes ($p>0.05$) at an average of 101 ± 2 kg cap^{-1} $year^{-1}$. A review of factors involved in changes in the pattern of consumption of dairy products is necessary to foresee some perspectives of future changes.

The increase in per capita consumption of dairy products was part of a more general change in the nutritional pattern. The demand for energy and animal-based proteins in Mexico increased strongly until the beginning of the 1980s. Afterwards, those rates of change became lower (Figures 2a and 2b). These long-term dietary shifts also involved reductions in the proportions of protein and energy contributed by maize and beans - traditionally considered the basis of Mexican diets – with a change of slope at the beginning of the 1980s (FAO, 2000a). Dairy products contributed with more than one third of the demand for animal-based proteins (FAO, 2000a). Such a high contribution is probably due to the fact that protein in milk was cheaper than most other animal-based proteins (Domínguez, 1990; Alvarez, 1998).

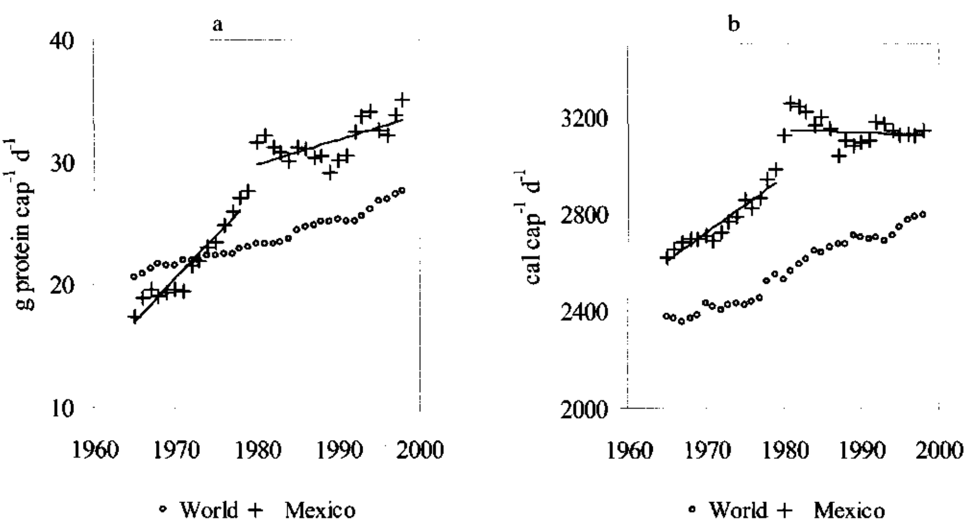

Figure 2. Changes in dietary pattern. Demand for animal-based protein (a) and total energy (b) in Mexico and the world between 1965 and 1998. Lines depict linear equations that minimise RSD. After FAO (2000a).

Changes in the nutritional pattern in developing countries are usually ascribed to the migration of rural populations to urban areas, which usually result in up-graded diets with shifts towards animal-based proteins (Alvarez, 1998; Jachnik, 1999; OECD, 2000). The proportion of urban population in Mexico, which was already high in 1960 (55%), grew to 74% in 1999 (FAO, 2000b). However, there were no changes in the rate of increase of the proportion of urban population during the 1980s (INEGI, 2000), and therefore migration of rural populations to urban areas is not clearly related to the change in slope of per capita consumption of dairy products that occurred at the beginning of the 1980s.

In developing countries the demand for dairy products and other animal-based proteins is also closely linked to consumer spending power (Griffin, 1999; OECD, 2000). Changes in spending power of the majority of the Mexican population can be described by the evolution of the minimum wage. Also in this case, a change of slope took place at the beginning of the 1980s (Figure 3a). The change in slope in Figure 3a is closely related to important changes in economic policy that started in 1982 with the government of Miguel de la Madrid (Valle, 1998; Arriaga *et al.*, 1998).

More than half of the variation in per capita consumption of dairy products is related to variation in the minimum wage (Figure 3b; R^2=0.55, $p<0.001$). But two other factors affected this relationship, namely i) the diverging distribution of incomes generating skewness (asymmetry) in the demand for dairy products, and ii) policies of the Mexican government aiming to protect the consumption of dairy products of sectors of the population with low incomes.

Asymmetry in the demand for dairy products is to be expected in a developing country, as milk and milk products might be unaffordable for the majority of the population (Griffin, 1999). Unfortunately information on the distribution of demand for dairy products related to income level in Mexico is scarce. According to INEGI (1988; quoted by Domínguez, 1990), two deciles of the population with the highest incomes accounted for 40% of the expenditure in dairy products, whereas at the other end two deciles with the lowest incomes accounted for only 4%. Distribution of incomes in 1997 (Figure 4) leads to the conclusion that asymmetry in demand for dairy products might still be an important factor. Incomes of almost two thirds (64%) of the economically active population are lower than twice the minimum wage, which is insufficient to cover the costs of basic needs (Conapo, 2000a).

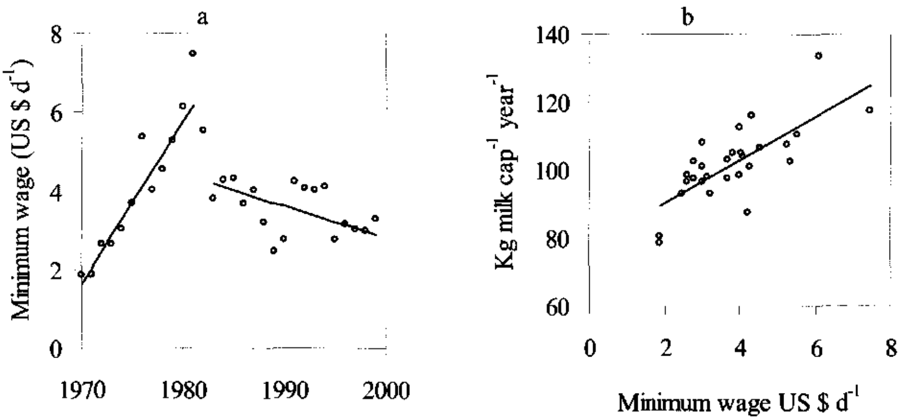

Figure 3. Purchasing power and consumption of dairy products. Evolution of minimum wage (a); lines depict linear equations that minimise RSD; period 1970-1976 after Rivera (1990), period 1978-1999 after Banco de México (2000). Relationship between the minimum wage and the per capita consumption of dairy products (b); data on consumption after FAO (2000a).

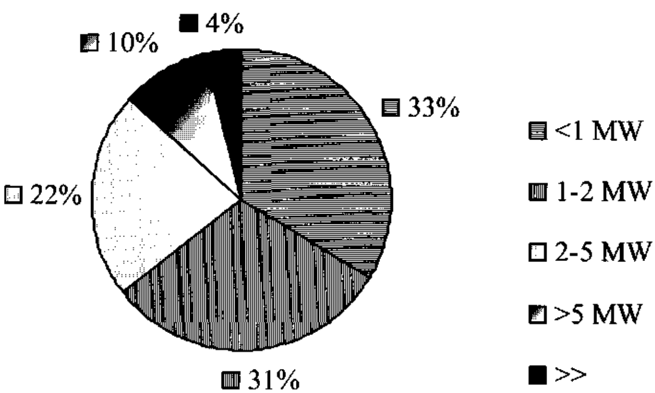

Figure 4. Distribution of incomes in Mexico (1997). Proportion of the population with incomes expressed in Minimum Wage (MW). Adapted from INEGI (1999).

Dairy policies

The effects of dairy policies have been widely discussed during the 1990s. The government protected consumption of dairy products with two kinds of policies: i) keeping the price low through official maximum prices, and ii) importing skim milk powder (SMP) for the

Programme of Social Supply. Both kinds of policies have had a huge impact on the balance of demand, production and import.

The Programme of Social Supply and imported skim milk powder.

The Programme of Social Supply run by the large state agency LICONSA received increasing governmental support during the 1980s. In 1992, a maximum of 1486 million litre milk per year was reached. Afterwards, the annual amounts of distributed milk gradually decreased (Figure 5). In the original definition, supply was granted to families with children younger than 12 years and incomes below twice the minimum wage (Domínguez, 1990). Small changes were introduced to this definition after 1991 (Muñoz *et al.*, 1999). Recombined milk (mostly from SMP) was delivered daily, but in isolated rural areas milk powder was delivered on a less frequent schedule (LICONSA, 1999). The price of this product was subsidised, and according to the statistics (Muñoz *et al.* 1995; Presidencia de la República, 2000), the average subsidy amounted to 0.23±0.02 US $ per litre between 1983 and 2000. Subsidy is defined here as the difference in price between milk sold by LICONSA and the average price of pasteurised milk.

The importance of this programme can be assessed with the amount of subsidy used. Even in the 1990s, when it was being reduced, subsidy assigned to this programme was 2.75 times higher than subsidy assigned to maize tortilla, and 5 times higher than subsidies for technological improvement in animal production systems within Alianza para el Campo (from data quoted by Presidencia de la República, 2000).

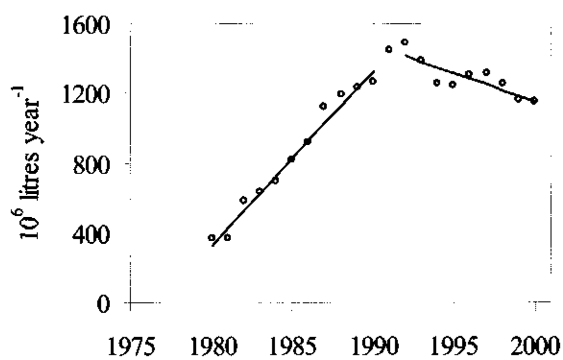

Figure 5. Annual amount of milk distributed through the programme of social supply. Lines represent linear equations that minimise RSD. Period 1980-1989 after Muñoz et al. (1995); period 1990-2000 after Presidencia de la República (2000).

A subprogram of LICONSA aiming to gather fresh milk represented only a very small proportion of the distributed milk (CEA, 1996). Therefore, the programme relied almost exclusively on imported milk powders (mainly SMP). Consistently, the growth of the Programme of Social Supply led to an increase in the import of SMP (Figure 6a). Milk powders were exclusively imported by LICONSA (Muñoz and Odermatt, 1992) and mainly used in the Programme of Social Supply. Before 1983, LICONSA used on average 45% of the imported milk powder in the Programme of Social Supply (Fonseca, 1988). Considering the total amount of milk powder imported between 1983 and 1999 (FAO 2000d; CEA, 2000) and the total amount of milk distributed by LICONSA (Muñoz *et al.*, 1995; Presidencia de la República, 2000), the subsidised distributed milk accounted for approximately 63% of imported SMP. The remainder of the milk powder was sold to private dairy enterprises, which after 1991 took place by auction (Muñoz *et al.*, 1999). During the 1980s, Nestlé transformed most of that milk powder into condensed and evaporated milk (Cuevas, 1988).

Import of dairy products

Following the trend of the Programme of Social Supply, import of dairy products, which was relatively low during the 1970s, grew steadily during the 1980s but tended ($p>0.05$) to decrease during the 1990s. A large year-to-year variation can be observed in the amount of imported dairy products (Figure 6a), reflecting price instability in the world market of SMP. The proportion of demand supplied by import rose substantially during the 1980s (Figure 6b). Between 1989 and 1994 imported dairy products supplied on average more than 25% of the demand, jeopardising national food security. After 1994 a decline is observed, reflecting a decrease of import and an increase of national production. Estimates of import of dairy products in terms of milk equivalents by Muñoz *et al.* (1999) are higher than those of FAO (2000d) in Figure 6b, reflecting differences in coefficients used to convert milk products into milk equivalents.

Between 1965 and 1998, milk powder (SMP and whole milk powder) accounted on average for 60±2% of the value of imported dairy products (Figure 7). According to Griffin (1999), the world market is shifting from bulk products to products more closely focused on consumer needs. Muñoz *et al.* (1997) predict in Mexico changes in the composition of import in concordance with trends in the world market. Some changes that took place during the 1980s agree indeed with changes in the world market. For instance, condensed and evaporated milk almost disappeared from the market. But concerning most other products, the trend of changes during the 1990s - that could be expected due to the reduction of the Programme of Social Supply - are not significant ($p>0.05$). These trends of changes involve a reduction in proportion of milk powder, increase in proportions of cheese and fresh products, and decrease in the proportion of butter. This lack of significance might be due to the high variation between years, caused inter alia by price fluctuations and devaluation of the Mexican peso. The proportion of whey (as the sum of different presentations imported from the United States) is an exception, showing a significant increase ($p<0.01$). According to Muñoz *et al.* (1997) and Valle (1998) this product was being used by dairy factories for adulteration in the industrial processes of pasteurised milk and cheese.

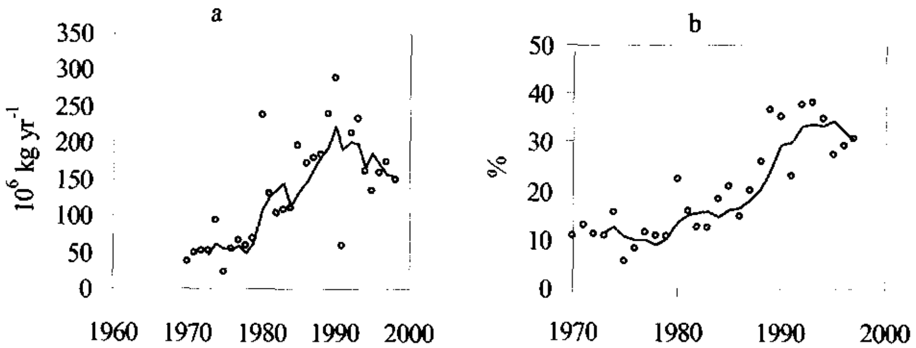

Figure 6. Moving averages (4 years) of import of milk powders (a) and proportion of demand for dairy products satisfied by import (b). After FAO (2000a; 2000d).

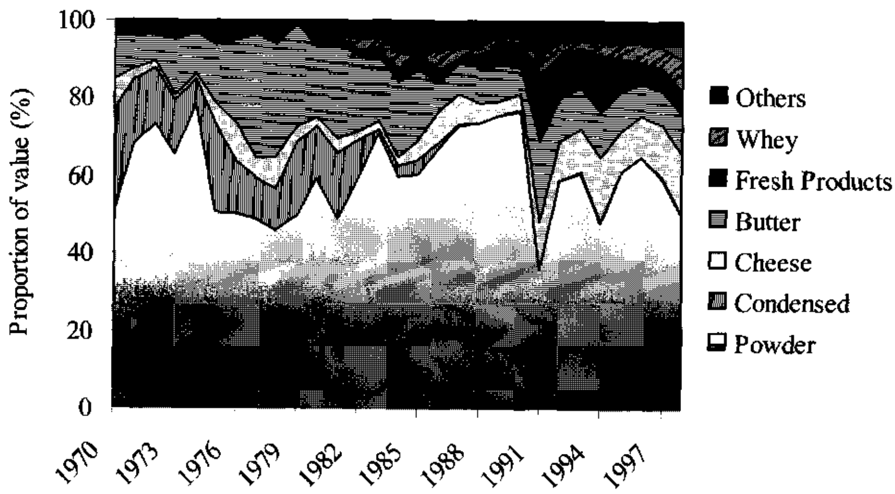

Figure 7. Composition of imported dairy products (percentage of total value), "Fresh Products" are the sum or proportions of fresh milk, fresh cream, yoghurt, buttermilk, ice cream and curd, and "Others" are the sum of proportions of casein and products of natural milk constituents. After FAO (2000d).

Mexico in the world dairy market

According to FAO statistics (FAO, 2000d), Mexico was the main importer of SMP in the world between 1980 and 1998 with on average 13.2 ±1.0% of SMP traded (excluding EU intratrade). Between 1989 and 1997, most important suppliers were the European Union (EU) with 47±5%, New Zealand with 20±4% and the United States (USA) with 21±5% (Muñoz *et al.*, 1995; Larrondo, 1998). These proportions reflect also the share in the world market of SMP (FAO, 2000d). However, the coefficients of variation of proportions delivered by each country are high (on average 60%). According to Muñoz *et al.* (1995), this variation was due to the strong position of Mexico in negotiations, as leading importer in a world dairy market subject to strong distortions.

Views on the international dairy market are presented by OECD (2000) and in the issues 339 and 343 of the Bulletin of the International Dairy Federation (IDF, 1999; Konandreas, 1999; Griffin, 1999; Jachnik, 1999; Suber, 1999; Ramos, 1999). Those views will be briefly discussed because it has long been recognised that since the beginning of the 1980s the world dairy market has exerted a strong influence on the Mexican dairy sector (Muñoz and Odermatt, 1992; ITESM, 1994). Attention will be drawn to long-term trends, ignoring transitory changes due to the financial and economic crisis that started in 1997 (IDF, 1999).

During the 1980s, the subsidised supplies from dairy exporting countries in the Northern Hemisphere (particularly the EU and in second place the USA) predominated the market, and the nature of subsidy programmes determined the form in which dairy products were exported. As the main interest of policy makers in those countries was surplus disposal, SMP as main component of the bulk market provided a useful safety valve in times of over-supply (Griffin, 1999). Konandreas (1999) states that transfers to producers in most of the developed countries - measured by Producer Support Estimates or Producer Subsidy Equivalents (PSE) – were so high that 60-80% of revenues by farmers came from government budgets. Data from USDA (1999b) on PSE show that between 1982 and 1989 dairy farmers received on average higher PSE than all other farmers in the USA and most other farmers in the EU. Governmental intervention in the dairy industry started earlier and has been stronger than in other sectors (Jachnik, 1999). As a result of subsidies, surplus production was generated and large sums were spent on public stockholding and on subsidised exports, leading to a depression of world market prices and contributing to world market instability (Konandreas, 1999). The instability of the SMP world market during the 1980s can be elucidated by the high variation coefficient of the price (CV=43%).

During the 1990s some changes took place in the dairy world market. In the first place, according to statistics of FAO (2000c; 2000d), world trade has been growing faster than production. Notwithstanding, it still represents only 7% of production (Griffin, 1999). In the second place, export is shifting from bulk products to products more closely focused on consumer needs and with higher added value. In the third place, even though protection remained very high, reductions in farm support have been taking place as a consequence of pressure exerted both from inside and outside each country.

Changes are also the result of attempts to integrate agriculture in a multilateral trading system. These attempts are expressed in the commitments agreed in the Uruguay Round Agreement on Agriculture under three main headings: capping and reducing export subsidies, limiting barriers to imports and reducing trade-distorting domestic support (OECD, 2000).

Important changes have been taking place in the EU and the USA, shifting assistance from direct price support towards less distorting direct compensatory payments to farmers (OECD, 2000). However, prices paid to farmers are still much higher than the theoretical world milk price, calculated as the return from the sale of products on the world market (Figure 8). Domestic support remains high, PSE still represents a high proportion of dairy farmer's incomes and milk shares almost 20% of all support given to agriculture (Table 1). Export subsidies also remain high. James (1999) estimates that the price of SMP from the EU and the USA on the international market still has a subsidy of 80-88% (depending on the countries of origin); prices of whole milk powder and butter have even higher subsidies (93 and 138% respectively).

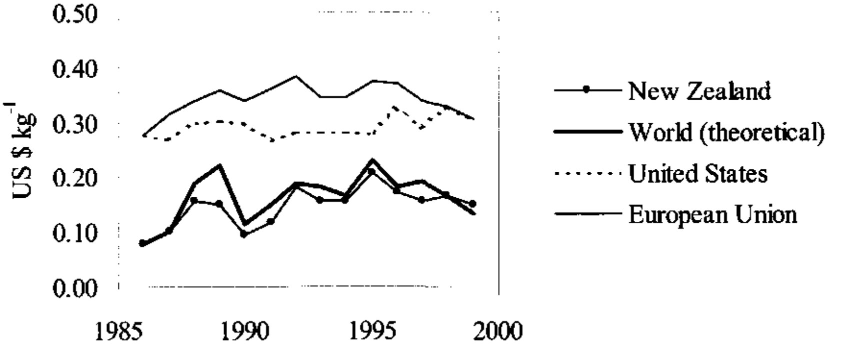

Figure 8. Price paid to farmers, the theoretical world price is calculated as the return from the sale of products on the world market. Adapted from IDF (1999).

Table 1. Producer Support Estimates (PSE) for OECD countries. Source: Konandreas (1999).

	1986-88	1991-93	1997	1998
Milk				
Amount of PSE (10^6 US $)	43977	49261	44919	53344
PSE as percentage of farm incomes	59	56	49	58
All Commodities				
Amount of PSE (10^6 US $)	246561	292005	245546	273649
PSE as percentage of farm incomes	41	39	32	37
PSE to milk (% of PSE to all commodities)	18	17	18	19

In spite of the relatively high protection of dairy sectors in countries of the Northern Hemisphere, statistics of FAO (2000d) show a shift in the proportions shared in the world market by the EU and the USA on one side, and countries of Oceania and the Southern Cone of South America on the other (Figure 9). The common feature of these countries of the Southern Hemisphere is that they are low-cost producing and able to export dairy products without the use of subsidies (Griffin, 1999). Prices paid to farmers in those countries are much lower than in the USA, the EU and Mexico (Table 2). Griffin (1999) predicts that production will keep moving from high-cost countries to low-cost countries. In general, production systems of the latter countries are based on year-round grazing of temperate and sub-tropical pastures, and the use of moderate amounts of conserved forages and few concentrates (Carámbula, 1987; Monti, 1987; Guy, 1993; Holmes, 1995).

Table 2. Price paid to farmers during 1998. Source: IDF (1999)

	US $ kg milk^{-1}		US $ kg milk^{-1}
EU [1]	0.333	Australia	0.179
USA	0.333	New Zealand	0.154
Mexico [2]	0.306	Argentina	0.190

[1] Weighted average
[2] From CEA (2000)

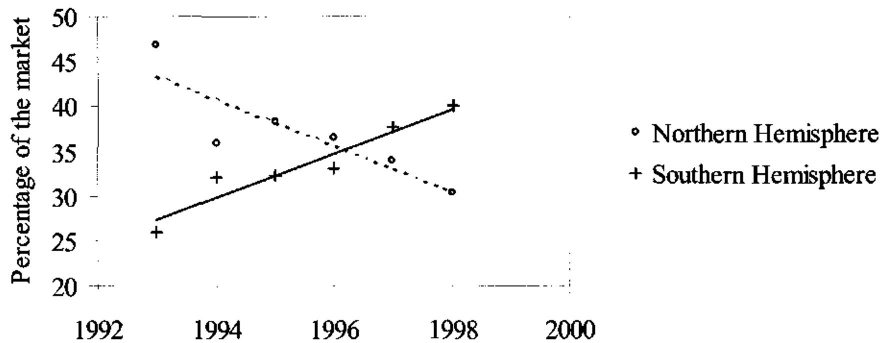

Figure 9. Proportion of export shared in the world dairy market (excluding EU intratrade) by countries of the Northern Hemisphere (EU and USA) and countries of the Southern Hemisphere (Australia, New Zealand, Argentina and Uruguay). Adapted from FAO (2000d).

Prices paid to farmers.

The other policy aiming to protect consumption of dairy products undertaken between 1974 and 1998 in Mexico was the establishment of official maximum prices. According to Muñoz *et al.* (1999), the system of maximum prices has had different regulations during that period. Between 1974 and 1989, reference (maximum) prices to be paid to farmers and dairies and to be paid by consumers were defined per regions. Between 1989 and 1995 only maximum prices to be paid by consumers were defined. After 1995, the only maximum prices established were those of pasteurised and UHT milk in standard 1-litre packages. The system ended in January 1998.

Production costs were not taken into account in the definition of reference prices. After three years of using the system of reference prices, Banrural (state bank for the rural sector) warned that the prices paid to farmers were on average 17% lower than production costs in all temperate dairy regions, excepting the States Cohauila and Durango where the major dairy region La Laguna is located (Banrural, 1977; quoted by Rivera, 1990). In spite of official statements concerning criteria used in the definition of reference prices - such as consultation and agreement with different sectors as quoted by Muñoz *et al.* (1999) -, statistics of prices reflect the use of different criteria in two periods. In the first period the prices paid to farmers were coupled to the minimum wage, and in the second period it was coupled to the international price of SMP of the previous year. Even though Valle (1998) states that price of SMP became the reference after 1991 (when sales of imported milk powders by auction started), there are strong indications that the change of criteria took place between 1983 and 1985. This will be discussed below.

The relationship between the daily minimum wage and the prices paid to farmers can be used to identify the period in which prices paid to farmers were coupled to the minimum wage. This relationship was calculated by dividing the daily minimum wage (US \$ d^{-1}) by the prices paid to farmers (US \$ kg $milk^{-1}$). Between 1975 and 1988 this ratio was on average high but became unstable after 1983. From 1988 onwards the ratio was rather low but stable (Figure 10). The stability of the ratio between 1975 and 1983 means that the prices paid to farmers were coupled to the minimum wage in that first period of reference prices. Changes that took place after 1983 were necessarily related to changes in policies concerning the agricultural sector undertaken by the government of Miguel de la Madrid (Valle, 1998; Arriaga *et al.*, 1998).

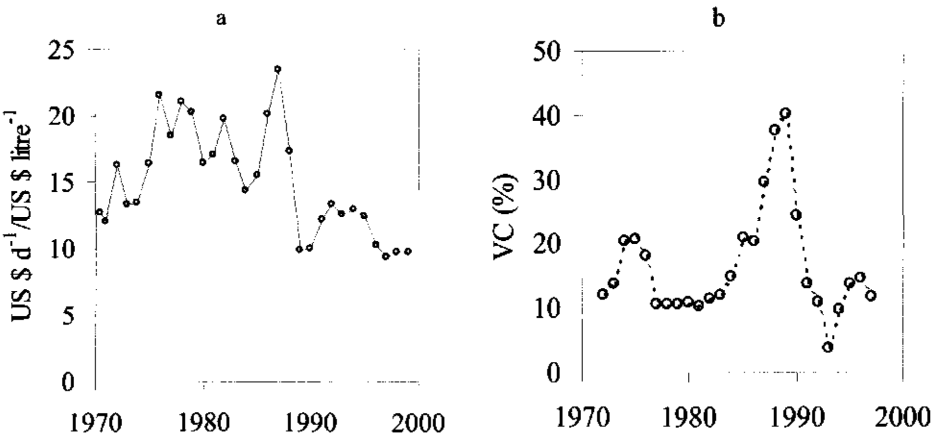

Figure 10. Ratio between the minimum wage and the prices paid to farmers [(US \$ d^{-1})/(US \$ kg^{-1} milk)] (a) and variation coefficient of the center- moving average (5 yr) of the ratio (b). Minimum wage period 1970-1976 after Rivera (1990), period 1978-1999 after Banco de México (2000). Price paid to farmers after FAO (2000e) and CEA (2000a, 2000b).

If the whole period of reference prices is considered (1974-1997), the residual standard deviation of the relationship between price paid to farmers and international price of SMP of the previous year is minimised when those 25 years are split into two periods, before and after 1985. Between 1974 and 1985 there was no relationship at all but afterwards (if 1995 is left out because of the strong devaluation of the peso in December 1994) it was highly significant (Figure 11). The increase in international prices that took place during the 1990s affected the way the adjustment took place, meaning that full transmission was not considered (see Konandreas, 1999). Muñoz *et al.* (1995), Téllez (1995), Cendejas (1998) and Sánchez (1999) estimated parity prices; a summary of those reports results in an average conversion factor of 0.19 (US$ $litre^{-1}$)/(US$ kg^{-1} SMP). Using such a conversion factor to compare parity prices and prices paid to farmers suggests that between 1984 and 1989 (when international SMP prices were extremely low), prices paid to farmers were on average 46% higher than parity prices. Between 1990 and 1994 they were similar to parity prices and between 1995 and 1997 they were 22% lower than parity prices.

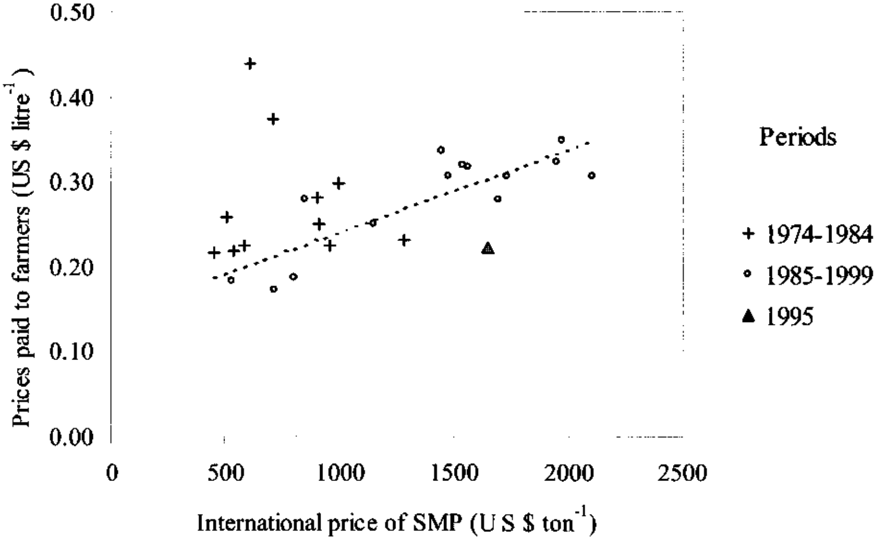

Figure 11. Relationship between the prices paid to farmers in Mexico and the international price of skim milk powder of the previous years in two periods. The broken line represents the linear relationship for the period 1985-1999 (R^2=0.75, $p<0.01$); data from 1995 are not taken into account in the relationship.

The effect of governmental dairy policies during the 1980s can also be assessed with average PSE and Consumer Subsidy Equivalents (CSE) as reported by USDA (1999b). Due to low milk prices and artificially expensive feed (CSE of Sorghum and Soybeans were –24.7% and –15.8% to consumer's cost respectively), Mexican dairy farmers received negative subsidy (PSE=-2.4±0.9% to producer's value). On the contrary, Mexican consumers of dairy products were subsidised more than consumers of any other agricultural product (CSE=7.6±1.6%). In spite of the high amount of subsidies devoted to the Programme of Social Supply, two thirds of CSE originated in Border Controls (Table 3). That means that dairy farmers had the largest share in the subsidy received by consumers of dairy products.

Table 3. Average composition of Subsidy Equivalents of dairy products in Mexico. Producer Subsidy Equivalents period 1982-1999 in ratio (%) to producers' value and Consumer Subsidy Equivalents period 1982-1990 in ratio (%) to consumers' cost. Adapted from USDA (1999b).

Producer Subsidy Equivalents	%	Consumer Subsidy Equivalents	%
Border controls[1]	-3.08	Border controls[1]	5.2
Credit subsidy	0.24	Direct subsidy (LICONSA)	2.9
Balanced feed subsidy	-0.1	Exchange rate adjustment	-0.5
Fiscal transfer subsidy	0.24		
Exchange rate adjustment	0.29		

[1] low prices paid to farmers

Dairy production

Dairy production in Mexico fluctuated strongly during the last 3 decades (Figure 12). Three distinct periods can be identified: diminishing growth rate until 1982, negative growth rate between 1982 and 1989 and high growth rate thereafter. As shown in Figure 12, 1985 and 1989 were very dissimilar years.

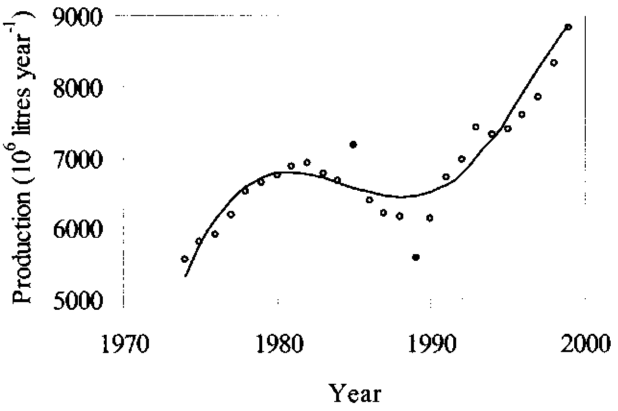

Figure 12. Dairy production in Mexico between 1974 and 1999. After FAO (2000 c) and CEA (2000 b). Line depicts a polynomial equation developed using stepwise regression.

Production correlates well with price paid to farmers. Based on data reported by FAO (2000c; 2000e) and CEA (2000) and considering up to 4 years of delay for the reaction of production to changes in prices, the regression model of production on price (Equation 1) was developed using stepwise regression (R^2=0.54, $p<0.001$):

$$y = 3356 + 3762\,x_1 + 4317\,x_2 + 4791x_3 \qquad (1)$$

where

y = annual milk production in Mexico (10^6 ton)

x_1 = price paid to farmers the same year (US \$ litre^{-1})

x_2 = price paid to farmers the year before (US \$ litre^{-1})

x_3 = price paid to farmers three years before (US \$ litre^{-1})

The response involved short-term and long-term effects of price. This means that by experiencing a new price the farmer took some decisions that affected the production immediately and also the following year. According to Herrera y Saldaña (1996) farmers responded to lower prices farmers by reducing costs. Taking into account responses reported in other systems (Ramos, 1999), the short-term decisions probably implied reducing the amount of concentrates. Farmers also took other decisions which affected production three years later. This long-term effect appears to be related to changes in the replacement policy. Based on numbers of specialised dairy cattle (mostly Holstein) and non-specialised dairy cattle (mostly crossbreed cattle in dual purpose tropical systems) for the periods 1972-1978 (DGEA, 1983) and 1980-1988 (Rivera, 1990) regression equations of numbers of cattle on price were developed using stepwise regression (Equation 2). The results show that the response of farmers with specialised dairy cattle to lower milk prices was to reduce cattle numbers (R^2=0.75, $p<0.001$):

$$y = 232 + 191\,x_1 + 308\,x_2 \qquad (2)$$

where

y = number of specialised dairy cattle in Mexico (thousands)

x_1 = price paid to farmers the same year (\$ litre^{-1}) *

x_2 = price paid to farmers the year before (\$ litre^{-1}) *

*Deflated according to National Producer Price Index, 1994=100 (Banxico, 2000).

The relationship between numbers of non-specialised cattle and price had a much lower determination coefficient (R^2=0.34), probably because farmers with this kind of cattle also rely on calf production (Muñoz *et al.*, 1995).

The effect of price on production was therefore strong (Equation 1). In the period that the price was coupled to minimum wage (1975-1983; Figure 10) the growth rate of production decreased (Figure 12). When the price was coupled to the international SMP price (1985-1997; Figure, 11) dairy systems of Mexico were exposed to a highly protected (subsidised) and unstable market and therefore the growth rate of production became highly variable (Figure 12). The huge effect of this exposure is confirmed by the relationship between the international price of SMP and the national milk production calculated using stepwise regression (Equation 3, $R^2=0.88$, $p<0.001$).

$$y = 2599 + 4432\,x_1 + 3871\,x_2 + 7592\,x_3 \qquad (3)$$

where

y = annual milk production in Mexico (10^6 litre)

x_1 = international price of SMP the same year (US\$ ton^{-1})

x_2 = international price of SMP the year before (US\$ ton^{-1})

x_3 = international price of SMP three years before (US\$ ton^{-1})

It is noteworthy that it was the price and not the volume of imports that exerted the negative effect on production. This might confirm the proposition stated by Cuevas (1988) that the Programme of Social Supply by itself did not represent a threatening competition for dairy farmers, because it was addressed to a sector of the population that otherwise would not consume dairy products.

Dairy systems.

Dairy production in Mexico takes place under many different ecological and socio-economic conditions, leading to a range of distinct production systems. A typification of characteristic production systems appears to be unavoidable in order to understand the response of the dairy sector to changes in the production environment, and to predict the reaction to probable future changes.

During the 1980s and 1990s, the predominant characterisation was that proposed by FIRA (Cuevas, 1988; Torres 1991). FIRA is a governmental institution that advises on the formulation and evaluation of agricultural projects submitted for credit solicitation. FIRA classified dairy production systems as Specialised, Familiy-based and Tropical, and allocated to those systems 25, 35 and 45% of the national dairy production, respectively. Main attributes described in that typification are summarised in Table 4. A diagnosis on competitiveness of the systems was coupled to the typification. It was concluded that a) the competitiveness of the Specialised System was low due to high production costs and dependence on imported inputs, b) the Family-based System had advantages due to reduced labour costs (unaccounted family labour) and c) the Tropical system was the most competitive due to very low costs and high improvement potential through technical innovation.

Table 4. Some attributes of dairy production systems in Mexico according to the typification by FIRA. Adapted from Cuevas (1988) and Torres (1991).

	Specialised	Family-based	Tropical
Size (number of cows)	230 (100-3000)	3-30	200 (only 10% milked)
Nature of labour	Not reported	Mostly from the family (not hired)	Not reported
Infrastructure (buildings and equipment)	Cows permanently housed, pen fed "technologically advanced"	Rudimentary, "backyard"	Not reported
Feeding	Cut- and- carry forages, concentrates	Extensive use of crop residues	Grazing of natural or seeded pastures
Number of farmers	1850	100,000	120,000
Number of cows	470,000	1,470,000	3,900,000
Trading	Mostly delivered to dairies (the system provides 80% of national supply of pasteurised milk)	Mostly informal (raw milk and milk sold to small processors, producing cheese and other dairy products)	Mostly informal, problems due to extremely seasonal production
Productivity (litres cow^{-1} $lactation^{-1}$)	5,000	2,500	700
Organisation	Most farmers integrated in large co-operative dairies (price of milk 15% higher than average)	Low	Low
Calving interval (months)	13-15	16	17

Even though in some reports the need for better descriptions of systems and new classifications was stressed (e.g. ITESM, 1994; Alvarez, 1998), the characterisation by FIRA remained the most frequently used until the end of the 1990s (e. g. Muñoz and Odermatt, 1992; ITESM, 1994; Muñoz *et al.*, 1997; Alvarez, 1998). A restraint of the classification by

FIRA was that the data bases used were not of the public domain (the reader was referred to FIRA´s internal documents). Moreover, the lack of sound statistical data was clearly stated by Cuevas (1988), and until the end of the 1990s that restraint remained almost unchanged. Other limitation of FIRA's classification was that the Family-based System (named Semi-Specialised or Family Dairy Systems by Muñoz *et al.*, 1995) included farmers of dissimilar characteristics. Valle (1998) presents a brief description of dairy systems considering the Semi-Specialised and Family-based Systems as distinct categories. Based on a survey addressed to farms receiving credit from FIRA, Sánchez *et al.* (1997) present an alternative typification of dairy farmers in different regions. In this typification, the Semi-specialised System is included as a distinct system and more detailed descriptions of the different systems are given (Table 5).

In the second half of the 1990s, CEA (Bureau for Agricultural Statistics) reported regularly statistics of the dairy sector (production, import, prices and industry). However, production data were presented per state with no specification per dairy system. In 1999, CEA started reporting production per dairy system. However, confusion concerning the broad "Semi-Specialised and Family-based System" led to presentation of data in contrasting ways. In the first report, production of the Semi-specialised System was reported together with production of the Family-based System (CEA, 1999a). In the second report it was reported together with that of the Specialised System (CEA, 1999b). Finally, in the third report statistics of 1998 were presented considering the three systems of the Plateau and North as distinct categories (CEA, 2000b).

The need to identify the Semi-specialised System as a distinct category is based on the following reasons:

1. Farmers within the category between 11 and 100 cows per farm represent approximately 22% of dairy farms and hold approximately 47% of the dairy cows (Alvarez, 1998).
2. Dairy production on these farms is the main source of income, but that is not the case for smaller farmers and therefore distinct responses to dairy policies might be expected.
3. There are important differences between these and bigger or smaller farmers concerning available resources; this affects the reaction to changes in production environment (credit, technological innovation, organisation etc.).

Dairy systems in the Plateau and North of Mexico

Dairy production in the Plateau and North of Mexico takes place under climates ranging from sub-humid and humid temperate to semi-arid and arid. Three characteristic dairy systems are predominant in these conditions: the Specialised System, the Semi-specialised System and the Family-based System. In the following, a brief description of these systems based on available literature (case studies and surveys) is included. The Semi-specialised System and the Family-based System are presented together, attempting to underline differences and to establish boundaries between these categories.

The Specialised Dairy System

Dairy production systems in the USA are paradigmatic for this type of farms (Cuevas, 1988). Technological advises originate from the USA since lecturers in seminars and conferences on technological innovation are mostly from there (e.g. FIRA, 1988; LALA, 1996, 1997, 1998 and 1999; INIFAP, 1998). Moreover, production targets are based on comparisons with farms in the USA (e. g. Armendáriz, 2000). Farms of this system are large. Cows (mainly Holstein) are of relatively high genetic merit, and productivity is relatively high. Animals do not graze and nutrition is based on concentrates and cut- and- carry forages. Forage production and animal management is highly mechanised. Farmers are well organised and highly integrated. According to CEA (2000b) this system is located in 6 major regions ("cuencas"): La Laguna (Coahuila and Durango), Bajío (Guanajuato, Michoacan, Queretaro and part of Jalisco), Altos de Jalisco-Zacatecas-Aguascalientes, Chihuahua, Puebla-Tlaxcala and Mexico-Hidalgo. Available descriptions of the system in La Laguna, Altos de Jalisco-Zacatecas-Aguascalientes and Mexico-Hidalgo show that there are some important regional differences.

The Specialised Dairy System at La Laguna

La Laguna evolved in the last 20 years as the most important dairy region of Mexico (Figure 13). According to statistics of CEA (1996 and 2000b) dairy production in the rest of the country increased by only 13% between 1980 and 1998, while that in La Laguna increased by 365%. La Laguna started its development as a dairy region by the end of the 1940s and experienced rapid growth in the 1960s as dairy production became an alternative for the crisis of cotton (LALA, 1995). Since 1950, the development of La Laguna as a dairy region has been coupled with that of LALA, the leader farmers-owned dairy enterprise (LALA, 1995; Armendáriz, 2000). Integration has been a major factor for the overwhelming growth of this region. The importance of integration for dairy production has been stressed in different situations such as those of New Zealand (Guy, 1993), Canada (DFO, 1999), and Europe (Gavito, 1988).

Table 5. Dairy systems in the Plateau and North of Mexico. Adapted from Sánchez *et al.* (1997)

	REGION[1]					
	North	West			South	
[2]Proportion of national milk production (%)	24	40			27	
Attribute	Specialised	Family-based	Semi-Specialised	Specialised	Family-based	Specialised
Productivity (kg cow^{-1} lactation^{-1})	7725	3788	4395	6522	3989	6142
Size (cows farm^{-1})	601	22	60	246	16	187
Integration[2]	54	7	9	38	19	18
Own forage [3]	32	85[6]	18	66	52	18
Investment (US$ cow^{-1})	3197	4498	3755	4009	5619[7]	3895
Debt[4]	22	Not reported	Not reported	Not reported	14	22
Profit (US $ litre^{-1})	0.009	0.045	0.032	0.036	0.042	0.041
Profit (US $ cow^{-1} year^{-1})	70	172	140	237	165	204
Price paid ($ litre^{-1})	0.24	0.24	0.25	0.24	0.23	0.24
Costs ($ litre^{-1})	0.23	0.20	0.22	0.20	0.18	0.20
Labour (number cow^{-1} year^{-1})	Not reported	38.4	27.9	17.6	60	12
Technical assistance[5]	Not reported	14	41	83	5	71

[1] The definition of regions is not the most accepted; the regions were defined according to FIRA's structure of organisation. North= Cohahuila, Chihuahua, Durango, Nuevo Leon and Tamaulipas; West= Aguascalientes, Guanajuato, Michoacan, Nayarit, Queretaro, San Luis Potosí and Zacatecas; South= Mexico City, Guerrero, Hidalgo, State of Mexico, Morelos, Oaxaca, Puebla, Tlaxcala and Veracruz

[2] Percentage of farms belonging to a farmer's organisation or dairy enterprise, i.e. organised for selling products of buying inputs and services

[3] Percentage of farms producing (most of) consumed forage

[4] Debt as percentage of investments

[5] Percentage of farm receiving some kind of technical assistance

[6] Mixed farmers producing grains and by-products used in cattle feeding

[7] The value of land (in the vicinity of big cities) accounts for a large proportion of investments

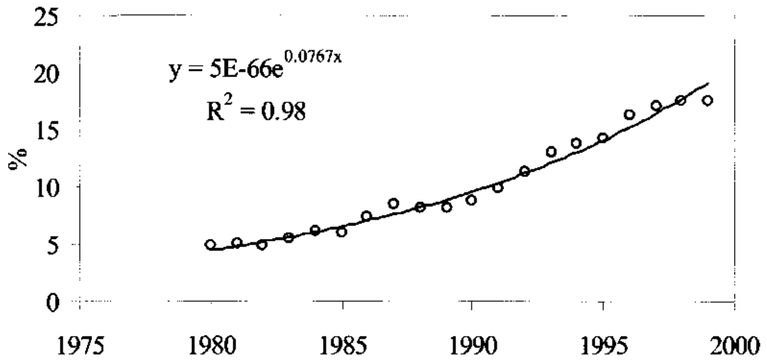

Figure 13. Proportion (%) of La Laguna in the national dairy production between 1980 and 1999. After Rivera (1990) and CEA (1996; 2000a).

Dairy farms in La Laguna are the biggest in Mexico, and their size continue to increase (Table 6). Productivity in La Laguna is the highest in Mexico and has a high rate of increase (Table 6). Production is evenly distributed throughout the year. For instance, in 1999 the coefficient of variation of monthly averages was only 1.8% (CEA, 1999b). This distribution couples with the requirements of the company, as revenues rely mainly on sales of pasteurised milk (Armendáriz, 2000).

Feeding is based on cut- and- carry forages, silage, hay and concentrates. Based on data covering the 1980s, Sánchez (1992) identified an average diet that in terms of dry matter consisted of 32% concentrates and 68% forages (fresh alfalfa, alfalfa hay, forage winter crops and maize silage). In terms of area with forages, the ratio alfalfa:annual forage crops was 70:30; within winter crops the ratio oats:annual ryegrass was 60:40 and within summer crops the ratio maize:sorghum was 70:30. Comparing forage production costs with market forage prices Sanchez concluded that producing (instead of buying) forage represented a reduction in 26% of production costs. In the 1990s, Sánchez *et al.* (1997) concluded that forage production was one of the major differences between farms with highest profitability and average farms. Statistical data quoted by Sánchez (1992) show that during the 1980s the area used to produce forage as well as yields remained rather constant. Therefore, the increase in cattle numbers and productivity during that decade had to rely completely on purchased feed with negative consequences for production costs.

Table 6. Number of farms integrated in LALA, productivity (litres cow^{-1} day^{-1}), number of cows, replacement heifers and calves and use of concentrates in farms between 1992 and 1998. Adapted from Armendáriz (2000).

	1992	1994	1996	1998
Number of farms	139	164	174	193
Number of cows	74,910	91,335	96,262	109,369
Litres cow^{-1} day^{-1}	22.7	23.2	23.7	25.8
Number of replacement heifers	21,050	25,852	35,660	35,292
Number of replacement calves	26,943	29,138	31,115	35,010
Concentrates sold[1] (10^9 kg $year^{-1}$)	214	311	369	557
Kg concentrates $animal^{-1}$ d^{-1}	4.8	5.8	6.2	8.5
Kg concentrates litre $milk^{-1}$*	0.41	0.48	0.53	0.65

[1] This figures represent concentrates sold by LALA to integrated farmers. Actual amounts of concentrates fed are higher because some of the concentrates used are self-made.

*Estimate assuming that lactations last 305 days, that all cows calve each year and that concentrates bought to the company are fed exclusively to cows

In the 1990s the amount of concentrates fed to cattle increased sharply, reaching very high levels per litre milk (Table 6). Moreover, taking into account that a high proportion of concentrates used in some farms is self-made (e.g. Rodríguez, 1997), average use of concentrates is even higher than given in Table 6.

Considering data reported by Rodríguez (1997), the proportion of alfalfa fed as hay increased in the 1990s. This change might be caused by economical and technical reasons. According to CEA (1999c), the price of alfalfa hay decreased between 1987 and 1998 ($p<0.01$), while that of fresh alfalfa ("green") increased ($p<0.01$). Besides, farms that produce their own forage, prefer to supply alfalfa as milled hay in order to make mechanisation easier (e.g. Cadena, 1988).

Dairy production in La Laguna is jeopardised by exhaustion of underground water used for irrigation. Between 1972 and 1986, groundwater levels decreased on average 1.76 m $year^{-1}$ (LALA, 1995). However, between 1992 and 1998 the area allotted to alfalfa in the states Durango and Coahuila increased by 63% (CEA, 1999c). Taking into account a) the huge increase in dairy production of the region, b) the dependence of profitability on on-farm forage production and c) limits to forage production within the region due to exhaustion of underground water, it can be concluded that dairy farmers of La Laguna were able to increase the area used for forage production outside the strict limits of the region. This kind of enlargement of areas allotted to forage production was enabled in the beginning of the 1990s by changes in the Constitution concerning regulation of land tenure (Arriaga *et al.*, 1998; Valle, 1998).

The increase in the number of animals per farm relied strongly on import of replacement heifers; 60,960 replacement heifers were imported between 1992 and 1994, accounting for 57% of the national import of dairy cattle (LALA, 1995).

The sustainability of the increase in production of La Laguna by increasing numbers of cattle as well as by improving productivity might be questioned since it depends on imports. The data in Table 6 show that the increase in productivity is closely linked to greater use of concentrates, and most concentrates include imported ingredients. Between 1994 and 1998, on average 30% of the national sorghum demand was supplied by imports, and Mexico bought 39% of world exports of sorghum (CEA, 1999d).

Specialised Dairy Systems in the Centre

The states of Mexico and Hidalgo have always been an important dairy region due to the high demand by the population of Mexico City. Texcoco and Zumpango are the most important dairy districts in the State of Mexico with 75% of its total milk production (INEGI, 1996; quoted by Sánchez, 1999). The growth in the state of Hidalgo is coupled with the founding of the region Tizayuca by the government in the first half of the 1970s, when this region was designed to relocate farms from Mexico City. In the 1990s Tizayuca accounted for approximately 50% of the milk produced in the State Hidalgo.

Reports on the Specialised Dairy System in these states have been presented by Rodríguez (1986), Téllez (1995), Cendejas (1998), García (1998), Guadalupe (1998) and Sánchez (1999). Farms are smaller than in La Laguna, on average ranging from 150 to 450 cows per farm. Average diets appear to be lower in concentrate and alfalfa hay, but higher in maize silage and fresh alfalfa than diets in La Laguna. Farmers rely more on purchased forage than farmers in La Laguna. Even though productivity per cow has grown steadily, it is still approximately 10% lower than in La Laguna. Milk production in Tizayuca increased approximately 55% between 1985 and 1995, while production in Texcoco and Zumpango remained practically unchanged between 1992 and 1995. Levels of organisation and integration are clearly lower than in La Laguna. In general terms, the above underlined differences concur with findings of Sánchez *et al.* (1997) summarised in Table 5.

The Semi-Specialised and Family-based Dairy Systems

Reliance on family labour is considered as a distinct attribute of the Semi-Specialised and Family-based Dairy Systems (e.g. Muñoz *et al.* 1995; Zorilla *et al.*, 1997). However, there is a transition between very small farms that rely exclusively on family labour and big farms of the Specialised System where all labour is hired. Considering farms classified as Semi-Specialised and Family-based, the proportion of family labour decreases with increasing size of the farm. The data shown in Figure 14 suggest that with farm sizes above 20 cows per farm, family labour begins to loose importance. Figures on labour requirement per cow and on average family size put together concur with these data. Farmers in different regions estimate that one "full time" family member can take care of 5 cows (Arriaga *et al.*, 1997; Tzintsun *et al.*, 1997). Conapo (2000b) reports that average sizes of families in rural and urban communities are 4.3 and 5.1 members respectively. Taking into account age groups, the number of potential economically active members per family is on average approximately 3 in both cases. Therefore, on average family labour can take care of only 15 cows.

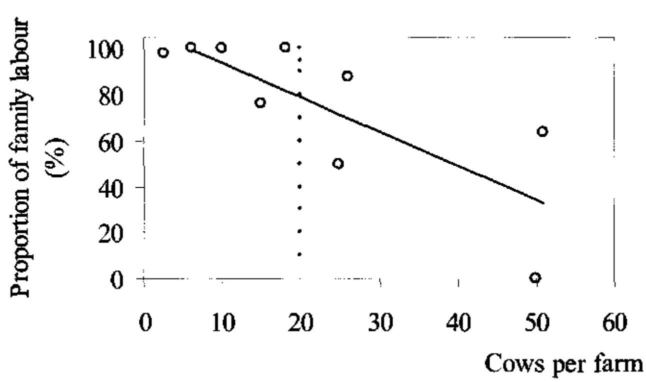

Figure 14. Relationship between farm size (cows $farm^{-1}$) and proportion of family labour in Texcoco and Zumpango. Data from Sánchez (1978), Cendejas (1998), García (1998) and Sánchez (1999).

Reports from different regions show that dairy production is not considered as the main source of incomes by small Family-based dairy farmers (Rodríguez, 1997; Arriaga *et al.*, 1997; Castelán *et al.*, 1997; Valle *et al.*, 1998). In many cases of small dairy farms, arable agriculture appears to be highly integrated with dairy production (Pérez *et al.*, 1991; Castelán *et al.* 1997; Sánchez *et al.*, 1997; Arriaga *et al.*, 1997). Arriaga *et al.* (1999b) report that in a community in the north east of the State of Mexico, farmers with less than 13 cows grew arable crops, while bigger farmers devoted all agricultural land to grow forages. Selfconsumption appears to be an important aim of dairy production on very small farms (Castelán, 1997; Barbabosa and García 1997), but that does not appear to be the case on bigger farms.

In very small farms of the Family-based System, buildings are extremely rudimentary and they are generally located in the backyard (Pérez *et al.*, 1991; Villeda *et al.*, 1992; Rodríguez, 1997), milking is by hand (Pérez *et al.*, 1991; Arriaga *et al.*, 1999a; García, 1998; Zorrilla *et al.*, 1997). Feeding strategies might vary even among communities of the same region, including grazing of crop residues and roadsides, utilisation of local by-products, purchased concentrates, pastures and forage crops (Domínguez, 1997). On the other hand, on bigger farms animals are housed at least part of the year. Buildings might include yards, stable, milking parlour and storeroom, and some farmers own a vehicle and a forage harvester (Cendejas, 1998; Guadalupe, 1998; García, 1998). Milking machines are mentioned in most reports on this kind of farms (Cendejas, 1998 Guadalupe, 1998; García, 1998; Sánchez, 1999; Muñoz *et al.*, 1999).

Productivity increases with size. Productivity on most farms with less than 20 cows is below 4000 kg cow^{-1} $lactation^{-1}$, whilst on most farms with more than 20 cows it is above that amount (Figure 15). Productivity of both systems is much lower than that of the Specialised System. Lower production during the dry winter of the Plateau has been reported for both systems (Arriaga *et al.*, 1997; Castelán *et al.*, 1997; Zorrilla *et al.*, 1997; Muñoz *et al.*, 1999).

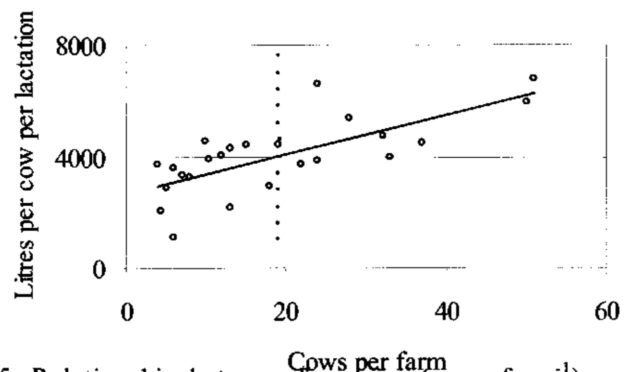

Figure 15. Relationship between farm size (cows $farm^{-1}$) and productivity (litres cow^{-1} $lactation^{-1}$) in the Semi-specialized and Family-based Dairy Systems during the 1990s. Adapted from Pérez *et al.*(1991); Villeda *et al.* (1992); Juárez (1994); Arriaga *et al.* (1997; 1999a; 1999b); Castelán *et al.* (1997); González *et al.* (1997); Rodríguez (1997); Tzintzun *et al.* (1997); Cendejas (1998); García (1998); Guadalupe (1998); Sánchez (1999).

In a study on dairy systems in Altos de Jalisco, Valle *et al.* (1998) use a size of 20 cows per farm as a boundary between small and medium size farms. Taking into account attributes discussed above, it appears that such a boundary would also be adequate to classify farmers into the Family-based or the Semi-specialised System. In most cases, farms with less than 20 cows rely almost exclusively on family labour, have few resources available for production and their productivity is low. According to results of Valle *et al.* (1998), their degree of integration is also lower. But the most important characteristic is that dairy production and selling the product is not their main activity. Therefore, dealing with problems of very small dairy farmers of the Family-based System requires special policies. Improvement of organisation should be affected prior to introduction of technological innovation (Alvarez *et al.*, 1998), and - as stressed by Arriaga *et al.* (1997) - innovation should be focused on increasing their nutritional security, enhancing opportunities for them to remain in their own communities, and improving ecological sustainability of their agricultural practices.

Production costs in dairy systems of the Plateau and North.

As agriculture integrates further in the multilateral trading system, production costs become determinant factors defining evolutionary trends among and within countries. Therefore, a comparison of the above described production systems in production costs is unavoidable. Production costs reported by different authors were converted in US $ per litre and summarised in Table 7; a size of 20 cows $farm^{-1}$ was used as boundary between the Family-based Dairy System and the Semi-Specialised Dairy System.

Coefficients of variation are extraordinarily high, particularly in items as depreciation and financial costs and remainder costs in all systems. The coefficient of variation of labour in the Family-based System is also high. This high variation probably originates in the low quality of data bases and in the lack of uniformity in standards used to evaluate costs.

Most data bases are not fully reliable because, on the one hand most small farms lack bookkeeping records and therefore studies are based on data quoted by hart (e.g. González *et al.*, 1997), and on the other hand, most specialised farms whose bookkeeping records are complete, are not willing to make those records available to researchers (e.g. Rodríguez, 1986).

Table 7. Production costs (US $ litre^{-1}) in dairy systems of the Plateau and North. Adapted from Rodríguez (1986); Domínguez (1990); Rivera (1990); Pérez *et al.* (1991); Sánchez (1992); ITESM (1994); Juárez (1994); Téllez (1995); Herrera (1996); Rodríguez (1997); Sánchez *et al.* (1997); Cendejas (1998); García (1998); Guadalupe (1998); Arriaga *et al.* (1999b); Sánchez (1999).

	System								
	Specialised			Semi-Specialised			Family-based		
Items	Mean	Std. error	CV[1]	Mean	Std. error	CV[1]	Mean	Std. error	CV[1]
Labour	0.022	0.004	48	0.041	0.005	32	0.085	0.021	68
Depreciation and financial costs	0.070	0.019	82	0.053	0.020	106	0.026	0.010	112
Remainder costs	0.037	0.003	26	0.022	0.005	69	0.018	0.008	125
Subtotal[2]	0.169	0.030	53	0.126	0.020	45	0.140	0.018	36
Feeding	0.201	0.012	19	0.200	0.006	8	0.186	0.022	36
Total	0.371	0.032	26	0.326	0.024	21	0.327	0.039	34

[1] Variation coefficient

[2] Costs other than feeding

Not all studies on production costs have used the same criteria, and in some cases cost items are not clearly depicted. In some reports, technical or economical parameters are used instead of - and sometimes in contradiction with - real data from the farms (e.g. Téllez, 1995; Cendejas, 1998; García, 1998; Sánchez, 1999). Financial costs are a subject where differences in criteria impede comparison. In many reports replacement of capital is calculated as rates of interest on loan. However, a survey revealed the even in the worst situation loans accounted for only 22% of investments (Sánchez *et al.*, 1997). Taking into account the exceptionally high rates of interest on loan prevailing in Mexico, this criterion has a profound but factitious effect on production costs. Standards used to allot costs to unpaid family labour dissent enormously among researchers (e.g. López, 1997; García, 1998; Cendejas, 1998; Rodríguez, 1997; Juárez, 1994; Arriaga *et al.* 1999b). Presenting costs as percentages of total costs (instead of costs in absolute terms), or as total costs of the farm (instead of costs per unit of product) makes comparisons of results from different reports a cumbersome task.

The lack of uniformity in standards used to evaluate costs is reflected in the probably unexpected outcome that costs of labour appeared to be highest ($p<0.05$) in the Family-based System (Table 7). Variation coefficients of feeding costs are lower than those of other costs. Estimation of feeding costs might be simpler than estimation of other costs, inducing higher uniformity of standards. As a consequence, results on that subject appear to be more reliable. Moreover, feeding costs are not only more reliable but they also represent the heaviest burden in all systems (Table 7).

Feeding costs did not differ between systems; however there were differences ($p<0.05$) in the way costs were allotted to forages and concentrates. While in the Specialised System the ratio forages:concentrates was 45:55, in the Semi-Specialised and Family-based Systems that ratio was on average 67:33. Feeding costs of all dairy systems of the Plateau and North are particularly high. With an average of US \$ 0.20 litre^{-1}, they represent 65% of average price paid to farmers and 92% of average theoretical world price during the 1990s. Market distortion contributed to the high level of costs. Prices paid by Mexican farmers for feedstuffs have been estimated to be 35% (Téllez, 1995) and 20% (Cendejas, 1998) higher than parity prices. Nevertheless, during the 1990s prices of two main components of diets (alfalfa hay and sorghum) tended to decrease and approached international prices (Figure 16). Therefore, market distortion is tending to disappear. Moreover, during 1997 and 1998 the prices paid for sorghum by Mexican farmers was respectively 9% and 12% lower than the parity price (CEA, 1999d). Considering information given by CEA (1999c) and USDA (1999c), it can be estimated that on average between 1987 and 1994, prices paid by Mexican farmers for alfalfa hay were 44% higher than those paid by farmers in the USA. However, between 1995 and 1998 that difference was reduced to only 5%.

A comparison of production costs in the Specialised Dairy System (Table 7) with those of dairy systems of the USA - average between 1987 and 1998 after USDA (1999d) - results in rather similar total costs (approximately US \$ 0.40 litre^{-1}). This means that profitability of intensive dairy systems in both countries is negative if replacement of investment is taken into account. But growth of dairy production in both countries indicates that replacement of capital is not included in the standards used by farmers to evaluate their profitability. If the costs of replacement of capital and other not precisely specified costs are set aside, and analysis is focused exclusively on the costs of feeding, labour, medicine and reproduction, results of both countries are also similar (approximately US\$ 0.25 litre^{-1}). However, Mexican farmers spend 22% more on feeding (39% more in forages and 9% more in concentrates) and 46% more on medicine and reproduction (inputs are mainly imported), but spend 66% less in labour.

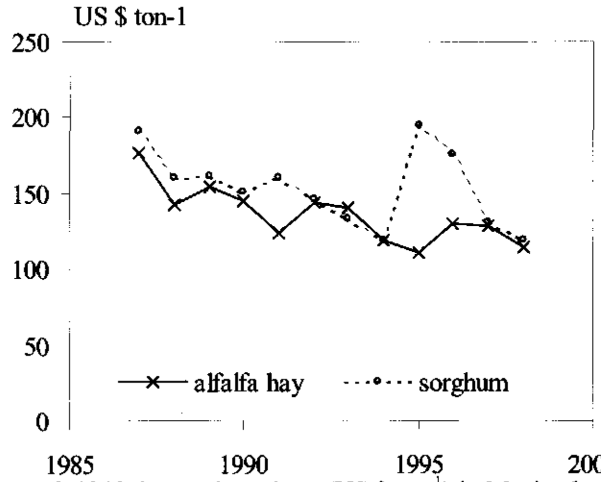

Figure 16. Prices of alfalfa hay and sorghum (US $ ton^{-1}) in Mexico between 1987 and 1998. Adapted from CEA (1999c)

Dairy production under grazing in temperate or semi-arid climates of the Plateau and North

The common feature of the low-cost producing leaders of the world dairy market is that their production systems are mostly based on grazing of temperate and sub-tropical pastures. They make moderate use of conserved forages and little use of supplementary feeding with concentrates. Researchers of different institutions envisaged that such a system could also result in reduction of production costs under Mexican conditions.

Research aimed to design systems of dairy production under grazing in temperate of Mexico had been undertaken since the 1970s (e.g. Cuadra and Briseño; 1978; Sánchez *et al.*, 1981). In the 1990s, FIRA (Torres, 1991; FIRA, 1994) promoted technological packages to convert farms of the Semi-Specialised Dairy Systems based on permanent housing and pen feeding into a dairy system based on grazing. These packages were based on research carried out by INIA-INIFAP –the National Institute for Agricultural Research- (Sánchez *et al.*, 1981; INIFAP, 1986; quoted by Torres, 1991), Chapingo University (Avendaño *et al.*, 1991; Sánchez *et al.*, 1996), and FIRA (1985; quoted by Torres, 1991) on research stations under irrigation in sub-humid to semi-arid temperate climates. Simultaneously, INIFAP worked on the improvement of the system used by small farmers in humid temperate climates (Ortiz et. al., 1991; 1992; 1993; 1994; Ortiz and Piña, 1995) and the University of the State of Mexico did the same in sub-humid temperate climates (Arriaga et al., 1997; 1998; 1999a; 1999b). Reported results and extended technological packages are summarised in Table 8.

Table 8. Attributes of systems of dairy production under grazing of temperate pastures in Mexico. Adapted from different reports.

	Reference[1]					
	1	2	3	4	5[2]	6[2]
Stocking rate (cows ha^{-1})	5	3.5	3.4	1.2	3.0-3.3	2.5
Productivity (litres cow^{-1} $lactation^{-1}$)	3846	4362	3817	4267	4000-6000	5500
Productivity (litres ha^{-1} $year^{-1}$)	19215	15260	12800	5137	11000-12000	13750
Seasonal distribution of pasture growth (%)[3]	50		59	63		
Concentrates (kg cow^{-1} $lactation^{-1}$)	610	0	0	1830		400
Fertilisation (N-P_2O_5-K_2O kg ha^{-1} $year^{-1}$)	685-45-0		22-43-0			
Production costs (US \$ $litre^{-1}$)	0.24	0.42		0.23		

[1] References: 1 Sánchez *et al.* (1981), 2 Avendaño *et al.* (1991), 3 Apaseo *et al.* (1990), Aniano and Ayala (1989); 4 Ortiz *et al.* (1991; 1992; 1993; 1994); 5 Torres (1991); 6 FIRA (1994)

[2] Extended technological packages.

[3] Pasture growth during the winter as percentage of pasture growth during the summer.

A diversity of pastures was used, including alfalfa (*Medicago sativa*), white clover (*Trifolium repens*), perennial ryegrass (*Lolium perenne*), orchard grass (*Dactylis glomerata*), oats (*Avena spp)*, kikuyu (*Pennisetum clandestinum*), and native pastures. Essential descriptors of grazing systems such as stocking rate, productivity, use of concentrates and nitrogen fertilisation show extremely high variability. Even though low production costs is a common feature of all reports, dissimilarity in criteria results in big differences in the estimates of costs.

Low pasture growth during the winter - in some situations aggravated by the lack of persistence - appeared to be a common problem, but no special attention was paid to it. This is an important shortcoming, taking into account that the system is aimed to produce with only small seasonal fluctuations. Mc Call and Sheath (1993) state that the achievement of an economically sound equilibrium between seasonal patterns of feed demand and supply is essential in the development of intensive grassland systems.

The Tropical Dual-purpose System

The Tropical Dual-purpose System aiming to simultaneously produce milk and weaned calves is dominant in the humid and sub-humid tropics of Mexico. For instance, a survey in the beginning of the 1990s (IMTA, 1992; quoted by Corro *et al.*, 1997) revealed that it was practised by 79% of farmers in the tropics of Veracruz. Some attributes of this production system are summarised in Table 9.

Table 9. Attributes of the Tropical Dual-purpose System.

	Reference							
Attribute	1	2	3	4	5	6	7	8
Size (cows farm^{-1})	39	40				25		30-40
Stocking rate (AU ha^{-1})*		1-1.2	1.3	1.12	1.08	1.25	1	
Days in milk	265	180	217	218	215	299	120	120-180
Productivity (litres cow^{-1} lactation^{-1})	1378	600	846	852	722	1692	372	360-1600
Calving interval (days)	441	540	621	630	427	460	713	
Calving (%)	61	55	58	58	51			
Weaning (%)	54	45-50					52	
Productivity (litres milk ha^{-1} year^{-1})		400	319	586	204	1971	372	
Productivity (kg live weight ha^{-1}year^{-1})		95	61					
Age at weaning (months)	7	6	8.4					
LW at weaning (kg)	148	150					280	
LW gain (g an^{-1} d^{-1})	340		230					

References

1 Mc Dowell (1996). Averages out of reports from Latin America, Asia, Africa and Europe.

2 Torres 1991.

3 Menocal *et al.* (1996). Survey in the centre of the State of Veracruz.

4 Valdovinos y Gutiérrez (1989; quoted by Muñoz *et al.*, 1995). Survey in the centre of the State of Veracruz.

5 Rivera (1989; quoted by Muñoz *et al.*, 1995). Survey in the State of San Luis Potosi.

6 Corro *et al.* (1997). Results obtained with co-operating farmers, State of Veracruz.

7 FIRA (1994; quoted by Muñoz et al., 1995).

8 CEA (2000b).

*AU= Animal Unit, an adult cow with a live weight of 450 kg.

According to the census of 1991 (quoted by Alvarez, 1998), most tropical dual-purpose farmers in Mexico own less than 100 animals, and estimates of average size range between 30 and 40 animals per farm (Torres, 1991; CEA, 2000b). Mexican dual-purpose farmers are frequently considered as relatively small farmers (e.g. Muñoz *et al.*, 1995). However, taking into account data reported by Mc Dowell (1996; Table 9) average size of dual-purpose farms in Mexico is similar to average size in other parts of the world.

Mc Dowell (1996) states that dual-purpose systems around the word are biologically and economically inefficient, and that probably malnutrition is the major cause of low productivity and unsatisfactory reproductive performance. A comparison between average values of production and reproduction parameters quoted by Mc Dowell and values of those parameters in Mexican dual-purpose farms (Table 9) indicates that at the beginning of the 1990s the system in Mexico was particularly inefficient.

The system is based on grazing of native and sown pastures. Torres (1991) describes the system in the states of San Luis Potosi, Veracruz and Tabasco. Percentage of area with sown pastures decreases southwards from 94% in San Luis Potosi to 60% in Tabasco. African stargrasses (*Cynodon plectostachyus* and *C. nlemfuensis)* are the most frequently used species. Menocal *et al.* (1996) found that even though 72% of the farmers in Veracruz considered low forage availability during the dry season as the main factor limiting milk production, very little was done about it. Only 30% of the farmers provided supplementary feeding - mainly molasses- during the dry season, and only 1% of the farmers grew forage crops aimed for feeding cattle during the dry season. Fertilisation was used by only 10% of the farmers. Other management practices as weed control and some kind of organisation of grazing (rotational or by types of animals) have already been adopted by a majority of farmers. Considering all management practices, adoption of technological innovation increased with size of the farm.

Most cattle are crosses of zebu with Brown Swiss breeds (Torres, 1991; Gómez and Pinto, 1997). However, results of Corro *et al.* (1997) with co-operating farmers suggest that the productivity of cattle resulting from crossing zebu with Holstein is higher.

The proportion of incomes provided by milk is higher than 50% (Corro *et al.,* 1997; Muñoz *et al.*, 1995), but Muñoz *et al.* (1995) suggest that reacting to price fluctuations, farmers might change that proportion by increasing or decreasing the proportions of cows that are milked.

Almost all research carried out on dairy production under grazing in Mexico was focused on this system (Escamilla and Solis, 1990). Different institutions promoted technological packages supposed to increase the productivity of tropical dual-purpose systems in substantial ways (Torres 1991; Menocal *et al.*, 1996; FIRA, 1994; quoted by Muñoz *et al.*, 1995). Implementation of rotational grazing was the main component of these packages. Mc Dowell (1996) doubted the adequacy of extended technological innovations and stated that there were few, if any, reasonable technological paradigms for tropical regions of Mexico.

Credits at preferential (subsidised) rates to finance adoption were made available by FIRA. There are no reports on adoption, but it appears to have been rather low. From data quoted by Carrizales (1997) it can be estimated that farmers adopting technological packages promoted by FIRA in the State of Veracruz represented less than 1% of the area used for cattle production in that state.

Low quality of the products, seasonality of production and lack of organisation and integration of farmers appear to be the main constraints for the competitiveness of dual-purpose systems (Mc Dowell, 1996). These factors play an important role in the case of Mexican dual-purpose systems, expressing themselves in the way milk is marketed. According to Muñoz *et al.* (1995), 81% of the milk was marketed as informal milk (51% as cheese made by small processors, 28% as raw liquid milk). Nestlé collected the remainder 19%. To improve quality, Nestlé began to install small cooling tanks (3500 litres) in the communities in 1990, with almost no improvement in price and thus transferring the cost of cooling tanks to farmers. At the same time, a farmers-owned dairy industry aimed to compete efficiently with Nestlé was not being as successful as expected.

Production of the different systems in the last 15 years

The production of the different dairy systems in those years –as reported by CEA (2000b)- is depicted in Figure 17. During the crisis in the second half of the 1980s, the production of the Specialised System remained constant ($p>0.05$), and increased between 1990 and 1995 at a rate of 0.55 million litres per year ($p<0.001$). Production of the Semi-Specialised and Family-based Systems (reported together by CEA, 2000b) decreased in the second half of the 1980s ($p<0.01$) and showed no significant changes during the 1990s ($p>0.05$). Dairy production of the Tropical dual-purpose system decreased in both periods ($p<0.05$).

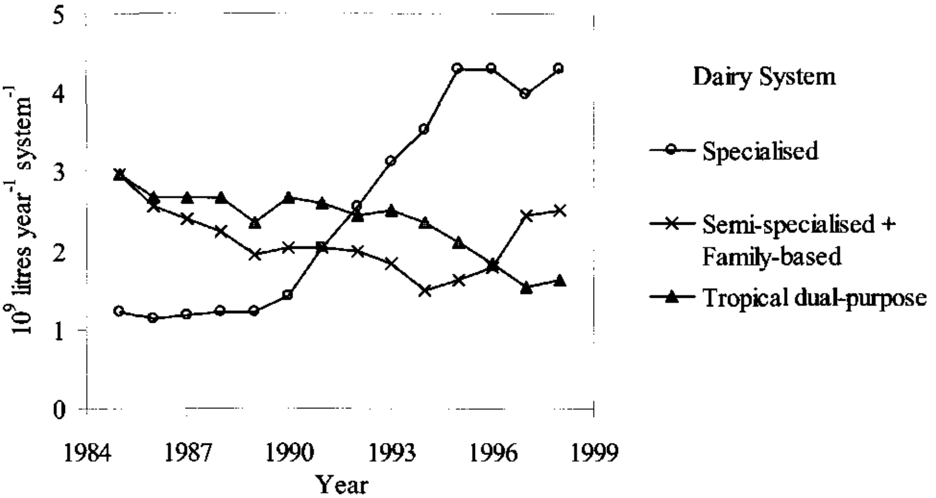

Figure 17. Annual milk production by the different dairy systems (production of the Semi-specialised and the Family-based Dairy Systems are reported together). After CEA (2000b)

Even though no statistics on production by the different dairy systems were available until 1999, there were already signs of this evolution in the statistics reported by CEA in previous years. The first signs were changes in production by three groups of States that were identified as representative of the different dairy systems: 1) Durango and Coahuila dominated by La Laguna, and Aguascalientes dominated by the farmers-owned GILSA since 1964 (Alvarez *et al.*, 1998); 2) Jalisco, Mexico and Michoacan where dairy production takes place under various systems with an important share of the Semi-Specialised and Family-based Systems (Sánchez *et al.*, 1997, Tzintzun *et al.*, 1997; Valle *et al.*, 1998); 3) Veracruz and Tabasco representing the tropical dual-purpose system (Torres, 1991; Corro *et al.*, 1997). The share of production by the different dairy systems in these states (that together accounted for 55% of the national milk production) during 1998 is reported in Table 10, while the milk production between 1985 and 1998 is reported in Figure 18. During the 1990s the rate of growth of production was very high in Group 1 (dominated by the Specialised Dairy System) and it was low in Group 2 (with an important share of the Semi-Specialised and Family-based Systems). During the same period, dairy production did not grow in Group 3 (dominated by the Tropical Dual-purpose System).

Table 10. Dairy production (10^6 litres $year^{-1}$) and proportion by dairy system of selected states during 1998. From CEA (2000b).

Group	State	Production (10^6 litres $year^{-1}$)	Proportion by System (%) Specialised	Semi-Specialised	Family-based	Tropical dual-purpose
1	Durango	819	84	0	12	4
	Coahuila	790	86	0	9	5
	Aguascalientes	390	86	0	14	0
2	Jalisco	1254	27	37	23	13
	Mexico	427	42	21	26	11
	Michoacan	284	10	63	5	21
3	Veracruz	566	17	0	0	83
	Tabasco	84	0	0	0	100
	National	8316	50	21	9	20

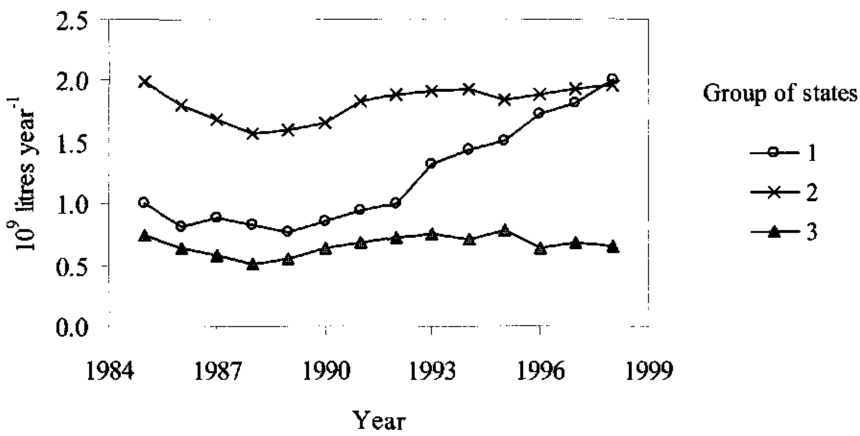

Figure 18. Annual production (1984-1998) by groups of states. Group 1: Coahuila, Durango and Aguascalientes (dominated by the Specialised Dairy System), Group 2: Jalisco, Mexico and Michoacan (with an important share of the Semi-Specialised and Family-based Systems), Group 3: Veracruz and Tabasco (dominated by the Tropical Dual-purpose System). After Rivera (1990), CEA (1996; 1999 b; 2000 b)

The second indication of the evolution of production in the different dairy systems was the steady reduction of asymmetry in seasonal distribution of national dairy production. According to CEA (2000a) the production during the rainy season (between June and October) increased at an average annual rate of 2% between 1993 and 1999, whereas the increase of production during the dry season was twice as high. In 1993, the average monthly production during the rainy season was 27% higher than that of the dry season; in 1999 that difference was reduced to 17%. Systems differ in the seasonal distribution of milk production. Production in Group 1 (dominated by the Specialised Dairy System) is almost constant throughout the year, whereas production in Groups 2 and 3 (dominated by other dairy systems) is on average approximately 50% higher during the rainy season (between June and October) than during the dry season (Figure 19). The increase of production during the dry season between 1993 and 1999 was highly correlated with production in the states dominated by the Specialised System ($R^2=0.82$, $p<0.01$). Therefore, the reduction in seasonal skewness of production communicated by CEA (2000a) is a consequence of the faster growth of the Specialised System.

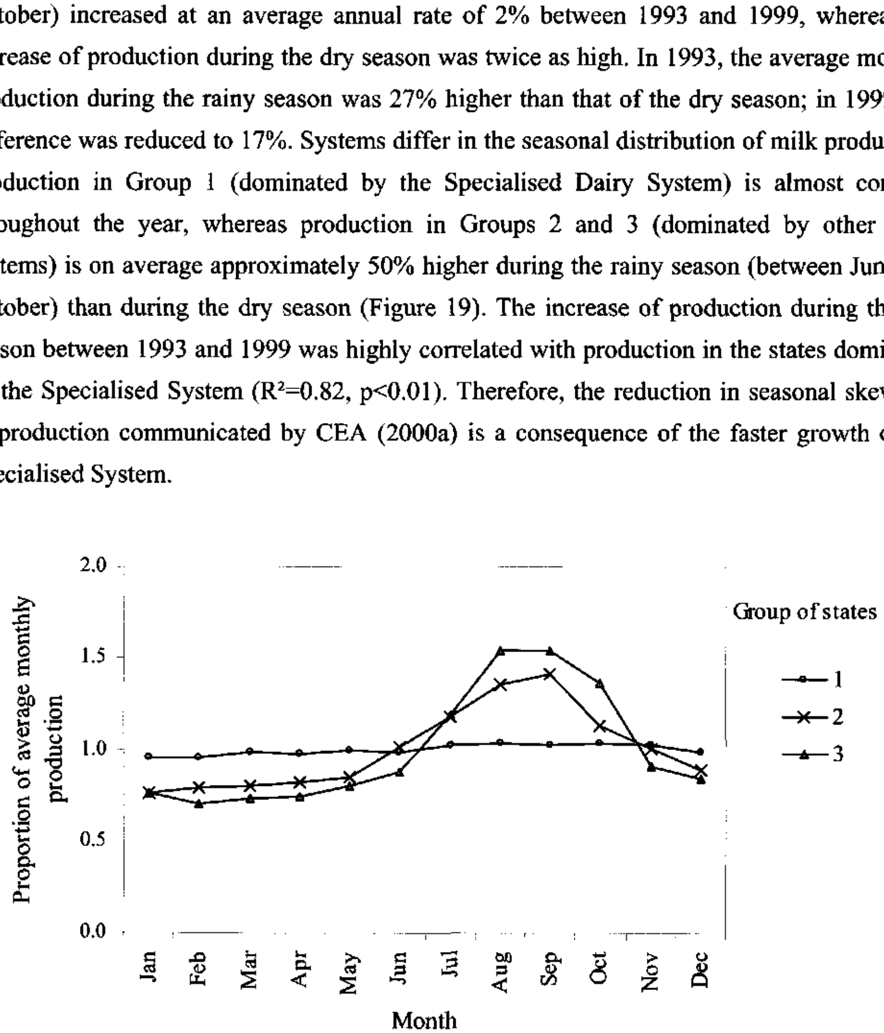

Figure 19. Relative monthly milk production during 1999 by groups of states. Group 1: Coahuila, Durango and Aguascalientes (dominated by the Specialised Dairy System), Group 2: Jalisco, Mexico and Michoacan (with an important share of the Semi-Specialised and Family-based Systems), Group3: Veracruz and Tabasco (dominated by the Tropical Dual-purpose System). After Rivera (1990), CEA (1996; 1999 b; 2000 b).

This evolution indicates that the dominant diagnosis, namely low competitiveness of the Specialised System, relative advantages of the Family-based System and high competitiveness of the tropical system (Torres 1991; Muñoz et al., 1995), was mistaken. This failure was probably caused by inaccuracies in the estimation of production costs, and underestimation of the importance of integration of farmers and of changes that were occurring in the market.

Production costs were a capital issue in that diagnosis. Feeding costs that represented the highest (and most reliably estimated) proportion of costs, were high not only in the Specialised System but in all systems of the Plateau and North (Table 7). Furthermore, due to the composition of diets, the Specialised System probably benefited the most from reduction in costs of main feedstuffs during the 1990s. Additionally, the reduced labour costs of the Family-based System and the Semi-specialised System (due to unpaid family labour) did not appear to be a relevant competitive advantage because labour costs in the Specialised System represented only a small proportion of total costs.

The presumable competitive advantage of the Tropical Dual-purpose System due to high potential for improvement through technological innovations was not expressed in growth of production either because adoption was very low or because extended technological innovations were inadequate. The other presumable competitive advantage, based on reduced feeding costs, was probably offset by the huge disadvantage caused by the very low degree of organisation and integration. The statement by García (1996, quoted by Muñoz *et al.*, 1997) that dairy production of this system was hampered because farmers preferred to produce meat (calves) due to the higher price of this product, might be questioned because the proportion of national bovine meat production (expressed in kg or heads) contributed by states where the dual purpose system dominates, was also reduced in those years (CEA, 1999c).

Proper credit might play an important role in the development of animal production systems (Mc Dowell, 1996). It has been stated that big farmers of the Specialised System have easier access to credit (Suarez, 1987; quoted by Domínguez, 1990; Larrondo, 1998). However, this statement is mistaken. FIRA was the main institution involved in the allocation of credit to dairy farmers with preferential rates (Torres, 1991; FIRA, 1994). Allocation of credit was based on the dominant diagnosis, and therefore credit was relatively higher for dual-purpose systems than for dairy systems of the Plateau and North. Within these latter systems credit was relatively higher for small farmers.

Considering credit in relative terms (US $ per litre milk produced), the Tropical Dual-purpose System received twice as much credit than dairy systems of the Plateau and North between

1989 and 1996 (Table 11). FIRA (1994) stated that the institution gave special support to small dairy farmers, and statistics quoted appear to confirm this statement because between 1989 and 1994 La Laguna received US \$ 0.041 litre^{-1}, and the average for systems of the Plateau and North was 14% higher. Therefore, the faster growth of the Specialised System took place even against the allotment of credit by FIRA.

Table 11. Relative distribution of credit (US \$ litre^{-1}) allotted by FIRA. Adapted from Muñoz *et al.* (1999) and CEA (2000b).

Dairy systems	1989	1990	1991	1992	1993	1994	1995	1996
Tropical dual-purpose	0.079	0.079	0.064	0.067	0.058	0.122	0.118	0.084
Dairy systems of the Plateau and North	0.043	0.047	0.045	0.041	0.043	0.056	0.019	0.042

Valle (1998) stresses that Pronthal was an important factor in the growth of production of the Specialised System after 1989. The author describes Pronthal as a programme originated in an agreement between the government, the dairy industry and dairy farmers (particularly from the Specialised Dairy System). Farmers were granted loans at preferential rates (resources came from USA and Canadian Banks), aimed to buy replacement heifers. In return farmers agreed to deliver all their products to the dairy industry.

The role of organisation and integration in efficient dairy production has been stressed by researchers (Muñoz *et al.*, 1995, Mc Dowell, 1996; Alvarez *et al.*, 1998), by the leader of the national organisation of dairy farmers (Larrondo, 1998), and by high executives of the main farmers-owned dairies (Gavito, 1988; Armendáriz, 2000). In all probability, the degree of organisation and integration was the major factor driving differential growth during the 1990s. Within the Specialised Dairy System this also might have been important. For instance, in the period 1985-98 production in the well integrated La Laguna and Aguascalientes grew 204%, while in the less organised and integrated Queretaro and Guanjuato the growth was only 46%.

Integrated farmers received between 12 and 33% higher prices for their products in different periods and regions, as estimated from data quoted by Sánchez (1978), Domínguez (1990), Sánchez *et al.*, (1997), Cendejas (1998), Guadalupe (1998) and Muñoz *et al.* (1999). Farmers of the Specialised System integrated into farmers-owned dairies, are paid 20-25% higher prices than smaller farmers integrated into other dairy industries (Alvarez *et al.*, 1998). Non-integrated farmers suffer lower prices, especially during the rainy season in the Plateau (Muñoz, 1999) and in the tropics (CEA 2000b). Integrated farmers pay lower prices for inputs as estimated from data quoted by Cendejas (1998) and Guadalupe (1998). Besides being assured of selling their products at reasonable prices, farmers integrated into farmers-owned dairies receive a certain proportion of the revenues originating from the difference between the prices paid to farmers and the price of pasteurised milk (Gavito, 1988). Furthermore, they receive regular technical advice (Sánchez *et al.*, 1997).

It appears that integration is becoming an unavoidable means of survival in the dairy sector. However, lack of organisation, low quality of the product and uneven seasonal distribution hamper integration of farmers of the Semi-specialised System (Muñoz *et al.*, 1999) and the Tropical dual-purpose system (Mc Dowell, 1996). According to Valle *et al.* (1998) and Alvarez *et al.* (1998), the number of small farmers integrated to big dairy companies (such as Nestlé, Parmalat, Danone) is increasing fast. By transferring costs and risks to farmers, eliminating intermediate agents, and ensuring quality and uniformity of the product, dairy companies benefit the most from this integration. Small farmers benefit the least from integration when their degree of organisation is low, or in regions where the competition between the dairy companies is low.

Dairy market

Some characteristics of the dairy market in Mexico during the 1980s resembled the description of less-developed markets reported by IDF (1999). In the first place, the proportion of milk in the informal market was high, making it difficult to keep accurate statistical records of production and processing. In the second place, liquid milk shared the highest proportion of dairy products.

Dairy products

The different ways milk and dairy products are marketed in Mexico depend on size of farms and consequently on dairy systems (Figure 20). Farmers of systems others than the Specialised System rely heavily on the informal market, and the role played by intermediate agents means a heavy burden for those farmers.

Since the government could not exert enough control to subject the informal market to the official maximum prices, many farmers of the Semi-Specialised and Family-based Systems could get higher prices for their product by selling raw milk for direct consumption (Valle, 1998). Therefore, in the 1980s when prices paid to farmers were particularly low, the proportion of milk in the informal market remained very high (Figure 21). But this relative advantage of non-integrated farmers began to disappear when prices paid to farmers raised in the 1990s, and therefore raw milk began to lose its share of the market very quickly. Two factors are involved in this evolution: i) the faster growth of the Specialised Dairy System and ii) the progressing integration of the Semi-specialised System (Muñoz *et al.*, 1999; Valle *et al.*, 1998) and the Family-based System (Alvarez *et al.*, 1998). According to Muñoz *et al.* (1995) milk sold by LICONSA was addressed to a sector of the population that otherwise would buy informal raw milk. Muñoz *et al.* conclude that by selling milk for lower prices to the same portion of the market, the Programme of Social Supply severely affected farmers that marketed informal milk (i.e. non-integrated, small farmers). This proposition can be doubted because the reduction in the proportion of milk in the informal market that took place in the 1990s (Figure 21) is positively correlated (p=0.02) with the reduction in the Programme of Social Supply that took place during the same period (Figure 5).

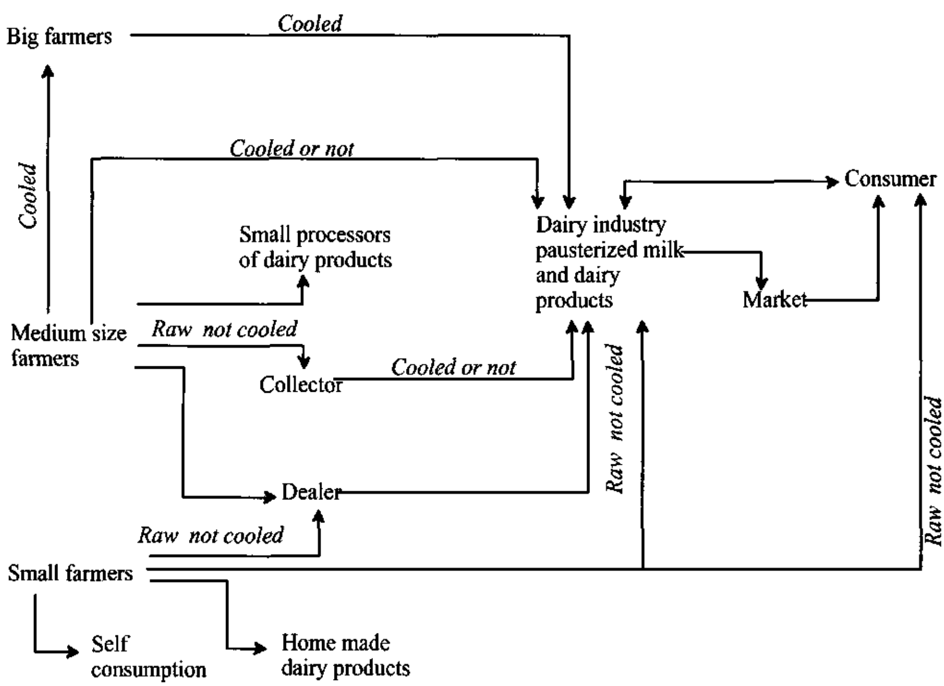

Figure 20. Marketing of milk in Mexico. Adapted from CEA (2000b).

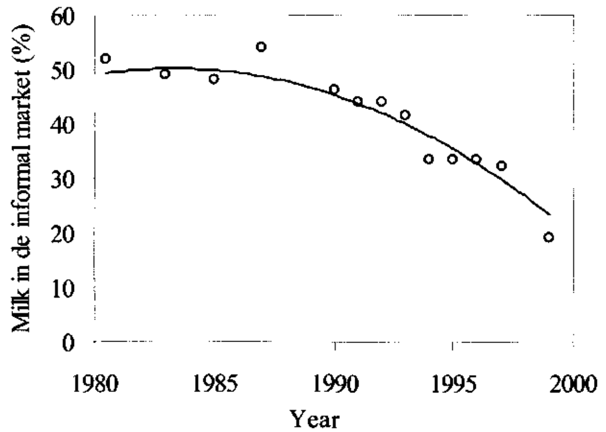

Figure 21. Proportion of milk in the informal market. Adapted from Rivera (1990), Domínguez (1990), Alvarez (1998) and CEA (2000 b)

Other changes that took place in the 1990s resembled processes in well-developed markets. In most developed countries, liquid milk accounts for less than one third of the total volume of processed milk (Jachnik, 1999). Considering consumption of dairy products (FAO, 2000a) and consumption of liquid milk (CDIC, 2000), it can be estimated than in the EU (weighted average) and the USA liquid milk accounts for 38% and 39% of the total consumption, respectively. Even though in Mexico liquid milk still prevailed in 1998 representing 66% of the market (Figure 22), its share of the market is being reduced (in 1994 it represented 79% of the market). Within the category liquid milk, changes described by Alvarez (1998) follow trends that were depicted by IDF (1999) in the world market. Processed milk looses importance against ready to drink milk, and within this last category UHT (ensuring long shelf life and enabling distribution without complete cooling chains) is rapidly increasing its share of the market.

The proportion of consumption of dairy products other than milk increased as a whole, and within that category yoghurt was growing fastest. Muñoz *et al.* (1995) and Alvarez (1998) state that the industrial sector induced these changes, incorporating products with higher added value as a means to increase profitability. According to LALA, these changes (that might become stronger) were induced by a new type of more refined consumers that demand new products (Armendáriz, 2000).

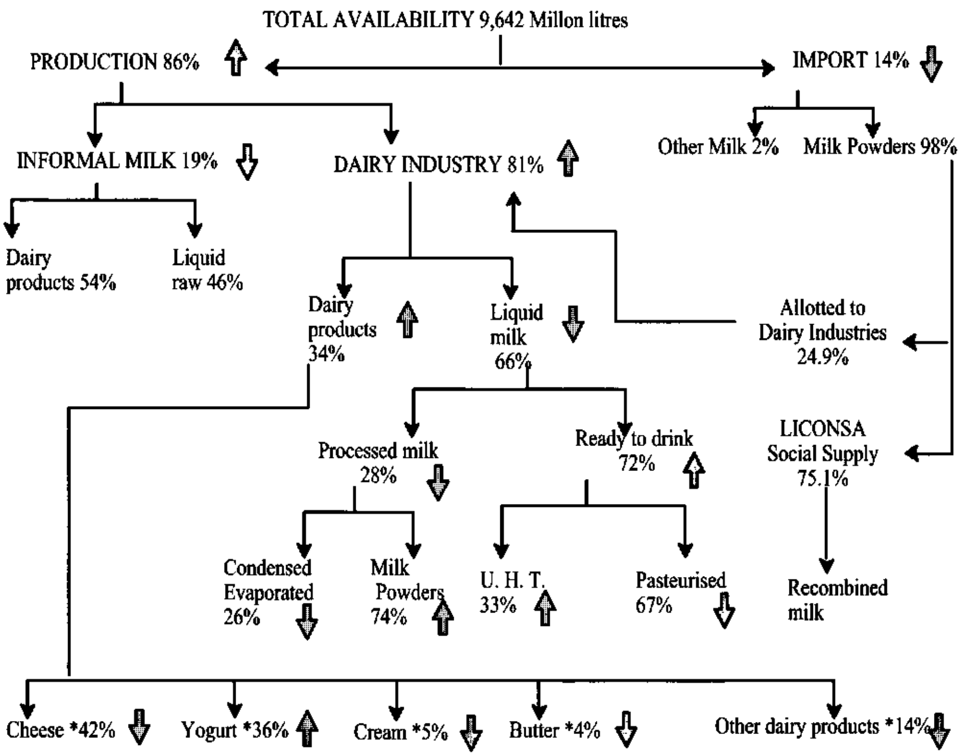

Figure 22. Dairy products in Mexico in the period 1997-1999. Figures represent percentages of volume per category, with the exception of * where percentages of value within the category are given. Grey arrows represent trend of changes in the second half of the nineties. Adapted from CEA (2000a; 2000 b), Alvarez (1998), Muñoz *et al.* (1999).

This kind of development is typical in most developed countries, with much higher per capita consumption, and where current levels of consumption of milk and dairy products are near saturation (Griffin, 1999). In Mexico, the distribution of consumption of milk and dairy products according to levels of incomes might become a crucial factor for future changes. It might be assumed that milk and dairy products are almost unaffordable for a high proportion of the population. That also means that the sector of the population with highest incomes might already have high levels of consumption and could be (according to Griffin, 1999) "near saturation". Dairy industries focusing on this sector of the population should therefore consider that demand might change much in composition but little in total amount (IDF, 1999).

Dairy industry

The industrial dairy sector is characterised by an uneven distribution of resources. There are more than 2800 dairies, of which 90% are very small factories producing cheese, butter and cream (Alvarez, 1998; Muñoz *et al.*, 1995). A few dairy companies controlled the market of ready to drink milk in the mid-1990s. Three farmer-owned companies (LALA, ALPURA and GILSA) accounted for 48% of processed milk (20%, 15% and 13% respectively). In many countries (e.g. USA, Italy, Germany, Ireland, Argentina and New Zealand) higher concentration of resources is taking place through merges or acquisitions (IDF, 1999) and this is also taking place in Mexico now. For instance, LALA raised its share in the market by practically 1% per year from 19.9% in 1992 to 25.8% in 1998 (Armendáriz, 2000). And by the end of the 1990s, Nestlé accounted for 97% of the market in milk powders (Muñoz *et al.*, 1999).

According to Hernández (1996; quoted by Muñoz *et al.*, 1999), Mayorga (1996), Alvarez (1998) and Valle (1998) the activity of worldwide operating dairy companies is increasing. Nestlé, Kraft, Danone and Parmalat - ranked among the six biggest worldwide operating dairy companies according to the 1999 report of Rabobank International (quoted by IDF, 1999) - operate in Mexico. The history of activities of these companies in Mexico is different. For instance, Nestlé has been operating for decades while Parmalat started operations in 1996 (Valle, 1998). In terms of the dairy industry this evolution will mean increased competition and further concentration. It will also mean that another characteristic of this industry in relation to non-integrated farmers will be accentuated: the high negotiation power of a few powerful takers against many unorganised suppliers (Alvarez, 1998, Valle *et al.*, 1998).

Underutilised processing capacity is another characteristic of the dairy industry (Fonseca, 1988; Alvarez, 1998). The higher production of the Tropical Dual-purpose and the Semi-specialised Systems during the rainy season is not being processed and is brought into the informal market (Figure 23). However, processing capacity is not the limiting factor. Nestlé processed part of the surplus into milk powders (CEA, 2000b) but that product is rapidly loosing share in the market. Even though it is technically feasible that seasonal surpluses could be processed into the emerging UHT (with long shelf life), it appears that high financial burdens are becoming a severe constraint (Alvarez, 1998).

Figure 23. Monthly averages (1994-1999) of dairy production and industrial processing in Mexico. Adapted from CEA (1996, 1999 b, 2000 a).

Conclusions

Jachnik (1999) states that forecasts for the dairy sector are more limited than for other products, and stresses that prospects should be cautiously issued. Nevertheless, based on the link between the above discussed evolutions in the different circles of which the production environment of Mexican dairy farmers is composed, some modest propositions concerning prospects for these farmers can be made.

Demand will probably grow at lower rates than in the past years. FAO forecasts an increase of approximately 10% in the per capita consumption of dairy products between 1995 and 2005 (Griffin, 1999). But even such a modest increase is doubtful taking into account a) the high income elasticity of the demand for dairy products and the evolution of minimum wages and b) the reduction of the Programme of Social Supply.

More precise prospects would require better information on the distribution of consumption of dairy products according to levels of income. According to FAO (Griffin, 1999), consumers are many and varied. Thus in the dairy market of the future some will ask for low-priced products, while others will pay a premium for quality and uniqueness. Some dairy companies (e.g. LALA) are focusing on products with higher added value, addressed to more refined consumers (Armendáriz, 2000), i.e. sectors of the population with high incomes. That leaves a broad sector of the market (the population with lower incomes) open for other companies that could - by paying less to farmers or importing bulk products - supply low-priced products in a profitable way.

International competition is becoming more intense. If the dairy sector of Mexico becomes increasingly exposed to that competition, prices will approach world milk price. Prospects for milk prices in the world market are diverse. OECD (2000) expects increases, but according to FAO (Griffin, 1990), Jachnik (1999) and IDF (1999) no recovery is expected, and the European Dairy Association fears further price drops (Van de Ven, 1999).

Taking into account the prospects for demand and competition, prices paid to Mexican dairy farmers could become lower. That appears to be most earnest in the case of farmers that are not integrated into farmers-owned dairy companies. Therefore, in the case of these farmers, improvements in organisation and consequently in the terms of integration become inevitable. Quality of the product and seasonal variation of production appear to be the main constraints for improvement (Mc Dowell, 1996, Muñoz *et al.*, 1999).

Regarding the Specialised and Semi-Specialised dairy systems of the Plateau and North of Mexico (that together account for more than 70% of national production), reduction of feeding costs is pressing, since these costs (Table 7) represent a high proportion of the virtual world milk price estimated by IDF (1999). In the second half of the 1990s feeding costs have been decreasing due to the reduction in market distortion of feed prices, but that distortion has already been brought to an end.

As happened in recent years in the Specialised Dairy System of Mexico, and as it has been regularly reported to happen in dairy systems of other countries, efficient forage production and forage utilisation might become the key issue to solve problems of high feeding costs and uneven seasonal distribution of dairy production. Dairy systems based on grazing and the use of moderate amounts of conserved forages and few concentrates are an essential component of the competitiveness of the leaders of the dairy world market. In other parts of the world, grazing-based dairying with a reduced use of concentrates is considered a viable way to face the new context, in which –as stated by Harvey and Saunders (1993)- the strategy at farm level must be based on competitive free trade world prices. The publications by Cherney and Cherney (1998) and Rook and Penning (2000) are examples of this concern in the U.S.A. and the EU, respectively.

In Mexico, dairy production based on grazing of temperate pastures is rather new, and the technological basis for the system is still weak. If a dairy system based on grazing of temperate pastures is to become an alternative for low-cost production in the Plateau and North of Mexico, solutions have to be found for a well-balanced feed supply throughout the year, taking into account the low persistence of pastures and the use of supplementary feeding. Potential productivity and economical feasibility of the system should be assessed as well in a reliable way.

Chapter 3
Supplementary feeding with maize silage

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Summary

Economic feasibility in dairy systems based on grazing is closely linked with production per unit of area, which is highly dependent on stocking rate. Responses of milk production per cow to supplementary feeding with maize silage are low if substitution rates are high. However, if substitution rates are high, stocking rate and production per unit of area can be increased. The adjustment of stocking rate to the level of supplementary feeding depends on substitution rates, but the estimates of substitution rates have a large error component.

An experiment was conducted to estimate the response in terms of stocking rate and milk production per hectare to four levels of supplementary feeding with maize silage (0, 1.6, 3.2 and 4.8 kg dry matter of maize silage offered cow^{-1} day^{-1}). Cows grazed oats and ryegrass pastures in the morning and alfalfa and orchard grass pastures in the evening and night. A high and uniform pasture utilisation was targeted, irrespective of the level of supplementary feeding. The experiment was also aimed to gather information on herbage production, composition and utilisation of both types of pastures.

Under the management used in the current experiment substitution rates were high. Herbage intake was estimated with three methods, namely i) faecal output, ii) animal requirements and iii) herbage sampling; the estimates of substitution rates by the three methods were -1.36, -1.39 and -1.94 kg DM herbage intake per kg DM maize silage intake, respectively. There were strong indications that with herbage sampling substitution rates were overestimated. Reductions in herbage intake were coupled with reductions in grazing time. Grazing time in turn appeared to be at least partially affected by reduced residence time in paddocks, but that reduction is required in order to achieve the targeted silage intake.

The effects of increasing supplementary feeding on average stocking rate and milk production per hectare could be accurately estimated, justifying the approach used in the current experiment. The high substitution rates were coupled with strong increments in stocking rate (0.32 cows ha^{-1} per kg dry matter of silage offered daily per cow).

There was a slight negative effect of increasing levels of supplementary feeding with maize silage on milk production per cow. In spite of this negative effect, due to the increase in stoking rate, milk production per hectare augmented with the level of supplementary feeding (0.79 kg milk per kg dry matter silage offered daily per ha). Taking into account the price ratio between maize silage and milk this increment justified supplementary feeding up to the highest level used in the current experiment.

Introduction

Maize silage is widely used as supplementary feed for grazing cows in dairy systems in many countries. Including maize for silage in those systems regularly aims to take advantage of the high yielding capacity of this crop, producing relatively low-cost feed that can be easily conserved and used during the winter (Moran, 1992; Moran and Stockdale, 1992). Furthermore, when maize silage is fed supplementary to cows grazing temperate pastures, it improves the efficiency of energy and nitrogen utilisation due to differences in chemical composition (Valk, 1994). Gómez and Jahn (1993) state that in areas where the production potential of maize is higher than that of temperate pastures, including up to 30% of the area with silage maize will produce highest net income per hectare, provided milk prices are not too low. In addition, supplementary feeding with conserved forages reduces the variation in annual income, and stability of annual income appears to be very important for many farmers (Phillips, 1988).

Reports on the response of grazing dairy cows to supplementary feeding with maize silage in terms of milk production per cow range between negative and 1.4 kg extra milk per kg dry matter (DM) of silage consumed (Bryant and Donnelly, 1974; Stockdale, 1997b). Responses to supplementary feeding are inversely related to substitution rate, i.e. the reduction in herbage intake resulting from supplementation, expressed in kg DM herbage per kg DM intake of supplementary feed. When herbage availability is adequate, the response to supplementary feeding is low (Meijs and Hoekstra , 1984, Stockdale 1994b and 1997a), because the substitution rate is high (Meijs, 1986; Holden *et al.*, 1995). In a review Phillips (1988) concluded that in case of maize silage substitution rates are equal or less than 1, but reported values - or estimates from reported data on herbage and supplement intake - range from 0 (Moran and Croke, 1993; Stockdale, 1994a) to 1.5 and 1.74 (Holden *et al.*, 1995; Moran and Wamungai, 1992). Substitution rates have been found to increase with the level of supplementary feeding (Moran and Croke, 1993; Stockdale, 1994a). Using concentrates as supplementary feed, Meijs and Hoekstra (1984) found that the substitution rate was affected by the interaction between the levels of herbage availability and supplementary feeding.

The response to supplementary feeding with maize silage increases with decreasing quality of grazed herbage (Stockdale, 1997b). It also depends on the proportions of the ingested energy partitioned to milk production or body reserves, which is expressed in changes in live weight or body condition (Moran and Wamungai, 1992).

Economic feasibility in dairy systems based on grazing is closely linked with production per unit of area, which is highly dependent on stocking rate (Clark and Kanneganti, 1998). As supplements substitute for the intake of herbage, stocking rate can be increased. According to Leaver (1985), this benefit of supplementation is frequently neglected when assessing the financial returns of supplementary feeding. Therefore, in terms of system efficiency, the most relevant response variables to supplementary feeding with maize silage are energy and nitrogen utilisation efficiency, stocking rate and productivity per hectare.

The adjustment of stocking rate or herbage allowance to the level of supplementary feeding depends on substitution rates. Estimation of substitution rates requires the comparison of herbage intake of control (unsupplemented) animals against that of animals receiving supplementary feeding. Measurement of herbage intake under grazing has a large error component (Poppi, 1996) and any error when measuring pasture intake in unsupplemented cows would accentuate errors in calculations of substitution rate (Moran and Croke, 1993). This brings uncertainty to the estimation of substitution rates and hence to the required accompanying adjustments of stocking rate or herbage allowance to the level of supplementary feeding.

However, if stocking rate and productivity per hectare are to be considered the most relevant response variables to supplementary feeding with maize silage, a different approach that is independent of the estimation of substitution rate might be more adequate. A basic principle in the management of grassland systems is efficient utilisation of produced herbage, which should be achieved irrespective of the level of supplementary feeding. Herbage intake is expected to decrease with the level of supplementary feeding and hence, in order to achieve the target of herbage utilisation (e.g. a certain residual herbage mass or height) higher stocking rates (i.e. lower herbage allowances) should be used. Therefore, herbage allowance and stocking rate become response variables like milk production per cow, milk production per hectare and changes in live weight or body condition (Figure 1).

It can be argued that by using this approach, elucidation of some causal relationships will be precluded by the fact that the effects of level of supplementary feeding and herbage availability are confounded, and therefore extrapolation may also be limited. However, confusion of effects depends on the definition of herbage availability. If herbage availability is defined as the average herbage mass, height and composition that cows face throughout the grazing sessions, the effects of level of supplementary feeding and herbage availability are not confounded because all cows will face the same average herbage mass, height and composition, irrespective of the level of supplementary feeding. Moreover, with this approach the most important response variables in terms of system efficiency will be conclusive for the system under study.

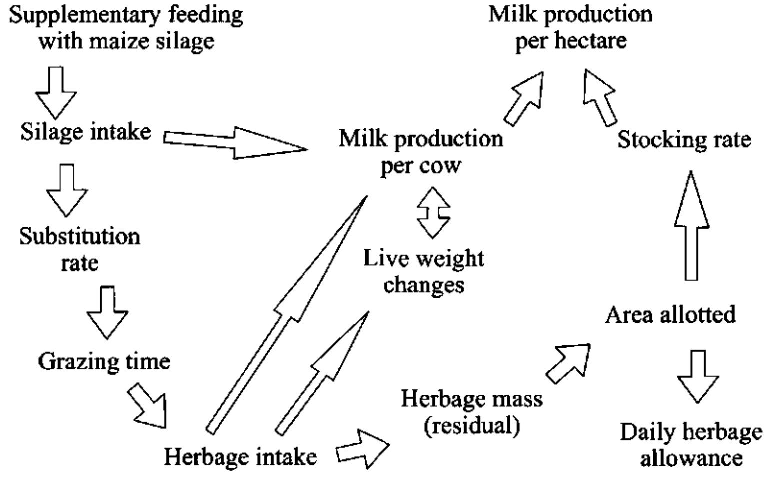

Figure 1. Relationship between supplementary feeding with maize silage and milk production per hectare under uniform pasture utilisation.

The dairy system in the current study is based on a sequential cropping system of permanent pastures – a mixture of alfalfa (*Medicago sativa*) and orchard grass (*Dactylis glomerata*) –, winter annual pastures – a mixture of oats (*Avena sativa*) and annual ryegrass (*Lolium multiflorum*) – and silage maize. Grazing dairy cows are supplementary fed with moderate amounts of concentrates during the lactation. Between November and April cows graze both types of pastures and between October and April they also receive supplementary feeding with maize silage. Knowledge on the responses to supplementary feeding with maize silage is required for many mutually related decisions involved in system design: i) adjusting stocking rate, ii) estimating the range of proportions of area to be allotted to the different phases of the rotation, iii) evaluating the economic feasibility of purchasing at least part of the maize silage to be fed (in order to maintain higher stocking rates) and iv) evaluating the economic feasibility of supplementary feeding with maize silage for periods longer than 7 months.

An experiment was conducted to estimate the response in terms of stocking rate and milk production per hectare to increasing levels of supplementary feeding with maize silage. Cows grazed oats and ryegrass pastures and alfalfa and orchard grass pastures; a high and uniform pasture utilisation was targeted irrespective of the level of supplementary feeding. Herbage intake and ingestive behaviour were measured in order to gain insight in the nature of the response. The experiment was also aimed to gather information on herbage production, composition and utilisation of both types of pastures.

Materials and methodos

Animals, pastures, treatments and management

The experiment was carried out between 1 February and 15 April 1998 at the Farmlet for Dairy Production under Grazing of Chapingo University, located at 19°29' N, 98°54' W and 2240 m above sea level. Climate is temperate and subhumid with summer rains; average rainfall is 620 mm, and average temperature is 18°C. The soil is loam of volcanic origin, deep, neutral and fertile.

Twenty-four Holstein cows with an average age of 1.6 lactations and an average live weight of 541 kg were allotted to four groups, balanced according to live weight, stage of lactation and age. Each group consisted of 5 cows in different stages of lactation (on average 158 days in milk at the beginning of the experiment) and one dry cow. Each group was offered 0, 1.6, 3.2 and 4.8 kg of dry matter of maize silage cow^{-1} day^{-1} respectively, with on average 27 % dry matter (DM).

Cows were milked between 06:30 and 08:30 and between 14:30 and 16:00. During milking, lactating cows received 1.5 kg of commercial concentrates (18% crude protein). The unsupplemented group was taken to the pastures immediately after milking. Cows receiving supplementary feeding were taken to the pastures when it was visually estimated that the group receiving the highest level of supplementary feeding had consumed at least 70 % of offered maize silage. Between the morning and afternoon milking, cows grazed annual pastures of oats and annual ryegrass and between the afternoon milking and the morning milking of the next day, they grazed permanent pastures of alfalfa and orchard grass. The schedule of activities of each group of cows is given in Table 1.

Table 1. Time schedule of activities for the groups receiving different levels of supplementary feeding with maize silage.

Activity	kg DM of maize silage cow^{-1} d^{-1}			
	0	1.6	3.2	4.8
Morning milking	08:00-08:30	07:30-08:00	07:00-07:30	06:30-07:00
Penned with maize silage in the morning		08:00-09:30	07:30-09:30	07:00-09:30
Grazing oats and ryegrass pastures	08:40-15:30	09:40-15:05	09:40-14:45	09:40-14:20
Afternoon milking	15:35-16:00	15:15-15:40	14:55-15:20	14:30-14:55
Penned with maize silage in the afternoon		15:40-17:00	15:20-17:00	14:55-17:00
Grazing alfalfa and orchard grass pastures	16:10-07:50	17:10-07:20	17:10-06:50	17:10-06:20

All 24 cows started grazing the same type of pastures, receiving the same amounts of concentrates and maize silage and the same management 6 weeks prior to starting the experiment. The experimental period was divided in two phases: one phase of adaptation to the levels of supplementary feeding between 3 February and 4 March 1998, and one phase of measurements between 5 March and 15 April 1998. During the first phase, cows were confined in one of the ends of the paddocks and, according to treatments, maize silage was offered collectively. During the second phase, cows were penned in a farmyard and silage was offered individually. Pasture measurements started in the first phase, whereas animal measurements took place in the second phase.

The area of annual pasture of oats and ryegrass was 3.6 ha; sowing took place between 5 September and 5 October 1998. Seeding densities in kg pure germinating seeds per ha were 60 and 25 for oats (cv. Cocker 234) and annual ryegrass (cv. Barspectra), respectively. Pastures were fertilised at sowing with 60 kg P_2O_5 ha^{-1} and 60 kg N ha^{-1} and after each grazing cycle with 60 kg N ha^{-1}. Sprinkler irrigation took place fortnightly with on average 67 mm per irrigation.

The area of alfalfa and orchard grass pastures was also 3.6 ha. Seeding densities in kg pure germinating seeds per ha were 12 and 15 for alfalfa (cvs. Aragón and ABT) and orchard grass (cv. Potomac), respectively. Pastures were fertilised annually with 60 kg P_2O_5 ha^{-1}; irrigation took place as on annual pastures. Pastures differed in age and condition. Two paddocks (0.8 ha) were second-year pastures in very good condition. Five paddocks (1.9 ha) were third-year pastures in good condition. The remainder two paddocks (0.9 ha) were third-year pastures with low alfalfa plant densities and a relatively high proportion of ground cover by invading kikuyu (*Pennissetum clandestinum*); the appearance of pastures in these paddocks resembled that of 4th year or older pastures. This bad condition was probably due to the fact that these paddocks had been sown after an old alfalfa pasture without previous crop rotation; high mortality of alfalfa plants was observed already in the first year of these pastures. An additional area of 0.6 ha of alfalfa and orchard grass pastures and 0.8 ha of pastures of perennial ryegrass (*Lolium perenne* L.) and white clover (*Trifolium repens* L.) was used as buffer area in order to start at the same time with grazing by the different groups in the next pair of experimental paddocks.

Cows grazed separate pasture strips as groups according to treatments. An uniform and relatively low mass of residual herbage of about 5 cm height was targeted irrespective of the level of supplementary feeding. By displacing an electrical portable fence, cows were offered fresh herbage at least twice per grazing session. Adjustment of areas allotted to each group took place based on a visual estimation of remaining herbage mass. Previously grazed strips of the paddock remained open, allowing for adjustment of the areas to be based on the whole grazing period and not necessarily on a daily basis. After finishing grazing a paddock, the area allotted to each group was measured.

The experimental farm of the University of Chapingo provided the maize silage used in the experiment. Different maize varieties were used to produce the silage but the highest proportion of the area was sown to V-107, a tall and high yielding variety with a long growth cycle of 180 days (Cortes, 1995). In the experimental farm, maize is usually harvested at a relatively early stage, with DM contents slightly above 22%, and most frequently yielding 18 to 20 Mg DM ha^{-1}. The chemical composition of silage used in this experiment is given in Table 2.

Table 2. Average composition of the maize silage with standard errors between brackets..

Crude Protein (g 100 g^{-1} DM)	Neutral Detergent Fibre (g 100 g^{-1} DM)	Acid Detergent Fibre (g 100 g^{-1} DM)	Metabolisable Energy (Mcal kg^{-1} DM)
9.6 (0.3)	55.3 (1.1)	33.8 (0.9)	2.30 (0.04)

Measurements

Herbage on offer was estimated the day before the start of grazing by cutting to ground level between 10 and 19 samples of 0.25 m² taken following a regular pattern. A schedule of the implemented measurements is presented in Table 1 of the appendix. After weighing, one compound subsample was taken for hand separation in botanical and morphological components and another subsample was taken for the estimation of DM content and chemical composition. Residual herbage in alfalfa and orchard grass pastures was estimated by taking 10 to 12 samples per area allotted to each treatment. Residual herbage in oats and ryegrass pastures was estimated using a single probe capacitance meter (Designs Electronics ®) with 10 calibration samples of 0.25 m^2 per sampling.

On three occasions herbage consumed by cows was sampled by means of hand-plucked samples (Langlands, 1974), taken by five previously trained observers imitating the grazing pattern of different cows. No hand-plucked samples were taken during night grazing. Herbage samples were dried in a conventional (forced air circulation) oven at 59°C during 72 hours, weighed, and ground in a Wiley® mill provided with 1 mm mesh. Near infrared spectroscopy (NIRS, Laboratory of LALA S.A. de C.V., Torreón, Mexico) was used to quantify Crude protein (CP), Neutral Detergent Fibre (NDF), Acid Detergent Fibre (ADF) and Metabolisable Energy (ME). DM digestibility of these samples was estimated based on ME content (Geenty and Rattray, 1987). Determinations were carried out on bulked samples. Bulked samples were composed per treatment, type of pasture and sampling dates (bulking over cow, observer and moment of the day).

Faecal output was estimated using chromium oxide as external marker. Cows were dosed with 7 g chromium oxide in paper capsules at each milking; dosing started 7 days prior to start sampling faeces. On 9 occasions within two weeks, rectal grab samples were taken after each milking (Holden *et al.*, 1995). Chromium concentration in faeces was estimated according to Le Du and Penning (1982). The mean of chromium concentrations in morning and afternoon samples was used as input for analysis of variance.

Silage refusals were weighed and subsamples were taken for the estimation of DM content. Refusals per group of cows were weighed in the first phase when silage was fed in the paddocks. Refusals per cow were weighed in the second phase when silage was fed individually to penned cows.

Measurements of activities and ingestive behaviour were carried out during five days in two periods of 72 hours and 48 hours, respectively (Appendix, Table 1). Observations of activities were registered per cow every 10 minutes; activities taken into account were grazing, eating silage, ruminating and resting. Drinking, eating minerals and activities related to milking where brought together in one category. Three distinct bouts were considered for the analysis of the daily activities of the cows namely: i) the morning grazing session, ii) the evening/night grazing session, and iii) the morning and afternoon periods when cows were confined for supplementary feeding with maize silage. The morning and evening/night grazing sessions were subdivided in four intervals: 0-30, 31-60, 61-90 and >90 minutes since the start of grazing. The time required to take 100 bites was registered during different moments of the grazing sessions; no measurements of biting rate were carried out during the night.

Body condition of cows was assessed on a weekly basis using a 0-5 score scale (Sniffen and Ferguson, 1991). Linear regressions of body condition of each cow on time were calculated. The linear estimate of changes in body condition was considered as the response variable.

Average herbage allowance per grazing session [kg DM (100 kg LW)$^{-1}$ (0.5 d)$^{-1}$)] was calculated per treatment and per paddock based on herbage mass on offer above ground level, live weight of the group, days of grazing and area allotted to the group in the paddock. Stocking rate (cows ha^{-1}) was calculated per grazing cycle taking into account stocking density, the length of the previous rest period and that of the grazing period. Net herbage production (kg DM ha^{-1} d^{-1}) was calculated as the difference between herbage on offer and residual herbage, divided by the length of the grazing cycle.

Milk production per cow was estimated by weighing milk of both milkings on 19 occasions within 6 weeks. Information on productivity of cows was scarce when the experiment started. The production during a whole lactation of each cow was used as a co-variable in the analysis of variance of milk production. It was estimated by means of fortnightly weighing of both milkings. During the last three weeks of the experiment milk was sampled for estimation of composition. Samples of both milking on two consecutive days were bulked and analysed by infrared analysis (Laboratory of Holstein de Mexico S. A. de C. V., Querétaro, Mexico). Milk production per hectare was estimated based on corresponding data of milk production per cow and stocking rate.

Based on NRC (1989), daily metabolisable energy requirements per cow were calculated considering 45 days of the second phase of the experimental period. Production requirements were calculated from average milk production and composition of each cow. To calculate energy requirements related to changes in live weight, changes in body condition were converted into changes in live weight using a linear relationship relating changes in body condition to live weight changes within age classes. This relationship was based on 594 paired observations of live weight and body condition carried out on the same cows during one year after the experiment. The calculation of maintenance requirements was done according to AFRC (1993) and considered energy requirements for standing, eating, ruminating and walking based on each cow's average pattern of daily activities. The calculation of the energy requirements for walking included the average distance covered daily to the milking installation (1150m) and the distance walked in the pastures. To estimate the distance walked in the pastures a ratio of 3.2 m per minute of grazing was used. This ratio was previously obtained, from observations of 11 replacement heifers during four consecutive days (unpublished data). Requirements for gestation were taken into account only for cows in the last 8 weeks of pregnancy.

Herbage intake was estimated in three ways: a) by means of herbage sampling, b) from faecal output and digestibility of the whole diet, and c) by estimating intake needed to meet requirements. Estimation by means of herbage sampling as the difference between herbage on offer and residual herbage resulted in an estimate of the herbage intake for each group of cows in each paddock. Estimation by means of faecal output and digestibility of the whole diet resulted in an estimate of the intake of each cow over a period of 9 days. Estimation of herbage intake based on requirements resulted in an estimate of mean herbage intake of each cow during a period of 45 days. Substitution rates were estimated by developing linear regressions between herbage intake and silage intake (Moran and Croke, 1993).

Statistical analysis

Data were subjected to analysis of variance using mixed models considering fixed and random effects (Littel *et al.*, 1996). Different response variables required different statistical models (see Appendix 1). The level of supplementary feeding, the type of pasture and the interval of the grazing session were considered as fixed effects. The paddocks, the day of measurement and the cow (nested in the level of supplementary feeding) were considered as random effects. The paddocks were composed of paddocks of both types of pastures which were grazed by all groups on the same days. Age, weeks in lactation and average daily production during a whole lactation were taken as co-variables in the analysis of variance of milk production per cow, body condition and intake based on requirements. Data on refusals of maize silage depending on the way of feeding (in the paddocks of individually to penned cows) were analysed completely at random. Models on which analysis of variance was based are included in Appendix 1.

Results

Maize silage intake and refusals

Silage intake and silage refusals increased with the level of silage on offer (Table 3 and Figure 2), the increase in silage refusals was particularly strong when silage was offered collectively in the paddocks (Figure 2).

Table 3. Intake of maize silage offered individually to penned cows.

	kg DM of maize silage cow^{-1} d^{-1}				
	1.6	3.2	4.8	Standard Error	P
Kg DM cow^{-1} d^{-1}	1.496	2.672	3.895	0.062	0.001
Kg DM (100 kg LW)$^{-1}$ d^{-1}	0.281	0.480	0.755	0.031	0.001

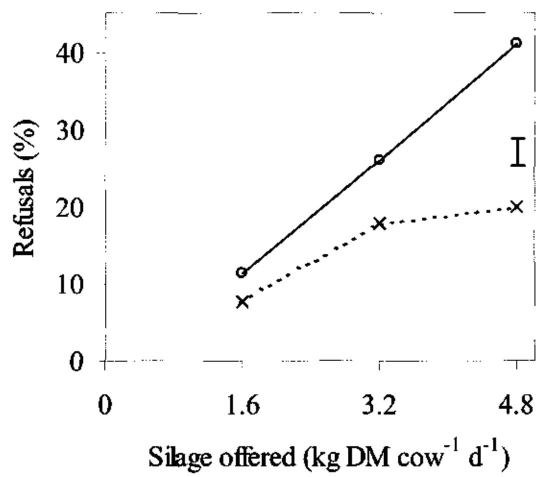

Figure 2. Maize silage refusals with increasing levels of maize silage offered individually to penned cows (- - -), or to groups of cows in paddocks (—). Vertical bar depicts standard error.

Herbage on offer

The number of samples taken led to reasonable precision in the estimation of herbage mass on offer, standard errors of means of herbage mass on offer per paddock were on average 165 kg DM ha^{-1} for oats and ryegrass pastures and 140 kg DM ha^{-1} for alfalfa and orchard grass pastures. In oats and ryegrass pastures the mass and proportion of green leaves on offer was much higher while the proportion of dead material was much lower than in alfalfa and orchard grass pastures (Table 4).

Chemical composition of herbage on offer was within the range of values reported for herbage of temperate grasses and legumes (Geenty and Rattray, 1987; NRC, 1989; Minson, 1990; Sheaffer *et al.*, 1998). In alfalfa and orchard pastures the legume was dominant (Table 5a) which corresponds with the high CP content of herbage on offer (Table 4).

Table 4. Herbage mass, morphological and chemical composition of herbage on offer in pastures of oats and annual ryegrass and pastures of alfalfa and orchard grass.

	Oats and annual ryegrass	Alfalfa and orchard grass	Standard Error	P
Herbage mass (kg DM ha^{-1})	5815	3765	157	0.001
Leaves (% of DM)	68.3	48.4	1.2	0.001
Leaves (kg DM ha^{-1})	3918	1822	126	0.001
Stems (% of DM)	28.2	30.1	1.7	0.432
Dead material (% of DM)	3.5	21.5	1.0	0.001
Crude protein (% of DM)	14.7	24.1	0.5	0.001
Acid Detergent Fibre (% of DM)	27.3	32.4	1.1	0.023
Neutral Detergent Fibre (% of DM)	46.5	47.0	2.7	0.892
Metabolisable energy (Mcal kg^{-1} DM)	2.73	2.42	0.06	0.015
DM Digestibility (%)	76.4	68.4	1.5	0.015

Differences in botanical and morphological composition between paddocks of the same type of pasture depended on different factors. In alfalfa and orchard pastures, third-year pastures sown without previous crop rotation had lower proportions of alfalfa and leaves and higher proportions of weeds and dead material (Table 5a). In oats and ryegrass pastures, the proportion of oats decreased and that of ryegrass increased as the growing season advanced (Table 5b), like reported by Améndola and Morales (1997). The onset of the reproductive stage in oats led to an increase in the ratio of stems to leaves.

Residual herbage, herbage utilisation

Average standard error of means of residual herbage in alfalfa and orchard grass pastures was 202 kg DM ha^{-1}. No significant difference was detected between calibration equations of residual herbage mass on capacitance meter readings. Therefore, as recommended by Laca *et al.* (1989), data from all samplings were pooled to calculate the following general calibration equation (Figure 3):

Residual herbage (kg DM ha^{-1}) = 353 + 16.65 CMR, $R^2 = 0.77$

where

CMR = Capacitance.

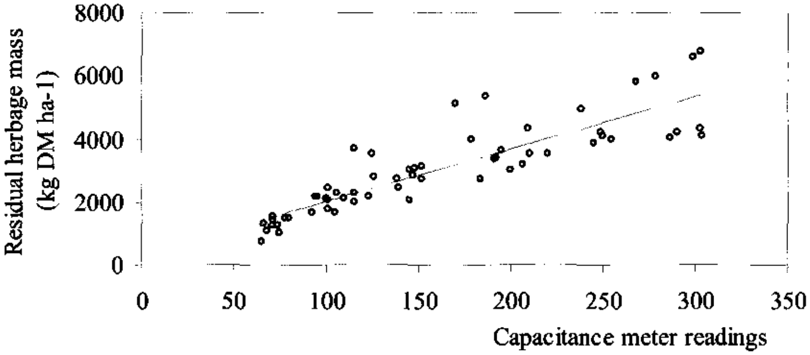

Figure 3. Relationship between capacitance meter readings and residual herbage mass.

Table 5. Morphological composition of herbage on offer (% of DM)

5a. Alfalfa and orchard grass pastures.

	Condition of pastures			
Component	Second-year pastures sown after crops	Third-year pastures sown after crops	Third-year pastures sown without previous crop rotation	Standard Error
Leaves of alfalfa	34.1	35.8	23.9	2.1
Stems of alfalfa	21.8	23.4	17.1	1.1
Leaves of orchard grass	14.8	12.6	17.7	0.8
Stems of orchard grass	9.1	9.6	9.7	0.3
Weeds	0.0	0.7	3.6	0.7
Dead material	20.2	17.9	27.8	1.6

5b. Oats and annual ryegrass pastures.

	Sampling date						
Component	1 February	11 February	6 March	13 March	28 March	4 April	Standard Error
Leaves of oats	57.9	43.2	37.4	41.2	32.0	20.7	5.1
Stems of oats	19.6	16.8	16.9	12.9	13.4	13.3	1.1
Ears of oats	0.0	0.0	0.0	0.0	4.1	6.6	1.2
Leaves of ryegrass	13.1	27.0	31.1	30.9	34.5	40.6	3.8
Stems of ryegrass	3.7	9.7	9.8	12.0	14.4	15.8	1.7
Dead material	5.6	3.2	4.8	2.9	1.5	3.0	0.6

Treatments did not differ in residual herbage mass and composition, which could be expected taking into account the criterion chosen to rule grazing management (uniform residual herbage irrespective of the level of supplementary feeding). The interaction between type of pastures and level of supplementary feeding was not significant. Mean herbage mass and composition per type of pastures are reported in Table 6. Average residual herbage mass of alfalfa and orchard grass pastures was 16% higher that that of oats and ryegrass pastures. Differences in morphological composition of residual herbage of both types of pastures were relatively small. Crude protein content of residual herbage of alfalfa and orchard grass pastures was higher, while its NDF and ADF contents were lower. With the exception of CP content, differences in composition of residual herbage between types of pastures did not resemble differences in composition of herbage on offer. No difference among treatments was detected in the utilisation of each type of pasture (Appendix, Table 2), but utilisation of oats and ryegrass pastures was much higher (Table 7). This higher utilisation of oats and ryegrass pastures should have necessarily led to less selective grazing (Poppi et al., 1987), and therefore to grazing residuals with poorer nutritional composition (Table 6). Net herbage production of oats and ryegrass pastures was 90% higher than that of alfalfa and orchard grass pastures (Table 7).

No differences among treatments were detected in the chemical composition of hand-plucked samples (Table 8). Nutritional composition of hand-plucked samples from alfalfa and orchard grass pastures appeared to be slightly more favourable.

Table 6. Herbage mass, morphological and chemical composition of residual herbage.

	Oats and Ryegrass	Alfalfa and orchard grass	Std. Error	P
Herbage mass (kg DM ha^{-1})	1949	2257	75	0.001
Leaves (% of DM)	22.1	23.8	0.9	0.048
Leaves (kg DM ha^{-1})	442	535	26	0.001
Stems (% of DM)	43.1	37.9	1.1	0.001
Dead material (% of DM)	34.8	38.3	1.2	0.002
Crude Protein (% of DM)	7.1	16.5	0.3	0.001
Acid Detergent Fibre (% of DM)	45.6	34.7	0.7	0.001
Neutral Detergent Fibre (% of DM)	74.0	54.4	1.3	0.001
Metabolisable energy (Mcal kg^{-1} DM)	1.91	2.32	0.03	0.001
DM Digestibility (%)	55.0	65.8	0.8	0.001

Table 7. Herbage production and utilisation of oats and ryegrass pastures and alfalfa and orchard grass pastures.

	Oats and ryegrass	Alfalfa and orchard grass	Standard Error	P
Utilisation (%)	66.6	39.5	1.1	0.001
Net herbage production (kg DM ha^{-1} d^{-1})	47.0	24.7	2.0	0.001

Table 8. Chemical composition of hand-plucked samples of oats and ryegrass pastures and alfalfa and orchard grass pastures.

	Type of pasture	kg DM of maize silage cow^{-1} d^{-1}								
		0	1.6	3.2	4.8	Std. Error	P	Mean	Std. Error	P
CP (% of DM)	Oats and ryegrass	15.7	18.9	15.0	14.8	2.2	0.72	16.1	1.1	0.001
	Alfalfa and orchard grass	27.0	28.4	27.1	22.2			26.2		
	Mean	21.4	23.7	21.1	18.5	1.6	0.19			
ADF (% of DM)	Oats and ryegrass	30.7	28.8	29.8	31.7	1.6	0.87	30.3	0.8	0.002
	Alfalfa and orchard grass	24.0	23.2	25.1	27.5			24.9		
	Mean	27.4	26.0	27.4	29.6	1.1	0.20			
NDF (% of DM)	Oats and ryegrass	53.8	48.1	52.3	54.7	2.7	0.86	52.2	1.4	0.001
	Alfalfa and orchard grass	40.4	39.1	40.5	44.7			41.2		
	Mean	47.1	43.6	46.4	49.7	1.9	0.21			
Digestible DM (% of DM)	Oats and ryegrass	72.7	75.3	74.0	71.4	1.9	0.87	73.3	0.9	0.015
	Alfalfa and orchard grass	78.1	78.8	76.9	74.0			76.9		
	Mean	75.4	77.0	75.4	72.7	1.3	0.18			
ME Mcal $kgDM^{-1}$	Oats and ryegrass	2.58	2.69	2.64	2.53	0.06	0.87	2.61	0.04	0.014
	Alfalfa and orchard grass	2.82	2.84	2.77	2.64			2.77		
	Mean	2.70	2.77	2.70	2.59	0.08	0.18			

Milk production, milk composition and body condition.

One cow of the treatment offered 3.2 kg DM maize silage cow^{-1} d^{-1} was removed from the experiment due to health problems, and was therefore not included in the analysis of any of the response variables. Milk production per cow was negatively affected by supplementary feeding with maize silage (Table 9). The level of supplementary feeding with maize silage did not affect milk composition (Table 9) and the change in body condition (Table 10). Average body condition improved during the experiment. Sixteen cows tended to improve condition ($p<0.20$) and only two tended to lose body condition ($p<0.20$). According to NRC (1989) such a change could be expected since most cows were in the second half of their lactation period. The effect of the co-variable months in lactation was significant ($p=0.016$).

Table 9. Milk production and composition from grazing cows offered different levels of maize silage.

	kg DM of maize silage cow^{-1} d^{-1}					
	0	1.6	3.2	4.8	Std. Error	P
Kg milk cow^{-1} d^{-1}	19.5	18.0	18.3	17.6	0.2	0.001
Fat (%)	3.68	3.83	3.41	3.70	0.23	0.638
Protein (%)	3.09	3.15	2.94	2.98	0.13	0.637
Lactose (%)	4.50	4.54	4.61	4.64	0.07	0.416
Non fat solids (%)	8.27	8.37	8.24	8.33	0.14	0.916
Milk Urea Nitrogen (mg dl^{-1})	32.4	31.9	34.4	34.1	3.0	0.857

Table 10. Changes in body condition of cows offered different levels of maize silage.

	kg DM of maize silage cow^{-1} d^{-1}					
0-5 score scale	0	1.6	3.2	4.8	Std. Error	P
Initial body condition of cows in milk	3.0	2.9	3.0	3.1	0.2	
Final body condition of cows in milk	3.4	3.5	3.4	3.4	0.2	
Linear increase in units d^{-1}	0.0085	0.0086	0.0063	0.0050	0.0029	0.776

Dry matter intake and substitution rate.

Herbage intake was strongly affected by the level of supplementary feeding and the type of pastures. However, the interaction between these two factors was not significant (Table 11). Herbage intake was 83% higher in oats and ryegrass pastures than in alfalfa and orchard grass pastures and was severely depressed in both types of pastures by increasing levels of supplementary feeding with maize silage. Intake on oats and ryegrass pastures represented 65% of total herbage intake (Appendix, Table 2).

Least square means of intake estimates using requirements and faecal output were almost the same (Table 12). Data from both methods correlated well (r = 0.81), though on average estimates based on requirements were slightly higher. Intake estimates based on pasture sampling were higher than with the other two methods, but the difference decreased with increasing levels of supplementary feeding.

Table 11. Herbage intake estimated by sampling of pastures [kg DM $(100\ kg\ LW)^{-1}(0.5\ d)^{-1}$] of dairy cows receiving different levels of supplementation with maize silage while grazing oats and ryegrass pastures and alfalfa and orchard grass pastures.

Type of pasture	kg DM of maize silage $cow^{-1}\ d^{-1}$						Type of pasture		
	0	1.6	3.2	4.8	Standard Error	P	Mean	Standard Error	P
Oats and annual ryegrass	1.99	1.63	1.32	1.15	0.07	0.001	1.52	0.06	0.001
Alfalfa and orchard grass	1.09	0.89	0.74	0.62	0.07		0.83		
Mean	1.54	1.26	1.03	0.88	0.06	0.001			

The estimation of substitution rates depended on the method used to estimate intake (Figure 4; Appendix, Table 3). The differences among the estimates of substitution rates based on requirements and faecal output were rather small. The estimate of substitution rate based on herbage samplings was much higher and also higher than the highest reported values (Holden *et al.*, 1995; Moran and Wamungai, 1992).

Table 12. Least square means of herbage and total DM intake of grazing dairy cows (kg DM cow^{-1} d^{-1}) receiving different levels of supplementation with maize silage, estimated using three different methods.

	kg DM of maize silage cow^{-1} d^{-1}					
	0	1.6	3.2	4.8	Std. error	P
Intake estimates based on pasture samplings						
Herbage intake	16.48	12.93	11.21	8.97	0.638	0.001
Total DM intake	18.70	16.62	15.93	14.41	0.748	0.001
Intake estimates based on faecal output						
Herbage intake	13.6	11.7	10.8	8.2	0.81	0.001
Total DM intake	15.9	15.9	15.7	14.4	1.00	0.662
Intake estimates based on requirements						
Herbage intake	13.84	11.55	9.68	8.66	1.162	0.025
Total DM intake	16.54	15.74	15.05	15.25	1.150	0.800

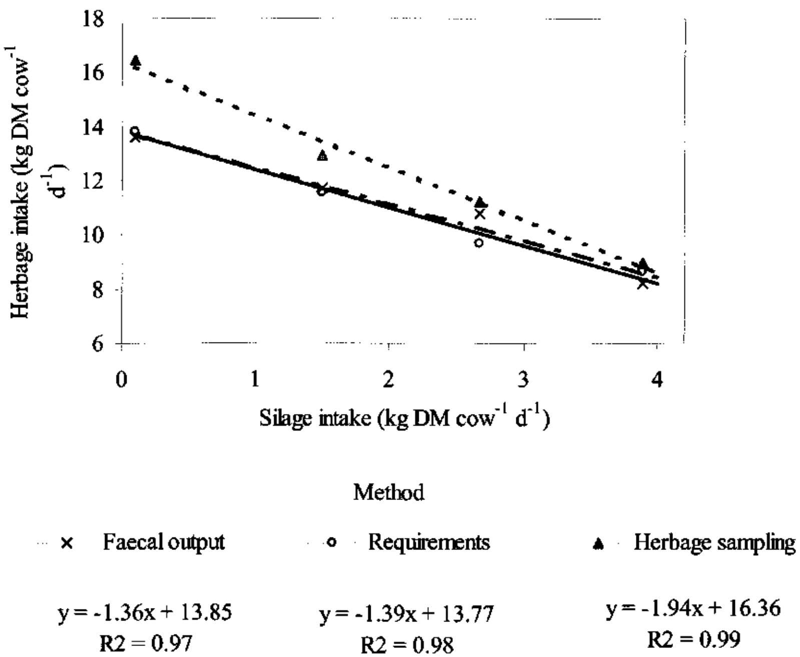

Figure 4. The effect of silage DM intake on herbage DM intake of dairy cows receiving different levels of supplementation with maize silage while grazing oats and ryegrass pastures and alfalfa and orchard grass pastures. Herbage DM intake was estimated with three different methods. Substitution rates are equal to the slopes of linear regressions equations.

Pattern of daily activities

Active grazing time decreased with increasing levels of supplementary feeding, while time spent eating silage increased and ruminating time tended to increase with it (Table 13). Reductions in grazing time took place only after the first 90 minutes of both grazing sessions (Table 14). When active grazing is expressed as proportion of the total time on paddocks (Table 13), it appears that at least part of the differences in grazing time were caused by the fact that grazing sessions of supplementary fed cows were shorter. On average, reduction of grazing time was 26 min per kg DM maize silage consumed (Table 15).

Average intake rate of maize silage was 35 g DM min^{-1} (Table 15) and appeared to be independent of level of supplementary feeding. It can be derived from Tables 3 and 13 that the average intake rate of maize silage was 33, 32 and 37 g DM min^{-1} for cows receiving 1.6, 3.2 and 4.8 kg DM maize silage per day respectively.

Table 13. Pattern of daily activities (min cow^{-1} d^{-1})

	kg DM of maize silage cow^{-1} d^{-1}					
	0	1.6	3.2	4.8	Std. Error	P
Active grazing	470	400	387	323	21	0.002
Active grazing (% of time on paddocks)	34.8	34.1	34.4	30.1	1.7	0.124
Eating silage	0	46	84	105	5	0.001
Ruminating	470	488	503	516	16	0.188
Resting	458	474	428	453	26	0.615
Other activities including milking	42	32	38	43	8	0.085

Ruminating time increased with increasing intake of supplementary forage (Table 15). This was also found by Phillips and Leaver (1986). A comparison of data in Tables 3 and 13 shows that the increase in ruminating time was 12.0, 12.4 and 11.8 min per kg silage DM consumed for cows receiving 1.6, 3.2 and 4.8 kg DM maize silage per day respectively.

Table 14. Time of active grazing during different intervals of the grazing sessions (minutes per interval).

		kg DM of maize silage cow^{-1} d^{-1}								
Type of Pasture	Interval (min)	0	1.6	3.2	4.8	Std. Error	P	Mean	Std. Error	P
Oats and Ryegrass	0-30	30	30	30	30	6.9	0.001			
	31-90	56	53	55	53					
	>90	160	145	125	96					
Alfalfa and Orchard grass	0-30	30	29	29	30					
	31-90	41	46	52	49					
	>90	141	116	133	86					
Oats and Ryegrass	Total	247	228	210	179	14	0.032	216	8	0.011
Alfalfa and Orchard grass	Total	212	190	215	165			195		

Table 15. Regression equations of silage intake (kg DM cow^{-1} d^{-1}) on time consuming silage (min d^{-1}), and grazing time and ruminating time (min d^{-1}) on silage intake.

	Intercept	Linear estimate	R^2	RSD	P	N
Silage intake	0	0.035	0.82	0.464	0.001	14
Grazing time	481	-26	0.54	38	0.001	19
Ruminating time	468	12	0.22	37	0.044	19

Data on biting rates did not cover night grazing on alfalfa and orchard grass pastures and standard errors of means were high. There was no significant effect of supplementary feeding on biting rate. Biting rate was high at the beginning of the grazing session and decreased as the grazing sessions progressed (Figure 5).

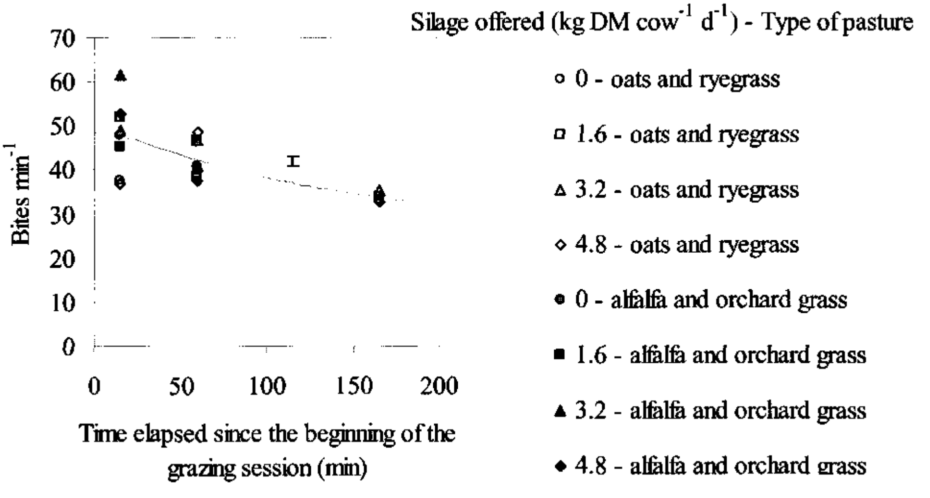

Figure 5. Biting rate of cows receiving different levels of supplementary feeding with maize silage at different moments of the grazing sessions. Vertical bar depicts standard error.

Stocking rate and milk production per hectare

Supplementary feeding with maize silage resulted in reduced herbage intake, and therefore daily areas allotted to cows decreased with increasing levels of supplementary feeding. It can be derived from Table 16 that herbage allowance for half a day in each type of pasture was reduced on average with 0.26 kg DM $(100 \text{ kg LW})^{-1}$ per kg of silage offered daily per cow. It can be also calculated that stocking rate increased with the level of silage on offer at a rate of 0.32 cows ha^{-1} per kg DM silage offered daily per cow. On alfalfa and orchard grass pastures, stocking rate as well as net herbage production and herbage intake tended to be lower in third-year pastures sown without previous crop rotation (Table 17). As a result of the increase in stocking rate (Table 16), and in spite of the reduction in milk production per cow (Table 9), milk production per hectare increased with the level of supplementary feeding (Table 18). Combining data in Tables 3, 16 and 18, in Figure 6 the responses to supplementary feeding in terms of kg extra milk per kg DM of silage offered (Figure 6a) and kg extra milk per kg DM of maize silage consumed (Figure 6b) were calculated as the slopes of the linear equations. It must be borne in mind that this is type of calculation only involves the response during the months when cows are supplementary fed with maize silage. To estimate the response of the system on an annual basis, the effect of allotting a certain proportion of the area to silage maize during the summer on stocking rate and productivity must be taken into account.

Table 16. Stocking rate and herbage allowance of dairy cows receiving different levels of supplementation with maize silage while grazing oats and ryegrass pastures and alfalfa and orchard grass pastures.

Dependent variable	Type of pasture	kg DM of maize silage cow^{-1} d^{-1}						Type of pasture		
		0	1.6	3.2	4.8	Std. Error	P	Mean	Std. Error	P
Stocking rate (cows ha^{-1})	Oats and annual ryegrass	2.21	2.54	3.22	3.79	0.14	0.851	2.94	0.07	0.382
	Alfalfa and orchard grass	2.10	2.58	3.12	3.61	0.14		2.85		
	Mean	2.16	2.56	3.17	3.70	0.10	0.001			
Herbage Allowance [kg DM (100 kg LW)$^{-1}$(0.5 d)$^{-1}$]	Oats and annual ryegrass	2.97	2.49	1.99	1.71	0.13	0.164	2.29	0.10	0.012
	Alfalfa and orchard grass	2.76	2.24	1.85	1.57	0.13		2.10		
	Mean	2.87	2.36	1.92	1.64	0.11	0.001			

Table 17. Stocking rate, net herbage production and herbage intake of alfalfa and orchard grass pastures in different condition.

	Condition of pastures				
	Second-year pastures sown after crops	Third-year pastures sown after crops	Third-year pastures sown without previous crop rotation	Standard Error	P
Stocking rate (cows ha-1)	3.1	2.7	2.5	0.15	0.001
Net herbage production (kg DM ha^{-1} d^{-1})	23.9	27.0	20.2	2.5	0.062
Herbage intake [kg DM (100 kg LW)$^{-1}$ (0.5 d^{-1})]	0.74	0.96	0.73	0.10	0.025

Table 18. Milk production per hectare with grazing dairy cows receiving different levels of supplementation with maize silage.

	kg DM of maize silage cow^{-1} d^{-1}					
	0	1.6	3.2	4.8	Std. Error	P
Kg milk ha^{1} d^{-1}	40.1	42.9	49.5	53.9	1.8	0.001

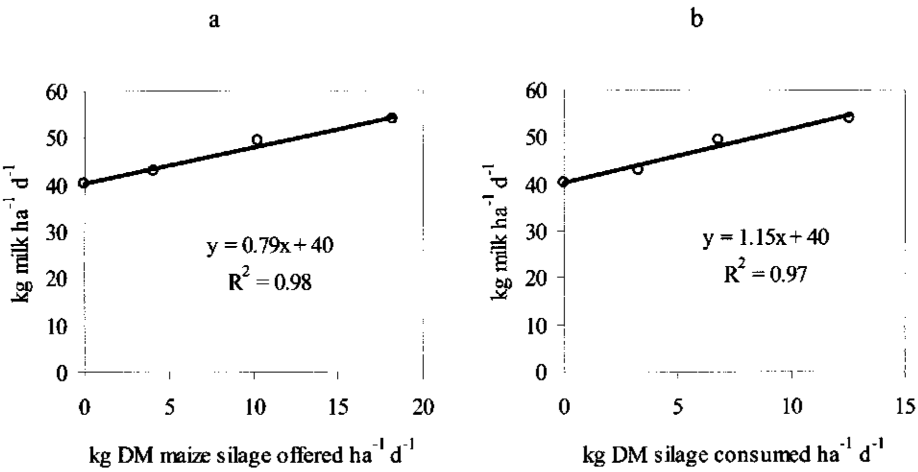

Figure 6. Relationship between daily milk production per hectare and silage offered daily per hectare (a) and silage consumed daily per hectare (b).

Discussion

Milk production per hectare

Milk production per hectare increased at a rate of 0.79 kg extra milk per kg DM silage offered^{-1} (Figure 6a). Based on the conceptual model in Figure 1 and the results in Tables 9 and 16 it can be concluded that this response was due to the increase in stocking rate in spite of the reduction in milk production per cow. In a three-year experiment, Mosqueda-Losada and González-Rodríguez (1998) also found that even though milk production per cow was reduced by the inclusion of maize silage, production per hectare increased if stocking rate was raised when including maize silage per hectare increased. If the response in milk production per hectare is expressed in terms of silage consumed, it amounts to 1.15 kg milk per kg DM silage consumed. Reported responses (estimated per cow) are usually below 1; Stockdale (1994a and 1997b) considers that responses of 1.2 to 1.4 kg extra milk per kg DM of maize silage consumed are very favourable. When data of Experiment 1 reported by Phillips and Leaver (1985) are converted to estimate the response on hectare basis, it appears that a response of 1.29 kg extra milk per kg DM grass silage consumed was attained.

The prices of maize silage and milk during 1998 and 1999 were US $ 0.025 per kg of purchased maize silage (US $ 0.092 kg^{-1} DM) and US $0.321 per kg milk (see chapter 7). Taking this price ratio into account, the alternative of purchasing the maize silage to be fed was economically feasible. In the most simplistic analysis, the net revenue was very large (US

$ 1.75 per US $ spent in maize silage). A sounder economical analysis should consider the costs involved in increasing stocking rate (depreciation of cattle, medicine and reproduction), the costs of the increase in labour requirements and the costs of installations required to make efficient utilisation of the silage offered (see Figure 2). However, the revenue was so large that these extra costs should be affordable.

The analysis of the economic feasibility of the alternative of cropping silage maize is more complicated because it requires the additional estimation of costs and carrying capacities of permanent pastures and winter and summer annual pastures. The silage required to feed cows during 7 months at the highest level used in this experiment (4.8 kg DM silage offered cow^{-1} d^{-1}, 18.2 kg DM silage offered ha^{-1} d^{-1}) could have been produced on 0.24 ha of silage maize per ha of grazed pastures. This estimates is based on conservative assumptions of yield and losses of 19 Mg DM ha^{-1} yield of maize and conservation losses of 15%. The proportion of area sown to annual pastures (during autumn and winter) and silage maize (during spring and summer) in the sequential cropping system on which the dairy system under study is based, can fluctuate between 20% (4 years of permanent pastures and one year of annual pastures and silage maize) and 40% (3 years of permanent pastures and two years of annual pastures and silage maize). If the proportion of the area sown to annual pastures and silage maize is 20%, approximately 15% of the maize silage to be fed should be purchased. On the other end, if the proportion of the area sown to annual pastures and silage maize is 40%, cropping approximately one half of that area with silage maize would produce the required maize silage. The other half of that area should be sown to summer annual pastures, in order to withstand during spring and summer the increased stocking rate.

Stocking rate

Stocking rate increased with the level of supplementary feeding. From the data in Table 16 it can be estimated that offering 3 kg DM silage cow^{-1} d^{-1} were required to increase stocking rate of 1 cow ha^{-1}. From the linear regression between data on silage intake (Table 3) and stocking rate (Table 16) it can be estimated that stocking rate increased with 0.4 cow ha^{-1} per kg DM of maize silage consumed. No reports were found in the literature on supplementary feeding with maize silage that could be confronted with these results. Only data reported by Phillips and Leaver (1985) using grazing cows supplementary fed with grass silage are useful. In their Experiment 1 the response in stocking rate was 0.67 cow ha^{-1} per kg silage DM consumed. Even though stocking rates in that experiment were substantially higher than in the current experiment, that response is rather close to the one found here.

The required adjustment of short-term decisions on grazing management can be estimated from data in Tables 3 and 16. The linear regression between silage intake in kg DM (100 kg LW)$^{-1}$ d^{-1} (Table 3) and herbage allowance in kg DM (100 kg LW)$^{-1}$ d^{-1} (Table 16) shows that daily herbage allowance decreased with 3.3 kg DM for each kg DM of maize silage consumed.

Herbage intake, ingestive behaviour and substitution rate

The increase in stocking rate as a response to increasing levels of supplementary feeding with maize silage (Table 16) was caused by the reduction in herbage intake (Figure 4) as depicted in Figure 1. When discussing results on herbage intake by grazing animals, it must be borne in mind that according to Coates and Penning (2000), "Making accurate estimates of digestibility and intake in grazing animals, the very factors that together determine animal productivity, still presents real difficulties in most situations and remains a challenge". Results obtained with different methods differ when they are used simultaneously to estimate intake (Moran and Croke, 1993; Reeves *et al.*, 1996b; Malossini *et al.*, 1996; Chilibroste, 1999). Chacon *et al.* (1976; quoted by Ungar, 1996) stated that "Without an absolute measure of herbage consumption by grazing animals there is doubt as to the accuracy of any technique".

Results on herbage intake and therefore on substitution rates differed among the methods used to estimate herbage intake. Estimates of substitution rates using faecal output and animal requirements, though high, were within the range of reported values. From Figure 4 and Table 12, it appears that the unreliable high estimate of substitution when using herbage samplings, originated in the high estimate of herbage intake of the group receiving no supplementary feeding. Moran and Croke (1993) stated that any error in the estimation of herbage intake by the group not receiving supplementary feeding accentuates errors in the estimation of substitution rates. Herbage DM intake of this group (as estimated by herbage samplings) was very close to the maximum DM intake of dairy cows assumed by Leaver (1985). Overestimation of herbage intake based on herbage sampling (as it appears to have been in this case), might originate in overestimation of herbage mass on offer or underestimation of residual herbage mass. This estimate of intake was done on an area basis, and when converted into intake per cow overestimation increases with the area allotted per cow, and therefore with decreasing levels of supplementary feeding.

Estimates of substitution rates based on requirements and on faecal output were -1.39 and -1.36 kg DM herbage per kg DM silage, respectively (Figure 4). Phillips (1988) concluded that in case of maize silage substitution rates are equal or less than 1, but reported values or substitution rates calculated from published data on herbage and supplement intake range from 0 (Moran and Croke, 1993; Stockdale, 1994a) to 1.5 and 1.74 (Holden *et al.*, 1995; Moran and Wamungai, 1992). Substitution rates have been found to increase with availability of herbage (Meijs, 1986; Holden *et al.*, 1995) and level of supplementary feeding (Moran and Croke, 1993; Stockdale, 1994a). Interactions between these two factors might occur such as reported by Meijs and Hoekstra (1984) using concentrates as supplementary feed for grazing cows.

Reduction in intake due to supplementary feeding with maize silage was linked to reduction in grazing time. Krysl and Hess (1993) conclude that supplementary feeding to grazing animals leads to a decrease in grazing time. Leaver (1985) estimated that when sward condition or grazing management are not particularly limiting intake, a maximum reduction in grazing time of 25 min per kg of concentrate DM can be expected. Reductions in grazing time when forages are fed supplementary appear to be higher. Phillips and Leaver (1986) report reductions of 14 to 37 min per kg DM forage consumed, which corresponds with the average value of 26 min per kg DM maize silage consumed as found in the current experiment (Table 15). Ruminating time increased with increasing intake of supplementary forage (Table 15). This is accordance with Phillips and Leaver (1986) and might be related to the increasing fibre content of the total diet. From data collected by Phillips and Leaver (1985) it can be estimated that grazing cows supplementary fed with grass silage increased ruminating time with about 15 min per kg silage DM consumed. In the current experiment the increase in ruminating time was about 12 min per kg DM maize silage consumed, independent of level of supplementation.

Return to pastures of unsupplemented cows took place immediately after milking. Return to pastures of the other groups was dictated by the silage intake of the group receiving the highest level of supplementary feeding. Cows receiving lower levels of supplementation had regularly finished eating silage earlier and were therefore experienced to some extent of fasting before the beginning of the grazing session. It has been reported by Phillips and Leaver (1986) that supplementary feeding has no effect on biting rate. Therefore, it might be assumed that the higher initial biting rate of those groups was a response similar to those reported by Demment and Greenwood (1988) for fasted animals. In accordance with Chilibroste (1999), biting rate diminished as the grazing session advanced (Figure 5). However, management and environment might affect the daily evolution of biting rate and therefore results might differ among experiments. Working with dairy cows receiving supplementary feeding with forages under continuous grazing, Phillips and Leaver (1986) found that biting rate increased with time of the day. Gibb *et al.* (1998) and Barrett *et al.*

(2000) report that biting rate decreased during the morning grazing session but increased towards the late evening during the afternoon and evening grazing session.

Average herbage intake rates can be roughly estimated from the least square means presented in Tables 12 and 13. When estimates of herbage intake based on faecal output and animal requirements were used for the calculation, herbage intake rates were the same across methods of estimating intake and levels of supplementary feeding, averaging 1.7 kg DM h^{-1}. This result is close to the daily average intake rate reported by Barrett *et al.* (2000) for cows strip-grazing perennial ryegrass (grazing periods of one day). However, when the estimates of herbage intake based on pasture sampling was used for the calculation, herbage intake rate decreased with the level of supplementary feeding in contrast with e.g. Phillips and Leaver (1986). Furthermore, the resulting average intake rate of the unsupplemented group (2.1 kg DM h^{-1}) is close to what Barrett *et al.* (2000) report as the potential intake rate of cows grazing a fresh strip of perennial ryegrass pasture of high intake potential (2.11 kg DM h^{-1}). These results reinforce the assumption that herbage intake was overestimated when based on samplings of pastures.

Milk production per cow

Milk production per cow decreased with increasing levels of supplementary feeding with maize silage (Table 9). Bryant and Donnelly (1974), Moran and Wamungai (1992) and Mosqueda-Losada and González-Rodríguez (1998) have also reported negative responses. Reports on the response to supplementary feeding with maize silage in terms of milk production per cow range between 1.4 kg extra milk per kg dry matter (DM) of silage consumed (Stockdale, 1997b) and negative (Bryant and Donnelly, 1974; Mosqueda-Losada and González-Rodríguez, 1998). Milk responses to supplementary feeding depend on many factors but it appears that the nature of this response depends strongly on the quality and the abundance of grazed herbage which can be expressed in different ways such as herbage allowance, average pasture height or hours that animals are allowed to graze. Responses increase with decreasing abundance of grazed herbage (Phillips, 1988; Stockdale 1994b, 1997a) and decreasing quality of grazed herbage (Stockdale, 1997b).

These results suggest that negative responses originate in high substitution rates particularly when the quality of the maize silage is lower than that of the herbage being substituted. In this experiment, substitution rates were relatively high, and the quality of maize silage was lower than that of herbage. Therefore, the negative response in milk production could be expected.

Milk composition

Fat and protein content in milk (Table 9) appeared to be in the range of values usually reported (Muller and Fales, 1998; Donovan *et al.*, 2000). However, fat content was somewhat lower than those reported by Moran, Stockdale and colleagues working in Australia (Moran, 1992; Moran and Stockdale, 1992; Moran and Wamungai, 1992; Moran and Croke, 1993; Stockdale 1994a). According to Butler (1998), levels of milk urea nitrogen (MUN) should be considered as too high, but were in the range of values reported for cows grazing temperate pastures (Holden *et al.*, 1995; Charmandarian *et al.*, 1997; Trevaskis and Fulkerson, 1999).

The level of supplementary feeding with maize silage did not affect milk composition (Table 9). Milk fat and protein are generally not affected by supplementary feeding with maize silage (Moran, 1992; Moran and Wamungai, 1992; Moran and Croke, 1993; Holden *et al.*, 1995; Mosqueda-Losada and González-Rodríguez, 1998). Whenever changes in fat or protein content have been reported, the effects are rather small and not consistent between reports (Meijs, 1986; Moran and Stockdale, 1992; Valk, 1994; Stockdale 1994a).

Supplementary feeding with maize silage did not affect MUN concentrations (Table 9). With increasing levels of supplementary feeding CP content of the average diet decreased. Therefore, a decrease in MUN concentrations would have been expected because this has been reported for related variables such as blood urea nitrogen (BUN) (Holden *et al.*, 1995), nitrogen content in urine (Valk, 1994) or ammonium nitrogen in rumen fluid (Stockdale and Dellow, 1995; Stockdale1994b and 1997b). By partial substitution of ryegrass pasture with maize silage, McCormick *et al.* (1999) reduced CP and rumen degradable protein contents of the diet; whereas plasma urea nitrogen concentrations were reduced from 25.0 to 20.1 mg dl^{-1}. On the contrary, when maize silage was used as a supplementary feed for cows grazing an orchard grass pasture with a very high CP, Holden *et al.* (1995) found only modest reductions in BUN concentrations from 29.6 to 27.3 mg dl^{-1}.

MUN concentrations were high and according to Butler (1998), MUN and BUN concentrations above 19 to 20 mg dl^{-1} may lead to decreased conception rates in dairy cows. Charmandarian *et al.* (1997) surveyed MUN concentrations and reproductive performance of cows grazing alfalfa pastures on dairy enterprises in Argentina. Milk urea nitrogen concentration averaged 25.3 mg dl^{-1}, ranging from 16.7 to 30.9 mg dl^{-1}, and was negatively correlated with the number of services per conception. Reducing plasma urea concentrations from 25.0 to 20.1 mg dl^{-1} resulted in improved reproductive performance of cows (McCormick *et al.*, 1999). However, Trevaskis and Fulkerson (1999) found no evidence of association between MUN levels and reproductive performance of dairy cows grazing kikuyu and ryegrass pastures. Results of McCormick *et al.* (1999) suggest that grazing cows may be more tolerant of high plasma urea concentrations than housed cows receiving total mixed rations.

Body condition

The response to supplementary feeding can be affected by the proportions of the ingested energy partitioned to milk production or body reserves, which is expressed in changes in live weight or body condition (see Figure 1). Most cows improved their body condition during the experiment and the level of supplementary feeding did not affect the change in body condition (Table 10). Reports on the effect of supplementary feeding with maize silage on body condition or live weight changes range from negative (Mosqueda-Losada and González-Rodríguez; 1998), no effect (Moran, 1992; Moran and Croke, 1993) to positive (Moran and Stockdale, 1992; Moran and Wamungai, 1992; Stockdale 1994a, Valk, 1994). As a result of supplementary feeding a certain proportion of the ingested energy might be partitioned to body reserves. It is regularly assumed that proportions of energy partitioned to milk production or body reserves depend on the stage of lactation (NRC, 1989) and genetic merit of the cows (Viglizzo, 1981). But in case of supplementary feeding, these proportions also depend on the composition of the supplement (Mould, 1993), or the composition of grazed herbage (Moran and Wamungai, 1992). Severe weight losses, which could be avoided by supplementary feeding, can adversely affect subsequent fertility (Moran and Wamungai, 1992). Therefore, the assessment of the financial returns of supplementary feeding should not ignore the longer-term benefits produced via body fat stores (Leaver, 1985).

Comparison between oats and ryegrass pastures and alfalfa and orchard grass pastures

Comparisons between the two types of pastures are not conclusive since the effect of type of pastures might be confounded with the effect of morning and later grazing activities of the cows. However, the management of morning grazing on annual pastures and afternoon and night grazing on permanent pastures is the one being used in the current system. Such management is aimed to balance the daily composition of the diet and to reduce the risks of bloat. Crude protein content of alfalfa and orchard pastures is much higher than that of oats and ryegrass pastures, and high levels of crude protein with a high rumen degradable protein fraction can jeopardise the efficiency of energy and nitrogen utilisation (Valk, 1994), and the reproductive performance of cows (McCormick *et al.*, 1999). Therefore, alternating on a daily basis grazing of alfalfa and orchard grass with grazing of oats and ryegrass grass aims to reduce the levels of highly rumen degradable protein in the diets of cows. The incidence of bloat for cattle grazing alfalfa pastures might be reduced by moving cattle onto fresh alfalfa pastures only in the afternoon (Maj *et al.*, 1995; quoted by Popp *et al.*, 1999). A rotational stocking method of alfalfa and orchard grass pastures is used in the current dairy system in order to increase the persistence of alfalfa (Blaser *et al.*, 1986). The grazing period is one day (strip grazing) in order to avoid fluctuations in daily milk production which occur with longer grazing periods (Blaser *et al.*, 1986). Grazing of alfalfa in the afternoon and night is implemented in order to reduce the incidence of bloat.

The net productivity of oats and ryegrass pastures doubled that of alfalfa and orchard grass pastures, partially due to the difference in utilisation (Table 7). Differences in herbage accumulation rate (not measured) might have also played a role because after similar rest periods oats and ryegrass pastures had 54% higher herbage mass on offer (Table 4). Consequently oats and ryegrass pastures contributed for about two-thirds to the total amount of herbage consumed by the cows (as estimated from herbage samplings). Oats and ryegrass pastures were superior to alfalfa and orchard grass pastures in nearly all of the attributes studied: i) higher net herbage production, ii) higher herbage intake at similar stocking rates and daily herbage allowances, iii) higher efficiency of utilisation, iv) higher proportion of green leaves and lower proportion of dead material and v) lower protein content (which might be considered as an advantage). According to Wheeler (1981), these advantages justify the use of annual forage crops in grazing systems, in spite or their higher costs per unit of dry matter. In the current system the annual costs of permanent pastures considering 3 years of duration were 799 US \$ ha^{-1} $year^{-1}$, whereas the costs of winter annual pastures were 717 US \$ ha^{-1} per growing season of 7 months (Chapter 7). These 54% higher production costs of annual pastures were counteracted by the 90% higher net herbage production (Table 7).

Herbage mass on offer and the amount and proportion of green leaves in oats and ryegrass pastures were much higher than in alfalfa and orchard grass pastures, whereas the proportion of dead material was much lower (Table 4). The vertical structure of the canopy was not measured in this experiment, but a comparison of results of alfalfa and orchard grass pastures obtained in previous research (López, 1995) with results of oats and ryegrass pastures reported in Chapter 4, suggests that annual pastures produce a higher proportion of the aboveground herbage above 5 cm height. These differences in vertical structure concur with the higher residual herbage mass of alfalfa and orchard grass (Table 6), even though both pastures were managed to a similar height of residual herbage. High herbage mass, high proportion of green leaves and low proportion of dead material are factors expected to favour herbage intake of grazing ruminants (Poppi et al., 1987). Bite weight and hence herbage intake are expected to be higher in taller canopies (Ungar, 1996). The more favourable structure of oats and ryegrass pastures explains why in these pastures the efficiency of herbage utilisation was 69% higher (Table 7) and herbage intake was 83% higher (Table 11), while the difference in daily herbage allowance was only 9% (Table 16).

Intake per bite is the component of ingestive behaviour most closely related with total daily intake, while biting rate might increase as a result of lower bite weight (Ungar, 1996). Comparing data on herbage intake (Table 11) with data on grazing time (Table 14) suggests that average intake rate was higher on the oats and ryegrass pastures. When Figure 7 is also included in this comparison it appears that the higher intake rate was the consequence of a higher average bite weight. Following Poppi *et al.* (1987) the higher initial bite weight on oats and ryegrass pastures can also be expected from data on mass and composition of herbage on offer (Table 4). Therefore, the higher intake on the oats and ryegrass pastures (Table 11) might have been the consequence of a higher average bite weight.

Crude protein content of alfalfa and orchard grass pastures was much higher than that of oats and ryegrass pastures. This content has been found to be closely related with the proportion of alfalfa (Ballesteros and Flores, 1994). Pastures in the current experiment were indeed dominated by alfalfa (Figure 3), and that appears to be the normal situation in this type of pastures particularly during the winter (Sánchez *et al.*, 1996). Composition of herbage of oats and ryegrass pastures might therefore be considered complementary to that of alfalfa and orchard grass in two aspects: a) by reducing the concentration of dietary crude protein which might impair the efficiency of energy and nitrogen utilisation and the reproductive performance of cows, and b) by reducing the risk of bloat which is a major problem when grazing pastures where alfalfa is dominant (Popp *et al.*, 2000), and thus when concentrations of soluble proteins are high (Coulman *et al.*, 2000).

The proportion of alfalfa in green herbage decreased from 70% in second-year pastures to 66% in third-year pastures and to 57% in third-year pastures which were sown without previous crop rotation (Table 5a). The decrease in the proportion of alfalfa with the age of pastures appears to be a normal event under grazing (Smith *et al.*, 2000). Cragnaz (1987) found that after grazing alfalfa and tall fescue (*Festuca arundinacea*) pastures during three seasons with a stocking method comparable to the one used in the current experiment (1 day grazing, 35 days rest), the density of alfalfa plants decreased with 43% and the productivity of pastures decreases with 28%. Popp *et al.* (1997) report that after 3 years of grazing the content of alfalfa in alfalfa and grass pastures decreased from 70% to 30-40%. Stocking rate and net herbage production were lower in third-year pastures which were sown without previous crop rotation (Table 17). In spite of the lower stocking rate, daily herbage intake was also lower (Table 17). Those changes might be linked with the lower proportion of alfalfa because

Ballesteros and Flores (1994) found that herbage accumulation rate and the efficiency of utilisation in alfalfa and orchard grass pastures increased with the proportion of alfalfa. The lower stocking rate, the lower net herbage production and the lower herbage intake of third-year pastures sown without previous crop rotation suggest that sowing without previous crop rotation should be avoided in this dairy system.

Composition of maize silage

The quality of the maize silage used in this experiment was low which might be partly due to the early stage in which the crop was harvested. The DM content was lower and the crude protein, neutral detergent fibre and acid detergent fibre contents were higher than values reported by Deinum *et al.* (1984), Meijs (1986), NRC (1989), and Holden *et al.* (1995).

The composition was comparable to what NRC (1989) reports as "maize silage with few ears". The silage used in this experiment had relatively few ears because when the cob is in the milk stage, many are taken by the local population for human consumption.

Nevertheless, the composition of the silage used in this experiment was better than that of maize silage produced in the regio as reported by Andrade and Contreras (1997). In that report dry matter and crude protein contents were lower while neutral detergent fibre and acid detergent fibre contents were higher than found in the current experiment.

Considering all components, the nutritional composition of maize silage (Table 2) was poorer than that of herbage on offer (Table 4) and consumed herbage (Table 8). However, due to its lower nitrogen:energy ratio it is to be expected that when this maize silage is fed supplementary to cows grazing temperate pastures (with a high nitrogen:energy ratio and a high rumen degradable protein fraction) the efficiency of energy and nitrogen utilisation and the reproductive performance will be improved.

Utilisation of maize silage.

Maize silage refusals increased with the amount of silage on offer (Figure 2). The same response can be calculated from data reported by Meijs (1986) and Stockdale (1994a). However, at comparable levels of silage on offer, refusals in those experiments were lower than found here. Silage refusals in the current experiment were also higher than those calculated from reports by Moran (1992) and Moran and Stockdale (1992), but lower than estimated from reports by Moran and Jones (1992) and Valk (1994).

Phillips and Leaver (1985) found that time of exposure to supplementary grass silage affected the amount of refusals. According to Campling and Morgan (1981; quoted by Moran and Jones, 1992), silage intake rates range between 1.5 and 2 kg DM h^{-1}. Meijs (1986) observed that two sessions of two hours each were sufficient to achieve a maize silage intake of 4 kg DM cow^{-1} d^{-1}. Therfore, time of exposure could not have been a limiting factor for intake in the current experiment. At the highest level of refusal, cows were exposed during 4.5 hours to 4.8 kg DM of maize silage. Intake rates of maize silage (35 g DM min^{-1}) were much lower than those reported by Phillips and Leaver (1986) for grass silage, whereas intake rates of maize silage appeared to be independent of the level of supplementary feeding (Tables 3 and 13).

Preference might also play a role in silage refusals. Phillips (1988) suggests that maize silage is generally consumed in preference to grazed herbage, and Leaver (1985) shares that opinion. However, Moran and Jones (1992) and Valk (1994) report that cows preferred herbage. In the experiment reported in Chapter 4, with cows grazing oats and ryegrass pastures, it was observed that cows preferred herbage and at high herbage allowances they were reluctant to eat silage and waited for herbage to be offered like reported by Valk (1994). The low DM content of maize silage used in the current experiment (27%) might have been involved in this preference, since Phipps (1990) concluded that DM content exerts a major effect on DM intake.

During the initial phase of the experiment, when silage was offered collectively on the paddocks, refusals of maize silage were much higher, particularly at the highest levels of silage offered (Figure 2). In his review, Phillips (1988) concludes that offering supplementary conserved forages in the field can result in increased feed wastage. Interference of dominant cows when supplements are offered to groups (Bowman and Sowel, 1997) might also have been involved in this response. In terms of efficiency at the system level these results imply that cows should be penned when fed maize silage. This should be taken into account when evaluating financial returns of supplementary feeding, because building of additional installations is then required.

Conclusions

In spite of uncertainty in the estimation of substitution rates, the effects of increasing supplementary feeding on average stocking rate and milk production per hectare could be accurately estimated, justifying the approach used in this experiment. Under the management used in this experiment substitution rate appeared to be high, leading to increments in stocking rate. These increments and those in milk production per hectare were strong and justified supplementary feeding up to the highest level used in this experiment. Reductions in herbage intake were coupled with reductions in grazing time. Grazing time in turn appeared to be at least partially affected by reduced residence time in paddocks, but that reduction is required in order to achieve the targeted silage intake. Oats and ryegrass pastures were superior to alfalfa and orchard grass pastures, justifying the use of annual forage crops in this dairy system, in spite of the higher costs per unit of dry matter.

Appendix to Chapter 3

Table 1. Schedule of implemented measurements; day 1 is 1 February 1998.

Measurement	Days
Silage refusals in the paddocks	1, 2, 3, 7, 8, 9, 14, 15, 16, 23, 24, 25,
Silage refusals of penned cows	42, 43, 50, 51, 56, 57, 63, 64, 70, 71,
Faecal output	58, 59, 60, 61, 62, 65, 66, 67, 68
Gathering of hand-plucked herbage samples	59, 65, 66
Herbage on offer	1, 9, 10, 19, 27, 33, 38, 40, 45, 47, 49, 55, 62, 69
Residual herbage	9, 10, 16, 19, 27, 30, 37, 39, 40, 47, 50, 51, 56, 60, 62, 68, 69, 74
Milk production per cow	32, 33, 38, 39, 40, 46, 47, 52, 53, 54, 55, 56, 59, 60, 66, 67, 73, 74,
Body condition	14, 30, 36, 43, 50, 57, 64, 71
Samples for milk composition	59, 60, 66, 67, 73, 74
Pattern of activities and ingestive behaviour	54, 55, 56, 73, 74
Stocking rate	3-9, 10-15, 19-26, 30-37, 40-43, 51-54, 62-64,

Models used in analysis of variance.

Model 1

$Y_{ij} = \mu + T_i + P_j + E_{ij}$

where

Y_{ijk} = Response variable: herbage mass on offer, proportions of morphological and chemical components in herbage on offer

μ = general mean

T_i = effect of type of pasture, i = 1, 2

P_j = effect of paddocks j = 1 to 7

E_{ij} = error term

Model 2

$Y_{ijk} = \mu + S_i + T_j + S\times T_{ij} + P_k + E_{ijk}$

where

Y_{ijk} = Response variable: mass and composition of residual herbage, daily herbage allowance, stocking rate, herbage intake based on herbage sampling

μ = general mean

S_i = effect of the level of supplementary feeding with maize silage, i = 1 to 4

T_j = effect of type of pasture j = 1, 2

$S\times T_{ij}$ = effect of the interaction between the level of supplementary feeding with maize silage and the type of pasture

P_k = effect of paddocks, k = 1 to 7

E_{ijk} = error term

Model 3

$Y_{ijk} = \mu + S_i + C_j(S_i) + D_k + E_{ijk}$

where

Y_{ijk} = Response variable: variables related to daily pattern of activities, intake based on faecal output, silage intake

μ = general mean

S_i = effect of the level of supplementary feeding with maize silage, i = 1 to 4

C_j = effect of cow nested in level of supplementary feeding, j = 1 to 24

D_k = effect of day of measurement, k = 1 to 5 for daily pattern of activities, k=1 to 9 for intake based on faecal output, k = 1 to 10 for silage intake

E_{ijk} = error term

Model 4

$Y_{ij} = \mu + S_i + D_j + B_1X_1 + B_2X_2 + B_3X_3 + E_{ij}$

where

Y_{ij} = Response variable: milk production and composition

μ = general mean

S_i = effect of the level of supplementary feeding with maize silage, i = 1 to 4

D_j = effect of day of measurement, k = 1 to 19

B_1X_1 = linear effect of weeks in milk

B_2X_2 = linear effect of number of lactation

B_3X_3 = linear effect of average daily production during a lactation

E_{ij} = error term

Model 5

$Y_{ijklm} = \mu + S_i + T_j + (S\times T)ij + I_k[(S\times T)ij] + C_l(S_i) + D_m + E_{ijklm}$

where

Y_{ijklm} = Response variable: variables related to ingestive behaviour

μ = general mean

S_i = effect of the level of supplementary feeding with maize silage, i = 1 to 4

T_j = effect of type of pasture, j = 1, 2

$(S\times T)_{ij}$ = effect of the interaction between the level of supplementary feeding with maize silage and the type of pasture

I_k = effect of Interval of the grazing session nested in level of supplementary feeding × type of pastures, k = 1 to 4
C_l = effect of cow nested in level of supplementary feeding, l = 1 to 24
D_m = effect of day of measurement m = 1 to 5
E_{ijklm} = error term

Model 6
$Y_{ij} = \mu + S_i + P_j + E_{ij}$
where
Y_{ijk} = Response variable: milk production per hectare, total DM intake based on herbage sampling
μ = general mean
S_i = effect of the level of supplementary feeding with maize silage, i = 1 to 4
P_j = effect of paddocks, k = 1 to 4
E_{ij} = error term

Model 7
$Y_{ij} = \mu + S_i + E_{ij}$
where
Y_{ij} = Response variable: intake based on requirements, change in body condition
μ = general mean
S_i = effect of the level of supplementary feeding with maize silage, i = 1 to 4
E_{ij} = error term

Model 8
$Y_{ijk} = \mu + S_i + W_j + (S \times W)_{ij} + E_{ijk}$
where
Y_{ij} = Response variable: silage refusals
μ = general mean
S_i = effect of the level of supplementary feeding with maize silage, i = 1 to 4
W_j = effect of way of feeding, j = 1,2
$(S \times W)_{ij}$ = effect of interaction between level and way of supplementary feeding
E_{ijk} = error term

Table 2. Utilisation and production of pastures grazed by dairy cows receiving different levels of supplementation with maize silage.

Dependent variable	Type of pasture	kg DM silage offered cow^{-1} d^{-1}						Type of pasture		
		0	1.6	3.2	4.8	Std. Error	P	Mean	Std. Error	P
Proportion of total herbage intake (%)	Oats and annual ryegrass	64.7	65.3	64.7	65.1	2.0	0.001	65.0	1.0	0.001
	Alfalfa and orchard grass	35.3	34.7	35.3	34.9			35.0		
Utilisation %	Oats and annual ryegrass	67.1	65.4	66.4	67.3	1.7	0.001	66.6	1.1	0.001
	Alfalfa and orchard grass	39.6	39.5	39.4	39.3	1.7		39.5		
	Mean	53.4	52.5	52.9	53.3	1.4	0.929			
Utilised herbage Kg DM ha^{-1} grazing $cycle^{-1}$	Oats and annual ryegrass	3903	3800	3852	3910	94	0.001	3866	60	0.001
	Alfalfa and orchard grass	1491	1489	1461	1457	94		1474		
	Mean	2697	2645	2656	2684	73	0.919			
Utilised herbage Kg DM ha^{-1} d^{-1}	Oats and annual ryegrass	48.1	45.5	46.6	47.7	2.5	0.001	47.0	2.0	0.001
	Alfalfa and orchard grass	25.2	25.0	24.5	24.1	2.5		24.7		
	Mean	36.7	35.3	35.5	35.9	2.1	0.850			

Table 3. Regression equations of herbage intake [y in kg DM (100 kg $LW)^{-1}$ d^{-1}] on silage intake [x in kg DM (100 kg $LW)^{-1}$ d^{-1}], for three methods of estimating intake. Data between brackets are the 95% confidence interval of coefficients.

Method	Model	R^2	P	Residual Standard Deviation	n
Herbage sampling	$y = 3.01\ (\pm 0.23) - 1.92\ (\pm 0.56)\ x$	0.65	0.001	0.355	28
Faecal output	$y = 2.61\ (\pm 0.12) - 1.22\ (\pm 0.23)\ x$	0.55	0.001	0.344	93
Requirements	$y = 2.75\ (\pm 0.28) - 1.14\ (\pm 0.58)\ x$	0.51	0.001	0.351	19

Chapter 4

Allowance - intake relationship for dairy cows grazing oats and annual ryegrass pastures

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Summary

The relationships between stocking rate and levels of production are of capital importance, but research conducted to establish the range of adequate stocking rates faces difficulties. Stocking rate and daily herbage allowance are closely related, and herbage intake is the variable on which these long- and short-term decisions are based. The response of herbage intake to daily herbage allowance is used to manage the short-term balance between feed demand and feed supply. However, the intake-allowance relationships are of low generality. The interpretation and extrapolation of results might be improved by analysing the response of herbage intake to herbage allowance in terms of the state-rate functional response.

An experiment was conducted to estimate the average stocking rate likely to maximise milk production per unit of area. The estimate was based on the response of herbage intake of dairy cows to four levels of daily herbage allowance [2.0, 4.1, 6.0 and 7.6 kg DM (100 kg LW)$^{-1}$ d^{-1})] while grazing oats-annual ryegrass pastures and supplementary fed with maize silage and concentrates. The experiment was also aimed to explore whether the response of herbage intake to herbage allowance, could be mechanically described as a function of the effect that the previously taken bites (per unit of area) exerted on herbage mass and structure. Herbage intake, the composition of consumed herbage, the daily areas allotted to cows, and the length of the grazing and rest periods were measured. The mass and structure of the sward and the ingestive behaviour of the cows were monitored during the grazing sessions.

The stocking rate attained with the level of herbage allowance 4.1 kg DM (100 kg LW)$^{-1}$ d^{-1} (4.6 cows ha^{-1}) maximised production per unit of area. The high productivity attained with this stocking rate (99 kg milk ha^{-1} d^{-1}) was partially due to supplementary feeding. The associated

height of residual herbage of 7 (±1.6) cm could be used as a target in short-term decisions of grazing management.

Herbage intake was severely depressed at the lowest level of herbage allowance. This decrease was the consequence of lower average bite weight and reduced active grazing time. Increasing herbage allowance above 4.1 kg DM (100 kg LW)$^{-1}$ d^{-1} reduced the efficiency of herbage utilisation without improvement in the performance per cow.

Average bite weight decreased with declining average herbage mass above 5 cm irrespective of the combination of allowances and intervals of the grazing session. This relationship and the number of bites taken per unit of area explained herbage utilisation during the first 90 minutes of the morning grazing session. Therefore, the number of bites taken per unit of area was a suitable variable to analyse the response of intake to herbage allowance in terms of the state-rate functional response.

Introduction

The design and management of grazing systems involve decisions on the balance between feed demand and feed supply (Sheath and Clark, 1996). In the long-term, the balance is largely affected by stocking rate. Consequently, the relationships between stocking rate and levels of production are of capital importance. However, research conducted to establish the range of adequate stocking rates for any system faces difficulties in terms of interpretation (Bransby, 1989) and extrapolation of results (Burns *et al.*, 1989). In the short-term, decisions on herbage allowance are used to manage the balance. However, decisions taken on stocking rate have a dominant effect since average herbage allowances are negatively related to stocking rate (Holmes, 1987).

Sheath and Clark (1996) state that decisions on stocking rate compromise individual animal performance and levels of pasture utilisation because it is not possible to maximise simultaneously intake per animal and animal production per hectare. According to Ungar (1996) herbage intake is a major determinant of animal production. Therefore, it is the most appropriate criterion to base many within-season management decisions (e.g. daily herbage allowance). Herbage intake is therefore the link between system management decisions taken at different levels of the time scale. It has been stated by Ungar (1996) that better knowledge and understanding of intake should facilitate better management. However, as stated by Wade and Carvalho (2000), if understanding of intake is sought as a means to improve management, mechanisms that control intake should be analysed with reference to limitations to intake that result from grazing pressure or method. Taking this into account, at the system level efficiency must be evaluated with consideration of the interplay between daily intake per animal and intake per unit area.

The relationship between intake rate and abundance of food is termed functional response. It has been widely shown that the shape of this function is a saturation curve. On a daily time-scale the post-ingestive processes limit intake by available grazing time and by the intake rate during active grazing. Within periods of active grazing, intake rate is limited by the spatial and morphological properties of the vegetation (Ungar, 1996). Many attributes have been used to describe pastures in terms of herbage availability to grazing animals. Burns *et al.* (1989) list among these sward height, bulk density and mass per unit area, botanical and morphological composition.

Ungar (1996) states in his review that even though some of these attributes of pastures may correlate well with intake rate, none of them is by itself an adequate explanatory variable, due to the complexity of the process of grazing. In the short-term, intake rate is considered as the product of bite weight and biting rate. The functional relationship between intake rate and sward structure (height, bulk density, stiffness, morphology, strength) is complex. It involves effects of the sward structure on bite area and depth, leading to bite weight.

There is doubt whether the knowledge on the functional response can be used to improve grazing management under intensive rotational grazing. According to Ungar (1996), the functional response is a state-rate relationship and is therefore strictly instantaneous. Each bite taken by an animal depletes the sward and changes the mean sward structure. This effect is relevant under intensive rotational grazing because animals must select bites from already grazed areas. Consequently, the initial conditions of the sward are not relevant to what the animal experiences on a daily time-scale and a state-rate functional response that attempts to predict daily intake rate does not hold. For this reason, intake studies on high depletion systems must attempt to relate daily intake rate to herbage allowance.

The responses of herbage intake to herbage allowance are difficult to translate into management practices because of two main reasons. In the first place, since herbage allowance tells nothing about sward structure, the intake-allowance relationships are of low generality (Ungar, 1996) and might be useful only in the environment in which they were generated (Stockdale, 1985). The generality of the intake-allowance relationships is also limited because it its affected by the levels of herbage mass on offer and of supplementary feeding (Wales *et al.*, 1999). In the second place, the responses to herbage allowance are usually studied in terms of intake per animal but intake per unit of area is not analysed. If high production per unit of area is targeted, intake per animal must be compromised. But the levels of restriction to individual intake likely to maximise production per unit of area cannot be precisely derived from the response of herbage intake per animal.

It is posed that results on the response of herbage intake to herbage allowance can be used to estimate the levels of stoking rate likely to maximise production per unit of area. This approach enables an objective translation of that response into management practices. Moreover, it is also posed that at a bite level, the response of herbage intake to herbage allowance can be described as a function of the effect that the previously taken bites per unit of area exerted on herbage mass and structure. This approach, which is based on number of bites per unit of area, enables an analysis of the interplay between intake per animal and intake per unit of area.

An experiment was conducted to estimate the response of herbage intake of dairy cows to increasing levels of daily herbage allowance while grazing oats-annual ryegrass pastures and supplementary fed with maize silage and concentrates. According to the classification by Ungar (1996) of approaches to study intake, the experiment was designed primarily as management-oriented problem solving but allowing also for the elucidation of some causal relationships. The experiment was aimed to establish the average stocking rate likely to maximise production per unit of area, based on the response of herbage intake to herbage allowance. In order to accomplish this objective, besides herbage intake, also the composition of consumed herbage, the daily areas allotted to cows, and the length of the grazing and rest periods were measured. The experiment was also aimed to explore whether the response of herbage intake to herbage allowance, could be mechanically described as a function of the effect that the previously taken bites (per unit of area) exerted on herbage mass and structure. In order to accomplish this objective, the mass and structure of the sward and the ingestive behaviour of the cows were monitored during the grazing sessions.

Materials and methods

Pastures, animals, treatments and design

The experiment was carried out in 1999 between 22 February and 16 April at the Farmlet for Dairy Production under Grazing of Chapingo University, located at 19°29' N, 98°54' W and 2240 m above sea level. Climate is temperate and sub-humid with summer rains; average rainfall is 620 mm and average temperature is 18°C. The soil is loam of volcanic origin, deep, neutral and fertile.

Three hectares of a mixture of oats (*Avena sativa*), annual ryegrass (*Lolium multiflorum*) and barley (*Hordeum vulgare*) were used. Heavy rain in September and October 1998 precluded sowing and therefore pastures were sown during the first and second week of November. Due to the late sowing, barley was included in the mixture in order to reduce the interval between sowing and first grazing. Seed rates in kg pure germinating seed per ha were 60, 25 and 40 for oats (cv. Cocker 234), annual ryegrass (known as "common Westerwolds", cv. not specified) and barley (cv. Esmeralda), respectively. Pastures were fertilised at sowing with 60 kg P_2O_5 and 150 kg N ha^{-1} and after each grazing cycle with 150 kg N ha^{-1}. Sprinkling irrigation took place fortnightly with on average 67 mm per irrigation. The evaluation was carried out during the second and third grazing cycles of a rotational stocking system with 1 day of grazing and average rest periods of 46.6 (± 2.5) days. The first grazing took place in January 1999 (about 60 days after sowing).

Sixteen Holstein-Friesian dairy cows were allotted to four groups of 4 cows each, balanced according to number of days in lactation, previous production and live weight. During the experimental period, the average age was 2.66 (±0.18) lactations, average live weight was 560 (±17) kg, days in lactation were 185 (±30), and average production was 22.7 (±1.6) kg milk cow^{-1} d^{-1}. The experimental design was a latin square with 4 groups of cows that were offered 4 levels of targeted daily herbage allowance above ground level (2.5, 4.5, 6.5 and 8.5 kg DM $(100\ kg\ LW)^{-1}$ d^{-1}) during 4 periods of one week each. An estimation of herbage on offer was used to calculate the area to be allotted daily to each group. After dividing the daily area in halves with an electrical portable fence, it was offered as fresh pasture after each session of supplementary feeding with maize silage. The area offered in the morning remained open during the evening and night grazing session. Treatments are referred to as 'targeted' herbage allowance since actual herbage allowances could only be estimated after correcting herbage mass estimation for soil contamination and using pooled calibration equations. Between periods of evaluation, all cows were kept in the same groups and grazing was managed in order to maintain a uniform low residual herbage height.

Cows were offered 3 kg of concentrates and 4.9 kg DM of maize silage on a daily basis. Their average composition is given in Table 1. Milking took place between 7:00 and 8:00 and between 15:00 and 16:00 hours, 1.5 kg of concentrates was offered at each milking. After each milking, the cows were confined at one of the ends of the paddocks and were offered 36 kg maize silage per group. Grazing sessions did not start until it was visually estimated that at least 70 % of the offered silage had been eaten. At the lower allowances, utilisation of maize silage was usually higher than 70% because grazing sessions did not start if some cows were still eating silage. Rejected silage was weighed twice daily. At the higher herbage allowances the cows were reluctant to eat maize silage and even though they remained confined for longer periods (Table 2), silage refusal was higher than at the lower herbage allowances (Table 3).

Table 1. Average composition of maize silage and commercial concentrate offered to cows (g kg^{-1} DM); n.d.: not determined.

	Maize silage	Concentrate
Crude Protein	85	221
Acid Detergent Fibre	330	n. d.
Neutral Detergent Fibre	545	n. d.
Crude Fibre	n. d.	129
Fat	n. d.	40

Table 2. Average length of periods of confinement with maize silage and of grazing sessions (min d^{-1}).

	Targeted herbage allowance [kg DM (100 kg LW)$^{-1}$ d^{-1}]			
	2.5	4.5	6.5	8.5
Morning grazing session	148	148	124	123
Evening and night grazing session	750	746	715	705
Confinement with silage	450	468	539	543

Table 3 Least square means of maize silage refusals (g DM kg^{-1} DM offered).

	Targeted Herbage allowance [kg DM (100 kg LW)$^{-1}$ d^{-1}]				Standard error	P
	2.5	4.5	6.5	8.5		
Maize silage refusal	147	218	278	329	35	0.01

Pasture sampling

Herbage mass on offer and residual herbage mass

Sampling of pastures to estimate herbage on offer were carried out twice per grazing period, the day before the start of grazing and on day 4; sampling for the estimation of residual herbage took place on days 4 and 7.

Double sampling techniques were used for the estimation of herbage mass. Most techniques used involve visual estimates, capacitance meters, height measurements and compressed height measurements with discs or plates. Considering evaluations based on the comparison of residual standard deviations (RSD), until now no technique has proven to be clearly superior under a wide range of situations. Taking this uncertainty into account, five different techniques were used simultaneously: a single probe capacitance meter (Design Electronics ®), a rising plate (Jenquip®), a falling disc (50 cm diameter, 484 g weight), a sward stick based on the design shown by Hodgson (1990) adapted to the height of the pastures, and the comparative yield method (Haydock and Shaw, 1975) with two independent observers.

At each sampling, 7 to 12 calibration samples were randomly selected and cut. Following regular patterns, at each paddock measurements were taken at 100 points with the rising plate and the capacitance meter and at 50 points with the sward stick and the falling disc; visual estimations were done at 25 points by each observer. During the first two periods reference samples of herbage on offer were cut in three steps. In the first step, a strip of 1.75*1.0 m was cut with a Gravely® motorscythe at cutting heights varying between 6 and 9 cm. Due to irregular cutting height, a second strip of 1.75*0.52 m located in the centre of the first strip was cut to 5 cm height with a Snapper® rotary mower and in the third step the remainder herbage below 5 cm was cut to ground level using a 0.9 × 0.3 m frame and a knife. Due to mechanical failure of the motorscythe during periods 3 and 4, samples were then taken with the 0.9 × 0.3 m frame, in two steps, herbage above 5 cm and herbage between 5 cm and ground level. Calibration samples of residual herbage were cut to ground level using the 0.9 × 0.3 m frame.

After weighing, samples were divided in two sub-samples. The first sub-sample was used for a rapid estimation of DM content and the second one was used for ashing. Rapid estimation of DM content took place by drying 200 g of fresh herbage during 24 minutes in a microwave oven at high power followed by 7 hours in a conventional forced air circulation oven at 59°C. Calculated dry matter (DM) content was used to estimate herbage DM mass of the calibration samples. The second sub-sample was dried in a conventional oven at 59°C during 72 hours, weighed, ground in a Wiley® mill fitted with 1mm mesh and ash content was determined according to A. O. A. C. (1965).

Based on the estimated herbage DM mass of the calibration samples (without correction for soil contamination), regression equations were calculated for each indirect technique and herbage mass of each paddock was calculated with each technique using the average of the indirect measurements. The mean of all herbage masses on offer estimated by the different techniques was used to calculate the area to be allotted daily to each group according to treatments.

Samples of herbage taken with the motorscythe and of herbage above 5 cm using the frame were considered free of soil contamination. The average ash content of those samples [10.54 ± 0.17 g $(100\ g)^{-1}$ DM, n=65] was used to correct for soil contamination in the other herbage samples.

Botanical, morphological and chemical composition of herbage on offer and residual herbage

On day 4 (for herbage on offer) and on day 7 (for residual herbage), 20 samples per treatment were cut to ground level using a circular frame of 25 cm diameter. Samples were mixed to obtain one bulked sample per treatment, dried in a conventional forced air oven at 59°C during 72 hours, weighed, and ground in a Wiley® mill provided with 1 mm mesh.

Botanical and morphological composition was estimated using micro histological analysis (Williams, 1969). Leaf blade, leaf sheath, stem and inflorescence of each species were identified. In order to estimate the component pseudostems, the average proportion of leaf sheath and unemerged leaf in pseudostems was estimated in a set of hand-separated samples of pseudostems of each species. Data on density of components were converted into proportion of dry weight using prediction equations developed from samples of known composition.

Near infrared spectroscopy (NIRS, Laboratory of LALA S.A. de C.V., Torreón, Mexico) was used to quantify Crude protein (CP in % of DM), Neutral Detergent Fibre (NDF in % of DM), Acid Detergent Fibre (ADF in % of DM) and Metabolisable Energy (ME in Mcal kg DM^{-1}).

Sampling at different moments of the grazing session

On days 6 or 7 of each grazing period (two treatments per day), herbage samples were taken before morning grazing and after 30, 60 and 90 minutes of grazing. At those different moments, heights were measured with the sward stick, and visual estimation (comparative yield method Haydock and Shaw, 1975) was carried out by two observers working together. The means were calculated and a 0.90×0.30 m sample was located that represented simultaneously the average height and the average of visual estimation. This method of selecting samples is an adaptation of the paddock-mean method proposed by Thomson (1983). Using an adapted frame, samples were stratified clipped: herbage above 20 cm, between 10 and 20 cm, between 5 and 10 cm and between ground level and 5 cm. The samples were used for botanical, morphological and chemical analyses following the same protocol as for samples of herbage on offer and residual herbage. The amount of herbage of some stratified clipped samples was too small and therefore in those cases NIRS analysis was performed on pooled samples. Pooling of samples was based on herbage mass within canopy layer and period, irrespective of the combination of herbage allowance and moment of the grazing session.

Herbage intake, efficiency of utilisation and stocking rate

Herbage intake was calculated as the difference between herbage on offer and residual herbage and expressed as kg DM (100 kg LW)$^{-1}$ d^{-1}. Intake of maize silage was estimated in the same way. The degree of utilisation of herbage above ground level was calculated expressing the difference between herbage on offer and residual herbage as proportion of herbage on offer. Average daily areas allotted to each treatment during the one-week periods were used to calculate average stocking density in each treatment. Taking into account the length of the previous rest period, stocking rate during the grazing cycle was calculated according to Equation 1.

$$SR = \frac{SD \times GD}{GD + RD} \qquad (1)$$

where:

SR: stocking rate [cows ha^{-1} (grazing cycle)$^{-1}$]

SD: stocking density (cows ha^{-1})

GD: grazing days (days)

RD: length of the previous rest period (days)

Pattern of activities of cows and ingestive behaviour

Measurements of activities and ingestive behaviour were carried out during 48 hours on the 6th and 7th day of each grazing period. Observations of activities of the cows were registered every 10 minutes. The activities taken into account were active grazing, eating silage, ruminating, resting, activities related to milking and other activities. Data were analysed considering three main bouts. The sum of morning and afternoon periods when cows were confined for supplementary feeding with maize silage was considered as a single bout. The morning and the evening and night grazing sessions were considered separately (bouts 2 and 3) and were subdivided in four intervals since the start of grazing: 0-30, 31-60, 61-90 and >90 minutes.

Biting rate was estimated by measuring the time required to take 100 bites at different moments of the grazing sessions. Number of bites per interval of the grazing session was calculated by multiplying biting rate by active grazing time. Total number of bites per day was calculated as the sum of bites taken during the different intervals of the grazing sessions. Average bite weight was not measured, but could be estimated by dividing daily intake of the group by total number of bites of the group.

Milk production

Daily milk production per cow was estimated by weighing milk of both milkings on the 7th day of each period. Milk production per hectare was calculated for each treatment by multiplying the stocking rate of each period by the least square mean of production per cow of the same period.

Statistical analysis

Data were subjected to analysis of variance using mixed models considering fixed and random effects (Littel *et al.*, 1996). Different response variables required different statistical models (see Appendix). Herbage allowance and interval of the grazing session were considered as fixed effects, while period, group of cows and cow nested in the group of cows were considered as random effects (Table 1 of the Appendix).

Results

Herbage on offer

Regression equations of herbage DM mass of samples (corrected for soil contamination) and readings of each indirect measurement were calculated using pooled data of both samplings within each period. Residual standard deviations (RSDs) and determination coefficients (R^2) were submitted to analysis of variance, considering effects of indirect measurements, period, nature of herbage mass (herbage on offer above 5 cm, herbage on offer above ground level and residual herbage) and the interactions among these factors. Data from period 4 were not included in the analysis because the capacitance meter was not used in that period, neither was the sward stick used in the measurements of residual herbage in that period. No difference ($p<0.05$) was detected between RSDs and R^2 of different indirect measurements (Table 4), and ranking of indirect measurements according to RSD and R^2 differed among periods (Table 5). Average RSD were lower for herbage on offer above 5 cm than for herbage on offer above ground level and residual herbage (Table 4).

Table 4 Main effects of nature of herbage mass and indirect measurement method on residual standard deviations (RSDs) and determination coefficients (R^2) of calibration equations.

	RSDs (kg DM ha^{-1})	R^2
Nature of herbage mass		
Herbage on offer above 5 cm	491 b	0.690 a
Herbage on offer above ground level	577 a	0.611 a
Residual herbage above ground level	657 a	0.701 a
Indirect measurements		
Sward stick	521 a	0.705 a
Falling disc	525 a	0.697 a
Visual estimation Observer 1	558 a	0.703 a
Visual estimation Observer 2	588 a	0.649 a
Capacitance meter	605 a	0.619 a
Rising plate	623 a	0.619 a

Means within columns with same letter are not significantly different ($p>0.05$).

Considering that none of the indirect measurements proved to be superior and taking into account that the precision of the estimate might be increased by pooling of data (Earle and McGowan, 1979) and the combination of different indirect measurements by means of multiple regression equations (Gabriëls and Van der Berg, 1993), the stepwise method was used to develop prediction equations for each nature of herbage mass. Capacitance readings were not considered in order to be able to include period 4 in the same equation. By means of these equations RSDs were reduced (Table 6). The resulting estimation of herbage mass was used to calculate actual herbage allowance, herbage intake and degree of utilisation.

Table 5. Ranking of indirect measurements according to residual standard deviations of calibration equations in three periods.

	Period		
Indirect measurement	First	Second	Third
Sward stick	2	6	2
Falling disc	3	3	1
Visual estimation Observer 1	6	1	3
Visual estimation Observer 2	5	2	4
Capacitance meter	4	5	5
Rising plate	1	4	6

Table 6. Regression equations of herbage mass (kg DM ha^{-1}) on indirect measurements.

	Herbage on offer		Residual herbage	
	Above 5 cm	Ground level	Periods 1, 2 and 3	Period 4
R^2	0.88	0.753	0.89	0.96
P	0.0001	0.0001	0.0001	0.0001
RSD	387	772	459	362
Intercept	-684	529	588	-3
Sward stick (cm)	68.33	58.84	183.3	
Falling disc (cm)	32.71			202.3
Rising plate (cm)	74.53	61.09		
Visual estimation Observer 2 (scale from 1 to 10)	136.06			
Visual estimation Observer 1 (scale from 1 to 10)			115.6	
N	65	65	31	17

The regression equations in Table 6 were used to estimate herbage mass on offer (Table 7). Actual allowances were on average 10% lower than targeted. Soil contamination of herbage samples below 5 cm is the most probable cause of these differences.

Table 7. Herbage mass on offer and actual herbage allowances.

	Targeted herbage allowance above ground level [kg DM (100 kg LW)$^{-1}$ d^{-1}]					
	2.5	4.5	6.5	8.5	Standard error	P
Herbage mass on offer (ground level) (kg DM ha^{-1})	4750	4815	4971	4874	355	0.470
Herbage mass on offer above 5 cm (kg DM ha^{-1})	2244	2392	2558	2439	278	0.239
Actual Herbage allowance above ground level [kg DM (100 kg LW)$^{-1}$ d^{-1}]	2.2	4.1	6.0	7.6	0.4	0.001

Average botanical composition of pastures showed a reasonable equilibrium among the three species (Table 8). The leaf:stem ratio was rather low and it appears that even though the inclusion of barley might have helped to reduce the interval between sowing and first grazing it also deteriorated the composition of herbage in the following grazing cycles (Tables 8 and 9). Cortes (1998) reported a stronger negative effect of barley on the composition of herbage on offer, which might have been caused by longer rest periods than in the current experiment.

The description of the structure of herbage on offer (Figure 1 and Table 9) is based on stratified clippings of paddock means taken on days 6 or 7 of each grazing period. Results of paddock means agree with those of herbage mass estimates based on indirect samplings and botanical and morphological composition estimated by means of compound samples. Herbage mass on offer for days 6 and 7 was 5324 (±530) kg DM ha^{-1} based on stratified clipped samples and 5194 (±116) kg DM ha^{-1} based on indirect sampling. The morphological compositions of stratified clipped samples and compound samples were similar. The correlation between the contents of leaves and stems of the different species of both types of samples was high (R^2= 0.75, P<0.001), the intercept was not different from 0 (P>0.05) and the linear estimate was not different from 1 (P>0.05).

Table 8. Average botanical and morphological composition of herbage on offer (% of total DM)

	Oats			Barley			Ryegrass	
	Leaves	Stems	Ears	Leaves	Stems	Ears	Leaves	Stems
Mean	15.3	13.4	1.7	7.8	16.7	2.7	23.9	18.5
Standard error	1.3	2.1	1.0	1.0	3.5	1.9	3.8	3.1

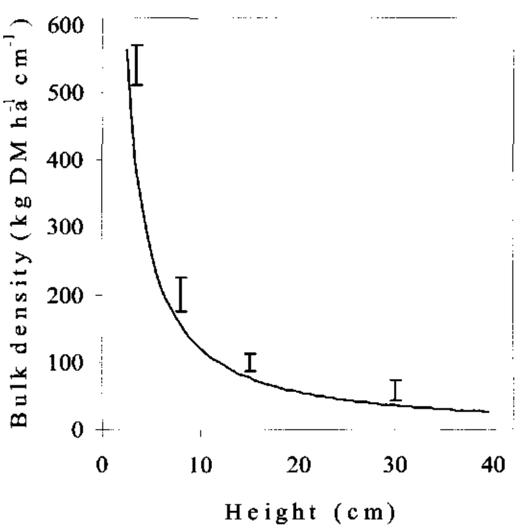

Figure 1. Average vertical distribution of the herbage on offer. Vertical bars depict standard error. Bulk density (kg ha^{-1} cm^{-1}) = $e^{7.35 - 1.11 \text{ Ln height (cm)}}$, R^2=0.84, p<0.001.

Table 9. Vertical distribution of botanical and morphological components in herbage on offer above ground level (kg DM ha^{-1})

	Layer of the canopy (cm from ground level)					
Component	0-5	5-10	10-20	>20	Standard error	P
Leaves of oats	272	156	318	182	53	0.001
Stems of oats	425	160	210	159	32	0.001
Ears of oats	1	1	13	111	19	0.001
Leaves of barley	125	67	118	96	23	0.017
Stems of barley	431	125	217	161	45	0.001
Ears of barley	0	1	4	81	17	0.001
Leaves of ryegrass	650	203	103	4	44	0.001
Stems of ryegrass	796	122	14	0	45	0.001

Oats and barley dominated the upper layers of the canopy and since both species were in the reproductive stage, the proportion of stems in those layers was high. The bulk density of herbage on offer decreased with height in the canopy (Figure 1). Burlison *et al.* (1991) reported that bulk density of the grazed stratum (upper layer of the canopy) of oats swards was lower than the mean bulk density. Mean bulk densities in that experiment were lower than found here. The lowest layer of the canopy had a high bulk density (Figure 1) and was dominated by stems and pseudostems (Table 9); most ryegrass was found in it, corresponding with the vegetative stage of this species and its (relative to oats and barley) less erect growth habit.

Mean values of Crude protein (CP), Neutral Detergent Fibre (NDF), Acid Detergent Fibre (ADF) and Metabolisable Energy (ME) contents of herbage on offer and its botanical and morphological components (Tables 10 and 11) were within the ranges quoted for temperate pastures (NRC, 1989; Minson, 1990; Sheaffer *et al.*, 1998). The nutritional quality of leaves of oats and stems of barley might be considered highest and lowest, respectively. Quality of herbage on offer increased with height within the canopy (Table 12). This agrees with findings of Buckmaster *et al.* (1997). Variation in proportions of botanical and morphological components between different layers of the canopy of herbage on offer explained 64% to 90% of the variation in chemical composition of those layers (Table 13).

Table 10. Average chemical composition of herbage on offer

	Crude Protein (% of DM)	Acid Detergent Fibre (% of DM)	Neutral Detergent Fibre (% of DM)	Metabolisable Energy (Mcal kg DM^{-1})
Mean	20.1	23.7	55.8	2.62
Standard error	0.9	0.5	2.2	0.02

Table 11. Chemical composition of pooled samples of morphological components.

Component	Crude Protein (% of DM)	Acid Detergent Fibre (% of DM)	Neutral Detergent Fibre (% of DM)	Metabolisable Energy (Mcal kg DM^{-1})
Leaf blades of oats	25.9	15.1	42.3	2.98
Leaf blades of barley	26.2	22.3	45.2	2.69
Leaf blades of ryegrass	19.9	17.6	46.8	2.87
Stems of oats	12.0	30.7	69.0	2.32
Stems of barley	9.6	30.3	72.8	2.35
Stems of ryegrass	15.9	26.7	62.6	2.50

Table 12. Average composition of herbage on offer of different layers of the canopy

	Component			
Layer (cm)	Crude Protein (% of DM)	Acid Detergent Fibre (% of DM)	Neutral Detergent Fibre (% of DM)	Metabolisable Energy (Mcal kg DM^{-1})
0-5	18.4	29.2	60.8	2.40
5-10	20.0	23.5	55.0	2.63
10-20	21.0	21.8	53.4	2.71
>20	22.4	20.7	53.9	2.76
Standard Error	1.4	1.0	2.1	0.04
P	0.012	0.001	0.001	0.001

Table 13. Regression equations of chemical composition on botanical and morphological composition.

	Chemical component			
	Crude Protein (% of DM)	Acid Detergent Fibre (% of DM)	Neutral Detergent Fibre (% of DM)	Metabolisable Energy (Mcal kg DM^{-1})
Morphological component	Estimate	Estimate	Estimate	Estimate
Stems of oats	-0.21	0.58	0.52	-.025
Leaves of barley	0.22			
Stems of ryegrass	0.13		-0.16	
Leaves of ryegrass	0.10			
Intercept	19.7	12.3	47.3	3.11
R^2	0.90	0.64	0.77	0.67
P	0.001	0.001	0.001	0.001
RSD	1.04	2.32	2.34	0.09

Changes in the canopy during the first 90 minutes of the morning grazing session.

Herbage utilisation above ground level during the first 90 minutes of the morning grazing session followed the expected evolution along four axes: herbage allowance, time elapsed since the beginning of grazing, vertical position in the canopy and relative preference of the components (Figure 2). The evolution of mean canopy height, which was closely linked to that of herbage mass above 5 cm (Figure 3), is depicted in Figure 4. Detailed information on herbage mass is given in Table 14 and information on herbage mass per morphological component is given in Table 15. Considering the combinations of herbage allowance and interval of the grazing session, utilisation of herbage above 20 cm and herbage between 10 and 20 cm (Table 14) did not differ and were closely correlated as shown in Figure 5. Albeit utilisation of herbage above 20 cm tended to be 8 points higher than that of herbage between 10 and 20 cm, the high correlation and the lack of differences suggest that the first horizon of grazing encompassed herbage above 10 cm. Therefore, in further analyses herbage above 10 cm was considered as a single layer of the canopy.

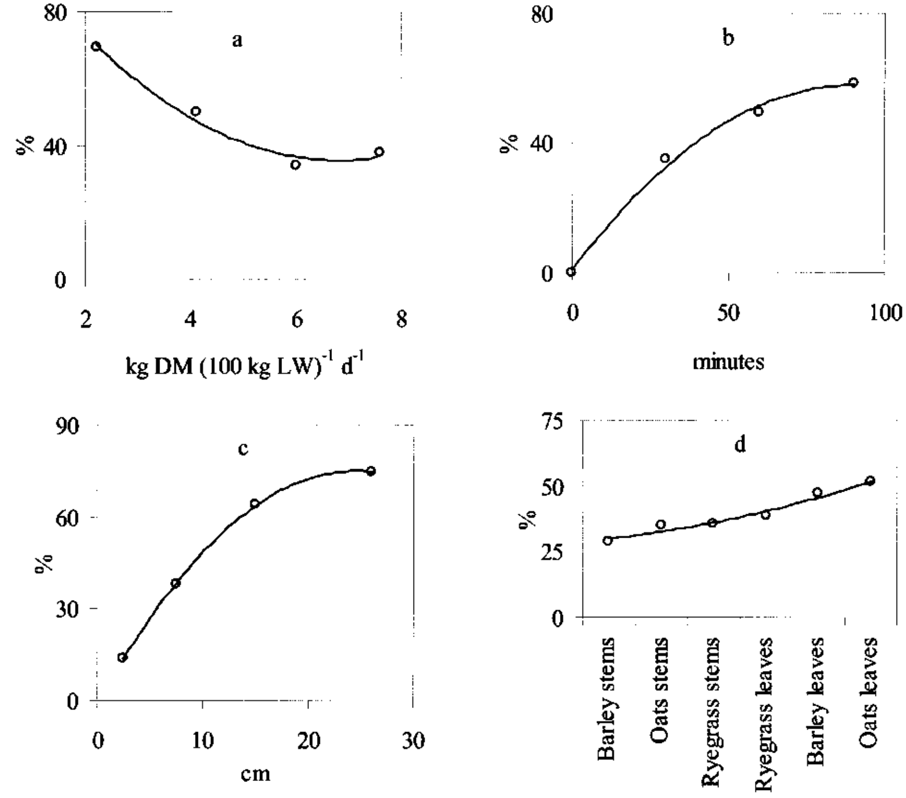

Figure 2. Herbage utilisation (%) during the first 90 minutes of the morning grazing session as affected by daily herbage allowance (a), interval of the grazing session (b), mean height of the canopy layer (c) and botanical and morphological component (d).

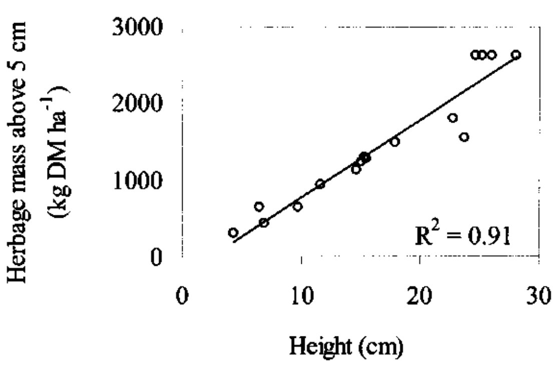

Figure 3. Relationship between least square means of herbage height and herbage mass above 5 cm during the first 90 minutes of the morning grazing session.

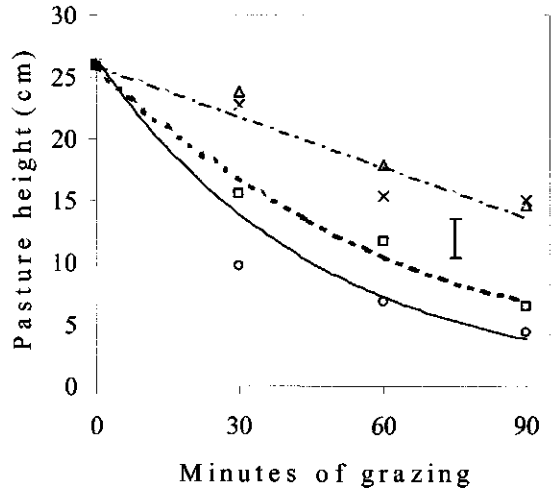

Figure 4. Least square means of pasture height (cm) during 90 minutes of grazing at four levels of daily herbage allowance: 2.0 (○), 4.1 (□), 6.0 (Δ) and 7.6 (×) kg DM (100 kg LW)$^{-1}$ d^{-1}. Vertical bar depicts standard error.

The interactions between the four major effects on utilisation become evident in Tables 14 and 15 by following a diagonal line from situations with very low utilisation at the lower left corner of the tables to situations with very high utilisation at the upper right corner of the tables.

Utilisation of herbage above 10 cm increased with decreasing allowance and increasing time elapsed since the beginning of the grazing session (Table 14). Differences between allowances became smaller as the grazing session progressed. At the lowest allowance utilisation of all components (except stems of barley) was above 80% after 30 minutes of grazing (Table 15a). At the two highest allowances, after 90 minutes of grazing, utilisation of leaves was 90% while that of stems was only 54%.

Deeper in the canopy differences between allowances became more striking. After 90 minutes of grazing the two lower allowances reached reasonable degrees of utilisation of all components between 5 and 10 cm, while at the two higher allowances that was only the case for the leaves of oats and barley (Table 15b). Significant herbage utilisation of the lowest layer of the canopy only took place at the lowest allowance during the first 30 minutes of grazing (Table 14), and this utilisation mainly concerned leaves of oats (Table 15c). Herbage mass in this layer increased after 30 minutes of grazing with the allowance 6.0 kg DM (100 kg LW)$^{-1}$ d^{-1}, probably due to trampling of herbage (Table 14). Standard errors of chemical composition were high and significant changes in herbage chemical composition due to utilisation could only be detected in the upper layer of the canopy (Figure 6).

Table 14. Least square means of herbage mass (kg DM ha^{-1}) in different layers of the canopy at different moments of the morning grazing session with herbage utilisation (%) between brackets.

		Minutes after the start of grazing					
Canopy Layer cm	DHA[1]	0	30	60	90	Standard error	P[2]
>20	2.2	794	128 (84)	79 (90)	0 (100)	186	0.001
	4.1		205 (74)	41 (95)	45 (94)		
	6.0		262 (67)	260 (67)	172 (78)		
	7.6		486 (39)	314 (60)	231 (71)		
10-20	2.2	997	262 (74)	74 (93)	50 (95)	138	0.001
	4.1		415 (58)	322 (68)	190 (81)		
	6.0		549 (45)	495 (50)	328 (67)		
	7.6		635 (36)	546 (45)	284 (72)		
5-10	2.2	834	244 (71)	274 (67)	245 (71)	125	0.002
	4.1		647 (22)	568 (32)	390 (53)		
	6.0		731 (12)	723 (13)	618 (26)		
	7.6		670 (20)	423 (49)	508 (39)		
0-5	2.2	2700	1771 (34)	1639 (39)	1447 (46)	323	0.179
	4.1		2653 (2)	2492 (8)	2215 (18)		
	6.0		3283 (-22)	3549 (-31)	3418 (-27)		
	7.6		2619 (3)	2361 (13)	2451 (9)		

[1] Daily herbage allowance kg DM (100kg $LW)^{-1}$ d^{-1}

[2] P of minutes after the start of grazing nested within daily herbage allowance.

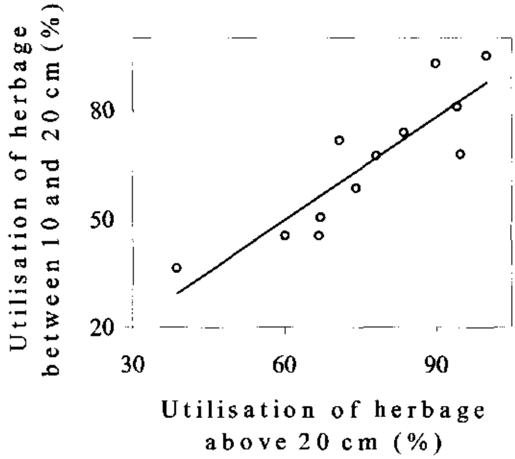

Figure 5. Relationship between the herbage utilisation of the two upper layers of the canopy.

Table 15. Least square means of herbage mass (kg DM ha^{-1}) of morphological components above 10 cm of height (Table 15a), between 5 and 10 cm height (Table 15b) and below 5 cm of height (Table 15c) at different moments of the grazing session at four daily herbage allowances with utilization (%) between brackets.

Table 15a.

		Stems			Leaves		
[1]DHA	[2]Mo	Barley	Ryegrass	Oats	Ryegrass	Barley	Oats
2.2	90	27 (93)	0 (100)	11 (98)	1 (99)	7 (96)	4 (99)
	60	85 (79)	0 (100)	40 (93)	1 (99)	15 (92)	12 (98)
	30	144 (64)	0.5 (97)	106 (82)	8 (91)	67 (66)	65 (87)
	0	400	15.8	577	87	196	516
4.1	90	121 (78)	0 (100)	66 (86)	4 (96)	26 (85)	19 (96)
	60	165 (70)	3.5 (81)	109 (77)	15 (87)	32 (82)	41 (91)
	30	227 (58)	2.5 (86)	187 (61)	39 (65)	78 (56)	87 (81)
	0	541	18.5	480	113	176	463
6.0	90	218 (51)	1.3 (87)	177 (56)	10 (92)	37 (86)	58 (89)
	60	308 (31)	5.5 (44)	216 (47)	26 (80)	102 (61)	99 (82)
	30	292 (35)	1.8 (82)	228 (44)	46 (65)	95 (63)	148 (72)
	0	446	9.8	406	132	260	537
7.6	90	300 (40)	0 (100)	132 (68)	7 (93)	46 (79)	28 (95)
	60	401 (19)	29.3 (-159)	211 (50)	36 (62)	99 (55)	83 (85)
	30	351 (29)	0.5 (96	332 (21)	23 (76)	180 (18)	233 (58)
	0	496	11.3	418	94	220	552
[3]SE		144	8	91	25	47	62
[4]P		0.003	0.309	0.001	0.004	0.001	0.001

Table 15b.

		Stems						Leaves					
[1]DHA	[2]Mo	Barley		Ryegrass		Oats		Ryegrass		Barley		Oats	
2.2	90	64	(50)	48	(63)	36	(74)	84	(61)	10	(86)	6	(96)
	60	44	(66)	57	(55)	48	(65)	92	(57)	11	(85)	24	(84)
	30	38	(70)	54	(58)	46	(67)	63	(71)	16	(77)	27	(82)
	0	128		128		139		214		71		154	
4.1	90	72	(57)	80	(25)	70	(61)	88	(54)	26	(52)	55	(59)
	60	95	(43)	94	(12)	129	(28)	132	(32)	33	(39)	85	(37)
	30	104	(37)	95	(11)	135	(25)	162	(16)	49	(9)	102	(24)
	0	166		107		180		193		54		134	
6.0	90	102	(14)	101	(23)	108	(19)	195	(9)	45	(43)	69	(56)
	60	141	(-18)	84	(36)	112	(16)	241	(-13)	49	(38)	96	(39)
	30	87	(27)	130	(1)	115	(14)	215	(0)	48	(399	137	(13)
	0	119		131		133		214		79		158	
7.6	90	114	(-11)	80	(39)	82	(46)	143	(21)	31	(48)	60	(71)
	60	62	(40)	106	(20)	69	(54)	107	(41)	19	(68)	60	(71)
	30	114	(-11)	130	(2)	127	(16)	149	(17)	33	(45)	119	(43)
	0	103		132		151		180		60		208	
[3]SE		28		39		30		44		11		34	
[4]P		0.048		0.612		0.014		0.170		0.004		0.001	

Table 15c.

		Stems						Leaves					
[1]DHA	[2]Mo	Barley		Ryegrass		Oats		Ryegrass		Barley		Oats	
2.2	90	275	(41)	429	(46)	311	(25)	260	(52)	56	(63)	116	(66)
	60	245	(47)	463	(41)	279	(33)	461	(14)	63	(58)	128	(62)
	30	316	(32)	510	(35)	294	(29)	355	(34)	96	(36)	200	(41)
	0	465		789		416		539		151		340	
4.1	90	428	(-1)	672	(-11)	351	(29)	468	(37)	91	(22)	205	(35)
	60	423	(0)	694	(-14)	426	(14)	551	(26)	91	(22)	308	(3)
	30	479	(-14)	641	(-5)	513	(-3)	658	(11)	77	(34)	286	(9)
	0	422		608		496		743		117		316	
6.0	90	515	(-7)	855	(-7)	630	(-77)	872	(-21)	105	(-7)	443	(-79)
	60	775	(-60)	970	(-22)	523	(-47)	917	(-27)	185	(-89)	179	(28)
	30	401	(17)	889	(-12)	554	(-56)	945	(-31)	110	(-12)	384	(-55)
	0	483		796		355		721		98		248	
7.6	90	344	(7)	829	(18)	247	(26)	755	(-31)	116	(11)	161	(44)
	60	379	(-2)	629	(37)	351	(-5)	715	(-24)	70	(46)	216	(24)
	30	459	(-24)	738	(27)	253	(24)	730	(-27)	77	(41)	362	(-27)
	0	371		1005		334		577		130		285	
[3]SE		99		143		82		147		31		91	
[4]P		0.444		0.653		0.396		0.765		0.153		0.065	

[1] Herbage allowance Kg DM (100 kg LW)$^{-1}$ d^{-1}; [2] Minutes after the start of the morning grazing session; [3] Standard error; [4] P of minutes after the start of the morning grazing session nested within daily herbage allowance.

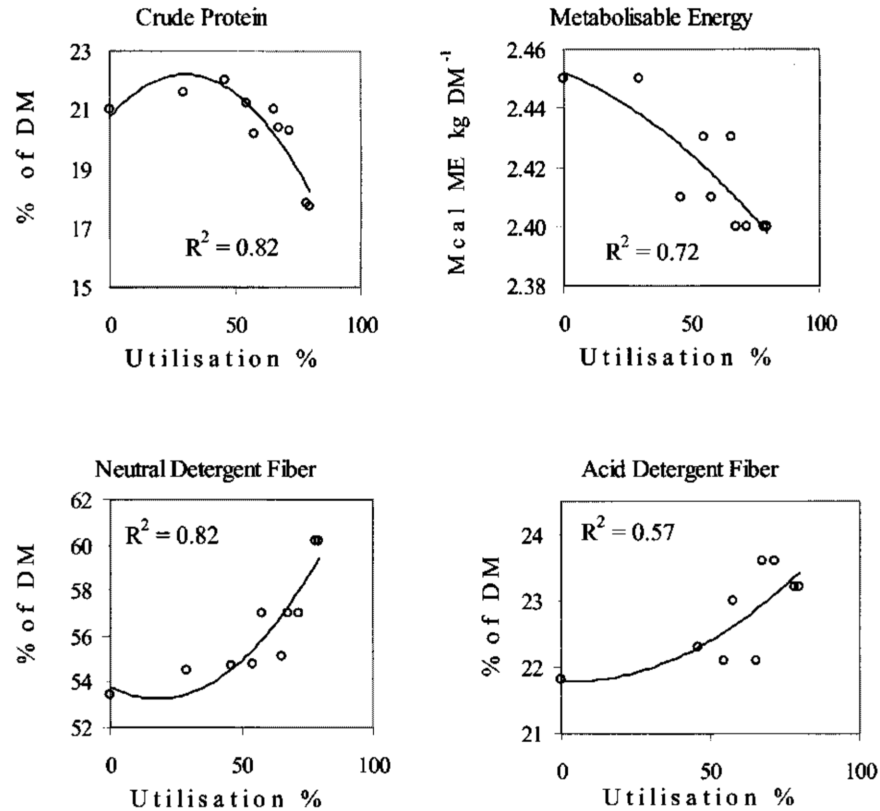

Figure 6 Relationship between utilisation and chemical composition of herbage above 10 cm during the first 90 minutes of the morning grazing session.

Residual herbage

The response of residual herbage mass to herbage allowance was linear (Figure 7). Residual herbage mass and height were closely related (Figure 8). This height-mass relationship implied that bulk density of residual herbage at the two lowest allowances (315 and 263 kg DM ha^{-1} cm^{-1}, respectively; calculated from Figures 7a and 7b) was lower than that of herbage on offer at the same height of the canopy (400 and 300 kg DM ha^{-1} cm^{-1}, respectively; calculated from the equation in Figure 1). This was probably related to preferential grazing of leaves that led to an upper horizon dominated by stems and pseudostems.

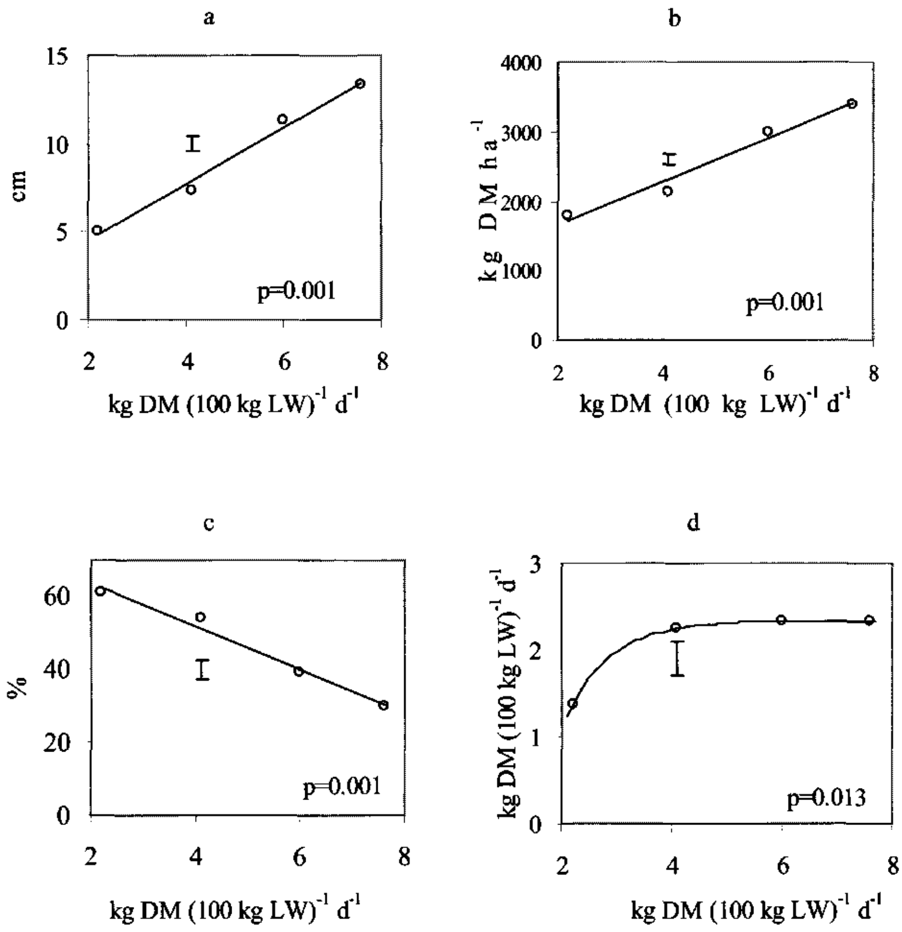

Figure 7. Least square means of canopy height of residual herbage measured with the sward stick (a), herbage mass to ground level of residual herbage (b), herbage utilisation (c) and herbage intake (d) at four levels of daily herbage allowance. Vertical bars depict standard error; p indicates the probability of the effect of herbage allowance.

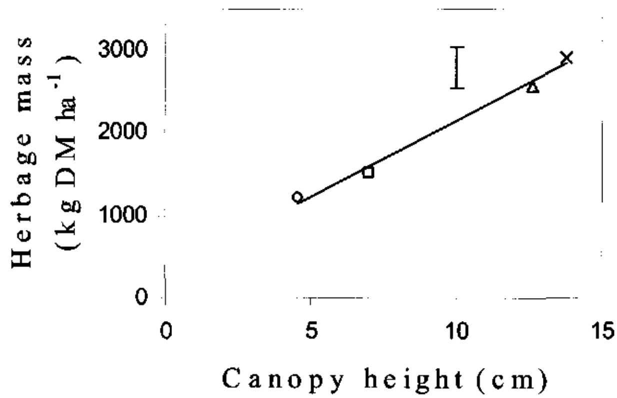

Figure 8. Relationship between canopy height and herbage mass of residual herbage at four levels of daily herbage allowance: 2.0 (○), 4.1 (□), 6.0 (Δ) and 7.6 (×) kg DM (100 kg LW)$^{-1}$ d^{-1}. Vertical bar depicts standard error.

As expected, increasing herbage allowance decreased the efficiency of utilisation (Figure 7c) and increased herbage intake (Figure 7d). The response of herbage intake was rather steep between 2.2 and 4.1 kg DM (100 kg LW)$^{-1}$ d^{-1}. Increasing the allowance from 2.2 to 4.1 kg DM (100 kg LW)$^{-1}$ d^{-1} reduced the efficiency of utilisation with 11%, but increased herbage intake with 64%. A further increase in allowance led to reductions in the efficiency of utilisation without improvement in herbage intake.

Herbage allowance did not exert a strong effect on the botanical or morphological composition of residual herbage (Table 16). At the highest allowance the content of stems of barley was highest and that of stems of ryegrass lowest. However, also the content of leaves of ryegrass tended to be lowest. This reflects the greater opportunities for selective grazing at this very high allowance and is the consequence of strong rejection of stems of barley in the upper layers of the canopy. Stems of oats did not appear to be strongly rejected, which agrees with findings of Burlison *et al.* (1991) with grazing sheep.

Concerning the chemical composition of residual herbage, differences were found between the two lowest and the two highest allowances (Table 17). The chemical composition of ingested herbage was calculated based on the composition of herbage on offer and residual herbage and the degree of utilisation (Table 17). The precision of this estimation is particularly low since the calculation involves four errors (in the estimation of herbage mass and composition of herbage on offer and residual herbage). The trends of changes in the composition of ingested herbage associated with each increment of allowance in 1 kg DM

(100 kg LW)$^{-1}$ d^{-1} were an increment of 0.4 points in the content of CP, a decrease of 0.6 points in the content of NDF and an increment of 0.026 Mcal ME. No trend was detected in the ADF content of ingested herbage (p=0.62).

Table 16 Morphological composition (% of DM) of residual herbage above ground level.

	Herbage allowance kg DM (100 kg LW)$^{-1}$ d^{-1}					
	2.2	4.1	6.0	7.6	Standard error	P
Leaves of oats	5.9	3.5	6.3	3.6	1.2	0.18
Stems of oats	8.5	10.4	9.7	10.4	2.0	0.87
Ears of oats	1.1	1.2	1.5	3.3	1.3	0.42
Leaves of barley	5.9	5.8	9.0	9.5	1.5	0.12
Stems of barley	21.5	18.9	23.2	29.5	4.6	0.01
Ears of barley	1.6	2.4	4.6	4.8	2.6	0.11
Leaves of ryegrass	25.4	30.1	27.0	19.3	3.4	0.08
Stems of ryegrass	30.0	27.8	18.8	19.7	5.3	0.05

Table 17. Chemical composition of residual herbage above ground level and calculated chemical composition of ingested herbage

	Herbage allowance [kg DM (100 kg LW)$^{-1}$ d^{-1}]					
	2.2	4.1	6.0	7.6	Standard error	P
	Residual herbage					
Crude Protein (% of DM)	16.8	17.1	18.1	18.2	1.0	0.14
Neutral Detergent Fibre (% of DM)	28.9	29.3	27.3	27.2	0.6	0.04
Acid Detergent Fibre (% of DM)	64.4	64.4	60.3	59.6	1.8	0.04
Metabolisable Energy (Mcal kg^{-1} DM)	2.39	2.40	2.48	2.47	0.03	0.03
	Ingested herbage					
Crude Protein (% of DM)	22.2	23.0	23.7	24.5	1.7	0.18
Neutral Detergent Fibre (% of DM)	21.8	20.4	19.9	18.5	1.5	0.15
Acid Detergent Fibre (% of DM)	50.2	47.7	48.2	45.2	5.9	0.62
Metabolisable Energy (Mcal kg^{-1} DM)	2.73	2.77	2.79	2.88	0.07	0.13

Daily pattern of activities of cows

Due to the reduction in canopy height, herbage mass and mass of leaves during the first 90 minutes of grazing, a decrease of bite weight could be expected both with decreasing allowance and increasing time elapsed since the beginning of the grazing session. If these results are extrapolated to the whole day, average bite weight could be expected to decrease with decreasing allowance. Based on the relationship between bite weight, biting rate and grazing time described by Ungar (1996), an increase in biting rate and grazing time could be expected when bite weight decreases. However, grazing time of cows at the lowest allowances was shorter than those of cows at higher allowances; the higher time spent resting tended to be the complement (Figure 9). Differences in grazing time during the night accounted for the shorter grazing time at the lowest allowance (Table 18, Figure 10). With the exception of night grazing at the lowest allowance, the achievement of total grazing time per grazing session followed the same pattern irrespective of time of the day and daily herbage allowance (Figure 11).

The time elapsed since the beginning of the grazing session appeared to be the main variable controlling biting rate. Biting rates were high at the beginning of the grazing session and decreased steadily during the first 90 minutes, to remain constant afterwards (Table 19, Figure 12).

The effects of herbage allowance and the interaction between herbage allowance and interval of the grazing session on biting rate were not very strong and only a few differences could be detected. During the first 30 minutes of the morning grazing session, biting rate of the two lower allowances was higher, and between 30 and 90 minutes of the evening grazing session biting rate of the lowest allowance was lower (Table 19). The higher initial biting rate at lower allowances in the morning grazing session could have been caused by a higher eating drive (also expressed in a lower reluctance to eat silage), as reported by Demment and Greenwood (1988) for fasted animals.

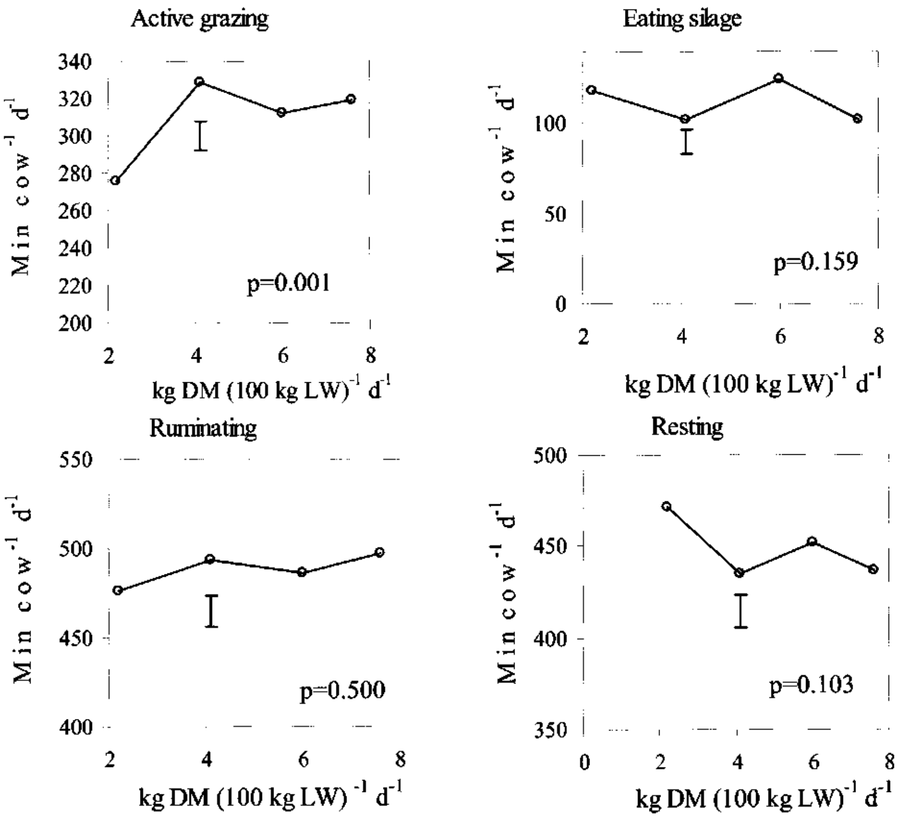

Figure 9. Patterns of daily activities of cows in minutes per cow. Least square means of active grazing, eating silage, ruminating and resting. Vertical bars depict standard error; p indicates the probability of the effect of herbage allowance.

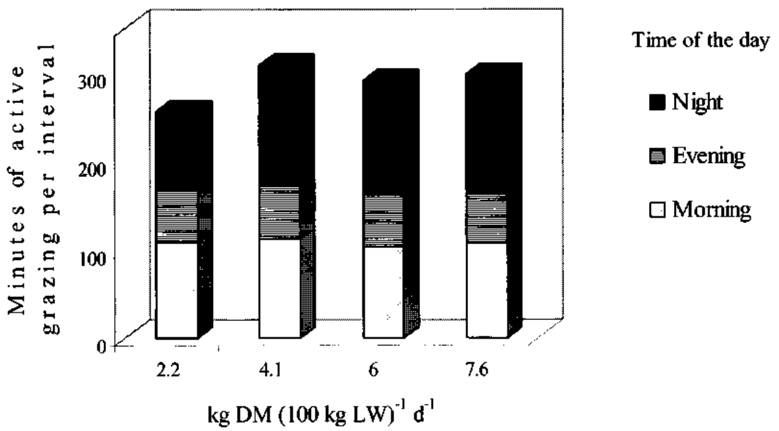

Figure 10. Grazing time at different daily herbage allowances [kg DM (100 kg LW)$^{-1}$ d^{-1}] during different moments of the day.

Table 18. Daily pattern of activities of cows (min cow^{-1} d^{-1})

		Daily herbage allowance [kg DM $(100kg\ LW)^{-1}$ d^{-1}]					
Period[1]	Activity	2.2	4.1	6.0	7.6	Standard error	P
a	Active grazing	108	112	103	106	9.1	0.322
	Eating silage	1	1	3	0	1.3	0.340
	Ruminating	15	11	4	5	4.1	0.001
	Resting	23	22	12	10	5.6	0.002
	Other activities	1	2	2	2	0.9	0.568
b	Active grazing	148	195	188	192	12.7	0.001
	Eating silage	12	12	20	9	5.6	0.480
	Ruminating	326	305	296	300	9.3	0.048
	Resting	262	231	207	201	10.1	0.001
	Other activities	2	3	4	3	1.2	0.501
c	Active grazing	19	22	20	18	6.1	0.001
	Eating silage	105	89	92	91	6.8	0.159
	Ruminating	132	163	183	193	7.9	0.495
	Resting	188	180	230	226	19.5	0.103
	Other activities	6	14	14	15	3.0	0.002
Activities related with milking		92	78	62	69		

[1] a: morning grazing session; b: evening and night grazing session c: cows penned with maize silage (morning + afternoon).

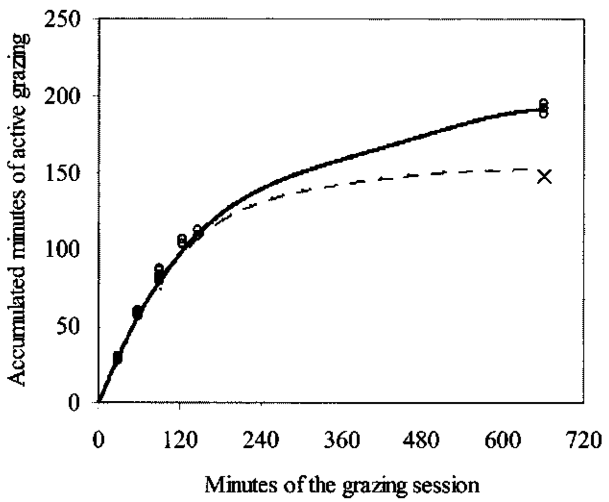

Figure 11. Least square means of accumulated grazing time per grazing session. Night grazing at the lowest allowance is depicted with a different symbol (×).

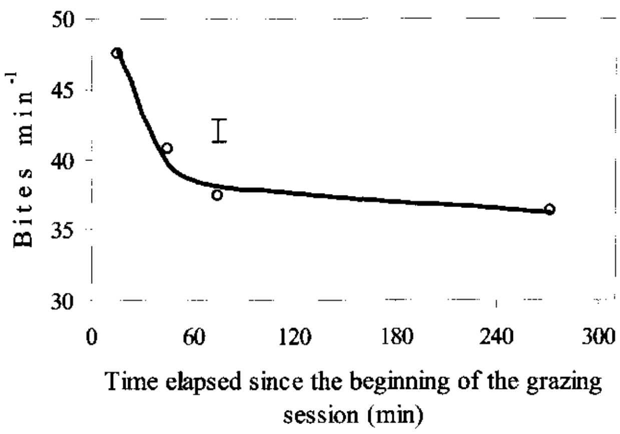

Figure 12. Least square means of biting rate during grazing sessions (all herbage allowances). Vertical bar depicts standard error.

The total number of bites per cow (the product of active grazing time and biting rate) depended mainly on the time elapsed since the beginning of grazing sessions, and followed the same trend for all allowances during the morning grazing session and the first hour of the evening and night grazing session (Table 20). On average, the evening and night grazing sessions started approximately one hour before sunset. Therefore, grazing after 60 minutes of started that session corresponded with night grazing. On average the total number of bites taken during daylight (the morning grazing session plus the first hour of the evening and night grazing session) was 7220 (calculated from Table 20) without differences between treatments. However during night grazing the total number of bites with the lowest allowance was 33% lower than with the other treatments. Consequently, the lower number of daily bites at the lowest allowance (Table 20) was caused by shorter night grazing (Figure 10). The cumulative number of bites taken during the first 90 minutes of the morning grazing session followed the same pattern irrespective of the herbage allowance (Figure 13).

Table 19. Least square means of biting rate (bites min^{-1})

Period[1]	Daily herbage allowance [kg DM $(100kg\ LW)^{-1}\ d^{-1}$]	Interval of the grazing sessions (minutes after the start of the session)						
		0-30	31-60	61-90	>90	Std. error	P[2]	P[3]
a	2.2	48.6	40.3	38.8	32.1	2.18	0.001	0.001
	4.1	48.8	42.1	38.1	43.6			
	6.0	44.1	38.8	37.4	36.4			
	7.6	44.3	40.6	34.0	34.9			
b	2.2	46.4	36.9	27.1	37.4	1.88	0.001	0.001
	4.1	49.5	41.9	37.0	36.6			
	6.0	48.6	40.6	38.9	37.1			
	7.6	47.4	43.5	40.0	35.9			

[1] a: morning grazing session; b: evening and night grazing session

[2] Probability of the effect of interval of the grazing session.

[3] Probability of the effect of daily herbage allowance.

Table 20. Least square means of number of bites per cow during different intervals of the grazing sessions.

Period[1]		Herbage allowance [kg DM $(100\ kg\ LW)^{-1}\ d^{-1}$]					
	Interval[2]	2.2	4.1	6	7.6	Std. error	P
a	0-30	1419	1468	1256	1377	76	0.001
	31-60	1116	1163	1127	1221		
	61-90	1073	942	1020	855		
	>90	1049	1081	1064	1075		
	Total	4657	4654	4240	4235	326	0.893
b	0-30	1351	1479	1458	1315	161	0.001
	31-60	1063	1239	1222	1289		
	61-90	371	788	728	886		
	>90	2944	4404	3784	4266		
	Total	5729	7909	7194	7754	449	0.001
Daily total		10387	12563	11394	12029	623	0.001

[1] a: morning grazing session; b: evening and night grazing session.

[2] Minutes after the start of the grazing session.

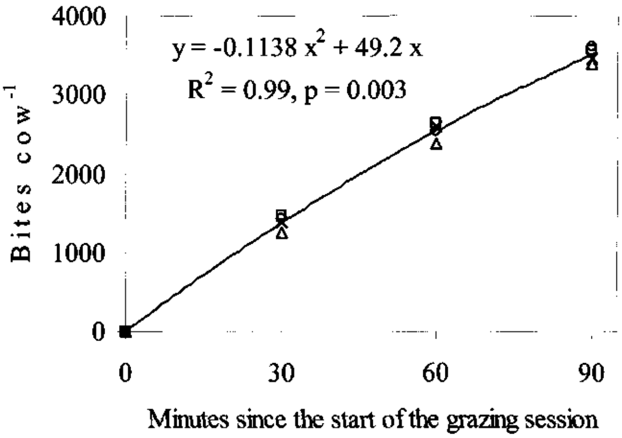

Figure 13. Total numbers of bites per cow taken during the first 90 minutes of the morning grazing session at four levels of daily herbage allowance: 2.0 (○), 4.1 (□), 6.0 (Δ) and 7.6 (×) kg DM (100 kg LW)$^{-1}$ d^{-1}. The relationship is based on least square means of bites per interval.

Herbage intake

Herbage intake was reduced by the lowest herbage allowance (Figure 7d); this kind of effect is usually ascribed to the effect on average bite weight (Hodgson, 1990). Average bite weight on a daily basis was calculated based on daily DM intake of the group of cows (Figure 7c) and daily bites of the same group (Table 20). Average bite weight was reduced by the lowest herbage allowance (Table 21). Average bite weights during three intervals of the morning grazing session (0-30, 31-60 and 61-90 minutes) were calculated based on changes in herbage mass above 5 cm (Table 14) and the number of bites per interval (Table 20). Average bite weight decreased with declining average herbage mass (Figure 14). All but one combination of allowances and intervals of the grazing session fitted into the same relationship.

Table 21. Active grazing time, biting rate, total number of bites and average bite weight at different herbage allowances.

	Herbage allowance [kg DM (100 kg LW)$^{-1}$ d^{-1}].					
	2.2	4.1	6.0	7.6	Standard Error	P
Active grazing time (min d^{-1}),	276	329	312	319	15.7	0.001
Biting rate (bites min^{-1})	41.5	42.5	41.9	40.6	2.0	0.118
Total number of bites (bites d^{-1})	10,387	12,563	11,394	12,029	623	0.001
Average bite weight (g DM bite^{-1})	0.76	1.03	1.19	1.08	0.17	0.003

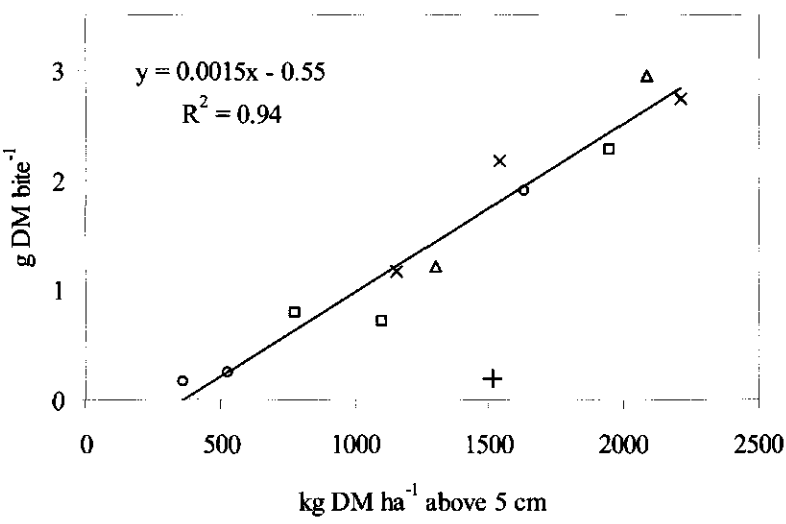

Figure 14. Average bite weight at four levels of daily herbage allowance: 2.0 (○), 4.1 (□), 6.0 (Δ) and 7.6 (×) kg DM (100 kg LW)$^{-1}$ d^{-1}, as a function of average herbage mass above 5 cm during the first 90 minutes of the morning grazing session. The relationship is based on least square means of both variables. The data of the interval 31-60 min at the herbage allowance 6.0 kg DM (100 kg LW)$^{-1}$ d^{-1} (+), was not included in the regression equation.

A very simple dynamic mechanical model was used to rationalise the response of herbage intake to herbage allowance in terms of the functional response to abundance of food described by Ungar (1996). The model was based on the number of bites taken per unit of area during the first 90 minutes of the morning grazing session and changes in herbage mass above 5 cm height during the same period. The steps taken to develop the model are briefly presented below.

On average 13.5, 24.6, 34.3, 45.2 m² cow^{-1} were allotted per grazing session at the allowances 2.2, 4.1, 6.0 and 7.6 kg DM (100 kg LW) $^{-1}$ d^{-1}, respectively. Based on these data and on the evolution of the number of bites taken rate during the first 90 minutes of the grazing session, the number of bites taken per m², bite weight and herbage mass were calculated with time-steps of 1 minute according to Equations 2 to 5:

$$BTt = 49.2 - .02264\ t \qquad (2)$$

$$NBt = \frac{BTt}{Aa} \qquad (3)$$

$$BWt = -0.55 + 0.0015\ HMt\text{-}1 \qquad (4)$$

$$HMt = HMt\text{-}1 - (NBt\text{-}1 \times BWt\text{-}1 \times 10) \qquad (5)$$

where

t = time in minutes since the start of the grazing session

BTt = number of bites taken per cow in time t (bites min^{-1} cow^{-1}; see Figure 13)

NBt = number of bites per m² taken in time t (bites m^{-2} min^{-1})

Aa = area allotted per cow as a function of daily herbage allowance (a), A = 13.50, 24.58, 34.30, 45.24 m² cow^{-1} when a is 2.2, 4.1, 6.0 and 7.6 kg DM (100 kg LW) $^{-1}$ d^{-1}, respectively

BWt = bite weight in time t (g DM $bite^{-1}$; see Figure 14)

HMt = Herbage mass above 5 cm (kg DM ha^{-1}) in time t

This simple model simulated accurately the evolution of standing herbage mass above 5 cm during the first 90 minutes of the morning grazing session (Figure 15). The number of bites taken per unit of area was an appropriate variable to describe the measured effect of grazing on canopy height, irrespective of the combination of herbage allowance and interval of the grazing session (Figure 16).

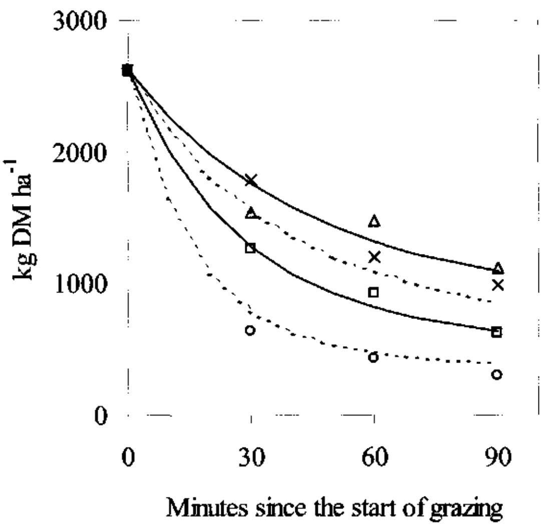

Figure 15. Calculated (lines) and observed (symbols) herbage mass above 5 cm during the first 90 minutes of the morning grazing session at four levels of daily herbage allowance: 2.0 (- -○ - -), 4.1 (—□—), 6.0 (- - Δ - -) and 7.6 (—×—) kg DM (100 kg LW)$^{-1}$ d^{-1}.

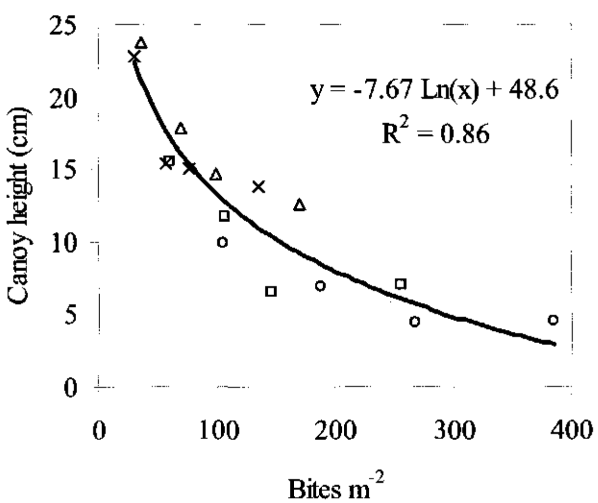

Figure 16. Canopy height (cm) as a function of bites taken per square meter during the first 90 minutes of the morning grazing session at four levels of daily herbage allowance: 2.0 (○), 4.1 (□), 6.0 (Δ) and 7.6 (×) kg DM (100 kg LW)$^{-1}$ d^{-1}.

The model was also used to rationalise the effects of herbage allowance on selectivity. Irrespective of the combination of herbage allowance and interval of the grazing session, the proportions of components in herbage above 5 cm (derived from Table 15) were related to the calculated degree of utilisation of herbage above 5 cm (a mirror image of Figure 15) according to Equations 6 to 10:

$$\text{Oats} = 49.5 + -0.076\,U - 0.0023\,U^2,\ R^2 = 0.83 \quad (6)$$

$$\text{Ryegrass} = 17.4 - 0.173\,U + 0.0047\,U^2,\ R^2 = 0.74 \quad (7)$$

$$\text{Barley} = 33.1 + 0.249\,U - 0.0024\,U^2,\ R^2 = 0.41 \quad (8)$$

$$\text{Leaves} = 48.7 - 0.260\,U + 0.0013\,U^2,\ R^2 = 0.82 \quad (9)$$

$$\text{Stems} = 51.3 + 0.260\,U - 0.0013\,U^2,\ R^2 = 0.82 \quad (10)$$

where

Oats, Ryegrass, Barley, Leaves and Stems = proportions of the components in herbage above 5 cm (% of DM)

U = herbage utilisation (%)

These equations were used to calculate with time-steps of 1 minute the proportions of the components in standing herbage above 5 cm based on the calculated degree of utilisation. Subsequently, the mass of the component in standing herbage, the amount of the component consumed, the proportion of the component in ingested herbage and the preference index were calculated with time-steps of 1 minute according to Equations 11 to 16:

$$PSH\,(c)\,t = \beta_0 + \beta_1\,Ut + \beta_2\,(U\,t)^2 \quad (11)$$

$$M\,(c)t = \frac{HMt \times PSH\,(c)t}{100} \quad (12)$$

$$I\,(c)\,t = M\,(c)\,t\text{-}1 - M\,(c)\,t \quad (13)$$

$$HIt = HM\,t\text{-}1 - HM\,t \quad (14)$$

$$PIH\,(c)t = \frac{I\,(c)t}{HIt} \times 100 \quad (15)$$

$$PI\,(c)t = \frac{PIH\,(c)t}{PSH(c)t-1} \quad (16)$$

where

PSH (c) t = proportion (% of DM) of the component c in standing herbage above 5 cm at time t: c = oats, ryegrass, barley, leaves and stems

β_0, β_1, and β_2 = coefficients of Equations 6 to 10

M (c) t = mass (kg DM ha^{-1}) of the component c in standing herbage above 5 cm at time t

HM t = standing herbage mass above 5 cm (kg DM ha^{-1}) at time t (see Equation 5)

I (c) t = intake of the component c at time t (kg DM ha^{-1})

HI t = herbage intake at time t (kg DM ha^{-1})

PIH (c) t = proportion (% of DM) of the component c in ingested herbage at time t

PI (c) t = preference index of the component c at time t

According to the results of the model (Figure 17), oats was preferentially grazed at a fairly constant PI (on average 1.33). Barley was rejected at the onset of grazing, but rejection disappeared at higher degrees of utilisation. Ryegrass was preferentially grazed early in the grazing session but was rejected afterwards. At the beginning of the grazing session leaves were preferentially grazed and stems were rejected. However, as utilisation increased differences in preferences for leaves and stems tended to disappear.

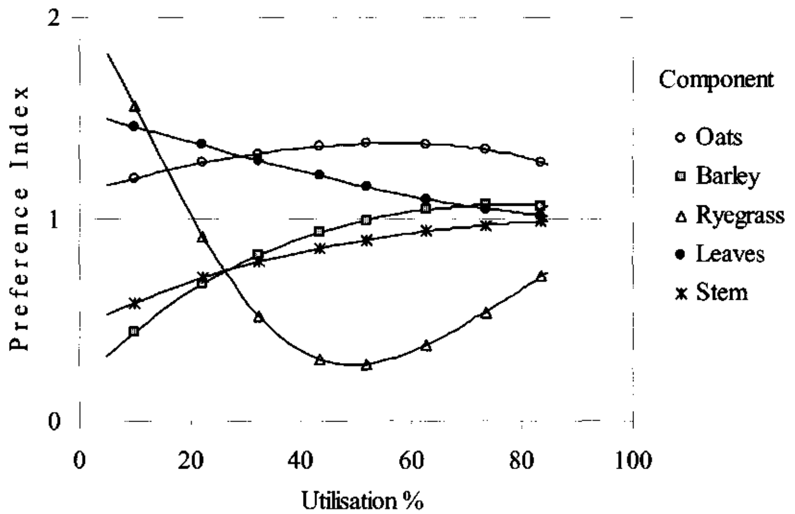

Figure 17. Calculated preference index of botanical and morphological components as a function of utilisation of herbage above 5 cm.

The results of the model suggest that the number of bites take per unit of area is a highly suitable variable when analysing the effects of herbage allowance on herbage intake and selectivity. The circumstantial coincidence between the total number of bites per unit of area taken at the allowance 2.2 kg DM (100 kg $LW)^{-1}$ d^{-1} after 90 minutes of the morning grazing session (246 bites m^{-2}) and total daily bites at the allowance 4.1 kg DM (100 kg $LW)^{-1}$ d^{-1} (242 bites m^{-2}), was used to evaluate the suitability of the number of bites take per unit of area. Herbage mass and composition to ground level after 90 minutes of the morning grazing with the allowance 2.2 kg DM (100 kg LW)$^{-1}$ d^{-1} (Tables 14 and 15) were compared with those of residual herbage after whole-day grazing with the allowance 4.1 kg DM (100 kg LW)$^{-1}$ d^{-1} (Table 16 and Figure 7). The correlation between both sets of data is very high and the relationship is very close to the 1:1 relationship (Figure 18).

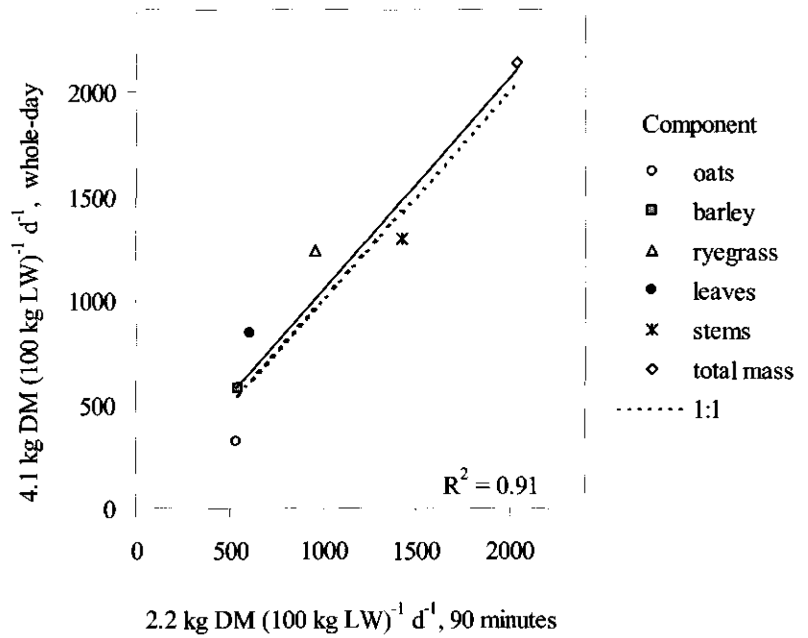

Figure 18 Comparison between least square means of residual herbage above ground level after 90 minutes of grazing in the morning grazing session at an allowance of 2.2 kg DM (100 kg LW)$^{-1}$ d^{-1} and least square means of residual herbage above ground level after whole-day grazing at an allowance of 4.1 kg DM (100 kg LW)$^{-1}$ d^{-1}.

Stocking rate and milk production

Increasing herbage allowance decreased stocking rate and tended to increase milk production per cow (Figure 19a and 19b). However, the response in milk production should be considered as the very short-term (one week) effect because body reserves generally act as buffer masking responses to short-term changes in nutritional level. Long-term effects can be envisaged using estimated energy requirements according to NRC (1989) in two ways: i) estimating expected live weight changes according to the attained level of milk production and energy intake (Figure 19c) or ii) estimated expected milk production in the absence of live weight change (Figure 19d). Then it appears that in the long-term the severely restricted herbage intake of the cows at the lowest allowance would have resulted in lower milk production and live weight loss. Combining the data from Figures 19a and 19d yield the expected response in productivity per cow or per ha to stocking rate as presented in Figure 20. The highest estimated milk production per hectare was attained with a stocking rate of 4.6 cows ha^{-1} grazing $cycle^{-1}$, associated with the level of herbage allowance of 4.1 kg DM (100 kg $LW)^{-1}$ d^{-1}. The height of residual herbage is a suitable variable for guiding short-term decisions of grazing management. Using that herbage allowance led to an average height of residual herbage of 7 ± 1.6 cm (Figure 7a).

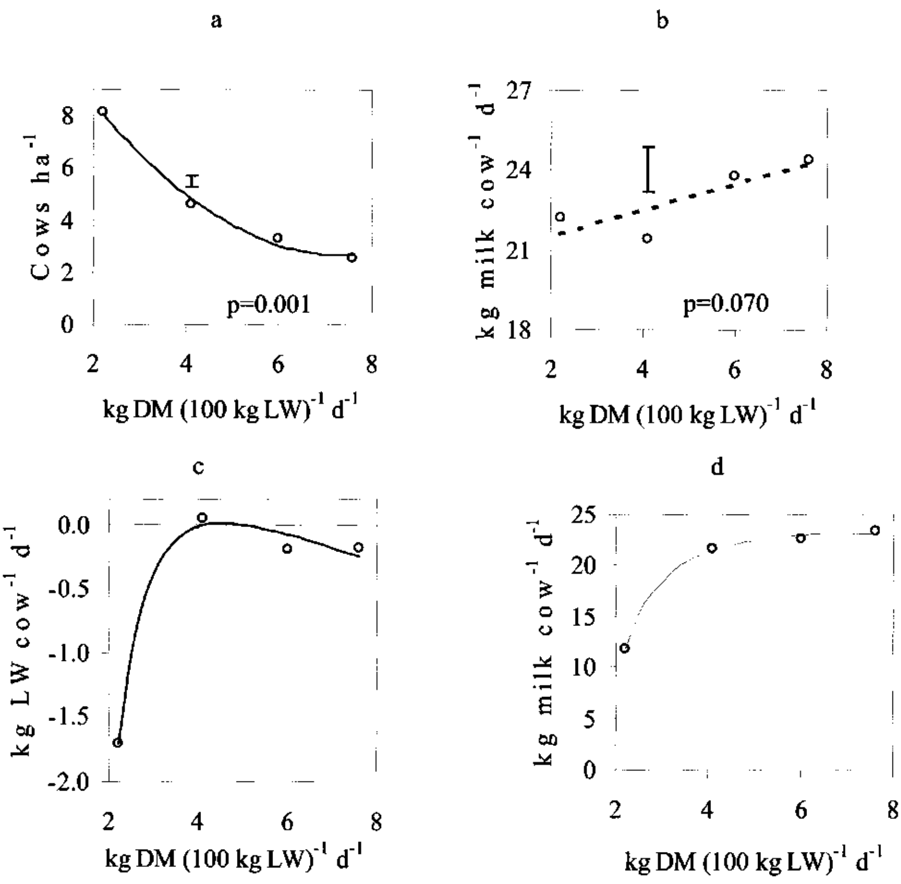

Figure 19. Least square means of stocking rate (a), daily milk production per cow (b), expected live weight changes according to the attained level of milk production and energy intake (c) and estimated daily milk production per cow without live weight change (d) at four levels of daily herbage allowance. Vertical bars depict standard error; p indicates the probability of the effect of daily herbage allowance.

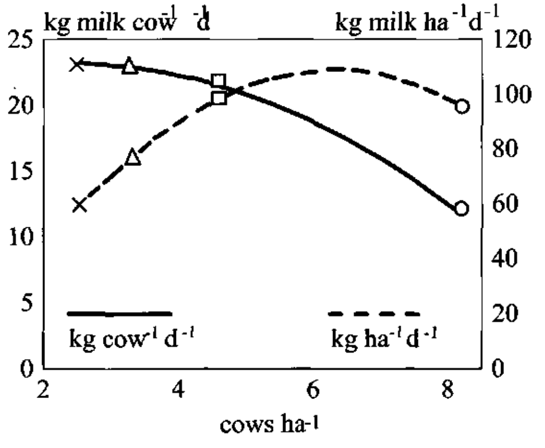

Figure 20. Estimated response of productivity without live weight change to stocking rate associated with four levels of daily herbage allowance: 2.0 (○), 4.1 (□), 6.0 (Δ) and 7.6 (×) kg DM (100 kg LW)$^{-1}$ d^{-1}.

Discussion

The effect of daily herbage allowance on the productivity of the system

Considering stoking rate as a response variable enabled an objective translation of the response of herbage intake to herbage allowance into management practices. The level of stocking rate of 4.6 cows ha^{-1} grazing cycle^{-1} that was attained with the level of herbage allowance of 4.1 kg DM (100 kg LW)$^{-1}$ d^{-1} maximised production per unit of area (Figure 20). As expected, stocking rate decreased with increasing levels of daily herbage allowance (Figure 19a). The levels of stocking rate were within the range quoted by Holmes (1987) in his review for comparable levels of herbage allowance. The response of herbage intake to herbage allowance (Figure 7d) was also within the range of responses quoted by Holmes (1987). Milk production per cow increased with the increase in herbage allowance up to 4.1 kg DM (100 kg LW)$^{-1}$ d^{-1} (Figure 19d, Figure 20), while milk production per hectare decreased with the increase in herbage allowance above that level (Figure 20). However, due to supplementary feeding with maize silage and concentrates, these estimates of productivity were higher than results quoted by Holmes (1987).

The response of residual herbage mass to increasing levels of daily herbage allowance (Figure 7b) was also similar to that quoted by (Holmes 1987). Residual herbage mass and height were closely related (Figure 8). With the level of herbage allowance 4.1 kg DM (100 kg LW)$^{-1}$ d^{-1} the average height of residual herbage was 7 (±1.6) cm. This result suggests that this height could be used as a management target. Increasing this height would reduce the efficiency of herbage utilisation without improvement in the performance per cow. Reducing this height could affect herbage intake of the cows. Data in Figure 16 show that reducing the height of residual herbage below this height became particularly difficult for grazing dairy cows (1 cm decrease in canopy height required 15% increase in the number of bites per square meter). This can result in severe reductions of herbage intake per cow. Reducing the height of residual herbage below 7 cm can also affect the growth of the pasture. Roman (2000) found that reducing the cutting height from 8 to 5 cm reduced the growth rate of oats and ryegrass pastures.

The effect of daily herbage allowance on herbage intake

Herbage intake was severely depressed at the lowest level of herbage allowance. The decrease in herbage intake was the consequence of lower average bite weight and reduced active grazing time (Table 21). As stressed by Wade and Carvalho (2000), mechanisms that control intake were analysed with reference to limitations to intake, which resulted from grazing pressure. The effect that the previously taken bites per unit of area exerted on herbage mass and structure was used to explain the interplay between daily intake per animal and intake per unit area.

Bite weight

The initial bite weight at the two highest allowances was high (Figure 14) concurring with theoretical estimations of potential bite dimensions. Theoretical estimations of potential bite dimensions as functions of canopy height and density (Ungar, 1996) were used to estimate the potential bite dimensions that could be expected with the average canopy height and bulk density of herbage on offer in the current experiment. Bite area should have been between 160 and 170 cm^2 and bite depth should have been between 14 and 15 cm. Considering those estimates and taking into account that average bulk density was slightly above 100 kg DM ha^{-1} cm^{-1}, bite weight would have been between 2.6 and 2.7 g DM bite^{-1}, which corresponds with the values in Figure 14. Working with caged sheep, Burlison *et al.* (1991) observed considerably higher bite weights in tall oats swards than in shorter grass swards. The authors ascribe this higher bite weight partially to the fact that "on the taller oats swards the sheep were frequently observed to sever, at a single harvesting bite, long leaves and stems that were then gradually drawn into the mouth by nibbling".

The estimated potential bite depth between 14 and 15 cm agrees with the results on utilisation of herbage above 10 cm. With an average initial canopy height of 26 cm (Figure 4), a bite depth between 14 and 15 cm would have encompassed most herbage above 10 cm. Utilisation of herbage above 20 cm and herbage between 10 and 20 cm did not differ and were closely correlated (Figure 5), suggesting that the first horizon of grazing encompassed herbage above 10 cm.

The nature of the relationship between herbage allowance and average bite weight is dynamic. Under rotational grazing with a half-day grazing period the area allotted to grazing animals is smaller that the area potentially affected by daily bites. Therefore, the bites taken modify the canopy to be faced when taking consecutive bites. The area encompassed by a bite might overlap with that of a previous bite, and the probability of such an event increases with the number of bites already taken. According to Ungar (1996) "Even within a horizon, bite weight tends to decline somewhat because there is some degree of overlap in the area swept by adjacent bites". This means that the effect of bites already taken on successive bites starts before the moment when the upper horizon of the canopy has been affected by defoliation in all the area allotted. Average bite weight decreased with declining average herbage mass above 5 cm irrespective of the combination of allowances and intervals of the grazing session (Figure 14). Considering i) a potential bite area between 160 and 170 cm^2, ii) no overlapping of bites, and iii) the number of bites taken per unit of area as calculated with Equation 3, the upper horizon of the canopy would have been affected by bites in the whole area after 17, 32, 47 and 65 minutes of grazing with the herbage allowances 2.2, 4.1, 6.0 and 7.6 kg DM (100 kg LW) $^{-1}$ d^{-1}, respectively. Initial bite weight was lower with the allowance 4.1 kg DM (100 kg LW) $^{-1}$ d^{-1} than with higher allowances, and bite weight with the allowance 7.6 kg DM (100 kg LW) $^{-1}$ d^{-1} decreased between the first and second half hour of the grazing session (Figure 14). Therefore, the reduction in bite size in the current experiment took place before defoliation could have affected the upper horizon of the canopy in the whole area. Consequently, overlapping of attempted bite area with area already affected by previous bites played an important role in reducing initial bite weight. Burlison *et al.* (1991) observed overlapping bites in tall oats swards, even though sheep were only allowed to take twenty bites per patch. However, in that experiment no evidence of overlapping bites was found in the shorter grass swards.

Biting rate and active grazing time

The frequently reported increases in biting rate and grazing time in response to reduced bite weight (Ungar, 1996) were not observed in the current experiment with high rates of depletion of available herbage.

At all allowances biting rates were high at the beginning of the grazing session and decreased afterwards (Table 19, Figure 12). This reduction in biting rate took place while bite size was decreasing (Figure 14). Chilibroste (1999) found a similar pattern of biting rate. Average biting rate measured by Chilibroste (1999) in short grass swards was much higher than found in the current experiment, but the decrease of biting rate with grazing time in that experiment was almost parallel to the one found in the current experiment. However, the daily pattern of biting rate of dairy cows under continuous stocking as reported by Gibb *et al.* (1998) is different, particularly during the evening grazing session when biting rate in their experiment tended to increase with time. These results suggest that the functional link between bite weight and biting rate holds when comparing different pastures but does not hold for the interpretation of changes in biting rate within a grazing session with a high rate of depletion of available herbage.

Active grazing time during the night was reduced at the lowest level of herbage allowance (Figure 10). In agreement with these results, Rook *et al.* (1994a) found that differences in daily grazing time among treatments arose from the proportion of the night spent grazing, and no differences were found in grazing time during daylight.

Grazing time might increase or decrease with decreasing herbage availability (expressed as herbage allowance or average sward height). Height of the sward plays an important role in the nature of the response. Le Du *et al.* (1979) report that at low herbage allowance cows were reluctant to graze down in very short remaining herbage. Wales *et al.* (1999) found that grazing time was reduced at the lowest herbage allowance. Chilibroste (1999) reports reduced grazing time in very short grass. However, Parga *et al.* (2000) found with rather high post-grazing heights (8.4 cm), that grazing time increased with decreasing herbage allowance. Under continuous stocking, Rook *et al.* (1994a) found that compared to cows grazing taller pastures, cows grazing pastures at an average height of 40 mm increased grazing time when unsupplemented and decreased it when supplemented. Explanations for the responses differ among authors. Le Du *et al.* (1979) assumed that the behavioural component of this response was very important (i.e. the difficulty of grazing short swards led to awaiting the opening of fresh pasture). Rook *et al.* (1994a) suggested that there was some total energy intake threshold below which the behaviour of the animals changed. Wade and Carvalho (2000) state that the generally observed reduction of grazing time at low herbage allowances under strip grazing is a response to sward conditions. However, Chilibroste (1999) concluded that mechanisms and factors controlling grazing time are not completely understood.

Herbage intake

The relationship between bite weight and average herbage mass (Figure 14) and the number of bites taken per unit of area (Equation 3) explained the changes in herbage mass above 5 cm due to herbage intake during the first 90 minutes of the morning grazing session (Figure 15). This result means that the state-rate functional response of bite weight can be used to understand the response of intake to herbage allowance. However, the effect of the previous bites has to be taken into account. The results in Figures 15 and 18 show that the number of bites taken per unit of area was a suitable variable to analyse the effects of herbage allowance on herbage intake.

Selectivity

Irrespective of the combination of herbage allowance and interval of the grazing session the proportion of components in standing herbage correlated well with the corresponding degree of herbage utilisation (Equations 6 to 10). This suggests that the pattern of selective grazing was mainly affected by the effect of the previous bites on herbage mass and composition. The rejection of barley in the upper horizon at the highest herbage allowance was the only exception (Equation 8, Table 15).

Preferential grazing can be strongly affected by spatial distribution of herbage components in the vertical plane (Hodgson, 1990) as well as in the horizontal plane (Laca, 2000). The vertical distribution of components is described in Table 9. In the horizontal plane the growth habit of the species implied that cows could easily differentiate between plants of oats and barley. The results of Equations 11 to 16 (Figure 17) increased the insight in the way preferential grazing took place. While oats was always preferentially grazed, barley was rejected by the onset of grazing but rejection disappeared at higher degrees of utilisation. Due to differences in leaf:stem ratio between these two species (Table 9) preference for oats also involved a certain degree of preference for leaves.

At the onset of grazing, leaves were strongly preferred compared to stems. With increasing utilisation, preference indices of both components approached the value of indifference (Figure 17). This reduction in preference for leaves probably reflects the increase in the costs of selective grazing (as discussed by Parsons and Chapman, 1998) since the proportion of leaves in herbage above 5 cm decreased and most leaves tended to be located in lower layers.

It appears that facing the option of further grazing in the upper layers partially depleted of preferred components or grazing deeper in the canopy, cows preferentially took the first option. This might also explain the unusual evolution of the ryegrass preference (Figure 17). This species was preferentially grazed when available in the upper layers of the canopy but once those layers were depleted of the component and most ryegrass was only located in lower layers (Table 15), it was rejected because of its position in the canopy.

As expected, diet composition reflected mainly the composition of grazed canopy layers. Differences between treatments in the chemical composition of residual herbage above ground level and the calculated chemical composition of ingested herbage (Table 17) correspond with the vertical distribution of chemical components (Table 12), and the differences in herbage utilisation (Figure 7). However, there was also some degree of preferential grazing within the grazed canopy layers (Figure 6). Taking into account i) the differences in chemical composition of morphological components (Table 11), and ii) the relationship between morphological and chemical composition of the canopy layers (Table 13), it can be concluded that active selection against stems (particularly those of barley) in the upper layer of the canopy is one of the probable causes of the decrease in the nutritional quality with increasing degree of herbage utilisation in this layer of the canopy (Figure 6).

Conclusions

A stocking rate of 4.6 cows ha^{-1} grazing $cycle^{-1}$ maximised production per unit of area. This assessment was based on the response of herbage intake and stocking rate to increasing levels of daily herbage allowance. The high productivity attained with this stocking rate (99 kg milk ha^{-1} d^{-1}) was partially due to supplementary feeding. A height of residual herbage of 7 (±1.6) cm could be used as a target in short-term decisions of grazing management. The number of bites taken per unit of area was a suitable variable to analyse the response of herbage intake to herbage allowance in terms of the state-rate functional response. The frequently reported responses in biting rate and grazing time to reduced bite weight did not hold for the conditions of the current experiment.

Appendix to Chapter 4

Models used in analysis of variance.

Model 1

$Y_{ijk} = \mu + P_i + G_j + A_k + E_{ijk}$

where

Y_{ijk} = Response variable: residual herbage (herbage mass and botanical, morphological and chemical components), herbage intake, degree of utilisation, stocking rate, milk production per hectare

μ = general mean

P_i = effect of period, i = 1 to 4

G_j = effect of group of cows, j = 1 to 4

A_k = effect of herbage allowance, k = 1 to 4

E_{ijk} = error term

Model 2

$Y_{ijk} = \mu + P_i + G_j + A_k + I_l(A_k) + E_{ijk}$

where

Y_{ijk} = Response variable: herbage mass and components of canopy layers

μ = general mean

P_i = effect of period, i = 1 to 4

G_j = effect of group of cows, j = 1 to 4

A_k = effect of herbage allowance, k = 1 to 4

I_l = effect of the interval within the grazing session nested in herbage allowance, l = 1 to 4

E_{ijk} = error term

Model 3

$Y_{ijk} = \mu + P_i + G_j + C_k(G_j) + A_l + E_{ijkl}$

where

Y_{ijk} = Response variable: milk production per cow

μ = general mean

P_i = effect of period, i = 1 to 4

G_j = effect of group of cows, j = 1 to 4

C_k = effect of cow nested in group of cows, k = 1 to 16

A_l = effect of herbage allowance, k = 1 to 4

E_{ijkl} = error term

Model 4

$Y_{ijk} = \mu + P_i + G_j + C_k (G_j) + A_l + I_m (A_l) + E_{ijkl}$

where

Y_{ijk} = Response variable: grazing time per interval, biting rate.

μ = general mean

P_i = effect of period, i = 1 to 4

G_j = effect of group of cows, j = 1 to 4

C_k = effect of cow nested in group of cows, k = 1 to 16

A_l = effect of herbage allowance, k = 1 to 4

I_m = effect of the interval within the grazing session nested in herbage allowance, m = 1 to 4,

E_{ijkl} = error term

Table 1. Fixed and random effects in the analysis of variance of data from different dependent variables.

Dependent variables	Fixed effects	Random effects
All variables	Herbage allowance	Period and Group of cows
Variables related to stratified clippings	Period within morning grazing session	
Variables related to ingestive behaviour and milk production per cow		Cows nested within group of cows
Variables related to ingestive behaviour	Period of the day nested within herbage allowance	

Chapter 5

Supplementary feeding with concentrates

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Summary

Feeding concentrates to lactating cows is used in dairy systems based on grazing of temperate pastures with the main objective of increasing profitability. The response to supplementation per hectare might be more closely affected by changes in stocking rate (SR) than by changes in per cow production. Therefore, in order to evaluate the feasibility of supplementary feeding the economic analyse must take into account the potential effect on SR and hence on milk production per hectare. An experiment was conducted to estimate the response of stocking rate and milk production per hectare to four levels of supplementary feeding with concentrates (0, 2, 4 and 6 kg cow^{-1} d^{-1}). The used concentrates had a low content of rumen degradable protein and a high content of rumen undegradable protein. The cows grazed oats and ryegrass pastures and alfalfa and orchard grass pastures and received 4.3 kg of dry matter (DM) of maize silage offered cow^{-1} d^{-1}. In order to estimate the effect on SR, a high and uniform degree of pasture utilisation was targeted irrespective of the level of supplementary feeding. The response in milk production per cow was 0.90, 0.83 and 0.57 kg extra milk per kg of concentrates consumed with 2, 4 and 6 kg of concentrates cow^{-1} d^{-1}, respectively. When cows consumed 2 kg of concentrates did not reduce the intake of grazed herbage. Therefore, SR could not be increased with that level of supplementary feeding. Stocking rates were 3.60, 3.11, 4.36 and 4.54 cows ha-1 with 0, 2, 4 and 6 kg of concentrates cow^{-1} d^{-1}, respectively. The response in milk production per ha was –0.80, 1.58 and 1.24 kg extra milk per kg of concentrates consumed with 2, 4 and 6 kg of concentrates cow^{-1} d^{-1}, respectively. The response of milk production per hectare was mainly affected by the response of SR. The response to 2 kg of concentrates cow^{-1} d^{-1} was not economically feasible while that to 4 kg of concentrates was economically attractive and should be able to withstand deterioration in the price ratio between concentrates and milk. Basing the economic evaluation on the response of milk production per cow to supplementary

feeding might lead to mistaken conclusions. Oats and ryegrass pastures were superior to alfalfa and orchard grass pastures in terms of SR and net herbage production.

Introduction

Feeding concentrates to lactating cows is common in dairy systems based on grazing of temperate pastures. The objectives of farmers when using supplementary feeding are to increase profitability (McCall and Clark, 1999; Leaver, 2000) and stability of incomes (Phillips, 1988). Leaver (2000) states that economic analyse, which are carried out in support of experimental work on supplementary feeding with concentrates, do not take into account the potential effect on stocking rate (SR). Therefore, these analyses do not consider the effect of supplementary feeding on net returns relative to the most limiting farm resource (usually land). Taking this into account, the response to supplementary feeding with concentrates on milk production per hectare should be considered more relevant than the response of individual cows. However, objectives of researchers appear to differ from those of farmers, because no reports on the response of milk production per hectare to supplementary feeding with concentrates were found.

The response per hectare depends on the response of individual cows and the increment in SR. Results of simulations reported by McCall and Clark (1999) suggest that the response in milk production per hectare to supplementation is more closely affected by changes in SR than by changes in production per cow.

Reported responses of individual cows to supplementary feeding with concentrates (expressed in kg extra milk per kg of concentrates consumed) range between 0.0 (Penno *et al.* 1996; quoted by Stockdale, 1999a) and 1.4 (Reeves *et al.*, 1996a; Wales *et al.*, 1999). Mean response from 36 reported data sets (different references quoted in this paper) is 0.74 with a high variation coefficient (41%). Seventy two percent of the responses are within the range 0.6-1.1, which could therefore be considered as the range of frequently reported responses. The response depends on many factors related to the level of production of the cow (genetic merit, age, stage of lactation), quantity and composition of the concentrates and quality and availability of herbage (which depend on the pasture type and its management). The response is influenced mainly by effects on herbage intake and on the efficiency of utilisation of the ingested nutrients. Within this complexity, it appears that the effects on intake (substitution rates in kg herbage DM per kg of concentrates DM consumed) play the most important role: when substitution rates are high, responses are low (e.g. Wales *et al.*, 1999). Substitution rates are highly dependent on herbage availability whereas herbage intake by unsupplemented cows appears to be a very good indicator for this availability. Grainger and Mathews (1989) and Wales *et al.* (1999) reported that substitution rates increased with increasing herbage DM intake of unsupplemented cows.

No reports were found on the possibility of increasing SR in response to supplementary feeding. Average sward height (Clements *et al.*, 1992; Rook *et al.* 1994b; Pulido and Leaver, 1997), daily herbage allowance (Meijs and Hoekstra, 1984; Grainger and Mathews, 1989; Wales *et al.*, 1999) and herbage mass on offer (Stockdale, 1996; Wales *et al.*, 1999) have been used to control herbage availability. However, with the exception of Clements *et al.* (1992), associated stocking rates were not reported. Theoretically, increments in SR are expected to become higher with increasing substitution rates. However, the response is difficult to predict. Consequently, the effect of substitution rates on the response in milk production per hectare is also difficult to predict because responses per cow increase with decreasing substitution rates (Wales *et al.*, 1999) while rises in SR are expected to increase with increasing substitution rates.

However, when stocking rate and productivity per hectare are to be considered the most relevant response variables to supplementary feeding with concentrates, a different approach that is independent of the estimation of substitution rates might be more adequate. A basic principle in the management of grassland systems is efficient utilisation of produced herbage, which should be achieved irrespective of the level of supplementary feeding. Herbage intake is expected to decrease with the level of supplementary feeding and hence, in order to achieve the target of herbage utilisation (e.g. a certain residual herbage mass or height) higher stocking rates (i.e. lower herbage allowances) should be used. Therefore, herbage allowance and stocking rate become response variables such as milk production per cow, milk production per hectare and changes in live weight or body condition.

Even though supplementary feeding with concentrates is mostly used as a means to increase metabolisable energy intake, it might also be used to achieve a better nutrient balance (Muller and Fales, 1998). Herbage of temperate pastures is relatively low in readily fermentable carbohydrates (RFC) and high in crude protein (CP). A high proportion of this CP is rumen degradable (RDP). McCormick *et al.* (2001) report that 87.5% of CP of a ryegrass-oats pastures was RDP. Such an imbalance might lead to inefficiency in nitrogen and energy utilisation (Valk, 1994; McCormick *et al.*, 2001). Reproductive performance might also be jeopardised by high levels of RDP in the diet (McCormick *et al.*, 1999). Furthermore, based on results of a simulation model Kolver *et al.* (1998) predicted that some amino acids (lysine and methionine) might limit milk production in grazing cows and that feeding a supplement with rumen undegradable protein (RUP) might alleviate that limitation.

The dairy system under study is based on a sequential cropping system of permanent pastures – a mixture of alfalfa (*Medicago sativa*) and orchard grass (*Dactylis glomerata*) –, winter annual pastures – a mixture of oats (*Avena sativa*) and annual ryegrass (*Lolium multiflorum*) – and silage maize. Grazing dairy cows are supplementary fed with moderate amounts of concentrates during the lactation. Between November and April cows graze both types of pastures and between October and April they also receive supplementary feeding with maize silage. Knowledge on the responses to supplementary feeding with concentrates is required in order to i) adjust the stocking rate and ii) evaluate the economic feasibility of supplementary feeding with concentrates.

An experiment was conducted to estimate the response in terms of stocking rate and milk production per hectare to increasing levels of supplementary feeding with concentrates rich in RUP. Cows grazed oats and ryegrass pastures and alfalfa and orchard grass pastures and received 4.3 kg DM of maize silage offered cow^{-1} d^{-1}. In order to estimate the effect on SR, a high and uniform degree of pasture utilisation was targeted irrespective of the level of supplementary feeding. Herbage intake and ingestive behaviour were measured in order to estimate substitution rates and to gain insight in the nature of the response. The experiment was also aimed to gather information on herbage production, composition and utilisation of both types of pastures.

Materials and methodos

The experiment was carried out between 10 March and 10 May 2000 at the Farmlet for Dairy Production under Grazing of Chapingo University, located at 19°29' N, 98°54' W and 2240 m above sea level. Climate is temperate and subhumid with summer rains; average rainfall is 620 mm, and average temperature is 18°C. The soil is loam of volcanic origin, deep, neutral and fertile.

Animals, pastures, treatments and management

Twenty Holstein cows were used. Age of cows ranged between 1 and 3 lactations and was on average 2.0 ± 0.2 lactations. Average live weight was 541 ± 13 kg. Average number of days in milk at the beginning of the experiment was 157 ± 14. Averaged over a whole lactation the cows produced 21.4 ± 0.6 kg milk cow^{-1} d^{-1}.

Cows were allotted to four groups of 5 cows each, balanced according to age, days in milk and average production (multiparous cows) or pedigree (primiparous cows). Each group was offered 0, 2, 4 and 6 kg of concentrates cow^{-1} day^{-1}, respectively. In a previous experiment (Chapter 3) cows grazing oats-ryegrass pastures and alfalfa-orchard grass pastures were supplementarily fed with increasing levels of maize silage while receiving 3 kg of commercial concentrates. The levels of milk urea nitrogen (MUN) were too high suggesting that CP content of the diet might have been too high. Furthermore, according to requirements by NRC (1989), levels of rumen undegradable protein (RUP) might have been too low. The proportion of RUP of that concentrate was unknown. However, it might be assumed that it was rather low because, such as reported in Chapter 2 soybeans is the primary source of protein in commercial concentrates fed to dairy cattle in Mexico. Taking that into account, concentrates were formulated containing only 15.1 % CP of which 61.5% was RUP (Table 1).

Cows were milked between 06:30 and 08:30 and between 15:00 and 16:20. Before and after the morning milking and after the afternoon milking cows were penned and offered the daily amount of supplementary feeding, which consisted of 4.3 kg maize silage per cow (27% dry matter, 8.8% CP and 68.4% Neutral Detergent Fibre) mixed with the concentrates according to treatments. Cows were brought into the pastures when it was estimated visually that the group receiving no concentrates had consumed at least 80 % of the offered silage. Between the morning and the afternoon milking, cows grazed annual pastures of oats and annual ryegrass. Between the afternoon milking and the morning milking of the next day, they grazed permanent pastures of alfalfa and orchard grass. Mean schedule of daily activities is reported in Table 2.

Table 1. Composition of the used concentrates.

Component	g kg^{-1} DM
Maize grain ground	815
Fish meal	86
Meat meal	45
Molasses	36
Minerals	18
[1]Crude protein	151
[1]Rumen undegradable protein	93
[1]Net Energy for Lactation (Mcal kg^{-1}DM)	1.84

[1] Estimated according to average composition of components reported by NRC (1989)

Table 2. Mean schedule of daily activities.

	kg of concentrates cow^{-1} d^{-1}	
	0 and 2	4 and 6
Confinement with supplementary feeding	05:45-06:30	05:45-07:15
Milking	06:30-07:00	07:15-0:800
Confinement with supplementary feeding	07:00-10:45	08:00-10:45
Grazing in oats-ryegrass pastures	10:50-14:55	10:50-15:40
Milking	15:00-15:30	15:45-16:20
Confinement with supplementary feeding	15:30-18:50	16:20-18:50
Grazing in alfalfa-orchard grass pastures	18:55-05:40	18:55-05:40

Between 30 December 1999 and 31 January 2000 all cows grazed together on the same pastures while receiving 3 kg of commercial concentrates and 4.3 kg DM of maize silage per cow daily. Between 1 February and 9 March 2000 cows were allotted to groups, received supplementary feeding according to treatments and grazed as groups according to treatments. Measurements took place between 10 March and 10 May 2000.

During measurements, four paddocks (1.9 ha in total) of annual pastures and 5 paddocks (2.5 ha in total) of permanent pastures were used. Annual pastures were sown between 15 September and 30 October 1998. Seeding densities were 60 kg ha^{-1} of oats (cv. Walken) and 25 kg ha^{-1} of ryegrass (cv. Abundant). Annual pastures were fertilised at sowing with 60 kg P_2O_5 ha^{-1} and 60 kg N ha^{-1} and after each grazing cycle with 100 kg N ha^{-1}. Sprinkling irrigation took place fortnightly with on average 67 mm per irrigation. Permanent pastures were sown in December 1998 (one paddock, 0.3 ha) and between 15 November and 30 December 1999 (four paddocks, 2.2 ha in total). Seeding densities in kg pure germinating seed per ha were 12 and 15 for alfalfa (land varieties Valenciana and Atlixco) and orchard grass (cv. Potomac), respectively. Pastures were annually fertilised with 60 kg P_2O_5 ha^{-1}; irrigation took place as in the annual pastures. In the case of two paddocks, evaluation took place during the first grazing cycle of pastures.

A uniform and relatively low mass of residual herbage was targeted irrespective of the level of supplementary feeding. By displacing an electrical portable fence, cows were offered fresh herbage twice during the morning grazing session and once during the evening and night grazing session. Adjustment of areas allotted to each group took place based on a visual estimation of remaining herbage mass (with approximately 2000 kg DM ha^{-1} above ground level as targeted residual herbage). Daily areas allotted to each group were measured.

Notwithstanding the fact that the fraction of the total width of each paddock assigned to each group increased with decreasing levels of supplementary feeding, not all groups finished grazing their portion of the paddock on the same day.

Measurements

Sampling of pastures to estimate herbage on offer was carried out the day before the start of grazing; sampling for the estimation of residual herbage took place immediately after finishing grazing or one day later. Double sampling techniques were used for the estimation of herbage mass. Based on results of a previous experiment (Chapter 4), three different techniques were used simultaneously: a falling disc (50 cm diameter, 484 g weight), a sward stick based on the design shown by Hodgson (1990) and adapted to the height of the pastures, and the comparative yield method (Haydock and Shaw, 1975). At each sampling 10 calibration samples were cut following a regular pattern. Samples consisted of a strip of approximately 3 × 0.52 m. Before cutting, measurements were taken at 5 points with the sward stick and at 4 points with the falling disc and the sample was assigned a visual estimate in a 1-10 scale (Haydock and Shaw, 1975). Samples were cut to a target height of 6 cm with a Trupper® rotary mower. After cutting, the length of the cut strip was measured and the height of the remainder herbage was estimated by measuring at 4 points with the sward stick. At the centre of the cut strip a sample of 0.90 × 0.30 m of the remainder herbage was cut to ground level. Herbage was weighed and a subsample was taken. After drying in a conventional oven at 59°C during 72h samples were weighed, ground in a Wiley® mill provided with 1mm mesh and ash content was determined according to A.O.A.C. (1980). Pre- and post-grazing samples were paired, i.e. samples of residual herbage were placed as close as possible (in a standard orientation) to the place where samples of herbage on offer were taken (Lantinga *et al.* 2001). Indirect measurements were taken in the same way as in the calibration samples in 32 samples of approximately 3 × 0.52 m. Botanical composition was estimated by hand separating samples of approximately 200 g fresh weight which were cut to ground level in places adjacent to each calibration sample. On each paddock 10 hand-plucked samples were taken to estimate the ash content of herbage free of contamination with soil.

Refusals of supplements were weighed twice weekly and samples were taken for determination of DM content and chemical composition. After drying in a conventional oven at 59°C during 72h samples were weighed, and ground in a mill (Wiley®) provided with 1mm mesh. Near infrared spectroscopy (NIRS) was used to quantify CP and neutral detergent fibre (NDF) content.

Average herbage allowance per grazing session [kg DM (100 kg LW)$^{-1}$ (0.5 d)$^{-1}$)] was calculated per treatment and paddock based on herbage mass on offer, live weight of the group, length of the grazing period and area allotted to the group. Stocking rate (cows ha^{-1}) was calculated per grazing cycle (the sum of the grazing period and the previous rest period) taking into account the stocking density and the length of the grazing cycle. Stocking rate was calculated for each treatment at each paddock, SR of the treatment was the average of the stocking rates on annual and permanent pastures. Net herbage production (kg DM ha^{-1} d^{-1}) was calculated as the ratio between the herbage consumed (the difference between herbage on offer and residual herbage) and the length of the grazing cycle. Herbage allowance, stocking rate and net herbage production were estimated considering paddocks of annual and permanent pastures that were grazed during the same days. The last pair of paddocks was composed of one paddock of the annual pasture and the mean of two paddocks of permanent pastures. Due to lack of synchrony in changes to a new paddock in both pastures, paddocks taken into account did not cover the totality of the experimental period (Figure 1).

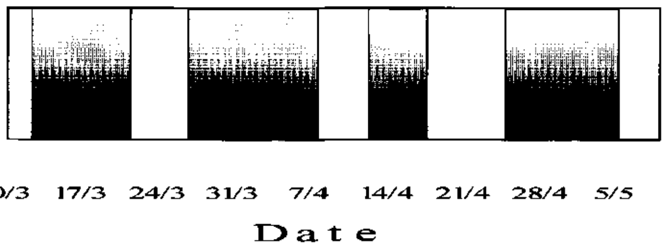

Figure 1. Periods taken into account for the estimates of herbage allowance, stocking rate and net herbage production (coloured in grey).

Milk production of each cow was weighed twice weekly on consecutive days. During the last week of the experiment a bulked sample of the four milkings was analysed for fat, protein, lactose, solids non-fat and MUN contents by infrared analysis (Holstein de Mexico SA de CV Laboratory, Querétaro, Mexico). Milk production per hectare was estimated based on corresponding least square means of milk production per cow and stocking rate for each of the 4 pairs of paddocks. Cows were weighed once a week immediately after the morning milking; linear regression equations of live weight in time were developed for each cow.

Measurements of activities and ingestive behaviour were carried out on 29 March and 14, 15, 28, 29 and 30 April 2001. Observations of activities were registered per cow every 10 minutes; activities taken into account were grazing, eating silage, ruminating and idling. Drinking, eating minerals and activities related to milking where brought together in the 5th category. Three distinct bouts were considered for the analysis of the daily activities of the cows namely: i) the morning grazing session, ii) the evening/night grazing session, and iii) the morning and afternoon periods when cows were confined for supplementary feeding. The morning and evening/night grazing sessions were subdivided in four intervals: 0-30, 31-60, 61-90 and >90 minutes since the start of grazing. The time required to take 100 bites was registered during different moments of the grazing sessions.

Faecal output was estimated using chromium oxide as external marker. Cows were dosed with Captec® controlled release capsules with a daily release of 1.43 g Cr_2O_3. Rectal grab samples were taken after each milking (Arriaga–Jordan and Holmes, 1986). Sampling started 8 days after dosing and was carried out during 15 days; 8 days later cows were dosed again and the sampling procedure was repeated. Compound samples of morning and afternoon faeces were dried, ground and chromium concentration was estimated according to Le Du and Penning (1982).

Based on NRC (1989), daily metabolisable energy requirements per cow were calculated for the period 10 March-10 May 2000. Production requirements were calculated according to average milk production of each cow and average composition. Energy requirements related to changes in live weight were calculated using the linear time course of live weight. The calculation of maintenance requirements followed AFRC (1993); energy requirements for standing, eating, ruminating and walking were based on each cow's average pattern of daily activities. The calculation of the energy requirements for walking included the average distance covered daily to the milking installation (1150m) and the distance walked in the pastures. To estimate the distance walked in the pastures a ratio of 3.2 m per minute of active grazing was used. This ratio was obtained earlier based on daily totals from observations of 11 replacement heifers during four consecutive days (unpublished data). Requirements for gestation were included only in the case of cows in the last 8 weeks of pregnancy.

Herbage intake was estimated in three ways: a) by means of herbage sampling, b) by means of faecal output and digestibility of the whole diet and c) through estimating intake needed to meet animal's requirements. A mean DM digestibility of 75% of herbage consumed was assumed. This value resulted from sampling the same type of pastures grazed by the same type of cows under similar grazing management (Chapter 3). The estimate by means of herbage sampling as the difference between herbage on offer and residual herbage resulted in an estimate of the herbage intake for each group of cows in each paddock. The estimate by means of faecal output and digestibility of the whole diet resulted in an estimate of the average herbage intake of each cow during 30 days. The estimate of herbage intake based on requirements resulted in an estimate of the average herbage intake of each cow during a period of 60 days.

Substitution rates were estimated by developing linear regressions of herbage intake on concentrates DM intake (Moran and Croke, 1993).

Statistical analysis

Data were subjected to analysis of variance using mixed models considering fixed and random effects (Littel *et al.*, 1996). Different response variables required different statistical models. The level of supplementary feeding, the type of pasture and the interval of the grazing session were considered as fixed effects. The paddocks, the day of measurement and the cow (nested in the level of supplementary feeding) were considered as random effects. Age, weeks in lactation and average daily production during a whole lactation (estimated by fortnightly measurements carried out one year before and 7 months after the experiment) were taken as co-variables in the analysis of variance of milk production per cow, body condition and intake per cow by means of faecal output and animal's requirements. Models on which analysis of variance was based are included in the Appendix.

Results

Herbage mass and composition

Cutting heights were higher in annual pastures than in perennial pastures, but within type of pasture they were similar for herbage on offer and residual herbage (Table 3). Frame (1993) states that due to uneven ground conditions, cutting height might be higher than intended. Seedbed of annual pastures was much coarser than that of perennial pastures. This might have caused a more irregular soil surface in annual pastures, affecting average cutting height.

Ash contents of samples taken with the rotary mower and cut to ground level with a scalpel were consistently higher than those of hand-plucked samples (Table 4). Differences between hand-plucked samples and other samples tended to be higher for permanent pastures than for annual pastures. Ash content in herbage on offer tended to be higher for herbage cut to ground level while the opposite occurred in residual herbage. This probably reflects differences in the suction of soil by the rotary mower because after grazing the upper layer of soil was drier than before grazing.

Table 3. Cutting height of the rotary mower (cm) in herbage on offer and residual herbage of annual and perennial pastures.

	Herbage on offer		Residual herbage	
	Mean	Standard Error	Mean	Standard Error
Annual pasture	7.03	0.15	7.03	0.16
Permanent pasture	6.30	0.13	6.48	0.11

Table 4. Ash contents (% of DM) of hand-plucked samples and samples taken with a rotary mower and below cutting height to ground level with a scalpel.

		Annual pasture		Permanent pasture	
	Height	Mean	Std. Error	Mean	Std. Error
	Hand-plucked	11.05	0.19	10.44	0.16
Herbage on offer	Rotary mower	13.65	0.31	14.28	0.86
	Below cutting height to ground level	16.10	0.38	18.99	0.81
Residual herbage	Rotary mower	15.88	0.83	18.63	0.79
	Below cutting height to ground level	14.26	0.33	13.84	0.44

According to Frame (1993), the suction or flailing action of rotary mowers mixes soil with herbage samples, affecting herbage mass estimates. Therefore, communication of results in terms of organic matter (OM) has been recommended (Lantinga et al., 2001). However, taking into account that most results are reported in terms of DM, results of this experiment are presented in terms of DM. In order to express the results in terms of DM, herbage organic matter of calibration samples was converted into herbage DM using average ash content of hand-plucked samples.

Based on previous results (Chapter 4) the stepwise method was used to develop prediction equations for herbage mass on offer and residual herbage mass for each type of pastures. Pooling of data from all paddocks resulted in equations with higher residual standard deviations (RSD) than average RSD of equations for each paddock. Therefore, equations per paddock were calculated which are reported in the Appendix. These equations were used to estimate herbage mass on offer (Table 5) and residual herbage mass (Table 6). Residual standard deviations (RSDs) of the regression equations might be considered high, particularly for herbage on offer in paddock 4 of the annual pasture. However, those high RSDs were partially caused by very high masses of herbage on offer; variation coefficients of those equations were within the normal range. Variation coefficients were lower for herbage on offer than for residual herbage, which is the normal situation according to Frame (1993).

Paddocks of permanent pastures were less uniform than paddocks of annual pastures, leading to differences among treatments in herbage mass on offer in three of the five paddocks. As could be expected from the targeted residual herbage mass management, differences among treatments in residual herbage mass were significant only in one of the nine paddocks. Herbage intake calculated as the difference between herbage on offer and residual herbage in paired (calibration) samples correlated with herbage mass on offer. The correlation was higher in permanent pastures than in annual pastures (Table 7).

Table 5.Herbage mass on offer (kg DM ha-1).

		kg of concentrates cow^{-1} d^{-1}							
Pasture	Paddock	0	2	4	6	Mean	Std. Error	Significance $P<0.05$	Mean height cm
Annual pasture	1	4017	4154	4229	4136	4134	78		38.4
	2	5779	6047	5692	5995	5878	150		52.0
	3	6037	5225	6623	6465	6088	214		56.0
	4	6958	5456	7065	6571	6512	272		63.7
Permanent pasture	1	4199	4871	4468	4281	4455	103		40.0
	2	4749	5016	4373	4668	4701	79	*	43.9
	3	1949	1993	3249	2849	2510	167	*	36.6
	4a	4862	4453	4427	4381	4531	115		50.8
	4b	6130	4736	5827	4417	5278	196	*	49.7

The proportion of weeds in herbage on offer was higher in permanent pastures; annual pastures were practically weed-free (Table 8). Herbage on offer of permanent pastures had higher proportions of leaves and tended to have lower proportions of stems and dead material. As the growing season progressed, the proportion of oats and leaves decreased while those of ryegrass and stems increased (Figure 2). The proportion of herbage above cutting height also increased during the growing season. In the case of permanent pastures, the proportion of orchard grass and dead material tended to increase with increasing age while those of alfalfa, weeds, leaves and stems tended to decrease. The proportion of herbage above cutting height also decreased with the age of pastures (Figure 3).

Table 6. Residual herbage mass (kg DM ha^{-1}).

		kg of concentrates cow^{-1} d^{-1}							
Pasture	Paddock	0	2	4	6	Mean	Std. Error	Significance P<0.05	Mean height cm
Annual pasture	1	1591	1668	1589	1479	1582	77		9.9
	2	3238	2894	2949	3174	3064	153		15.9
	3	2614	2327	2395	2261	2399	26		16.1
	4	2914	2546	2682	2934	2769	132		11.2
Permanent pasture	1	1973	1821	1714	1749	1814	58		8.9
	2	1287	1281	1323	1281	1293	37		9.2
	3	1488	1485	1365	1443	1445	52		5.5
	4a	1420	1370	1338	1346	1369	31		10.8
	4b	1330	1812	1151	1728	1505	79	*	10.1

Table 7. Regression equation of herbage intake [kg DM ha^{-1} (grazing cycle)$^{-1}$] on herbage mass on offer (kg DM ha^{-1}) based on paired calibration samples.

	Intercept	Linear Estimate	R^2	P	N
Annual Pasture	-816	0.72	0.72	0.001	40
Permanent pasture	-1254	0.95	0.82	0.001	50

Table 8. Morphological composition and weed content (% of DM) of herbage on offer of annual and permanent pastures.

	Weeds	Leaves	Stems	Dead Material
Annual pastures	0.2	48.7	41.2	10.1
Permanent pastures	13.1	52.9	38.4	8.7
Standard Error	4.4	2.0	3.2	3.3
P	0.01	0.01	0.11	0.16

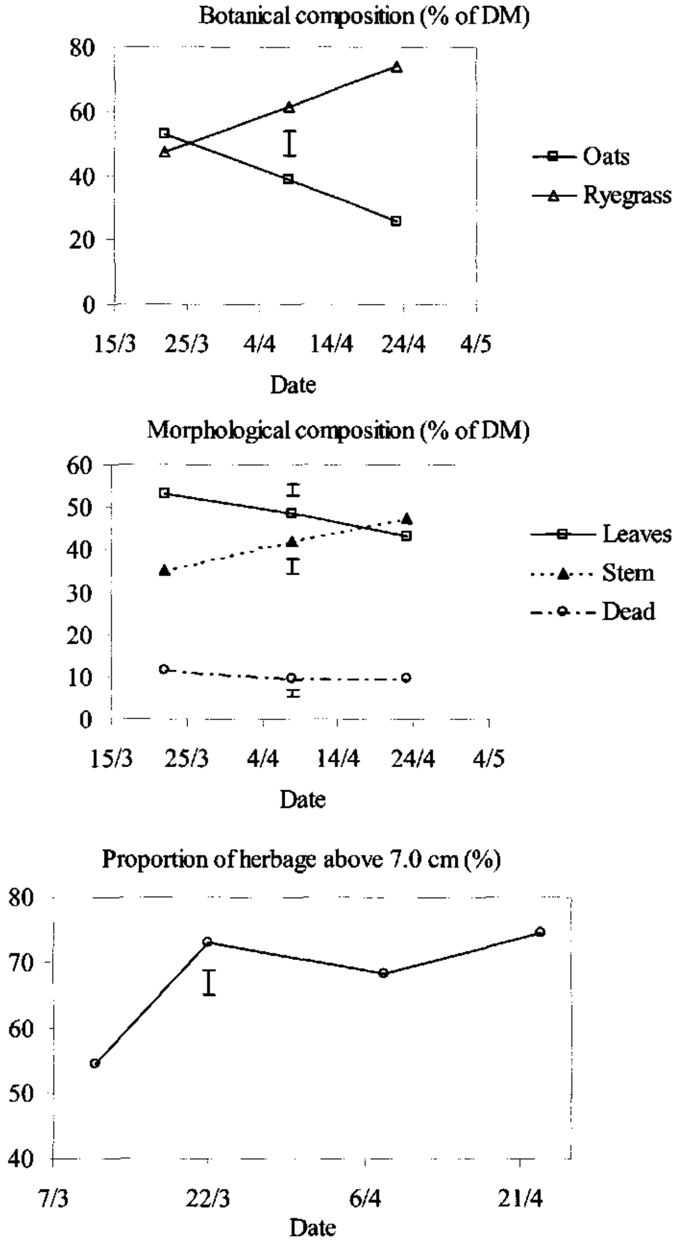

Figure 2. Botanical composition, morphological composition and structure of oats and ryegrass between the end of winter and the beginning of spring. Vertical bars depict standard errors.

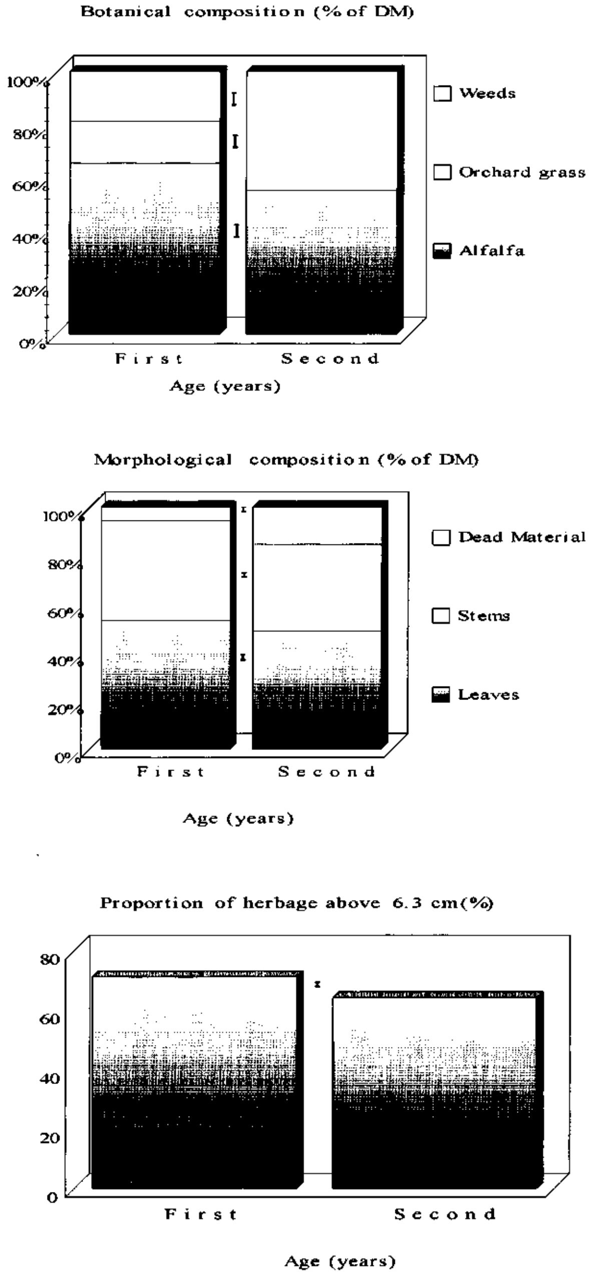

Figure 3. Botanical composition, morphological composition and structure of alfalfa and orchard pastures of different age. Vertical bars depict standard errors.

The effect of the interaction type of pasture × level of supplementary feeding was not significant. Therefore, in Tables 9 and 10 least square means of type of pasture and level of supplementary feeding are presented. Herbage mass on offer, residual herbage mass and herbage allowance were higher in annual pastures. The estimate of utilisation is highly dependent on the reference height of sampling. The established average level of utilisation of about 60% in both pasture types was high considering reports on utilisation based on sampling to ground level (Stockdale, 1985; Wales *et al.*, 1999). Annual pastures were superior in terms of average stocking rate and net herbage production (Table 9).

Table 9. Least square means of annual and permanent pastures for herbage on offer, residual herbage, herbage allowance per grazing session, utilisation (above ground level), herbage intake (based on pasture sampling) and stocking rate.

	Annual Pastures	Permanent Pastures	Standard Error	P
Herbage on offer (kg DM ha^{-1})	5653	4168	401	0.001
Residual herbage (kg DM ha^{-1})	2454	1502	135	0.001
Herbage allowance [kg DM $(100 \text{ kg LW})^{-1}$ $(0.5 \text{ d})^{-1}$]	1.68	1.42	0.08	0.022
Utilisation	0.569	0.603	0.036	0.430
Herbage intake [kg DM $(100 \text{ kg LW})^{-1}$ $(0.5 \text{ d})^{-1}$]	0.955	0.837	0.075	0.215
Herbage intake [kg DM cow^{-1} $(0.5 \text{ d})^{-1}$]	5.15	4.51	0.40	0.203
Stocking rate (cows ha^{-1})	4.68	3.12	0.50	0.001
Net herbage production (kg DM ha^{-1} d^{-1})	47.3	27.0	3.63	0.001

Intake of concentrates was expected to depress herbage intake. Due to the criterion used for allotting areas, herbage allowance was expected to decrease with increasing level of supplementary feeding. That was indeed the case for the two highest levels of supplementary feeding, but when cows received 2 kg of concentrates, herbage allowance unexpectedly increased compared to that of the unsupplemented group (Table 10). Feeding 2 kg of concentrates cow^{-1} d^{-1} made no increment of stocking rate possible, but stocking rate increased with supplementary feeding above that level.

Refusals of silage decreased with increasing levels of concentrates (Table 11), suggesting that mixing maize silage with concentrates increased the acceptability of the silage. Mixing increasing levels of concentrates with maize silage increased the CP content of refusals.

Table 10. Least square means of daily herbage allowance, intake in annual pastures as proportion of total herbage intake and stocking rate.

	kg of concentrates cow^{-1} d^{-1}				Standard Error	P
	0	2	4	6		
Daily herbage allowance [kg DM $(100\ kg\ LW)^{-1}$ d^{-1}]	3.33 b	3.88 a	2.68 c	2.55 c	0.14	0.001
Intake in annual pastures as proportion of total herbage intake (%)	52.8 a	53.1 a	57.1 a	55.4 a	6.38	0.747
Stocking rate (cows ha^{-1})	3.60 b	3.11 b	4.36 a	4.54 a	0.49	0.001

Means with the same index within a row are not different ($p>0.05$)

Table 11. Silage refusals as percentage of the amount of silage offered and their crude protein and neutral detergent fibre content.

	kg of concentrates cow^{-1} d^{-1}				Standard Error	P
	0	2	4	6		
Silage refusals (%)	20.4 a	17.9 a	15.0 a	8.0 b	3.0	0.006
Crude protein (% of DM)	7.8 c	8.5 b	9.2 a	9.1 a	0.25	0.005
Neutral Detergent Fibre (% of DM)	63.0	62.9	58.5	64.8	1.91	0.156

Means with the same index within a row are not different ($p>0.05$)

Milk production increased with supplementary feeding up to 4 kg of concentrates cow^{-1} d^{-1} (Table 12). The response in terms of kg extra milk per kg of concentrates consumed per cow decreased with increasing levels of concentrates. The responses to 2 and 6 kg of concentrates were in the upper and lower end of the range of frequently reported responses (0.6 to 1.1 kg extra milk per kg of concentrates consumed), respectively. Diminishing returns when increasing the level of supplementation with concentrates to grazing dairy cows have been reported by Reeves *et al.* (1996a), Pulido and Leaver (1997) and Reis and Combs (2000). The response in terms of kg extra milk per kg of concentrates consumed per hectare was negative for 2 kg of concentrates fed daily per cow. This negative response reflects the lack of response in stocking rate. The marginal response above 4 kg of concentrates fed daily per cow was very low when estimated per kg of concentrates consumed per cow and highly variable when estimated per kg of concentrates consumed per ha.

Milk fat and protein contents were within the range of contents reported by Donovan *et al.* (2000) and slightly higher than contents considered normal for Holstein cows by Muller and

Fales (1998). Although MUN concentrations tended to be higher in unsupplemented cows ($p=0.06$), the level of concentrate feeding had no significant effect on milk composition.

All but two cows tended to gain weight during the experiment ($p<0.20$), which according to NRC (1989) could be expected since on average the cows were in mid-lactation. However, weight gain was not significant in any of the unsupplemented cows ($p>0.05$), while it was significant ($p<0.05$) in 80% of the cows receiving concentrates. Feeding concentrates increased average live weight gain, with no marginal response above 2 kg cow^{-1} d^{-1}. Stockdale (1997a) reported that supplementary feeding in late lactation resulted in improvement of body condition.

Table 12. Least square means of milk production per cow, milk production per hectare, milk composition and changes in live weight.

	kg of concentrates v^{-1} d^{-1}				Standard Error	P
	0	2	4	6		
Kg milk cow^{-1} d^{-1}	19.6 c	21.4 b	23.0 a	23.0 a		
Fat (%)	3.82 a	3.79 a	4.01 a	3.75 a	0.20	0.794
Protein (%)	3.03 a	3.21 a	3.42 a	3.22 a	0.11	0.162
Lactose (%)	4.53 a	4.71 a	4.66 a	4.59 a	0.07	0.312
Solids non fat (%)	8.40 a	8.79 a	8.93 a	8.64 a	0.15	0.119
Milk Urea Nitrogen (mg dl^{-1})	18.6 a	14.7 a	11.5 a	15.7 a	2.6	0.060
Increase in live weight (kg cow^{-1} d^{-1})	0.199 b	0.540 a	0.496 a	0.457 a	0.07	0.015
kg milk ha^{-1} d^{-1}	75.6 b	70.7 b	105.1 a	110.5 a	10.8	0.001
[1]Response kg extra milk (kg $concentrate)^{-1}$ consumed per cow		0.901	0.832	0.568		
Response kg extra milk (kg $concentrate)^{-1}$ consumed per ha		-0.804 b	1.576 a	1.240 a	0.299	0.002

Means with the same index within a row are not different ($p>0.05$)
[1] Not submitted to analysis of variance

Feeding concentrates decreased grazing and ruminating time and increased time used eating supplements and idling (Table 13). Grazing time is expected to decrease in response to concentrates intake (Leaver 1985; Krysl and Hess, 1993). Grazing time was reduced with on average 12 minutes d^{-1} per kg of concentrates consumed. Grazing time was affected by the age of the cow with a reduction of 35 min d^{-1} per year of age, but this effect might be confounded with previous experience because primiparous cows had been grazing for only 3 to 4 months. Grazing time decreased with increasing stage of lactation [3 min cow^{-1} d^{-1} (week in milk)$^{-1}$], which might reflect the effect of the level of production (Pulido and Leaver, 1997). The decrease in ruminating time of 10.9 min per kg of concentrates probably reflects the lower fibre content of the total diet.

Table 13. Pattern of daily activities (min d^{-1})

	kg of concentrates cow^{-1} d^{-}					
	0	2	4	6	P	Std. Error
Active grazing	397 a	385 a	332 b	335 b	0.001	14
Eating supplements	101 bc	90 c	121 a	112 ab	0.001	5
Ruminating	516 a	499 ab	481 bc	450 c	0.001	12
Idling	364 c	408 b	440 ab	474 a	0.001	14
Other	62 a	58 a	66 a	69 a	0.340	4

Means with the same index within a row are not different ($p>0.05$)

Mixing the silage with relatively high amounts of concentrates increased the acceptability of the supplements. The cows spent more time eating silage when it was mixed with 4 or 6 kg of concentrates (Table 13). Differences between treatments were evident after the first 30 minutes of both sessions (Figures 4a and 4b). When none or low quantities of concentrates were mixed with maize silage, cows were reluctant to eat the supplements and eating rates decreased rapidly (Figure 4c). However, when 4 or 6 kg of concentrates were mixed with maize silage, the cows kept higher eating rates in the first 70 minutes of the sessions. As a consequence acceptable levels of refusals could have been achieved with these treatments within two hours per session. Almost no benefit was obtained from extending the sessions of supplementary feeding longer than two hours because thereafter the eating rates were very low (Figure 4c).

It appears that mixing the silage with concentrates increased the eating rate of supplements but not the intake rate of silage. Intake rates during the sessions of supplementary feeding were 34, 59, 59 and 82 g DM min^{-1} for 0, 2, 4 and 6 kg of concentrates cow^{-1} d^{-1}, respectively. However, when expressed exclusively in terms of the DM of silage consumed, the rates of intake were 34, 39, 30 and 35 g DM min^{-1} for 0, 2, 4 and 6 kg of concentrates cow^{-1} d^{-1}, respectively. The average rate (35±1.9 g DM min^{-1}) results similar to that reported in Chapter 3 (35 ±1.7 g DM min^{-1}) and found in Chapter 4 (39±1.4 g DM min^{-1}).

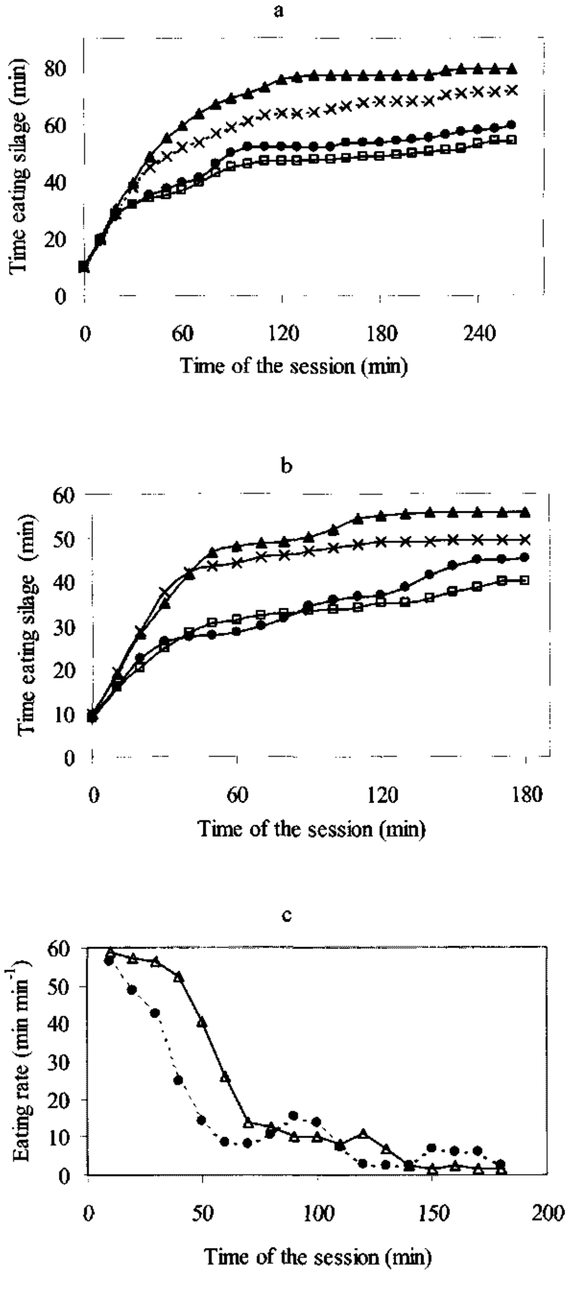

Figure 4. Time spent eating silage during the morning (a) and afternoon (b) sessions of supplementary feeding with maize silage mixed with four levels of concentrates: 0 (—●—), 2 (—□—), 4 (—×—) and 6 (—▲—) kg of concentrates cow^{-1} day^{-1}. Average eating rate of cows receiving 0 or 2 (- -●- -) and 4 or 6 (—Δ—) kg of concentrates cow^{-1} day^{-1} (c).

Results of grazing time during different bouts (Table 14) show that differences in daily grazing time arose mainly from differences after the first 90 minutes of the afternoon and night grazing session on permanent pastures. Therefore differences in daily grazing time were mainly due to differences in night grazing.

Table 14. Least square means of active grazing (min) during different intervals of the morning grazing session in annual pastures and during the same intervals of the afternoon and night session in permanent pastures.

		kg of concentrates cow^{-1} d^{-1}								
Grazing session and pasture	Interval (min)	0	2	4	6	Std. Error	P	Mean	Std. Error	P
Morning, annual pasture	0-30	30	30	30	28	4.1	0.001			
	31-60	29	30	29	29					
	61-90	29	29	29	26					
	>90	87 a	98 a	75 b	79 b					
Afternoon and night, permanent pasture	0-30	29	30	29	28					
	31-60	29	29	28	29					
	61-90	28	26	26	26					
	>90	135 a	113 b	87 c	91 c					
Annual pasture	Total	174 ab	184 a	162 ab	159 b	17	0.014	170	13	0.001
Permanent pasture	Total	222 a	198 ab	170 b	174 b			189		

Means with the same index within a row are not different (p>0.05)

Average biting rate (Figure 5) decreased with the level of supplementary feeding and with the time elapsed since the beginning of the grazing sessions. Biting rates were higher in permanent pastures than in annual pastures (Table 15). Due to the combination of effects on grazing time and on biting rate, total number of bites decreased with levels of concentrates above 2 kg cow^{-1} d^{-1} (Table 16).

Table 15. Least square means of biting rate (bites min^{-1}) during different intervals of the morning grazing session in annual pastures and during the same intervals of the afternoon and night session in permanent pastures.

		kg of concentrates cow^{-1} d^{-1}						
Pasture	Grazing session	0	2	4	6	Mean	Std. Error	P
Annual pasture	Morning	35.8 a	38.8 a	33.6 b	29.4 b	34.4	1.53	0.001
Permanent pasture	Afternoon and night	48.3 ab	48.5 a	38.6 bc	36.5 c	43.0		
Treatments	Mean	42.0 a	43.7 a	36.1 b	32.9 b		2.09	0.010

Means with the same index within a row are not different (p>0.05)

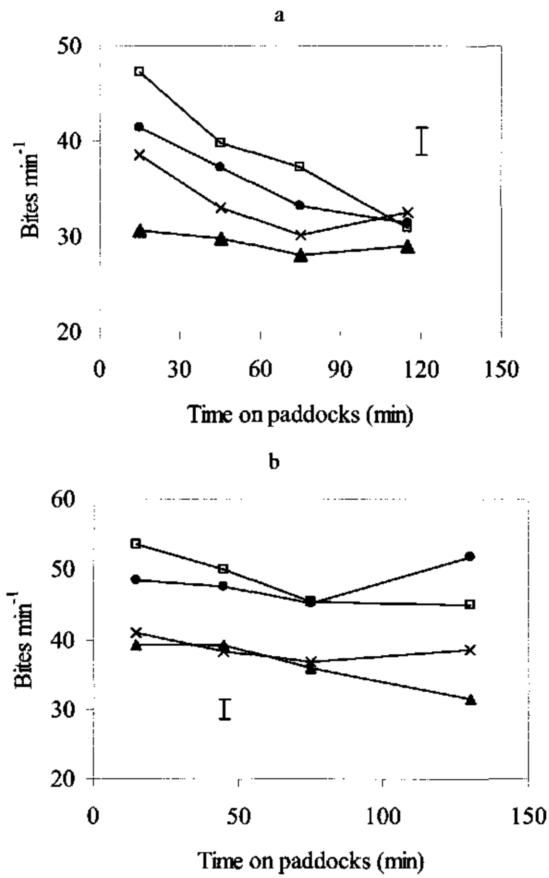

Figure 5. Biting rates (bites min^{-1}) at different moments of the morning grazing sessions on annual pastures (a) and the afternoon and night grazing sessions on permanent pastures (b) of cows supplementary fed with four levels of concentrates: 0 (—•—), 2 (—□—), 4 (—×—) and 6 (—▲—) kg concentrates cow^{-1} day^{-1}. Vertical bars depict standard errors.

An estimate of intake of supplements per cow was needed for the estimation of intake per cow based on faecal output and on requirements. Following Phillips and Leaver (1985), this estimate was based on the total intake of the group and the time eating supplements of each cow. As shown above, the intake rate of silage in this dairy system appears to be rather constant. It was assumed that because maize silage and concentrates were completely mixed, selective consumption of concentrates was not possible. Results on CP content of supplement refusals appear to confirm that the assumption was correct (Table 11).

Table 16. Least square means of total number of bites during different intervals of the morning grazing session in annual pastures and during the same intervals of the afternoon and night session in permanent pastures.

		kg of concentrates cow^{-1} d^{-1}								
Grazing session and pasture	Interval (min)	0	2	4	6	Std. Error	P	Mean	Std. Error	P
Morning, annual pasture	0-30	1248	1390	1145	828	158	0.001			
	31-60	1110	1218	963	832					
	61-90	969	1086	879	676					
	>90	2593	2831	2508	2243					
Afternoon and night, permanent pasture	0-30	1418	1578	1170	1074					
	31-60	1378	1435	1090	1122					
	61-90	1364	1252	1088	1011					
	>90	3392	4401	3888	2941					
Annual pasture	Total	5920	6525	5495	4579	445	0.714	5630	304	0.001
Permanent pasture	Total	7552	8666	7236	6148			7400		
Treatments	Total	13472ab	15191a	12731b	10727c				796	0.001

Means with the same index within a row are not different (p>0.05)

Total DM intake increased but herbage DM intake decreased when the intake of concentrates was above 2 kg cow^{-1} d^{-1} (Table 17 and Figure 6). With the exception of the estimate of herbage intake of the unsupplemented group based on herbage sampling, estimates of intake by the different methods were within an interval of ± 10% of the mean. The correlation coefficient (r) among estimates of intake per cow based on faecal output and requirements was 0.83. This correlation was higher than that between estimates of herbage intake by grazing dairy cows based on the n-alkanes and chromium oxide methods reported by Malossini *et al.* (1996). Furthermore, the relationship between both estimates was highly significant ($p<0.001$), the intercept was not different form 0 ($P>0.05$) and the linear estimate was not different from 1 ($p>0.05$). These results indicate that estimates based on those two methods might be considered similar.

However, relatively small differences in the estimates of intake by different methods caused large differences between the estimates of substitution, particularly in the case of cows supplementarily fed with 2 kg of concentrates per day. Considering estimates of herbage intake based on faecal output, the rate of substitution was constant (Table 17, Equation 1). When estimates of herbage intake based on requirements were used in the calculation of the substitution rate, this rate increased with increasing levels of concentrates (Table 17, Equation 2).

$$HIFO = 11.782 - 0.676\ IC,\ R^2 = 0.61,\ RSD = 1.3,\ p < 0.001,\ n = 20 \qquad (1)$$

$$HIER = 12.275 - 0.1447\ IC^2,\ R^2 = 0.56,\ RSD = 2.1,\ p < 0.001,\ n = 20 \qquad (2)$$

where

HIFO = Herbage intake estimated by means of faecal output (kg DM $cow^{-1}\ d^{-1}$)

HIER = Herbage intake estimated by means of energy requirements (kg DM $cow^{-1}\ d^{-1}$)

IC = Intake of concentrates (kg DM $cow^{-1}\ d^{-1}$)

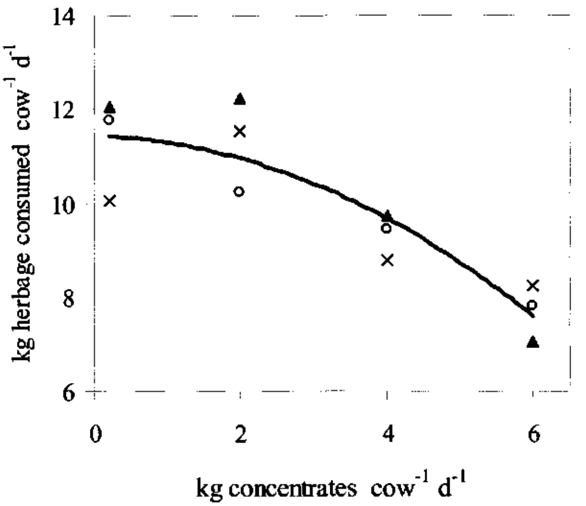

Figure 6. Herbage intake estimates based on faecal output (○) Energy requirements (▲) and Herbage sampling (×).

Rough estimates of intake of metabolisable energy (ME), rumen degradable protein (RDP) and rumen undegradable protein (RUP) by the different groups of cows were compared with requirements for mean levels of production considering no live weight change according to NRC (1989). Results suggest that the intake of RDP was too high and that of RUP too low when cows were fed less than 4 kg of concentrates (Figure 7). However it must be considered that NRC (1989) might overestimate RUP requirements (Dunlap *et al.*, 2000). The rather constant estimate of surplus in ME of supplemented cows is compatible with the rather constant live weight gain of those cows (498 ± 70 g cow^{-1} d^{-1}; Table 12).

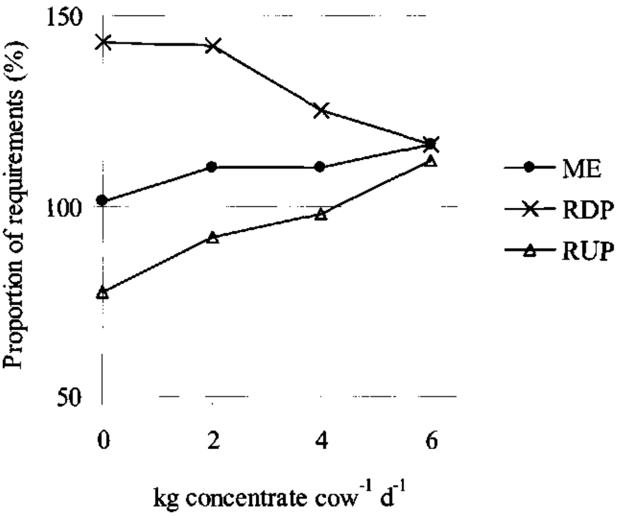

Figure 7. Total intake of metabolisable energy (ME), rumen degradable protein (RDP) and rumen undegradable protein (RUP) as proportion of requirements according to the level of production. Requirements were calculated according to NRC (1989), considering no live weight change.

Table 17. Least square means of herbage and total DM intake based on faecal output, requirements and pasture sampling; substitution rate according to the different methods used to estimate intake.

		kg of concentrates cow^{-1} d^{-1}					
	Method	0	2	4	6	St. Error	P
Kg herbage DM cow^{-1} d^{-1}	Faecal output	11.77 a	10.22 a	9.44 b	7.81 b	0.70	0.009
	Requirements	12.05 a	12.23 a	9.73 ab	7.05 b	1.09	0.013
	Pasture sampling	10.04 ab	11.55 a	8.80 b	8.26 b	0.77	0.005
Kg herbage DM $(100\ kg\ LW)^{-1}$ d^{-1}	Faecal output	2.30 a	1.90 a	1.73 ab	1.40 b	0.14	0.003
	Requirements	2.34 a	2.27 a	1.80 ab	1.27 b	0.21	0.008
	Pasture sampling	1.94 a	2.15 a	1.61 b	1.47 b	0.14	0.002
Kg total DM cow^{-1} d^{-1}	Faecal output	15.21 c	15.57 bc	16.87 ab	17.89 a	0.50	0.006
	Requirements	15.49	17.59	17.16	17.13	0.93	0.423
	Pasture sampling	13.10 b	16.53 a	15.85 a	17.85 a	0.90	0.006
Kg herbage DM $(100\ kg\ LW)^{-1}$ d^{-1}	Faecal output	2.97	2.90	3.10	3.25	0.18	0.538
	Requirements	3.01	3.27	3.18	3.12	0.23	0.877
	Pasture sampling	2.53 b	3.07 a	2.89 a	3.18 a	0.17	0.034
Substitution rate	[1]Faecal output		-0.855	-0.620	-0.660		
kg DM grazed herbage	[1]Requirements		0.099	-0.618	-0.833		
$(kg\ DM\ concentrate)^{-1}$	Pasture sampling		0.833 a	-0.330 b	-0.297 b		
	[2]Faecal output		-0.676	-0.676	-0.676	0.61	0.001
	[3]Requirements		-0.262	-0.543	-0.868	0.56	0.001

Means with the same index within a row are not different ($p>0.05$)

[1] Not submitted to analysis of variance

[2] Estimate of substitution based on equation 1

[3] Estimate of substitution based on equation 2

Discussion

Herbage mass and composition, comparison between types of pastures

The proportions of oats and leaves decreased as the season progressed while those of ryegrass and stems increased (Figure 2). These changes in botanical and morphological composition of oats-ryegrass pastures are in line with previous results (Améndola and Morales, 1997; Chapter 3). Rest periods of these pastures increased as the season progressed leading to the very high herbage masses and heights of herbage on offer (Table 5). That is probably the reason for the increasing proportion of herbage mass above cutting height, which was higher than that found in a previous experiment (Chapter 4).

The proportion of alfalfa in herbage on offer decreased and that of orchard grass increased with the age of the pasture (Figure 3). This might be related to the lower initial growth rate of orchard grass (unpublished results). The higher proportion of orchard grass with increasing age might be the cause of the reduction in the proportion of herbage above cutting height. López (1995) reports that the proportion of orchard grass in herbage on offer in a 4-year-old alfalfa-orchard grass pasture (renovated after 3 years) was higher in the lower layers of the canopy. The proportion of herbage above 10 cm reported by López was 39%. By interpolating an exponential equation, that describes the structure of the canopy reported in that experiment, it can be estimated that 50% herbage was above 6.3 cm. This is much lower than found in the current experiment with younger pastures. The high proportion of weeds (mostly broad-leaved annual species) and the low proportion of dead material might also be considered as characteristic of the first and second grazing cycles of pastures (García and Juárez, 1994).

Grazing management was ruled by a target of high utilisation irrespective of the level of supplementary feeding. Residual herbage mass was uniform across supplementation levels (Table 6). Herbage utilisation to ground level was higher than the highest value (52%) reported by Wales *et al.* (1999), and than the results of 8 experiments reported by Stockdale (1985) which averaged 40.3 ± 3.6 %. As expected, under this rather intensive grazing management, herbage mass on offer affected herbage intake (Table 7). According to the equations utilisation was higher in permanent pastures than in annual pastures. These results contradict with those reported in Chapter 3. This contradiction is probably due to differences in age of the permanent pastures (older in that experiment), leading to differences in botanical composition, morphological composition and structure, and to differences in maturity of annual pastures (shorter rest periods in that experiment). In spite of the fact that differences between annual and permanent pastures arose in a different way than in the experiment of

Chapter 3, the higher stocking rate and the higher net herbage production achieved with annual pastures in the current experiment (Table 9) confirm the advantages of including them in the crop rotation.

Utilisation of maize silage

Dry matter and CP contents of the maize silage used in the current experiment were similar to those of silage used in previous experiments (Chapters 3 and 4); NDF content was slightly higher. Contents of all components were in the range of contents reported in the region by Andrade and Contreras (1997).

Results reported in Chapter 4 suggest that grazed herbage was preferred above maize silage because cows at higher herbage allowances were reluctant to eat the silage. The composition of the maize silage might partially be the cause of this preference. Reluctance to eat maize silage led in that experiment to long periods of confinement with this supplement, and consequently reducing residence time in pastures. Results reported in chapter 3 suggest that cows compensated only partially for the reduction in duration of the grazing sessions. Mixing the maize silage with 4 or 6 kg of concentrates improved the acceptability (Tables 11 and 13, Figure 4). Results shown in Figure 4 suggest that in this way there is scope for reducing the length of the periods of confinement.

Herbage intake

Active grazing and ruminating time

Active grazing time was on average reduced in 12 min d^{-1} per kg DM of concentrates consumed. This reduction is almost the same as those reported by Combellas *et al.* (1979), Pulido and Leaver (1997) and Wales *et al.* (2000). Taking into account the huge diversity of conditions of these experiments and the diversity of factors affecting grazing time when animals are supplementary fed with concentrates (Leaver, 1985), the question of this is a constant or the similarity of results is just coincidental deserves further exploration. For instance, Sayers *et al.* (2000) report higher rates of decline of grazing time. However, in that experiment reduction in grazing time might have depended on impediments for normal walking, because a relatively high proportion of cows receiving supplementation with a starch-rich concentrate, suffered acidosis and became lame.

Differences in grazing time arose mostly from differences in night grazing, concurring with results reported by Rook *et al* (1994a) and results reported in Chapter 4. Taking into account the effect of grazing time on herbage intake (Chilibroste, 1999), and therefore on production

(Mannetje, 2000), these results emphasise the importance of observing the response of night grazing to changes in management.

Ruminating time decreased with the level of supplementary feeding. This reflects the reduction in forage intake. The average intake of forages was estimated as the sum of silage intake (calculated from Table 11) and the average of herbage intake estimated by faecal output and requirements (Table 17). When ruminating time (Table 13) is divided by the intake of forages it results in a rather constant rate of 35 ± 1 min of ruminating time per kg DM of forages consumed.

Biting rate and total number of bites

Even though Leaver (1985) stated that supplementation has little effect on biting rate, in the current experiment supplementary feeding with 4 and 6 kg of concentrates reduced biting rate (Figure 5). This might the consequence of a reduced eating drive or feeling of hunger (Chilibroste, 1999; Soca *et al.*, 1999). Biting rate decreased with the time elapsed since the beginning of the grazing sessions. Taking into account the results reported in Chapters 3 and 4 and the results reported by Chilibroste (1999) and Soca *et al.* (1999) this appears to be the normal evolution of biting rate under this kind of grazing management.

The total number of bites per bout was affected by the interval of the grazing session nested within the interaction type of pastures × level of supplementary feeding (Table 16). However, it appears that cows receiving 2 kg of concentrates took rather consistently more bites. In spite of the effect of this interaction, when results are expressed as proportions of the number of bites taken by the cows receiving 2 kg of concentrates, in most intervals bites taken by cows receiving 0, 4 and 6 kg concentrates were respectively 11, 16 and 29 % lower.

Based on the average herbage DM intake (average of estimates obtained with different methods reported in Table 17) and the total number of bites (Table 16), rough estimates of intake rates and bite weight were made. Average intake rates (28 g DM min^{-1}) were in line with intake rates reported for grazing dairy cows on temperate pastures while receiving supplementary feeding with concentrates (Pulido and Leaver, 1997; Wales *et al.*, 2000), and with intake rates calculated from data reported by Sayers *et al.* (2000). It appears that in the current experiment bite weight and intake rate were not affected by the level of supplementary feeding ($P>0.10$). Leaver (1985) stated that supplementation is expected to have little effect on intake rates. Wales *et al.* (2000) found no effect of supplementation level on intake rate and the same result can be calculated from data reported by Sayers *et al.* (2000). On the contrary, Pulido and Leaver (1997) reported a reduction of herbage intake rate in 1.01 g min^{-1}

per kg of concentrates consumed. This might be due to the very high maximum level of concentrates used in that experiment (12.2 kg cow^{-1} d^{-1})

Intake rates in annual pastures (30.3 g DM min^{-1}) were higher than in permanent pastures (23.7 g DM min^{-1}) and were related to a higher average bite weight (0.92 vs. 0.61 g DM bite^{-1}). According to the functional relationship between bite weight and biting rate (Mannetje, 2000), this explains the higher biting rate attained in permanent pastures. This higher average bite weight in annual than in permanent pastures concurs with the results found in Chapter 3 and constitutes an additional treat among the relative advantages of annual pastures.

Herbage intake

Results on herbage intake (Table 17) and ingestive behaviour (Table 16) show that when cows were supplementarily fed with 2 kg of concentrates no substitution occurred. Reduction in herbage intake when concentrates are supplementarily fed is usually ascribed to the shifting in bacterial populations caused by reduced rumen pH (Caton and Dhuyvetter, 1997). However it is unlikely that a decrease in ruminal pH is the only cause of reduced herbage intake (Caton and Dhuyvetter, 1997; Dixon and Stockdale, 1999). Caton and Dhuyvetter (1997) suggest that low levels of energy supplementation (30 g kg^{-1} metabolic weight) would not greatly affect forage intake or ruminal function (i.e. minimal substitution). Considering average live weight of the cows used in the current experiment, such a level would be slightly above 3 kg cow^{-1} d^{-1}. That would explain why no substitution was found with the lowest level of supplementary feeding.

Body weight changes, milk composition and production

Supplementary feeding resulted in improvement of live weight gain (Table 12) concurring with reports by Hoden *et al.* (1991), Stockdale (1997a and 1999b) and Wales *et al.* (2000). However, Reeves *et al.* (1996a) and Sayers *et al.* (2000) report that supplementation had no effect on live weight. These different results might have been caused by the factors that affect the partition of energy intake between milk production and body reserves: i) the length of the experimental period (Stockdale, 1999b), ii) the stage of lactation (Stockdale 1997a) and iii) the age of the cow (Johnson, 1977).

Improved body weight change might result in a better energy balance later in the lactation or in the next lactation and improved reproductive performance. Stockdale (1999b) converted live weight changes into milk equivalents, concluding that by using that conversion the estimate of the response was improved with 20%. Applying the approach of Stockdale to the results of the current experiment increased the response reported in Table 12 to 0.43, 2.31 and

1.66 kg extra milk produced ha^{-1} per kg of concentrates consumed per ha. Taking into account the effects of supplementation on live weight gain changed the response to 2 kg of concentrates from negative to positive.

Supplementary feeding with concentrates had no effect on the fat and protein content of milk (Table 12). The frequently reported decrease of fat content when concentrates are fed (e.g. Grainger and Mathews, 1989; Reeves *et al.*, 1996a; Reis and Combs, 2000; Sayers *et al.*, 2000) is the consequence of a reduction in the proportion of NDF in the diet. However, the proportion of NDF that is required in order to maintain a constant milk fat content increases with the level of intake (Dixon and Stockdale, 1999). That is probably the reason why no effects of supplementary feeding with concentrates are frequently reported (e.g. Clements *et al.*, 1992; Rook *et al.*, 1994b; Wilkins *et al.*, 1994; Fisher *et al*; 1996; Wales *et al.*, 2000). Supplementary feeding with concentrates has been reported to increase the protein content of milk (Wilkins *et al.*, 1994; Reis and Combs, 2000; Sayers *et al.*, 2000). However, results are not consistent since no effect of supplementary feeding on the protein content of milk has been reported by Clements *et al.* (1992), Grainger and Mathews (1989), Fisher *et al*, (1996) and Reeves *et al.* (1996a).

The level of milk urea nitrogen (MUN) of unsupplemented cows (Table 12) was very close to the lower limit of MUN levels considered to affect reproductive performance (Butler, 1998). Supplementary feeding with concentrates rich in RUP tended ($p=0.06$) to reduce MUN levels. This was probably the consequence of reducing RDP content of the whole diet. Even though MUN levels appear to depend on many factors (Godden *et al.*, 2001), comparing MUN levels attained in this experiment with those reported in Chapter 3 suggests an important improvement.

Comparing the levels of production attained in the experiment of Chapter 3 with 3 kg of commercial concentrates and 3.2 or 4.8 kg DM of maize silage (18.3 and 17.6 kg milk cow^{-1} d^{-1}, respectively) with those attained in this experiment with 4.3 kg DM of maize silage and 2 or 4 kg of concentrates (21.4 and 22.9 milk cow^{-1} d^{-1}, respectively) also suggests an important improvement. Taking into account the similarity of the conditions of both experiments it might be concluded that the difference in production was at least partially due to the reduction in RDP content of the concentrate. McCormick *et al.* (1999), Schroeder and Gagliostro (2000), and O'Mara *et al.* (2000) report that feeding concentrates high in RUP improved milk production. Muller and Fales (1998) state that surplus RDP can account for a loss of energy equivalent to 1.5-3.0 kg milk.

The response in milk production per cow was one of diminishing returns (Table 12). The response to 2 kg of concentrates might be considered high while the response to 6 kg of concentrates might be considered low (frequently reported responses range from 0.6 to 1.1 kg extra milk per kg consumed concentrates). This was to be expected since herbage allowance decreased as the level of concentrates increased and milk production has been reported to show a curvilinear response to both variables.

As a consequence of the grazing management imposed, stocking rate increased with 4 or 6 kg of concentrates but not whit 2 kg of concentrates (Table 10). This result is the consequence of the effects on substitution rate already discussed (Table 17). Milk production per ha increased with 4 or 6 kg of concentrates but not with 2 kg of concentrates. The lack of response in milk production per ha when cows were fed with 2 kg of concentrates was due to the impossibility of raising SR, because the response in milk production per cow with that level of supplementary feeding was the highest. This results concur with findings of McCall and Clark (1999). Results from a simulation model led McCall and Clark to conclude that the best use of purchased feed in New Zealand dairy systems was to support increased stocking rate, rather than increase the production per cow. Responses to supplementary feeding with concentrates in terms of milk per cow and per hectare appear to be opposite to a certain extent. High responses per cow appear to be coupled to low substitution rates (Leaver, 1985, Grainger and Mathews, 1989; Wales *et al.*, 1999; Reis and Combs 2000) while increments in stocking rate are possible when concentrates substitute for the intake of herbage (Leaver, 1985).

Hoden *et al.* (1991) and Clements *et al.* (1992) studied the response of milk production to supplementary feeding under different stocking rates. The results of Clements *et al.* (1992) and those calculated from data reported by Hoden *et al.* (1991) are compared with the results of the current experiment in Figure 8. In both cases milk production per hectare was not reported but calculated from reported data on milk production per cow and stocking rate. Productivities reached in the current experiment with 4 or 6 kg of supplementary feeding and high SR are comparable to those attained by Clements *et al* (1992). The low productivity in the experiment of Hoden *et al.* (1991) was linked to the unexpectedly low SR (taking into account that a fertilisation rate of 300 kg N ha^{-1} $year^{-1}$ was used).

The adoption of this kind of technology reflects the price ratio between concentrates and milk (McCall and Clark, 1999). Therefore, responses per hectare were analysed considering this ratio such as carried out by Stockdale (1999b) when considering responses per cow. This type of estimates does not include the costs involved in the increase of SR as recommended by

Leaver (2000). Nonetheless, those costs clearly depend on the scale of the farm. The price of milk was US \$ 0.32 kg^{-1} and the cost of the concentrate used was US \$ 0.22 kg^{-1}. Using these prices in combination with the response in kg extra milk per kg of concentrates consumed per ha (Table 12) the gross revenues from milk sales per US \$ spent in concentrates were calculated. These gross revenues were -1.17, 2.29 and 1.80 US \$ from milk per US \$ spent in concentrates for 2, 4 and 6 kg of concentrates cow^{-1} d^{-1}, respectively. In spite of the good response per cow (Table 12), feeding 2 kg of concentrates was not profitable when the response was analysed per hectare. On the contrary, feeding 4 kg of concentrates was highly profitable and it appears that it should be able to withstand deterioration in the price ratio between concentrates and milk.

It is striking that even though at the system level, the feasibility of using supplementary feeding depends on the response per hectare, no reports on that response were found. As stated by Leaver (2000) " There is scarcity of research relating technology to farm financial return". It might be argued that extrapolation of results on responses per hectare would be limited. But that is also the case for the responses per cow. It might also be argued that is difficult to attain sufficient degrees of freedom in experiments concerning responses per hectare. Letting this argument preclude exploring that response should be weighed against the statement of Leaver (2000) on the need to "...ensure that meaningful questions are addressed in research projects, and that results are produced which are useful in practice".

Conclusions

The grazing management based on uniform utilisation of pastures irrespective of the level of supplementary feeding was suitable to detect the response of milk production per hectare to supplementary feeding. A high response in milk production per cow was coupled to low levels of substitution. On the contrary, the increase in stocking rate was coupled to high levels of substitution. Milk production per hectare was mainly affected by the increase in stocking rate. The response to 2 kg of concentrates cow^{-1} d^{-1} was not economically feasible while that to 4 kg of concentrates was economically attractive and should be able to withstand deterioration in the price ratio between concentrates and milk. Basing the economic evaluation on the response of milk production per cow to supplementary feeding would have led to mistaken conclusions. Oats and ryegrass pastures were superior to alfalfa and orchard grass pastures in terms of SR and net herbage production.

Appendix to Chapter 5

Models used in analysis of variance.

Model 1

$Y_{ij} = \mu + T_i + S_j + P_k + E_{ijk}$

Where

Y_{ijk} = Response variable: Herbage mass on offer. Proportions of morphological components in herbage on offer.

μ = general mean,

T_i = effect of type of pasture, i = 1, 2

S_j = effect of the level of supplementary feeding, j = 1 to 4

P_k = effect of pair of paddocks k = 1 to 4

E_{ij} = error term

Model 2

$Y_{ijk} = \mu + S_i + T_j + (S \times T)_{ij} + P_k + E_{ijk}$

Where

Y_{ijk} = Response variable: Residual herbage mass. Daily herbage allowance. Stocking rate. Herbage intake based on herbage samplings.

μ = general mean,

S_i = effect of the level of supplementary feeding, i = 1 to 4,

T_j = effect of type of pasture j = 1, 2

$(S \times T)_{ij}$ = effect of the interaction between the level of supplementary feeding with concentrate and the type of pasture,

P_k = effect of Pair of paddocks k = 1 to 4

E_{ijk} = error term

Model 3

$Y_{ijk} = \mu + S_i + C_j (S_i) + D_k + E_{ijk}$

Where

Y_{ijk} = Response variable: Variables related to daily pattern of activities.

μ = general mean,

S_i = effect of the level of supplementary feeding with concentrate, i = 1 to 4,

C_j = effect of cow nested in level of supplementary feeding, j = 1 to 24

D_k = effect of day of measurement, k = 1 to 6

E_{ijk} = error term

Model 4

$Y_{ij} = \mu + S_i + D_j + B_1X_1 + B_2X_2 + B_3X_3 + E_{ij}$

Where

Y_{ij} = Response variable: Milk production.

μ = general mean,

S_i = effect of the level of supplementary feeding, i = 1 to 4,

D_j = effect of day of measurement k = 1 to 15

B_1X_1 = linear effect of weeks in milk

B_2X_2 = linear effect of number of lactation

B_3X_3 = linear effect of average daily production during a lactation

E_{ij} = error term

Model 5

$Y_{ijklm} = \mu + S_i + T_j + (S\times T)_{ij} + [I_k (S\times T)\ ij] + C_l (S_i) + D_m + E_{ijklm}$

Where

Y_{ijklm} = Response variable: Variables related to ingestive behaviour.

μ = general mean,

S_i = effect of the level of supplementary, i = 1 to 4,

T_j = effect of type of pasture, j = 1, 2

$(S\times T)_{ij}$ = effect of the interaction between the level of supplementary feeding and the type of pasture,

I_k = effect of Interval of the grazing session nested in level of supplementary feeding × type of pastures, k = 1 to 4

C_l = effect of cow nested in level of supplementary feeding, l = 1 to 20

D_m = effect of day of measurement m = 1 to 6

E_{ijklm} = error term

Model 6

$Y_{ij} = \mu + S_i + P_j + E_{ij}$

Where

Y_{ijk} = Response variable: Milk production per hectare. Total DM intake based on herbage samplings.

μ = general mean,

S_i = effect of the level of supplementary feeding, i = 1 to 4,

P_j = effect of Pair of paddocks k = 1 to 4

E_{ij} = error term

Model 7

$Y_{ij} = \mu + S_i + B_1X_1 + B_2X_2 + B_3X_3 + E_{ij}$

Where

Y_{ij} = Response variable: Milk composition. Intake per cow (faecal output and requirements). Live weight change.

μ = general mean,

S_i = effect of the level of supplementary feeding, i = 1 to 4,

B_1X_1 = linear effect of weeks in milk

B_2X_2 = linear effect of number of lactation

B_3X_3 = linear effect of average daily production during a lactation

E_{ij} = error term

Model 8

$Y_{ij} = \mu + S_i + D_j + E_{ij}$

Where

Y_{ij} = Response variable: refusals of supplements.

μ = general mean,

S_i = effect of the level of supplementary feeding, i = 1 to 4,

D_j = effect of day of measurement k = 1 to 15

E_{ij} = error term

Calibration regression equations for herbage mass on offer

Paddock 1 of Annual pastures HM = 2307 + 290 VE

Paddock 2 of Annual pastures HM = 4069 + 1061 VE – 139 FD

Paddock 3 of Annual pastures HM = 3109 + 1218 VE-106 FD

Paddock 4 of Annual pastures HM = 219 + 1027 VE

Paddock 1 of Permanent pastures HM = 6862 –92 SS+ 37 FD

Paddock 2 of Permanent pastures HM = 1709 + 68 SS

Paddock 3 of Permanent pastures HM = -518 + 85 SS

Paddock 4a of Permanent pastures HM = 515 + 313 VE + 55 FD

Paddock 4b of Permanent pastures HM = 1115 + 819 VE

where

HM = Herbage mass (kg DM ha^{-1})

VE = Visual estimate in a 1-10 scale (Haydock and Shaw, 1975)

SS = Height measured with the Sward stick (cm)

FD = Height measured with the Falling disc (cm)

Table 1. Mean herbage mass of calibration samples, determination coefficient (R^2), probability (P), residual standard deviation (RSD) and coefficient of variation (CV) of the calibration equations for herbage mass on offer.

	Annual pasture				Permanent pasture				
	Paddocks								
	1	2	3	4	1	2	3	4a	4b
Mean (kg DM ha^{-1})	3631	6228	6778	7048	4389	4704	2741	4207	4836
R^2	0.53	0.67	0.72	0.72	0.69	0.45	0.87	0.65	0.86
P	0.018	0.021	0.022	0.002	0.017	0.035	0.001	0.025	0.001
RSD (kg DM ha^{-1})	499	527	775	1022	340	401	375	560	684
CV %	13.7	8.5	11.4	14.5	7.8	8.5	13.7	13.3	14.1

Calibration regression equations for residual herbage mass

Paddock 1 of Annual pastures HM = -1 + 360 VE

Paddock 2 of Annual pastures HM = -1926 + 538 VE + 110 SS

Paddock 3 of Annual pastures HM = -1724 + 255 SS

Paddock 4 of Annual pastures HM = 704 + 488 VE -31 SS

Paddock 1 of Permanent pastures HM = 718 + 120 FD

Paddock 2 of Permanent pastures HM = 561 + 240 VE

Paddock 3 of Permanent pastures HM = 54 + 209 VE + 16 FD

Paddock 4a of Permanent pastures HM = 497 + 166 VE

Paddock 4b of Permanent pastures HM = -332 + 448 VE

where

HM = Herbage mass (kg DM ha^{-1})

VE = Visual estimate in a 1-10 scale (Haydock and Shaw, 1975)

SS = Height measured with the Sward stick (cm)

FD = Height measured with the Falling disc (cm)

Table 2. Mean herbage mass of calibration samples, determination coefficient (R^2), probability (P), residual standard deviation (RSD) and coefficient of variation (CV) of the calibration equations for residual herbage mass.

	Annual pasture				Permanent pasture				
	Paddocks								
	1	2	3	4	1	2	3	4a	4b
Mean (kg DM ha^{-1})	1626	3046	2593	2615	1750	1608	1359	1220	1469
R^2	0.73	0.78	0.6	0.95	0.48	0.49	0.9	0.63	0.75
P	0.002	0.005	0.025	0.001	0.037	0.025	0.001	0.006	0.003
RSD (kg DM ha^{-1})	359	414	818	198	224	397	164	211	287
CV %	22.1	13.6	31.5	7.6	12.8	24.7	12.1	17.3	19.5

Chapter 6

Nitrogen fertilisation and irrigation on herbage and nitrogen yield of oats and annual ryegrass pastures

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Abstract

Nitrogen fertilisation and irrigation are two major inputs for oats and ryegrass pastures in temperate Mexico. The effect of four levels of N fertilisation (0, 50, 100 and 150 kg N ha^{-1} $harvest^{-1}$) and two levels of irrigation [67 and 100 mm $(14d)^{-1}$] on herbage dry matter and N-yield of oats and annual ryegrass pastures, was studied in three harvest cycles between November 1998 and April 1999 at Chapingo, Mexico. The apparent recovery of fertiliser N (ANR) averaged 46% and was lower with the highest level of irrigation and in the first and third harvest cycles when the average growth rate of pastures was low. The low ANR was partially ascribable to the high amount of N made available by the soil with the lowest level of irrigation. The average apparent effect of N fertilisation (ANE) was 17, 12 and 10 kg DM kg^{-1} N with 50, 100 and 150 kg N ha^{-1} $harvest^{-1}$, respectively. This average ANE was lower than usually observed with annual or perennial ryegrass and was the consequence of the low ANR. Nitrogen fertilisation increased DM yield by improving radiation interception. With the highest level of irrigation, increasing levels of N fertilisation tended to improve radiation use efficiency. The outcome of competition between oats and ryegrass depended strongly on the level of nitrogen fertilisation. In unfertilised pastures oats was more competitive than ryegrass. However, with increasing levels of N fertilisation ryegrass reduced the performance of oats by depletion of light. This was probably enabled by a steeper increase in the leaf area of ryegrass than in that of oats. The efficiency of use of irrigation water was lower in the first and third harvest cycles. Nitrogen fertilisation increased the efficiency of utilisation of irrigation water. The magnitude of this effect varied between harvests. On average, increasing the level of irrigation decreased ANR but increased the efficiency of utilisation of absorbed N.

Intervals between harvests of 5 to 6 weeks appear to be required in order to make efficient utilisation of fertiliser-N and irrigation water.

Introduction

Irrigated annual pastures of oats (*Avena sativa*) and annual ryegrass (*Lolium multiflorum*) are important suppliers of grazed forage during winter in a dairy system where these pastures are rotated with permanent pastures of alfalfa (*Medicago sativa*) and orchard grass (*Dactylis glomerata*) and silage maize (*Zea mays*). Nitrogen fertiliser and irrigation water are important inputs for these annual pastures. Increasing the efficiency of utilisation of both inputs becomes an important issue in terms of the economical and ecological sustainability of this dairy system.

According to Jarvis (1998), the driving force for the rates of fertiliser N used in dairy systems has been directed primarily at increased dry matter production. However, increasingly more attention has been given to the development of strategies for ensuring adequate nutrition for plants and ruminants while protecting soil, water and atmosphere. Jarvis states that it is likely that this concern over leakage of N materials to the wider environment will continue to grow. Nonetheless, Nores and Vera (1993) make a clear distinction of the relative importance of financial and environmental concerns in developed and developing countries. In developing countries with high population growth, the number one concern is economic and production growth. Demand for animal products is increasing. Hence, the search will be for sustainable production and productivity gains. Poverty, the need to induce economic growth and generate employment and to satisfy future demand for livestock products will partially or largely overshadow environmental concerns. Financial margins per hectare might be reduced by reducing N inputs to pastures (Vellinga *et al.*, 1996; Peel *et al.*, 1997; quoted by Jarvis, 1998). However, Leaver and Weissbach (1993) state that the correlation between the level of N fertilisation and farm profit might be low, and that means that efficient management of fertilisation makes the difference between profiting or not from N fertilisation. According to Jarvis (1998) good N management should attempt to balance flows into the mineral N pool against the demand of the crop, avoiding deficiencies at times of peak growth rate and surpluses at other times.

The exhaustion of underground water used for irrigation jeopardises sustainability of dairy production in some dairy regions of Mexico (LALA, 1995). Therefore, increasing the efficiency of utilisation of irrigation water is not only sought as a means of improving the short-term economic feasibility of dairy farms, but also as a key issue to increase their sustainability. Water-stressed plants do not utilise irrigation water more efficiently than non-stressed plants. Therefore, avoiding water stress is necessary in order to make efficient use of irrigation water (Cohen, 1993).

The response of oats and ryegrass pastures to N fertilisation has been recently studied at Chapingo, Mexico. Dorantes (1997) reported that the yield of oats and ryegrass pastures receiving 50 kg N ha^{-1} after each grazing was higher than the yield of pastures of the same mixture that included different legumes but did no receive N fertilisation. In another experiment, Pérez (1999) found that during periods of moisture stress, the response of these pastures to N fertilisation was severely limited. Dorantes (1997) found circumstantial evidence that the proportion of ryegrass in these pastures increased with increasing N availability. In the experiment of Pérez (1999), N-yield of ryegrass increased with increasing N fertilisation but that of oats decreased. The efficiency of utilisation of absorbed N was higher in oats than in ryegrass. However, herbage yield of oats decreased with increasing levels of N fertilisation. Therefore, N fertilisation changed the outcome of competition between oats and ryegrass. This might be an important factor in the response of oats and ryegrass pastures to N fertilisation, since Améndola and Mendez (1997) found that the productivity of these pastures depends on the balance between both species.

Responses to N are reduced in situations of low water availability and N fertilisation might increase the efficiency of water utilisation. A better understanding of these effects, particularly on changes that they might undergo during the growing season is required in order to improve the management of fertilisation and irrigation. The proportion of species in the pastures changes during the growing season (Améndola and Mendez, 1997) and with the level of N fertilisation (Pérez, 1999). Increasing the efficiency of utilisation of fertiliser N also requires an understanding of the changes in competition between oats and ryegrass brought about by N fertilisation.

The purpose of the present experiment was to increase the understanding of the effects of the levels of N fertilisation and of irrigation water on the efficiency of utilisation of fertiliser N and irrigation water. The effect of four levels of N fertilisation and two levels of irrigation water on herbage dry matter yield and N-yield of oats and annual ryegrass pastures was studied in three harvest cycles. The effect of treatments on N-uptake and herbage accumulation of both species was examined during the second harvest cycle.

Material and methods

The experiment was carried out between November 1998 and April 1999 at the Farmlet for Dairy Production under Grazing of Chapingo University, located at 19°29' N, 98°54' W and 2240 m above sea level. The soil is loam of volcanic origin, deep, neutral and fertile. The organic matter and nitrogen content of the soil are reported in Table 1, other physical and chemical properties of soils are reported in Table 1 of the Appendix. Previous crops were grazed oats and ryegrass pastures (autumn-winter 1996-1997), silage maize (spring-summer 1997), grazed oats and ryegrass pastures (autumn-winter 1997-1998), and grazed maize, oats and ryegrass pastures (spring-summer 1998). Climate is temperate and sub humid with summer rains; average rainfall is 620 mm, and average temperature is 18°C. Weekly averages of meteorological data registered at the meteorological station of Colegio de Posgraduados (located at 2 km from the experimental field) are reported in Table 2 of the appendix.

Table 1. Organic matter and nitrogen content of the soil.

Depth (cm)	Organic matter (%)[1]	Total nitrogen (%)[2]	Inorganic nitrogen (mg kg $^{-1}$)[3]
0-30	1.55	0.12	109
30-60	0.90	0.08	75

[1] Walkley and Black
[2] Estimated from organic matter content.
[3] Extraction with KCl 2N, measurement with Kjeltec auto analyser 1030.

Four levels of N fertilisation (0, 50, 100, 150 N ha^{-1} harvest^{-1}) were evaluated using a latin square design. The levels of N fertilisation were evaluated under the standard irrigation used at the Experimental Station of Chapingo University (sprinkler irrigation with 67 mm every 14 days), and a 50% higher level of irrigation (sprinkler irrigation with 67 mm and 33.5 mm on alternate weeks). The levels of irrigation were evaluated as replicated experiments separated by a 10 m wide strip of bare ground. Plot size was 44.1 m^2 (7.05 × 6.25 m). Heavy rains during September and October 1998 precluded sowing on time, the experiments were sown on 14 November 1998 and the first irrigation took place the same day. Species were sown by hand in alternate rows; the distance between rows of the same species was 15 cm. Seeding densities were 60 kg PSG (pure germinating seeds) ha $^{-1}$ of oats (cv Coker 234) and 20 kg PSG ha $^{-1}$ of ryegrass (cv Barspectra). At sowing plots were fertilised with 60 kg P_2O_5 ha^{-1} and with N according to treatments. Fourteen days after sowing, plants of oats ryegrass and weeds were counted on four 0.25 m^2 samples per plot.

Within a total growth cycle of 154 days three harvest were carried out: the first harvest on 11 February 1999 (89 days after sowing), the second harvest on 28 March 1999 (after 45 days growth) and the third harvest on 24 April 1999 (after 27 days growth). The growth period between the second and the third harvest was short because according to the crop rotation, silage maize must be sown before the end of April. After harvests, plots were fertilised according to treatments and irrigated. Harvests took place by cutting 3 strips of 5 × 1m per plot with a Gravely® motorscythe at cutting heights varying between 6 and 9 cm. Due to irregular cutting height of the motorscythe a Snapper® rotary mower was used to cut at a uniform height of 5 cm, 3 strips of 5 × 0.5m in the centre of the strips that had been cut by motorscythe. Remaining herbage below 5 cm (stubble) was sampled by cutting three 0.9 × 0.3 m samples to ground level with a knife. After weighing, sub samples were taken for determination of dry matter, ash and nitrogen content.

Samples of herbage harvested with the motorscythe were considered free of contamination with soil. Organic matter yield of samples taken with the rotary mower or cut to ground level were converted to dry matter yield based on the organic matter content of corresponding herbage samples taken with the motorscythe.

Between the first and second harvests, pastures were sampled after 14, 24, 30 and 38 days of regrowth. Six different double sampling techniques were used simultaneously for the estimation of DM yield: a single probe capacitance meter (Design Electronics ®), a rising plate, a falling disc, a sward stick, light interception by the canopy measured with a sunfleck ceptometer (Decagon Devices Inc ®), and the comparative yield method (Haydock and Shaw, 1975). Following regular patterns, at each paddock indirect measurements were taken at 25 points with each instrument, visual estimation was carried out on ten 0.9 × 0.3 m samples per plot. On each sampling date 8 calibration samples representing the range of herbage mass of the plots were cut in two steps (herbage above and below 5 cm height) using a 0.9 × 0.3 m frame. Multiple regression equations between herbage mass and indirect measurements were calculated using stepwise regression.

On the same sampling dates, using a circular frame of 707 cm^2, ten samples per plot were cut at a height of 5 cm and afterwards to ground level. Both species were hand-separated at cutting. Samples were bulked to form one sample of each species per plot. After drying, samples were ground and used for the determination of N content. On the first three sampling dates these samples were also used to estimate the botanical composition of herbage. The botanical composition of herbage on the fourth sampling date was estimated by means of the Dry Weight Rank method (Mannetje and Haydock, 1963) previously calibrated against the results of hand-separated samples on the first three sampling dates.

The proportion of radiation intercepted each day was calculated by linear interpolation between data obtained with the sunfleck ceptometer on subsequent sampling dates. In order to be able to calculate the proportion of radiation intercepted during the first 14 days of regrowth, the proportion of radiation intercepted on the first day of regrowth observed in another experiment (Roman, 2000) was used. Data on global radiation were recorded at the meteorological station of Colegio de Posgraduados. Taking into account that most days were sunny (Table 2 of the Appendix), a constant proportion of photosynthetically active radiation (PAR) of 45% of global radiation was considered (Goudriaan and Van Laar, 1994). Accumulated PAR intercepted between two sampling dates was thereafter calculated. Radiation use efficiency [RUE in g DM (MJ PAR)$^{-1}$] was calculated as the linear estimate of the regression between accumulated herbage DM and accumulated PAR intercepted (Marino *et al.*, 1997).

The soil was sampled after each harvest for the estimation of N content. Following a regular pattern, 10 samples of approximately 100 g were taken from the upper 30 cm of soil and were bulked to form one sample per plot.

Herbage and soil samples of three of the four rows of the latin square design were used for chemical analysis. Total nitrogen content of herbage and soil samples was determined by the Kjeldahl method, while the contents of NO_3-N and NH_4-N in soil samples were estimated by vapour distillation (Bremmer, 1965; Laboratory of Plant and Soil Analysis of Colegio de Postgraduados, Montecillo, Mexico).

The efficiency of utilisation of irrigation water (IRR-WUE) was calculated by dividing the herbage DM yield per harvest into the amount of irrigation water given during the growth period of each harvest (Cohen, 1993). The amount of rain during the experiment was extremely low (17 mm, Table 2 of the Appendix) and was therefore not included in this calculation. The efficiency of utilisation of irrigation water was also evaluated considering the relative amount of irrigation water (Q/Ep). The relative amount of irrigation water is the quotient between the amount of irrigation water given during the growth period of each harvest and the accumulated pan evaporation during the same period (adapted from Cohen, 1993).

In the current experiment the apparent effect of N fertilisation (ANE in kg extra DM per kg fertiliser N) was evaluated under cutting. However in the dairy system concerned, herbage of these pastures is utilised by grazing cows. Taking that into account, the economic analysis performed avoided the use of an estimate of the value of produced herbage; treatments were evaluated in terms of the costs of produced herbage (US \$ kg^{-1} DM).

Results were submitted to analysis of variance using mixed models considering fixed and random effects (Littel *et al.*, 1996). The level of N fertilisation, the level of irrigation, the harvest number and the sampling date were considered fixed effects. Columns and rows of the latin square design nested within the level of irrigation were considered as random effects. Models on which analysis of variance was based are included in the Appendix. Least square means, standard errors and probabilities of effects are reported for the main effects and the interactions.

Results

Pastures were successfully established, the stand was dense and relatively weed free (Table 2). Weather during the experiment (Table 2 of the Appendix) was slightly cooler and drier than the long-term averages reported by García (1988). Both levels of irrigation exceeded pan evaporation during November, December and January (Figure 1). The relative amount of irrigation water (Q/Ep) decreased during the growth season, but with the highest level of irrigation was always greater than 1 (Table 3).

Table 2. Plant densities (plants m^{-2}) 14 days after sowing.

Irrigation	Oats		Ryegrass		Weeds	
mm $(14\ d)^{-1}$	Plants m^{-2}	Std. Error	Plants m^{-2}	Std. Error	Plants m^{-2}	Std. Error
67	187		250		10	
100	192	8.9	277	18.0	5	1.6

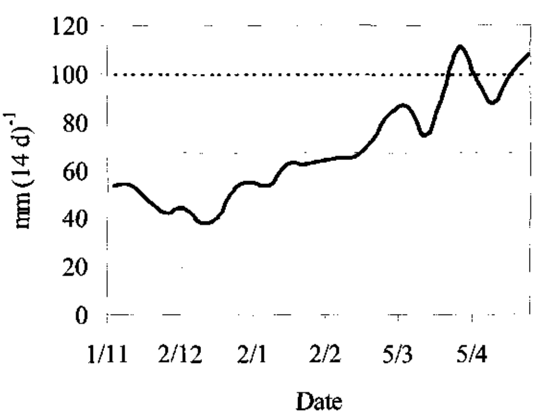

Figure 1. Mean pan evaporation [mm $(14\ d)^{-1}$] compared to the levels of irrigation used in the current experiment: 67 mm $(14\ d)^{-1}$(-----) and 100 mm $(14\ d)^{-1}$(— —).

Table 3. Relative amount of irrigation water (Q/Ep) as the ratio between the amount of irrigation water given during the growth period of each harvest (Q) and the accumulated pan evaporation during the same period (Ep).

	Level of irrigation [mm (14 d) $^{-1}$]	
Harvest number	67	100
1	1.57	2.23
2	0.91	1.35
3	0.82	1.20

Dry matter and nitrogen yield in three harvests

The responses of dry matter and nitrogen yield to N fertilisation and irrigation resulted from the triple interaction between the level of N fertilisation, the level of irrigation and the harvest cycle (Table 4, Figures 2, 3 and 4).

Nitrogen yield

On average N-yield was highest in the second harvest and lowest in the third harvest. The N-yield of unfertilised pastures was very low in the third harvest (Table 4; Quadrant IV of Figures 2, 3 and 4). The average increase in the N-yield with N fertilisation in the first harvest was 0.30 kg N harvested per kg N applied. This response increased 50% in the second and third harvests (on average 0.46 kg N harvested per kg N applied). Increasing the level of irrigation reduced the response in N-yield to higher levels of N fertilisation in the first harvest but not in the second and third harvests.

The efficiency of fertiliser N use can be expressed in the apparent recovery (ANR) i.e. the increase in the amount of N contained in the harvested herbage expressed as percentage of that applied in fertiliser (Deenen and Lantinga, 1993). Considering the whole season (154 d), the apparent recovery increased with the level of irrigation. However, this result was due to the very low N-yield of the unfertilised pastures with the highest level of irrigation. Increasing the level of irrigation reduced the N-yield of unfertilised pastures by 20 kg N ha^{-1} (Quadrant IV of Figures 2, 3 and 4). If ANR is calculated using as a reference the N-yield of the unfertilised pastures with the lowest level of irrigation (45 kg N ha^{-1}) it appears that increasing the level of irrigation reduced ANR from 44% to 31%.

Table 4. Probabilities and standard errors of dependent variables in three harvests of oats and ryegrass pastures with four levels of N fertilisation and two levels of irrigation.

		Source of variation						
		I[1]	N[2]	N×I	H[3]	I×H	N×H	N×I×H
Nitrogen yield	Pr > F	0.021	0.001	0.205	0.001	0.001	0.002	0.018
(kg N ha^{-1} $harvest^{-1}$)	Std Error	3.3	3.3	4.7	3.1	4.3	5.2	7.3
Nitrogen content in herbage	Pr > F	0.007	0.001	0.760	0.001	0.004	0.001	0.003
(g N kg^{-1} DM)	Std Error	0.79	0.80	1.13	0.75	1.06	1.28	1.81
Herbage yield per harvest	Pr > F	0.138	0.001	0.024	0.001	0.028	0.003	0.006
(kg DM ha^{-1} $harvest^{-1}$)	Std Error	85	102	144	90	127	168	237
Total N content in soil after harvests	Pr > F	0.052	0.148	0.089	0.933	0.606	0.250	0.460
(g N kg^{-1} Soil)	Std Error	0.073	0.061	0.087	0.064	0.090	0.097	0.137
Mineral N content in soil after harvests	Pr > F	0.894	0.021	0.976	0.305	0.016	0.851	0.799
(mg N kg^{-1} Soil)	Std Error	2.90	3.06	4.32	2.68	3.79	4.62	6.54
Efficiency of utilisation of irrigation	Pr > F	0.001	0.001	0.118	0.001	0.001	0.001	0.196
water (kg DM m^{-3} H_2O)	Std Error	0.034	0.034	0.047	0.038	0.053	0.067	0.094

[1] Level of irrigation
[2] Level of N fertilisation
[3] Number of harvest

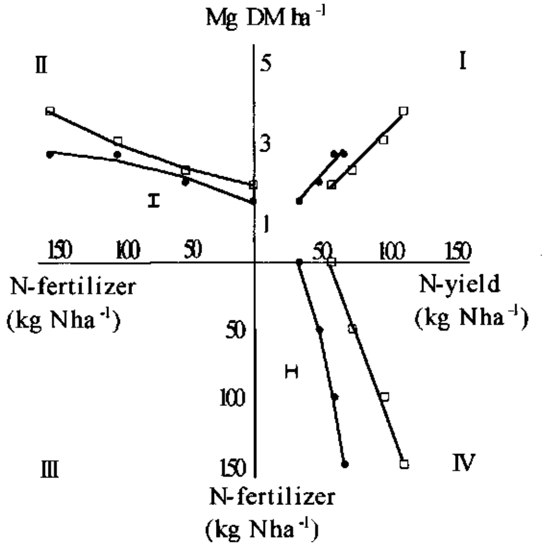

Figure 2. Herbage and nitrogen yield of oats and ryegrass pastures in the first harvest with four levels of N fertilisation and two levels of irrigation: 67 mm (14 d) $^{-1}$ (—□—) and 100 mm (14 d) $^{-1}$ (—•—). Bars depict standard errors.

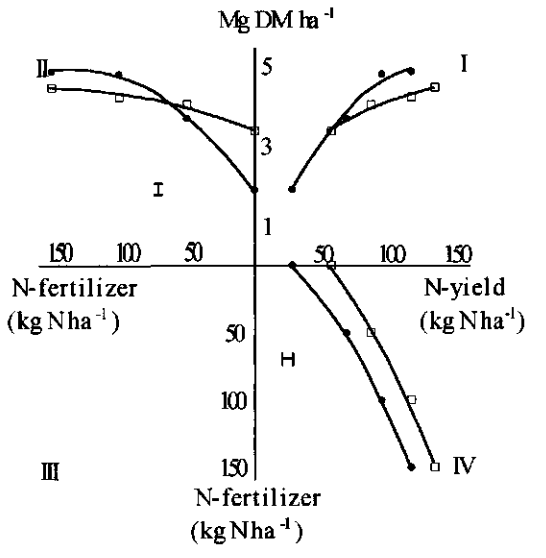

Figure 3. Herbage and nitrogen yield of oats and ryegrass pastures in the second harvest with four levels of N fertilisation and two levels of irrigation: 67 mm (14 d) $^{-1}$ (—□—) and 100 mm (14 d) $^{-1}$ (—•—). Bars depict standard errors.

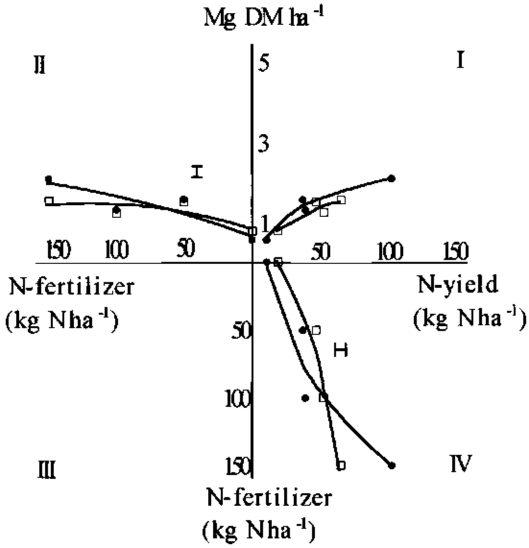

Figure 4. Herbage and nitrogen yield of oats and ryegrass pastures in the third harvest with four levels of N fertilisation and two levels of irrigation: 67 mm (14 d) $^{-1}$ (—□—) and 100 mm (14 d) $^{-1}$ (—•—). Bars depict standard errors.

Efficiency of use of absorbed N

The efficiency of use of absorbed N (EUN) was highest in the second harvest and lowest in the third harvest (Quadrant I of Figures 2, 3 and 4). In the fist harvest EUN did not depend on the amount of absorbed N (Quadrant I of Figure 2). In the second and third harvests EUN decreased with increasing amounts of absorbed N (Quadrant I of Figures 3 and 4). Increasing the amount of irrigation water applied increased EUN in the first two harvests but not in the third one. However, at low levels of N-yield, EUN did not depend on the level of irrigation (Quadrant I of Figures 2, 3, and 4).

The changes in EUN reflect the differences in growth conditions between harvests. The nitrogen content of standing herbage (harvested herbage plus stubble) was compared with the estimate of the dilution reference curve of non-limiting N concentration reported by Salette and Huché (1989) (Figure 5). In treatments receiving N fertilisation the differences in N content between harvests within a treatment are in general terms in agreement with the expected dilution since the highest N contents correspond with the lowest herbage masses in the third harvest and the lowest N contents correspond with the highest herbage masses in the second harvest. In the unfertilised treatments N contents were very low in the second and third harvests (below 50% of the dilution reference curve). N contents were lower with the highest level of irrigation reflecting the lower N-yield (Quadrant IV of Figures 2, 3 and 4) and the higher EUN (Quadrant I of Figures 2, 3 and 4). It is noteworthy that the nitrogen content of herbage of pastures receiving 150 kg N ha^{-1} $harvest^{-1}$ with the lowest level of irrigation was above the non-limiting N concentration in the three harvests.

Herbage yield

Average DM yield was highest in the second harvest and lowest in the third one (Table 4, Quadrant II of Figures 2, 3 and 4). On the average of both irrigation levels, in the first harvest the apparent effect of N fertilisation (ANE in kg extra DM per kg fertiliser N) was low and not affected by the level of N fertilisation (on average 10 kg DM kg^{-1} N). In the second harvest DM yield responded to N fertilisation up to the level 100 kg N ha^{-1} $harvest^{-1}$, while in the third one there was no response to N fertilisation above 50 kg N ha^{-1} $harvest^{-1}$. In the first harvest increasing irrigation reduced DM yield with the highest level of fertilisation (Quadrant II of Figure 2) and tended to reduce it with the other levels of fertilisation. In the second harvest increasing irrigation reduced DM yield of unfertilised pastures (Quadrant II of Figure 3). In the third harvest increasing irrigation tended to increase DM yield with the highest level of fertilisation ($p=0.11$, Quadrant II of Figure 4).

The stubble averaged 2278 kg DM ha^{-1} (data not shown) and was not clearly affected by the levels of fertilisation or irrigation; it was highest in the first harvest (2618 kg DM ha^{-1}) and lowest in the second harvest (1934 kg DM ha^{-1}). Nitrogen present in the stubble (Table 3 of the Appendix) ranged between 13 and 58 kg N ha^{-1} and responded to the levels of N fertilisation and irrigation in a similar way than N-yield. The N-content of the stubble (data not shown) was highly correlated with that of harvested herbage ($R^2=0.83$, $p<0.0001$). On average the N content of the stubble increased 0.56 g N kg^{-1} DM with the increase of 1 g N kg^{-1} DM in the N content of harvested herbage. Consequently, differences between the N content below and above cutting height became higher as the N content of herbage increased.

Nitrogen content of the soil after harvests

The total N content of the soil after harvests tended to be higher with the highest level of irrigation but it was not affected by other factors (Table 4 and Figure 6). The mineral N content of the soil was higher with the highest level of N fertilisation than with other levels (Table 4, Figure 7a). Even though the interaction level of irrigation × harvest was significant (Table 4), differences were small (Table4, Figure 7 b).

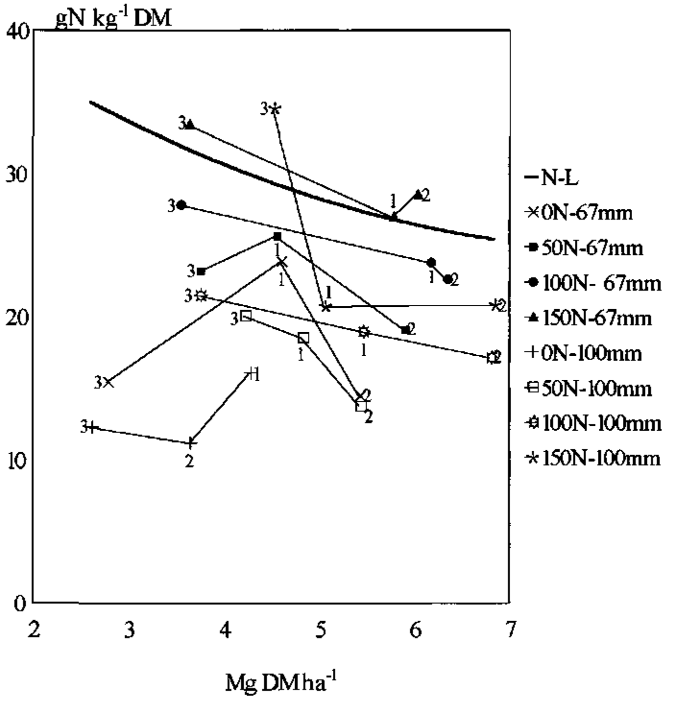

Figure 5. Relationship between herbage mass to ground level (kg DM ha^{-1}) and N content (g N kg^{-1} DM), with four levels of N fertilisation (0, 50, 100 and 150 kg N ha^{-1} $harvest^{-1}$) and two levels of irrigation ([67 and 100 mm $(14\ d)^{-1}$] in three harvests. Numbers (1, 2 and 3) correspond to harvest number. The N-L line represents the reference dilution curve of non-limiting N concentration reported by Sallete and Huché (1989)

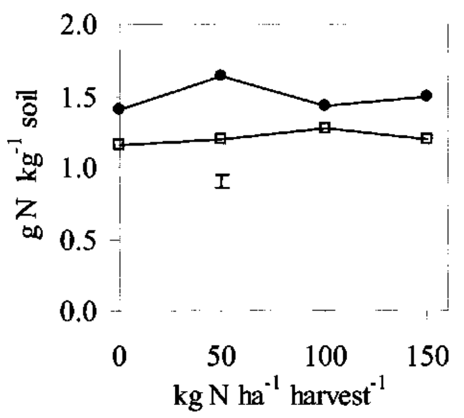

Figure 6. Total nitrogen content of the soil after harvests with two levels of irrigation: 67 mm $(14\ d)^{-1}$ (—□—) and 100 mm $(14\ d)^{-1}$ (—•—). Vertical bar depicts standard error.

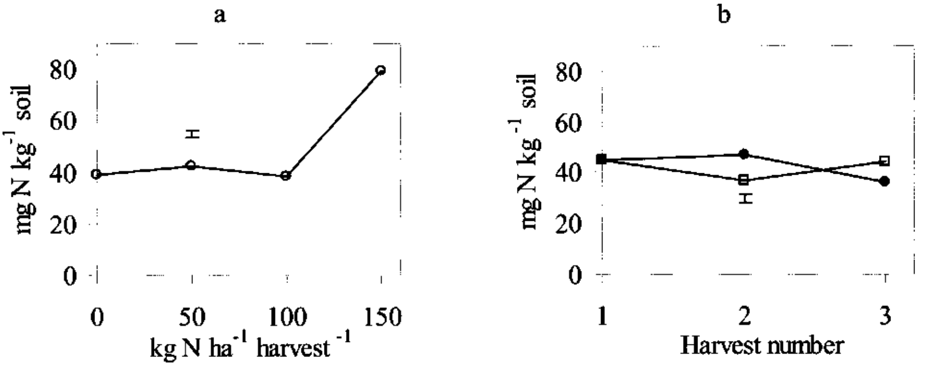

Figure 7. Mineral N content of the soil after harvest with four levels of N fertilisation (a) and in three harvests with two levels of irrigation: 67 mm (14 d) $^{-1}$ (—□—) and 100 mm (14 d) $^{-1}$ (—•—). Vertical bars depict standard errors.

Efficiency of utilisation of irrigation water

Nitrogen fertilisation increased the efficiency of utilisation of irrigation water (Table 4, Figure 8a). Increasing the level of irrigation reduced IRR-WUE (Figure 8b). The efficiency of utilisation of irrigation water was highest in the second harvest and lowest in the first harvest (Figure 8b). The low IRR-WUE in the first harvest was due to the high relative amount of irrigation water (Figure 9), while in the third harvest it was due to the short growth period that resulted in low herbage yield (Figure 9 and Quadrant II of Figure 4). Increasing the level of N fertilisation up to 100 kg N ha^{-1} harvest^{-1} increased IRR-WUE; a further increase in N-fertilization had no significant effect on IRR-WUE (Figure 9). In the first harvest the effect of N fertilisation on IRR-WUE was stronger with the lowest level of irrigation while in the second and third harvests it was stronger with the highest level of irrigation (Figure 9).

Production Costs

The effects of treatments on the costs of production of herbage were not strong. Increasing the level of fertilisation with the lowest level of irrigation led to a modest reduction in the costs of produced herbage (Table 9). Increasing the level of irrigation resulted in a small reduction of production costs only with high levels of N fertilisation.

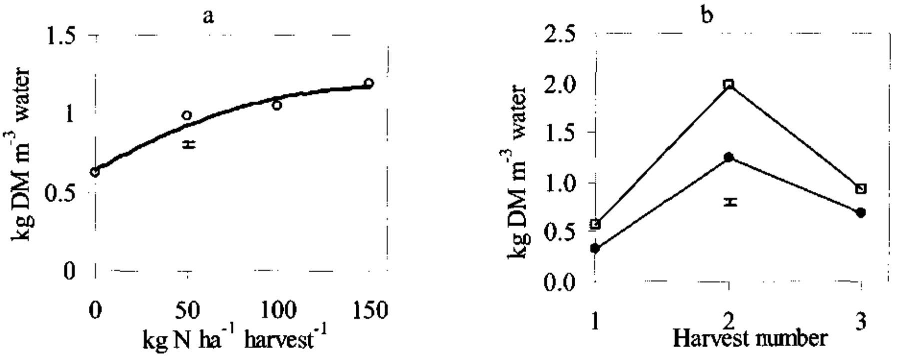

Figure 8. Efficiency of use of irrigation water with four levels of N fertilisation (a) and in three harvests with two levels of irrigation: 67 mm (14 d) $^{-1}$ (—□—) and 100 mm (14 d) $^{-1}$ (—•—). Vertical bars depict standard errors.

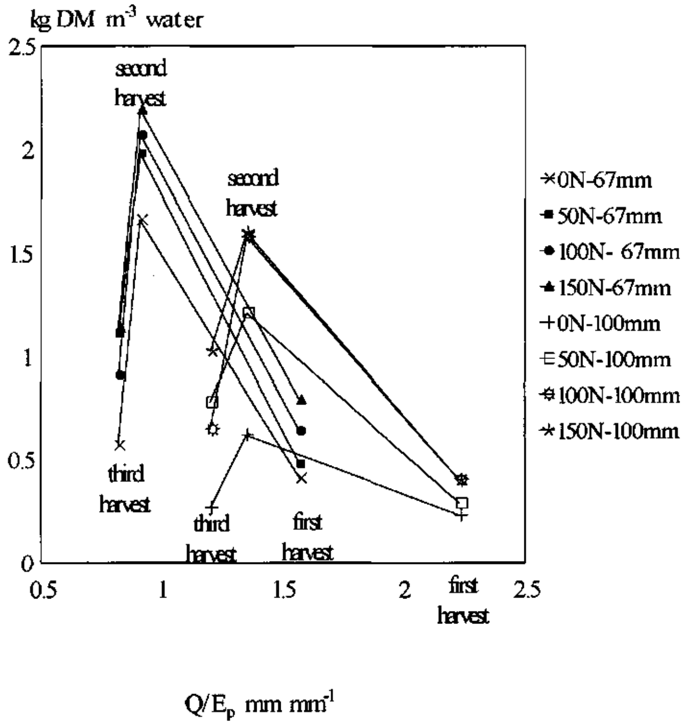

Figure 9. Relationship between the efficiency of use of irrigation water and the relative amount of irrigated water (Q/Ep) with four levels of N fertilisation in three harvests.

Table 9. Costs of produced herbage (US \$ kg^{-1} DM) of oats and ryegrass pastures with four levels of N fertilisation and two levels of irrigation in three harvests.

Level of irrigation [mm $(14\ d)^{-1}$]	67				100			
N fertilisation (kg N ha^{-1} $harvest^{-1}$)	0	50	100	150	0	50	100	150
Basic costs[1] (US \$ ha^{-1})	335	335	335	335	335	335	335	335
Nitrogen fertiliser (US \$ ha^{-1})	0	75	150	225	0	75	150	225
Irrigation (US \$ ha^{-1})	142	142	142	142	213	213	213	213
Labour (US \$ ha^{-1})	53	58	59	60	98	103	104	105
Total costs (US \$ ha^{-1})	529	610	686	762	646	726	802	878
Herbage yield kg DM ha^{-1}	5232	6247	7154	8122	4132	7091	8620	8966
Costs (US \$ kg^{-1} DM)	0.101	0.098	0.096	0.094	0.156	0.102	0.093	0.098

[1] Costs of land, seed, tillage, sowing, fences and phosphate

Regrowth between the first and second harvest

Indirect sampling

Calibration equations of herbage mass on indirect readings are reported in Table 10. The falling disc was the most accurate method for the estimation of herbage mass above 5 cm, while the rising plate was most accurate for the estimation of herbage mass above ground level. The falling disc exerted a lower pressure on herbage (2.5 kg m^{-2}) than the rising plate (4.5 kg m^{-2}) and that is the probable cause of this difference. The residual standard deviation of the equation for herbage mass above ground level was 90% higher than that of the equation for herbage above 5 cm (harvestable herbage). Fulkerson and Slack (1993) also found that considering herbage mass above 5 cm rather than herbage mass above ground level largely increased precision. Taking that into account and considering that the information on harvestable herbage is the most relevant, only data on harvestable herbage are reported in Tables 11, 12 and 13 and Figures 10, 11 and 12.

Table 10. Regression equations of herbage mass on readings of indirect techniques

	Herbage mass above 5 cm	Partial R^2	Herbage mass above ground level	Partial R^2
Intercept	-1485		338	
Ceptometer	15.49	0.0063	22.37	0.0084
Sward stick	-75.04	0.0076	-124.13	0.0044
Falling disc	122.8	0.8795	144.28	0.0214
Rising plate	34.47	0.0146	99.186	0.7601
Visual estimation	96.20	0.0078	31.63	0.0352
Model R^2	0.92		0.83	
Residual standard deviation	337		640	
Probability	0.0001		0.0001	

Nitrogen and herbage yield

On average, during 45 days of regrowth herbage yield increased according to a sigmoid curve (Figure 10). Herbage yield was affected by the interactions level of nitrogen fertilization × level of irrigation, level of nitrogen fertilization × day of regrowth and level of irrigation × day of regrowth (Table 11). Increasing the level of irrigation reduced herbage yield of unfertilised pastures but increased the yield of pastures fertilized with 100 of 150 kg N ha^{-1} $harvest^{-1}$ (Figure 11 a). As expected, the apparent effect of N fertilisation was very low at the beginning of regrowth but increased thereafter (Figure 11 b).

At the beginning of regrowth, the proportion of radiation intercepted was lower with the lowest level of irrigation but thereafter it was lower with the highest level of irrigation (Figure 12a). Nitrogen fertilisation up to 100 kg N ha^{-1} $harvest^{-1}$ increased the average proportion of radiation intercepted, which was particularly low in unfertilised pastures with the highest level of irrigation (Figure 12b). Radiation use efficiency (RUE) was not affected by N fertilisation with the lowest level of irrigation but increased with N fertilisation at the highest level of irrigation. Increasing the level of irrigation tended to improve RUE with the highest levels of N fertilisation but tended to reduce it in unfertilised pastures (Figure 13).

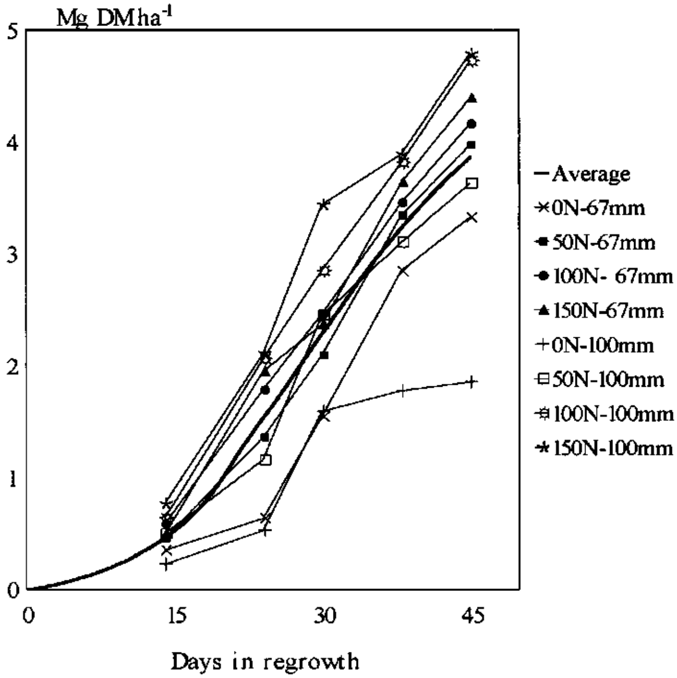

Figure 10. Herbage yield of oats and ryegrass pastures in 45 days of regrowth with four levels of N fertilisation (0, 50, 100 and 150 kg N ha-1 harvest-1) and two levels of irrigation ([67 and 100 mm $(14\ d)^{-1}$].

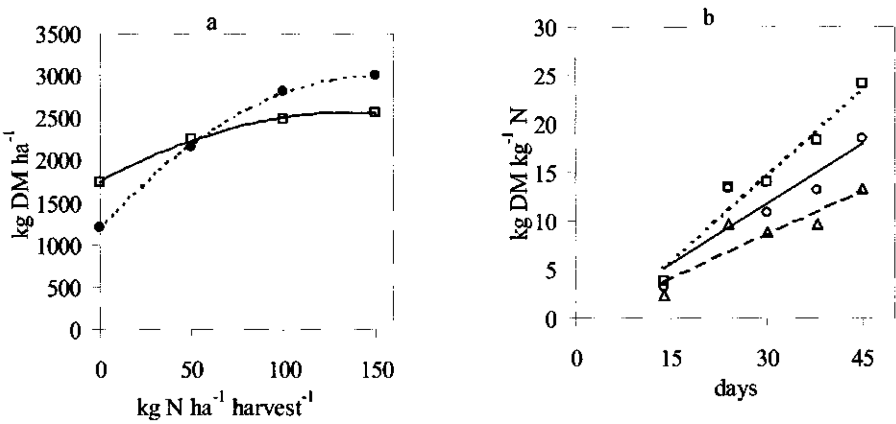

Figure 11. Average herbage yield of oats and ryegrass pastures in 45 days of regrowth with four levels of N fertilisation and two levels of irrigation: 67 mm $(14\ d)^{-1}$ (—□—) and 100 mm $(14\ d)^{-1}$ (—•—) (a), and apparent effect of N fertilisation (kg DM kg^{-1} N) with 50 (----□----), 100 (—○—) and 150 (—Δ—) kg N ha^{-1} $harvest^{-1}$ (b).

Table 11. Probabilities and standard errors of dependent variables in 38 days of regrowth of oats and ryegrass pastures.

		Source of variation						
		I[1]	N[2]	N×I	D[3]	I×D	N×D	N×I×D
Nitrogen yield ($kg\ N\ ha^{-1}\ harvest^{-1}$).	Pr > F	0.039	0.001	0.001	0.001	0.150	0.001	0.191
	Std Error	1.2	1.6	2.3	2.1	3.0	4.1	5.9
Nitrogen content in herbage ($g\ N\ kg^{-1}DM$).	Pr > F	0.021	0.001	0.221	0.001	0.004	0.001	0.319
	Std Error	1.0	0.9	1.3	1.0	1.4	1.6	2.2
Herbage yield ($kg\ DM\ ha^{-1}$)	Pr > F	0.166	0.001	0.001	0.001	0.002	0.001	0.112
	Std Error	40	43	61	56	79	106	149
Nitrogen yield of ryegrass ($kg\ N\ ha^{-1}$)	Pr > F	0.583	0.001	0.001	0.001	0.680	0.001	0.373
	Std Error	1.5	1.5	2.1	1.8	2.5	3.2	4.5
Nitrogen yield of oats ($kg\ N\ ha^{-1}$)	Pr > F	0.068	0.001	0.136	0.001	0.064	0.411	0.173
	Std Error	1.1	1.2	1.8	1.5	2.1	2.8	3.9
Herbage yield of ryegrass (kg DM ha-1)	Pr > F	0.371	0.001	0.001	0.001	0.002	0.001	0.001
	Std Error	45	43	61	46	65	79	112
Herbage yield of oats ($kg\ DM\ ha^{-1}$)	Pr > F	0.618	0.001	0.001	0.001	0.125	0.155	0.018
	Std Error	39	38	54	47	67	86	121

[1] Level of irrigation
[2] Level of N fertilisation
[3] Day of regrowth

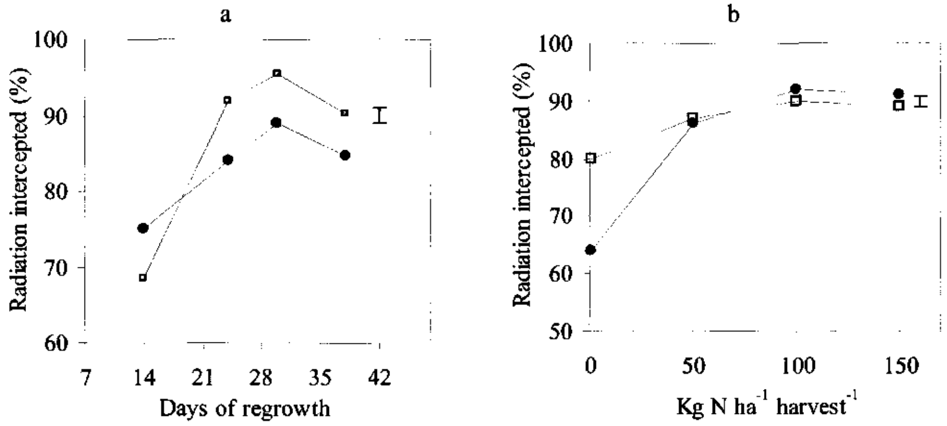

Figure 12. Proportion of radiation intercepted by oats and ryegrass pastures in 38 days of regrowth with two levels of irrigation: 67 mm (14 d) $^{-1}$ (—□—) and 100 mm (14 d) $^{-1}$ (a) and with four levels of N fertilization and two levels of irrigation: 67 mm (14 d) $^{-1}$ (—□—) and 100 mm (14 d) $^{-1}$ (b). Vertical bars depict standard errors.

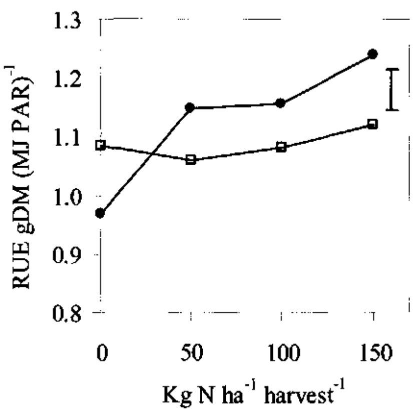

Figure 13. Radiation use efficiency of oats and ryegrass pastures during 38 days of regrowth with four levels of N fertilization and two levels of irrigation: 67 mm (14 d) $^{-1}$ (—□—) and 100 mm (14 d) $^{-1}$ (b). Vertical bar depicts standard error.

Botanical composition

On average, herbage yield of oats increased with N fertilisation up to 100 kg N ha^{-1} harvest^{-1} but decreased with a further increase in N fertilisation (Tables 11, 12 and 13). Nitrogen yield of oats did not increase by increasing N fertilisation beyond 50 kg N ha^{-1} harvest^{-1}, while that of ryegrass increased with N fertilisation up to the highest level (Tables 11, 12 and 13). The proportion of oats in herbage decreased with increasing levels of N fertilisation, increased as the regrowth progressed and was not affected by the level of irrigation (Figure 14). During the first 30 days of regrowth, the proportion of oats in nitrogen and herbage yield decreased with increasing nitrogen and herbage yields (Figure 15).

Table 12. Herbage yield of oats and ryegrass in 30 days of regrowth with four levels of N fertilisation and two levels of irrigation.

			N fertilisation (kg N ha^{-1} harvest^{-1})			
Days in regrowth	Level of irrigation mm (14 d)$^{-1}$	Species	0	50	100	150
14	67	Ryegrass	111	279	469	391
14	67	Oats	247	180	112	103
14	100	Ryegrass	87	277	421	535
14	100	Oats	118	237	209	244
24	67	Ryegrass	163	616	976	1254
24	67	Oats	483	743	807	699
24	100	Ryegrass	106	546	1257	1637
24	100	Oats	404	627	800	483
30	67	Ryegrass	571	1014	1309	1333
30	67	Oats	986	1079	1152	1036
30	100	Ryegrass	301	1047	1356	2603
30	100	Oats	1274	1418	1489	850

After 38 days of regrowth the N-yield of ryegrass responded linearly to N fertilisation, while that of oats did not respond to N fertilisation. In unfertilised pastures N-yield of oats was higher than that of ryegrass (Quadrant IV of Figure 16). The efficiency of use of absorbed N (EUN) of ryegrass decreased with increasing N-uptake (Quadrant I of Figure 16). At the level of the average N-yield of oats (44 kg N ha^{-1}), the EUN of both species were similar. Herbage yield of ryegrass increased with increasing N fertilisation (Quadrant II of Figure 16), after 38 days of regrowth the ANE of this species was 16.1, 14.0, and 11.2 kg DM kg^{-1} N with the levels of fertilisation 50, 100 and 150 kg N ha^{-1} harvest^{-1}, respectively. On the contrary, the response of oats tended to be negative. Oats dominated in unfertilised pastures, both species were in equilibrium with 50 kg N ha^{-1} harvest^{-1} and with further increases in N fertilisation the pastures were dominated by ryegrass.

Table 13. Nitrogen yield of oats and ryegrass in 30 days of regrowth with four levels of N fertilisation and two levels of irrigation.

			N fertilisation (kg N ha^{-1} $harvest^{-1}$)			
Days in regrowth	Level of irrigation mm $(14\ d)^{-1}$	Species	0	50	100	150
14	67	Ryegrass	3	10	12	17
14	67	Oats	6	4	4	4
14	100	Ryegrass	2	8	14	23
14	100	Oats	3	6	7	8
24	67	Ryegrass	4	15	32	52
24	67	Oats	13	25	26	24
24	100	Ryegrass	2	13	34	49
24	100	Oats	6	12	18	13
30	67	Ryegrass	13	27	39	53
30	67	Oats	23	29	36	31
30	100	Ryegrass	5	23	39	61
30	100	Oats	22	28	32	22

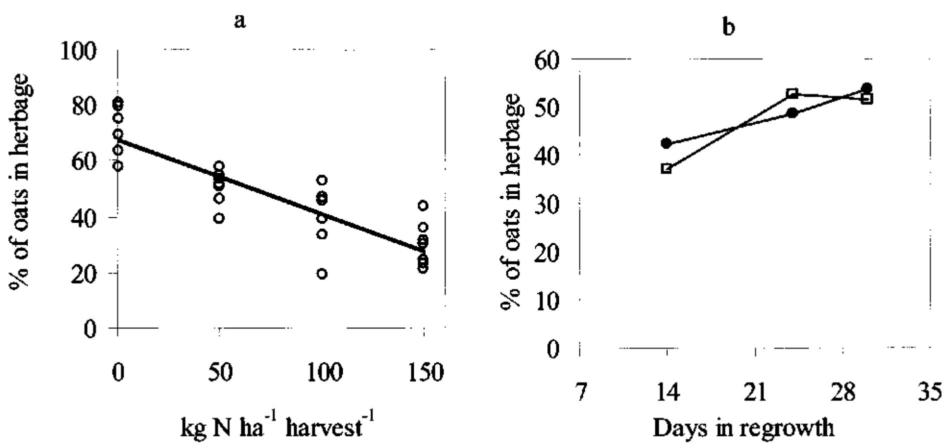

Figure 14. Proportion of oats in herbage in 30 days of regrowth with four levels of N fertilisation (a) and with two levels of irrigation: 67 mm $(14\ d)^{-1}$ (—□—) and 100 mm $(14\ d)^{-1}$ (b).

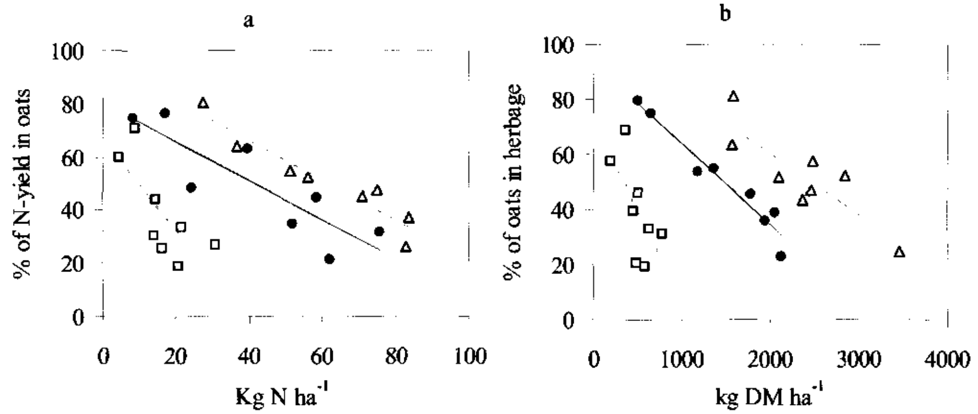

Figure 15. Relationship between N-yield and proportion of oats in N-yield (a) and between herbage yield and proportion of oats in herbage (b), after 14 (----□----), 24 (—•—), and 30(—Δ—) days of regrowth.

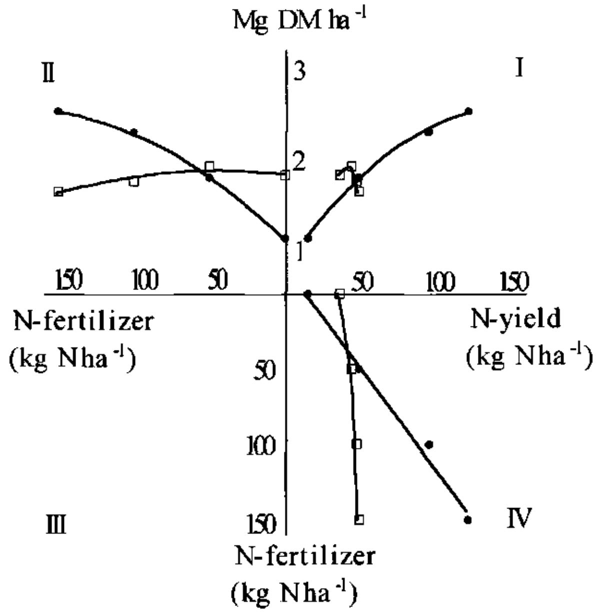

Figure 16. Herbage and nitrogen yield of oats (—□—) and ryegrass (—•—) after 38 days of regrowth.

These results suggest that the response of DM yield of oats to treatments was the outcome of competition with ryegrass. To test this hypothesis, based on data of the four sampling dates third degree polynomial equations predicting herbage DM of oats were developed using the Stepwise Procedure of SAS®. The results confirm that herbage yield of oats was primarily the outcome of competition with ryegrass because it could be predicted more accurately from the corresponding yield of ryegrass (Equation 2) than from treatments (Equation 1).

$$HYO = 530 + 12.1\ D - 8.88\ N + 2E\text{-}04\ N^3 \quad (1)$$

R^2 =0.44, Residual standard deviation = 370

where

HYO = herbage yield of oats (kg DM ha^{-1})

D = day of regrowth (14, 24, 30, 38)

N = N fertilisation (0, 50, 100, 150 kg N ha^{-1} $harvest^{-1}$)

$$HYO = -663 + 45.1\ D + 1.46\ HYR - 2.0E\text{-}03\ HYR^2 + 5.1E\text{-}07\ HYR^3 \quad (2)$$

R^2 = 0.61, Residual standard deviation = 311

where

HYO = herbage yield of oats (kg DM ha^{-1})

D = day of regrowth (14, 24, 30, 38)

HYR = herbage yield of ryegrass (kg DM ha^{-1})

Discussion

Dry matter and nitrogen yield in three harvests

The interaction N fertilisation × irrigation × harvest cycle affected the response of most variables. One of the factors generating this interaction was the difference in water balance between harvest cycles (Figure 1, Table 3). The other factor was the difference in average growth rate of the pastures between harvest cycles (30, 86 and 48 kg DM ha^{-1} d^{-1} in the first, second and third harvest, respectively). During the first harvest cycle, growth rates were low because of a relatively long period of incomplete light interception (the establishment phase of the pastures) and also because average temperatures and global radiation were lower than in the remainder of the growing season (Table 2 of the appendix). Average growth rates during the second cycle were high owing to good weather conditions and a sufficiently long harvest cycle. During the third harvest cycle weather conditions were favourable but the cycle was too short (27 days) and pastures were harvested when average growth rates were still low. For instance, in the regrowth of the second harvest pastures had reached fairly high levels of light interception (Figure 12a) and hence the linear phase of growth (Figure 10) just a few days before the 27th day. Based on the third degree polynomial that describes average herbage DM accumulation in the second growth cycle (Figure 10) it can be stated that: i) maximum instantaneous DM accumulation rate (126.2 kg DM ha^{-1} d^{-1}) took place on day 28, ii) maximum average DM accumulation rate (87.7 DM ha^{-1} d^{-1}) corresponded to day 42, and iii) 95% of the maximum average DM accumulation rate was reached only after 34 days of regrowth. Therfore, herbage yield of the third harvest was limited by the length of the growth cycle.

The average partition of N between herbage and stubble plus roots takes place with a ratio 2:1 (Whitehead, 1995). Considering this average partition ratio, an estimate of the average N-uptake rate of each harvest cycle was calculated based on the length of the growth period (82, 45 and 27 days in the first, second and third harvest, respectively) and the average N-yield (Quadrant IV of Figures 2, 3 and 4). On average N-uptake rate in the first harvest cycle (0.8 kg N ha^{-1} d^{-1}) was 55% lower than in the second and third harvest (1.9 and 1.8 kg N ha^{-1} d^{-1}, respectively). Nitrogen uptake rates depend on temperature (Whitehead, 1995); the growth rate of the plant also affects N-uptake rate because of feedback mechanisms and regulations (Gastal and Durand, 2000). Temperature and average growth rate were lower during the first harvest cycle explaining the low N-uptake rate. Nitrogen uptake rates in the second and third harvest cycle were similar; therefore, the low N-yield of the third harvest cycle was caused by the inadequate length of the cycle.

Due to the low uptake rate in the first growth cycle, relatively high N concentrations in the soil solution could have occurred. The lower N-yield (Quadrant IV of Figure 2) and the trend of increase in total N content of the soil with the highest level of irrigation (Figure 6) suggest that nitrogen not taken up by the pastures might have been leached or immobilised by the soil microflora. The fate of N applied with fertilisation it not always clear. Wouters and Hassink (1996) report that, as much as 60% of the N applied in the first harvest was not found in the harvested herbage or in mineral N in the soil. However, in that experiment about one half of that N resulted in an after-effect in the second harvest.

Differences between treatments in N-yield in the second and third harvest might not only have been the consequence of differences in N-uptake during these cycles. Nitrogen content of the stubble was affected by the levels of N fertilisation and irrigation; nitrogen in the stubble after a harvest can play and important role in the following growth cycle (Matsuknaka *et al.*, 1997). Differences in nitrogen present in the stubble between levels of irrigation after the first harvest averaged 12 kg N ha^{-1} (Table 3 of the Appendix). On average, those differences represented 50% of differences in N-yield observed in the second harvest (Quadrant IV of Figure 3).

Increasing the level of irrigation reduced the N-yield in the first and second harvests but not in the third harvest (Quadrant IV of Figures 2, 3 and 4). This was probably due to the higher Q/Ep in the first and second harvests (Table 3) that might have led to nitrate leaching. The average apparent recovery of fertiliser N (46%, from Quadrant IV of figures 2, 3 and 4) was lower than the 55% reported by ICI (1966; quoted by Whitehead, 1995) with annual ryegrass and much lower than reported by Deenen and Lantinga (1993). Deenen (1994) suggests that lower ANR can be attributed to less favourable weather conditions and high N-yield of unfertilised pastures. Whitehead (1995) states that ANR increases with the length of the interval between the application and the harvest. The amount of N made available by the soil under the lowest level of irrigation was comparable or higher than those reported under longer growing seasons (Deenen and Lantinga, 1993; Deenen, 1994; Whitehead, 1995). Therefore, the combination of i) excessive irrigation in the first half of the growth season, ii) high N-yield of unfertilised plots, iii) less favourable weather conditions during the first cycle and iv) inadequate length of the third cycle caused the low average ANR observed in this experiment.

Only small differences in mineral N content of the soil might be expected as a result of N fertilisation (Deenen and Lantinga, 1993). Therefore, the application 150 kg ha^{-1} $harvest^{-1}$, which led to higher mineral N content of the soil after harvests (Figure 7a) might have been excessively high. This results concurs with the fact that with the lowest level of irrigation the nitrogen content of herbage from pastures receiving 150 kg N ha^{-1} $harvest^{-1}$ was above the non limiting N concentration in the three harvests (Figure 5).

The average EUN observed in this experiment with the highest level of irrigation is comparable to those attained with perennial ryegrass under 4-weekly cuttings by Deenen and Lantinga (1993). However, the average EUN observed with the lowest level of irrigation was lower and comparable to that reported by Deenen (1994) for perennial ryegrass in a year with less favourable weather conditions. Differences in EUN between the levels of irrigation were observed during the first and second harvest cycles. Considering Q/Ep in both cycles (Table 3), these differences could hardly depend on the total amount of water applied with irrigation. However, irrigation treatments also differed in the frequency of irrigation (2-weekly in the lowest level and weekly in the highest level). This might have created differences in moisture in i) the upper densely rooted soil layer and ii) within the canopy. Taking into account the dry weather conditions that prevailed during the experiment (Table 2 of the Appendix) these differences could be the cause of higher growth rates and hence improved EUN with the highest level of irrigation.

The average apparent effect of N fertilisation observed in the current experiment (17, 12 and 10 kg DM kg^{-1} N with 50, 100 and 150 kg N ha^{-1} $harvest^{-1}$, respectively) was lower than usually observed with annual or perennial ryegrass (Withehead, 1995). From the discussion on the effect of treatments on ANR and EUN it can be concluded that this low ANE was the consequence of the low ANR. Jarvis (1998) states that good N management should attempt to balance flows into the mineral N pool against the demand of the crop, avoiding deficiencies at times of peak growth rate and surpluses at other times. Results observed in this experiment suggest that using a low level of N fertilisation in the first harvest and increasing it in subsequent harvests might improve the efficiency of N utilisation. However, Whitehead (1995) states that the effect of distribution might be small. Furthermore it should also be borne in mind that the value of produced herbage is highest at the beginning or the season when herbage availability in this dairy system is at its lowest level.

In spite to the low average ANE, N fertilisation led to a modest reduction in the costs of produced herbage (Table 9). This is the consequence of the high overhead costs of herbage production in this dairy system. Nitrogen content of herbage increased with the level of N fertilisation (Figure 5), and this might be seen as a negative effect of N fertilisation. McCormick *et al* (2001) report that an extremely high proportion of crude protein of herbage of oats-annual ryegrass pastures is rumen-degradable protein (RDP). Increasing RDP content of the diet jeopardises the efficiencies of N and energy utilisation by grazing dairy cows, and might affect negatively the reproductive performance of the cows. It will also lead to increased N leakages.

Efficiency of utilisation of irrigation water

The efficiency of utilisation of irrigation water differed strongly between harvests. In the first harvest, low average growing rates and high Q/Ep reduced the IRR-WUE. In the second harvest, average IRR-WUE was high though much lower than values of water use efficiency (WUE) reported for annual ryegrass (Pennman, 1970; quoted by Dovrat, 1993). This kind of differences between IRR-WUE and WUE is an indication of water losses (Cohen, 1993), which in the current experiment were due to the high Q/Ep values in the first two harvests and the short growth period that precluded achieving high average growth rates in the third harvest (Table 3, Figures 8b and 9).

Increasing the level of irrigation reduced N-yield probably due to nitrate leaching in the first two harvests. However, it increased the EUN probably due to better moisture conditions in the upper horizon of the soil and within the canopy. These results suggest that i) the level of water applied should be low at the beginning of the growing season and should be increased as the season progresses, and ii) the frequency of irrigation should be weekly instead of 2-weekly. Dovrat (1993) states that annual ryegrass is a very efficient user of soil water, but due to its shallow root system is very susceptible to rapidly developing soil water deficits. Therefore, Dovrat suggests that under conditions of high evaporative demand (such as observed in the current experiment) irrigation might be required every 7 to 10 days.

The economic outcome of increasing the frequency of irrigation is uncertain because i) it would improve the economic performance through the improvement of IRR-WUE and ANE, but ii) it would increase production costs because of the additional equipment and labour required. This economic outcome should be counterbalanced by the environmental benefits of reducing water losses and N leakage to the environment.

Regrowth between the first and second harvest.

Increasing N fertilisation to 100 kg N ha^{-1} $harvest^{-1}$ increased the proportion or radiation intercepted by the canopies (Figure 12b). The values of RUE found in the current experiment (Figure 13) are comparable to RUE of perennial ryegrass with different levels of N fertilisation and irrigation reported by Akmal (1997). However, they are lower than RUE of oats and annual ryegrass with increasing levels of N fertilisation reported by Marino *et al.* (1997). This is probably due to the fact that in the experiment of Marino *et al.* the average level of radiation intercepted was lower than in the current experiment.

Increasing the level of irrigation in fertilised treatments increased EUN (Quadrant I of Figure 3). Since there were no large differences in the proportion of radiation intercepted between levels of irrigation (Figure 12b), this increase was probably a consequence of the trend of increase in RUE with increasing N fertilisation with the highest level of irrigation (Figure 13). With the lowest level of irrigation, the level of N fertilisation did not affect RUE. This result corresponds with the lack of effect of N fertilisation on the gross assimilation rates of leaves of both species in pastures with the lowest level of irrigation of the current experiment reported by Roman (2000).

Reports on the effect of N fertilisation on RUE are not consistent. In the experiment of Akmal (1997) RUE of perennial ryegrass responded positively to increasing water levels but not to increasing levels of N fertilisation. Marino *et al.* (1997) report increases in RUE of oats and annual ryegrass with increasing levels of N fertilisation but the main effect of N fertilisation in that experiment was on the development of the leaf area index (LAI). Gastal and Durand (2000) quote several reports where a positive effect of N-concentration of leaves on assimilation rates has been found. However, according to Gastal and Durand (2000) and Thornton *et al.* (2000), it is most observed that N fertilisation increases DM accumulation by increasing LAI and therefore radiation interception.

Competition between oats and ryegrass

The outcome of competition between oats and ryegrass after 38 days of regrowth depended strongly on the level of nitrogen fertilisation (Figure 16). According to the theoretical framework to interpret results from competition experiments posed by Bullock (1996), increasing the level of N fertilisation changed the nature of the limiting resource. In unfertilised pastures N was the more limiting resource and, by sharing the highest proportion of N-yield (Quadrant IV of Figure16), oats proved to be more competitive than ryegrass in that situation. However, with increasing N fertilisation, light became the limiting resource (Figure 12b). In such situations the competitive ability of ryegrass was higher, and it reduced the performance of oats (Equation 2). This occurred by depletion of the limiting resource, because pre-emptive capture of resources is considered more effective in competition for light than toleration of low resource levels (Bullock, 1996).

To be an efficient competitor for light a plant has to be able to cast a shadow on neighbour plants. That trait is usually coupled with plant height i.e. taller plants that shade shorter plants (Bullock, 1996). After a long regrowth period, oats dominates the upper layers of the canopy (Chapter 4 of this Thesis). Therefore, plant height under average conditions was not the trait conferring ryegrass high competitiveness for light. In an experiment carried out simultaneously with the current experiment in a neighbouring paddock, Roman (2000) found that the rate of increase of leaf area of monocultures of ryegrass was much higher than that of monocultures of oats. Concurring with the result of Roman, Marino *et al.* (1997) report that responding to N fertilisation, the increase of LAI was steeper in ryegrass than in oats. That might be the consequence of N increasing the leaf appearance rate of ryegrass but not that of oats (Lattanzi *et al.*, 1997). Therefore the steeper increase in the LAI of ryegrass with N fertilisation led to an early depletion of light that reduced the performance of oats.

Conclusions

Nitrogen fertilisation between 50 and 100 kg N ha^{-1} $harvest^{-1}$ increased herbage production, reduced the cost of produced herbage and improved the efficiency of utilisation of irrigation water. The average apparent effect of N fertilisation might be improved without affecting herbage production if the level of N fertilisation is in the lower end of that range at the beginning of the growth season and in the upper end of that range after the first harvest. In unfertilised pastures oats was more competitive than ryegrass. Nitrogen fertilisation increased the proportion of ryegrass in the pastures by improving its competitiveness for light. Using a high level of irrigation (higher than the levels of pan evaporation) reduced the efficiency of utilisation of irrigation water and the recovery of fertilizer-N probably due to N-leakages. However, increasing the frequency of irrigation increased the efficiency of use of absorbed N, probably through the improvement in radiation use efficiency. Intervals between harvests between 34 and 42 days appear to be required in order to make efficient utilisation of fertiliser-N and irrigation water.

Appendix to Chapter 6

Table 1. Chemical and physical properties of the soil.

Chemical properties

Depth (cm)	PH[1]	MO[2] %	P[3]	K[4]	Ca[5]	Mg[5]	Fe[6]	Cu[6]	Zn[6]	Mn[6]
			mg kg^{-1}							
0-30	6.83	1.55	36.0	220	1705	345	16.71	0.43	1.07	14.08
30-60	6.92	0.90	22.5	208	2136	428	14.21	0.48	0.85	12.15
60-90	6.95	1.80	21.7	218	2240	443	12.06	0.44	0.67	43.75

Physical properties

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture[7]
0-30	42.16	35.28	22.56	Loam
30-60	37.44	40.00	22.56	Loam
60-90	37.44	34.00	28.56	Clay-loam

Pf curve (moisture as percentage of weight) [8]

Pressure (atm) / Depth (cm)	0.3	0.5	1	3	5	7	10	13	15
0-30	23.91	19.97	16.86	13.94	12.86	12.21	11.56	11.11	10.88
30-60	27.44	23.09	19.71	16.07	14.71	13.90	13.09	12.53	12.24
60-90	28.31	24.21	20.87	17.20	15.81	14.98	14.15	13.57	13.27

[1] Soil:water ratio =1: 2. [2] Walkley and Black. [3] Bray P-1. [4] Extraction with 1N ammonium acetate, pH 7.0, ratio 1:21, measured with flame emission spectrometry. [5] Extraction with 1N ammonium acetate, pH 7.0. ratio 1:21, measured with atomic absorption spectrometry. [6] Extraction with DPTA, ratio 1: 4, measured with atomic absorption spectrometry. [7] Bouyucos. [8] Membrane and pressure kettle.

Table 2. Weekly mean values of meteorological data.

Week (mean day)	Rainfall (mm week^{-1})	Temperature (°C)			Direct sunshine (h d^{-1})	Global radiation (cal cm^{-2} d^{-1})	Pan evaporation (mm d^{-1})	Relative humidity (%)
		Maximum	Minimum	Mean				
04/11/1998	0.0	23.6	6.3	15.0	8.4	420.1	3.7	65.0
11/11/1998	0.4	24.8	6.1	15.5	7.6	390.7	3.4	68.4
19/11/1998	0.0	22.4	6.9	14.7	6.7	374.7	3.7	67.1
26/11/1998	5.5	20.5	6.1	13.3	6.0	357.7	2.5	68.8
03/12/1998	0.0	22.2	1.1	11.6	9.3	442.3	3.2	61.9
11/12/1998	0.0	21.2	3.2	12.2	7.2	371.7	2.7	64.6
18/12/1998	0.0	21.0	-0.1	10.4	7.4	396.7	2.4	59.1
25/12/1998	0.0	22.2	2.6	12.4	8.6	396.4	3.0	60.2
02/01/1999	0.0	20.5	-0.4	10.1	8.8	402.5	4.1	61.0
09/01/1999	0.0	21.0	-0.9	10.1	8.8	398.0	3.3	59.9
16/01/1999	0.0	21.1	0.4	10.8	9.4	439.8	3.9	58.0
24/01/1999	0.0	22.9	-2.2	10.3	9.7	458.4	4.4	53.9
31/01/1999	0.0	23.9	2.4	13.1	8.2	459.6	3.9	58.8
07/02/1999	0.0	24.8	2.4	13.6	9.4	480.7	4.6	57.1
15/02/1999	0.0	20.4	0.9	10.6	7.9	464.0	4.1	60.8
22/02/1999	0.0	23.6	2.1	12.9	9.1	487.3	4.7	57.6
01/03/1999	0.0	24.2	4.6	14.4	9.3	541.1	5.0	54.7
09/03/1999	0.0	26.1	2.7	14.4	9.9	552.0	6.1	54.2
16/03/1999	0.3	24.6	4.1	14.3	8.0	501.1	5.4	58.9
23/03/1999	2.7	24.8	4.8	14.8	7.6	531.5	4.5	57.5
31/03/1999	0.0	25.7	5.8	15.8	9.8	583.0	7.4	52.5
07/04/1999	0.0	30.2	5.9	18.1	10.3	610.8	7.4	50.5
14/04/1999	5.1	26.2	8.1	17.1	8.4	513.1	5.6	55.5
22/04/1999	2.9	27.2	6.3	16.8	9.1	561.7	6.1	51.7
29/04/1999	12.7	28.0	11.2	19.6	9.7	587.1	7.2	51.2

Models used in analysis of variance

Model 1

$Y_{ijk} = \mu + W_i + N_j + H_k + W*N_{ij} + W*H_{ik} + N*H_{jk} + W*N*H_{ijk} + C(W)_l + R(W)_m + E_{ilm}$

where

Y_{ijk} = Response variable: variables related to harvests.

μ = general mean,

W_i = effect of the level irrigation, i = 1, 4

N_j = effect of level of N fertilisation, j = 1, 2, 3, 4

H_k = effect of the harvest, k=1, 2, 3

$W*N_{ij}$ = of the interaction between the level of irrigation and the level of N fertilisation

$W*H_{ik}$ = of the interaction between the level of irrigation and the harvest

$N*H_{jk}$ = of the interaction between the level of N fertilisation and the harvest

$W*N*H_{ijk}$ = of the interaction between the level of irrigation, the level of N fertilisation and the harvest

$C(W)_l$ = effect of column (North-South oriented) l =1, 2, 3, 4

$R(W)_m$ = effect of the row (East-West oriented); m = 1, 2, 3, 4 in the case of data concerning dry matter, m=1, 2, 3 in the case of data concerning N content.

E_{ilm} = error term

Model 2

$Y_{(ijk)} = \mu + W_i + N_j + D_k + W*N_{ij} + W*D_{ik} + N*D_{jk} + W*N*D_{ijk} + C(W)_l + R(W)_m + E_{ilm}$

where

Y_{ijk} = Response variable: variables related to regrowth between the first and the second harvest.

μ = general mean,

W_i = effect of the level irrigation, i = 1, 4

N_j = effect of level of N fertilisation, j = 1, 2, 3, 4

D_k = effect of the date of sampling (week), k=1, 2, 3

$W*N_{ij}$ = of the interaction between the level of irrigation and the level of N fertilisation

$W*D_{ik}$ = of the interaction between the level of irrigation and the date of sampling (week)

$N*D_{jk}$ = of the interaction between the level of N fertilisation and the date of sampling (week)

$W*N*D_{ijk}$ = of the interaction between the level of irrigation, the level of N fertilisation and the date of sampling (week)

$C(W)_l$ = effect of column (North-South oriented) l =1, 2, 3, 4

$R(W)_m$ = effect of the row (East-West oriented); m = 1, 2, 3, 4 in the case of data concerning dry matter, m=1, 2, 3 in the case of data concerning N content.
E_{ilm} = error term

Table 3. Nitrogen in the stubble (kg N ha^{-1}).

3a. Probabilities and Standard Errors

Source	Pr > F	Std Error
Irrigation	0.0803	2.6
Nitrogen	0.0001	2.3
Nitrogen* Irrigation	0.1166	3.2
Harvest	0.0001	2.1
Irrigation*Harvest	0.0464	2.9
Nitrogen* Harvest	0.0001	3.0
Nitrogen*Irrigation*Harvest	0.1432	4.2

3b. Least Square Means.

		Kg N ha^{-1} $harvest^{-1}$				Mean
Harvest	Irrigation mm $(14\ d)^{-1}$	0	50	100	150	
		29.0	34.4	40.5	40.5	
	67	33.8	37.2	47.8	42.8	40.4
	100	24.3	31.6	33.1	38.3	31.8
1		45.3	41.1	52.7	36.8	44.0
2		18.8	20.4	26.0	28.0	23.3
3		23.0	41.8	42.7	56.8	41.1
1	67	53.3	43.8	64.3	38.3	49.9
1	100	37.2	38.4	41.1	35.2	38.0
2	67	24.8	26.6	29.8	31.8	28.3
2	100	12.8	14.2	22.1	24.1	18.3
3	67	23.2	41.3	49.3	58.2	43.0
3	100	22.9	42.2	36.1	55.5	39.2

Chapter 7

Whole farm results

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Summary

Biophysical and economical results are reported on two years of operation of an experimental farmlet for dairy production under grazing in temperate Mexico. The dairy system was based on grazing of permanent pastures of alfalfa and orchard grass, which were rotated with winter and summer annual pastures and silage maize. Cows were supplementary fed with 3.5 kg of concentrates daily during the lactation, and in addition with 4.8 kg DM of maize silage (27% dry matter) between October and April. Average stocking rate was 2.60 cows ha^{-1} and 0.67 replacement heifers ha^{-1}; average productivity was 6200 kg milk cow^{-1} lactation $^{-1}$. Daily milk production of the herd was uniform throughout the year. Production costs amounted to 0.242 US \$ kg^{-1} milk; feeding costs represented 49% of that amount. Production costs were 29 to 46% lower than those of the dairy systems prevailing in the Plateau and the North of Mexico. Feeding costs were 43% lower than in those systems, in which cows are permanently housed and are fed cut and carry forages and high amounts of concentrates. Some factors affecting the system efficiency and its stability are pointed out.

Introduction

The design of an economically feasible dairy production system was the main objective of the project. This new system should enable the production of milk at lower costs than the Specialized and Semi-specialised dairy systems, which prevail in the Plateau and the North of Mexico. The main characteristics of these dairy systems are described in Chapter 2. In both systems, cows are permanently housed and are fed cut and carry forages and high amounts of concentrates.

Production systems of the USA are paradigmatic for farms of the Specialised Dairy System; technological advice originates in the USA and production targets are based on comparisons with farmers in the USA. Farms of this system are large, cows are mainly Holstein of relatively high genetic merit, and productivity is relatively high. Forage production and animal management is highly mechanised. Farmers are well organised and highly integrated. Farms of the Semi-specialised dairy system are much smaller. These farms rely to some extent on the use of unpaid family labour. The degree of adoption of modern technology (cooling tanks, artificial insemination, use of alfalfa, mechanical milking, etc) and the degree of integration increase with the size of the farm (Cervantes and Alvarez, 2001). The mean size, productivity and production costs in the Specialised and Semi-specialised Dairy Systems are summarised in Table 1. These are the means of values communicated in different reports published between 1995 and 1999.

Table 1. Mean size, productivity and costs in the Specialised and Semi-specialised Dairy Systems.

	Specialised[1]		Semi-specialised[2]	
	Mean	Standard Error	Mean	Standard Error
Size (cows per enterprise)	359	102	36	4
Productivity (kg cow^{-1} $lactation^{-1}$)	7296	147	5118	469
Costs per litre (US \$ kg^{-1} milk)	0.452	0.039	0.340	0.025
Feeding costs per litre (US \$ kg^{-1} milk)	0.214	0.022	0.202	0.007

[1] Mean of reports by Téllez (1995), Sánchez *et al.* (1997), Cendejas (1998) and Guadalupe (1998),

[2] Mean of reports by Herrera (1996), Cendejas (1998), García (1998), Guadalupe (1998) and Sánchez (1999).

Research carried out at Chapingo University during the 1980s led to the design of a dairy system based on grazing of alfalfa and orchard grass pastures as an option for lower production costs (Avendaño *et al.*, 1991). Under the name PIT (Pastoreo Intensivo Tecnificado, i.e. Technically Improved Intensive Grazing) governmental agencies extended this system (e.g. FIRA, 1994) and many farmers of the Specialised and Semi-specialised Dairy Systems adopted it. The performance of this dairy system on the farms has not yet been carefully evaluated. Notwithstanding, the observation of the system in some dairy farms revealed the following problems:

- low herbage availability during the winter
- lack of options for the problem of poor persistence of pastures
- high rumen degradable protein content of the diet
- high bloat-risks
- low productivity of cows

- poor body condition and reproductive performance of cows
- lack of estimates of the range of stocking rates leading to best performance of the system
- lack of estimates of economically feasible levels of supplementary feeding.

An alternative dairy system based on forages and grazing was designed aiming to solve these problems. This system was implemented on an experimental farmlet for dairy production under grazing (FDPG) in Chapingo, Mexico. The FDPG relied also on grazing of permanent pastures of alfalfa and orchard grass, but these pastures were included in a rotation with winter annual pastures (mixtures of oats and annual ryegrass) and silage maize. This crop rotation resembles that used in the Specialised Dairy System in La Laguna, which is mostly composed of alfalfa, silage maize and oats or annual ryegrass (Sánchez, 1992). The expected feed profile (Chapter 1) was calculated based on the following data:

- seasonal herbage accumulation rates of alfalfa and orchard grass pastures (Sánchez *et al.*, 1996)
- herbage accumulation rates of oats and annual ryegrass pastures during the winter (Améndola *et al.*, 1995; Améndola and Morales, 1997; Dorantes, 1997)
- dry matter yield of silage maize (Bravo, 1994; Cortés, 1995; Muñoz, 1997, Améndola, unpublished results).

According to this feed profile, grazing dairy cows would be supplementary fed with moderate amounts of concentrates during the lactation. Between May and October, cows would graze the permanent pastures, while between November and April they would graze both types of pastures. Between October and April, cows would also receive supplementary feeding with maize silage.

The experiments reported in Chapters 3, 4, 5 and 6 dealt with components of the system. In this chapter, these and other data obtained in the FDPG are used to evaluate the economical feasibility of the system. A stronger evaluation, for example by means of simulation models as proposed by Moore (1998), must await the development of a wider local data basis.

A short history

When the project started in 1996, there was no infrastructure available for milk production under grazing at Chapingo University. Therefore, designing and building the FDPG was the initial step of the project. The FDPG has operated as an independent unit since 1997.

Chapingo University owns a dairy (Sistema Lácteos) processing on average 2850 kg milk daily. The dairy was composed of three units: i) a unit producing forages run by the

Experimental Station (120 ha on average), ii) a dairy farm of the Specialised Dairy System run by the Animal Science Department (140 cows on average), and iii) an agro-industrial unit run by the Department of Agro-industries, which pasteurises the milk and produces cheese, yoghurt and other dairy products. The administration board of the dairy establishes prices of inputs and products (land, irrigation, forages and raw milk) to be considered in the calculation of the budgets of the different units. It also evaluates and eventually authorises investment projects of the different units. Since 1997 the FDPG constitutes a fourth unit of the dairy. The FDPG is working in close collaboration with the other units. However, the economic records of the FDPG are kept by the administration of the dairy as those of an independent unit.

The FDPG of Chapingo is located at 19°29' N, 98°54' W, and 2240 m above sea level. Climate is temperate and sub-humid with summer rains; average rainfall is 620 mm and average temperature is 18°C. The soil is loam of volcanic origin, deep, neutral and fertile.

The FDPG started as a 3-year project in January of 1997 with 16 dairy cows, 4.03 ha of permanent pastures, and 4.09 and 1.70 ha of annual pastures in the winter and summer, respectively. During 1997, the University appointed workers of the University to help in the operation of the FDPG. However, the operation of the FDPG during that first year relied mostly on the senior author and MSc and BSc students of the University. The FDPG started without buildings (milking took place in a rudimentary farmyard), and the equipment consisted of a second hand portable milking machine (2 units) and a second hand pick-up truck. No electricity was available. During 1997 a small storehouse was built with funding by Chapingo University (US $ 4197), the building of a very simple open-air milking parlour started and electricity was connected.

Taking into account the economical results of the FDPG during 1997, the administration board of the dairy authorised important changes in 1998. These changes implied investment of the net revenues of the previous year and increments in the operation costs of the FDPG. The following changes were considered to be economically feasible:

- hiring a young agronomist who should be in charge of the daily operation of the FDPG
- hiring two field workers
- building of the milking parlour and other required installations (US $ 7987 in 1998 and US $ 6349 in 1999) and adapting the portable milking machine into a stationary milking machine
- changing the 3-year project into a permanent one, providing it remains economically feasible
- increasing the area to 9.15 ha

- increasing stocking rate by taking more dairy cows and including replacement heifers.

The conceptual model on which the system was based assumed four years perennial alfalfa and orchard grass pastures and one year winter annual pastures and silage maize. Such a rotation would lead to an average proportion of 80% of the area sown to perennial pastures. However, due to research needs, the proportion sown to permanent pastures in the system was lower than that (on average 60%). That led to the need of including summer annual pastures.

Results and discussion

As stated above, the operation of the FDPG during 1997 could hardly be considered as a sustainable operating commercial farm (no buildings, no hired labour). Furthermore, supplementary feeding with concentrates and maize silage was applied only in the second half of that year. During 1998 and 1999 the dairy system of the FDPG was rather stable. The dairy system was based on grazing of annual pastures in the morning and permanent pastures in the afternoon. The proportion of area allotted to permanent pastures and to annual pastures and silage maize showed minor changes in those two years. Cows in milk were supplementary fed with 3.5 kg of concentrates daily. Between half September and the end of April, all cows were supplementarily fed with 4.8 kg maize silage (27 % dry matter) daily. The results reported in this chapter are the average of 1998 and 1999.

Biophysical results

Permanent pastures consisted of 4.40 ha alfalfa and orchard grass pastures and 0.83 ha perennial ryegrass and white clover pastures. Annual winter pastures were mixtures of oats and annual ryegrass in 1998 and oats, annual ryegrass and barley in 1999. Summer annual pastures consisted of maize, oats and ryegrass; the first grazing was carried out between 45 and 60 days after sowing when maize reached a height of around 1.50 m. In 1999, part of the area sown to summer pastures was not grazed. It was cut and fed during the end of the summer and the beginning of the autumn.

Results on the main biophysical variables of this dairy system are summarised in Table 2. Average stocking rate was lower than those achieved in different experiments (chapters 3, 4 and 5). Between January and April, average stocking rate of annual pastures was 132% higher than those of perennial pastures, however between May and October it was 12% lower (Figure 1).

Table 2. Main biophysical variables of the dairy system (yearly averages over 1998 and 1999).

Area (ha)*	8.76
Permanent pastures (ha)	5.23
Winter annual pastures (ha)	3.53
Summer annual pastures (ha)	2.64
Silage maize (ha)	0.89
Age of permanent pastures (years)	2.54
Estimate of net Maize silage produced (Mg DM ha^{-1} $year^{-1}$)	19.4
Number of cows	22.8
Number of replacement heifers	5.9
Stocking rate (cow-equivalents ha^{-1})	3.04
Supplementary concentrate (kg cow^{-1} $year^{-1}$)	1050
Supplementary maize silage (Mg DM cow^{-1} $year^{-1}$)	1.11
Purchased supplementary maize silage (Mg DM $year^{-1}$)	12.3
Production (kg milk $year^{-1}$)	141230
Productivity (kg milk ha^{-1} $year^{-1}$)	16128
Productivity (kg milk cow^{-1} $lactation^{-1}$)	6200
Age of cows (lactations)	2.1
Culling (%)	14.1
Deaths (%)	3.49
Calving interval (d)	444
Number of services per conception	2.2

*Does not include the area of buildings and the area used in agronomic experiments.

Stocking rate of annual pastures in November was very low. This was caused by delayed sowing of the first paddocks of annual winter pastures beyond mid-September 1998 due to heavy rains, which led to overgrazing in the perennial pastures. Due to this and the heavy frosts that occurred in January 1999, herbage production in the perennial pastures was very low during January 1999. Therefore, in February 1999 the FDPG faced a feed shortage that led to the need to purchase forage.

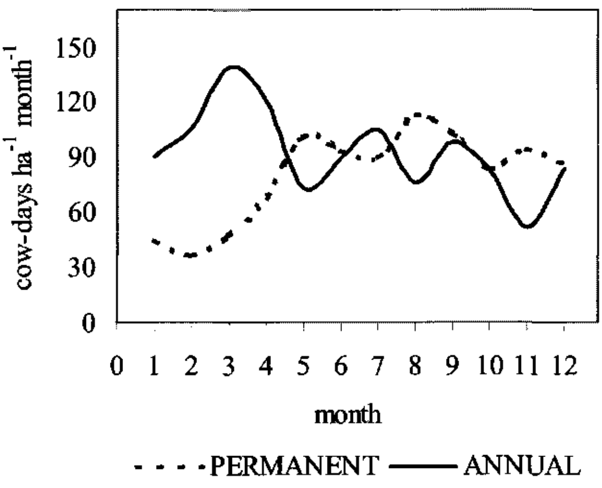

Figure 1. Time course of stocking rate on permanent and annual pastures (average 1998-1999)

Allotting 25% of the area under annual pastures to silage maize enabled the production of 63.8 of the 29.6 Mg DM of maize silage consumed in the system per year (Table 2). That proportion might be increased in the future, because herbage surpluses regularly occurred during the summer. Herbage from two 0.5 ha paddocks was cut and sent to the dairy farm of the University in June and July of both years. Other herbage "sold" involves the first utilisation of first year pastures in March 1999. Those pastures were cut in order to reduce competition by broad-leaved annual weeds and herbage was sent to the dairy farm of the University. The efficiency of utilisation of maize by grazing dairy cows was very high. However, when annual summer pastures were sown after the first half of April, the first grazing cycle took place after the start of the rainy season. Grazing of those pastures under almost daily rains caused severe poaching that depressed the regrowth of oats and ryegrass. As a result, stocking rate of summer annual pastures between May and September was 441 cow-days ha^{-1}, while that of permanent pastures was 499 cow-days ha^{-1} (see Figure 1).

Stocking rate of alfalfa and orchard grass pastures was highest in the second and third year (Table 3). However, in re-established pastures (without previous crop rotation), stocking rate during the third year was even lower than that attained during the fourth year of pastures established after crops.

Paniagua (1999) compared perennial ryegrass and white clover pastures with alfalfa and orchard grass pastures during the third winter of pastures. Stocking rate achieved with ryegrass and white clover pastures (1.54 cows ha^{-1} grazing cycle^{-1}) was 44% lower ($p<0.05$) than that achieved with alfalfa and orchard grass pastures. This superiority of alfalfa and orchard grass pastures in the third year of pastures in terms of stocking rate, concurs with results of DM matter production during the first year of pastures reported by Jiménez *et al.* (1986), Améndola *et al.* (1997) and Marín (1997).

Table 3. Stocking rate (cow-days ha^{-1} year^{-1}) of alfalfa and orchard grass pastures of different age (years) and previous use of the land (crops or pastures).

Age (years)	Previous use	1998	1999
First	Crops		699
Second	Crops	1368	
Third	Crops	1294	982
Third	Pastures	591	
Fourth	Crops		728

Average productivity per cow was lower than the best figures attained in the different experiments (Chapters 3, 4 and 5). Milk production was rather uniform throughout the year (Figure 2); the variation coefficient of monthly averages was 10%. A comparison of the trend in milk production per cow during the lactation (Figure 3a) with the average trend reported for housed cows by NRC (1989) suggests that peak production was relatively lower but the persistence was relatively higher. On the other hand, the average trend of body weight during lactation (Figure 3b) was similar to the average trend reported by NRC (1989).

The reproductive performance of the cows was unsatisfactory. The number of services per conception and the calving interval were higher than required in an efficient dairy system (Viglizzo, 1981). Average content of rumen degradable protein of the diet might have been too high and this was the probable cause of the relatively high number of services per conception (Charmandarian *et al.*, 1997). However, the high number of services per conception is not enough to explain the long calving interval. A long calving interval might also be due to i) a delay in the onset of oestrus after calving, which is usually related to poor body condition, or ii) failures in the detection of heats (Holmes, 1984). The average trend of changes in body weight during the lactation appeared to be within the normal range. Therefore, poor condition seems not to be the probable cause of the long calving interval, and this was in all probability due to inaccurate detection of oestrus.

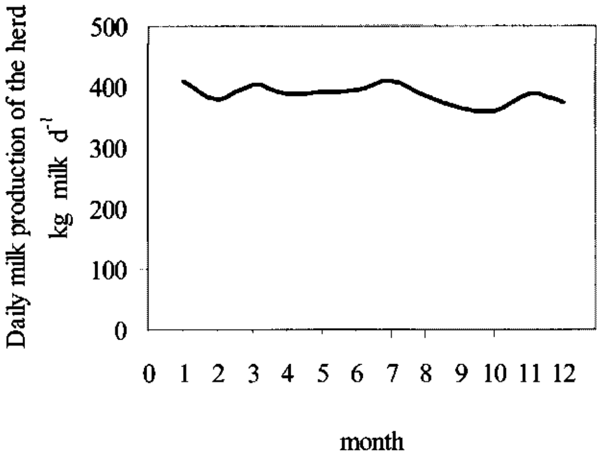

Figure 2. Daily milk production of the herd (average 1998-1999).

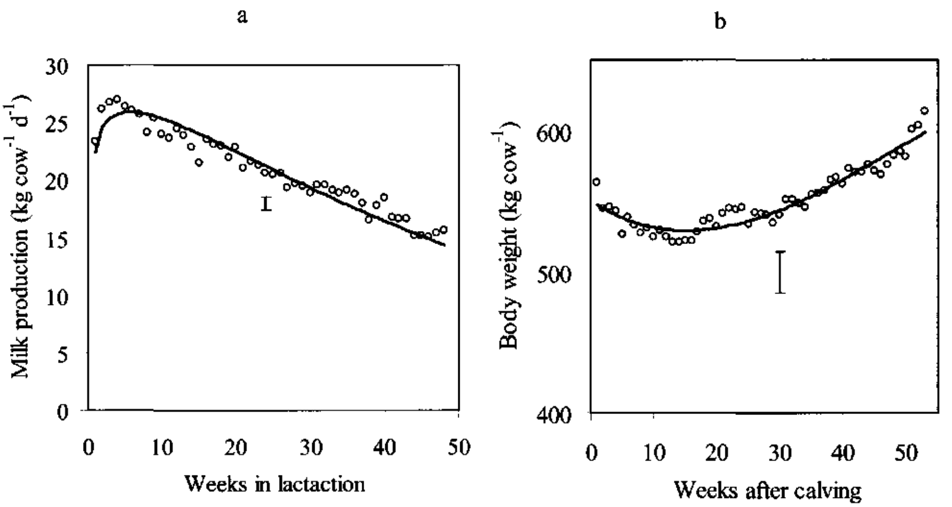

Figure 3. Trends of milk production (a) and body weight (b) during lactation. Vertical bars depict Standard Error.

The percentage of culling can be considered low (Table 2). However, taking into account that on average cattle was young and reproductive performance was the main reason for culling, it appears to have been too high for an efficient functioning of the system. This high culling percentage affects system efficiency because a replacement heifer costs more than the price of a culled cow, while it usually will produce less milk (Holmes, 1984).

During the winter and the early spring, the time of active grazing by cows receiving no supplementary feeding was measured in 1997 by Cortés (1998), while that of cows receiving supplementary feeding with concentrate and maize silage was measured in the experiments reported in Chapters 3, 4 and 5. Supplementary feeding reduced grazing time more than 3 hours (Figure 4); 36% of the reduction took place in the morning (between 08:00 and 11:00), 14% in the afternoon and evening (between 15:00 and 19:00) and the remainder 50% took place during the night (between 19:00 and 03:00). The reduction in grazing time in the morning and afternoon was at least partially the consequence of the time of exposure to supplementary maize silage. Reduced grazing time and hence reduced herbage intake of supplementarily fed cows had a positive effect on the productivity of the dairy system. The positive effect relied on the fact that reduced herbage intake could be coupled with increments in stocking rate and hence with increments in milk production per unit of area (Chapters 3 and 5).

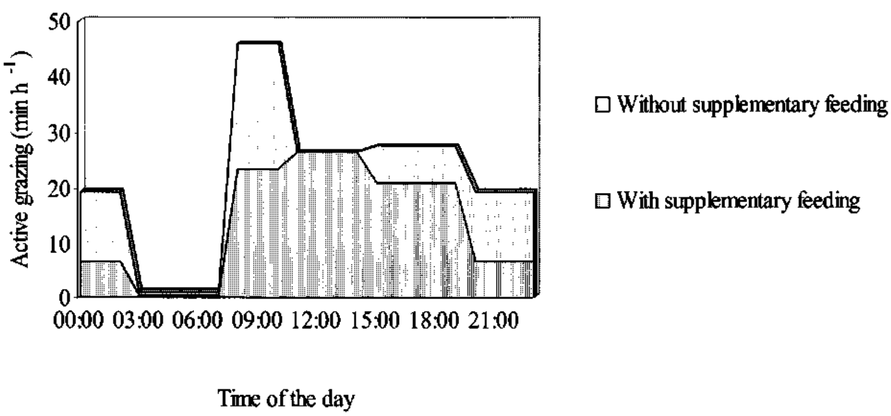

Figure 4. Average daily time course of active grazing of dairy cows receiving no supplements or supplementary fed with concentrates and maize silage.

Bloat is regularly a problem when grazing pastures where alfalfa is the main component (Popp *et al.*, 2000). During the first year of the FDPG, cases of bloat were frequent, including two fatal cases that occurred while grazing first-year pastures without supplementary feeding. During 1998 and 1999 bloat was not a problem, probably due to the following reasons:

- A preventive antifoam agent was added to the concentrates fed to cows. Due to the high costs of the antifoam agent (equivalent to the value of 0.5 kg milk per daily dose), it was only used when pastures with high proportions of relatively immature alfalfa were going to be grazed. Treatment began one week in advance of bloat-risky situations.
- Cows were offered fresh alfalfa and orchard grass pastures in the afternoon and not in the morning.
- Initial rate of herbage intake in pastures was reduced by the previous intake of supplementary concentrates and maize silage.

Economical results

Calculation of economical results followed in general the precepts stated by Moore (1998). The main modification was that the interest or the opportunity costs of capital were not taken into account. Those items were not taken into account in the calculation because it would imply assuming interest rates, and those are extremely variable in Mexico. The evaluation here reported concerns mainly the economical viability of the system. However, as stated by McGrann *et al.* (1995), in an environment of high costs of capital (high interest rates-high inflation index), and high instability of prices and costs (such as in Mexico in the 1990s), succeeding in an evaluation of financial viability might become very difficult. The cash flow of this system was very high. Therefore, the expenses that could be subjected to interest correspond only to the first year of the project (the expenses of the establishment of the first pastures, the cattle, the rent of land, the equipment, the fences and the initial buildings).

The average costs and returns of the FDPG during 1998 and 1999 are reported in Table 4; costs related to herbage and forage production are reported in Table 5. In contrast with most dairy enterprises of the same size that operate on own land, and use a high proportion of unpaid family labour, in the FDPG the cost of land and the totality of the costs of labour (including the operator) are cash expenses. Therefore cash expenses were high, involving 87% of total production costs.

This pasture based dairy system included the construction of a new milking centre but with used equipment. Total investment amounted to US $ 1814 per cow including US $ 1000 for the costs of the cow. This figure is only slightly lower than the estimate for a similar situation in Missouri USA: US $1914 per cow including US $ 1000 for the costs of the cow (Moore, 1998).

The specific operating costs of annual pastures were much higher than those of permanent pastures (Table 5). Yearly costs of tillage, seeds and fertilisers constitute the main difference. However, those specific costs are relatively small compared to the high generic costs of herbage and forage production (particularly the costs of land and irrigation). Costs of pastures in the FDPG are much higher than the estimate by Moore (1998) of costs of farmer-owned dairy pasture in Missouri (US $ 175 ha^{-1} $year^{-1}$).

Excluding the costs of feeding, the costs of labour (costs of labour accounted for in the costs of herbage and forage not included) constituted 45% of the remainder costs. The main reasons for these relatively high costs of labour are:

- The loan paid to the operator constitutes a high proportion of labour costs, and that is a consequence of the small scale of the enterprise.
- Loans paid in the FDPG are higher than those paid for similar work in neighbourhood dairy farms.
- Part of the labour is sub-utilised due to the small scale of the enterprise.

This negative effect might be partially offset in the future by increasing stocking rate without increasing labour.

Table 4. Average costs and returns of the FDPG during 1998 and 1999.

	US \$ year^{-1}
Costs	
1 Concentrates	4330
2 Purchased maize silage	1135
3 Supplementary minerals	419
4 [1]Annual pastures	2214
5 [1]Permanent pastures	707
6 [1]Silage maize	408
7 Purchased forage	364
8 Land (rent)	2722
9 Irrigation	2102
10 Labour	10037
11 Medicine	1469
12 Reproduction	667
13 Maintenance and repairs of buildings, fences and equipment	2381
14 Fuel	1431
15 Electricity	411
16 Total cash costs	30800
17 Depreciation of buildings	891
18 Depreciation of equipment	533
19 [2]Depreciation of cattle	2714
20 Depreciation of fences	316
21 Total ownership costs	4454
22 Total all costs	35253
Gross receipts	
23 Milk	45301
24 Calves	550
25 Forage (sold)	558
26 Total gross receipts	46408
27 Total income above total costs =26-22	11155
28 Net costs for milk production =22-24-25	34146
29 Costs per kg milk = 28/Milk production in Table 1 (US \$ kg^{-1} milk)	0.242
30 Feeding costs =1+2+3+7-25+ costs of herbage and forage in bottom line of Table 5	16625
31 Feeding costs per kg milk = 30/Milk production in Table 1 (US \$ kg^{-1} milk)	0.118

[1] For details see Table 5

[2] Estimate considering the difference between the value of the replacement heifers and that of the culled cows, distributed over an average longevity of 4 lactations, minus the added value of heifers raised in the FDPG.

Table 5. Costs related to pastures and silage maize.

	[1]Permanent pastures US \$ ha^{-1} year^{-1}	Winter annual pastures US \$ ha^{-1} cycle^{-1}	Summer annual pastures US \$ ha^{-1} cycle^{-1}	Silage maize US \$ ha^{-1} cycle^{-1}
	Specific Operating costs			
Tillage and sowing	38	65	93	112
Seeds	73	101	142	41
Fertilisers	25	164	164	90
Harvest				218
Subtotal	136	330	399	461
	Generic costs			
Land	314	126	188	188
Irrigation	226	186	40	40
Fences	36	18	18	18
[2]Labour	88	59	29	0
Subtotal	664	388	276	246
Total costs ha^{-1}	799	717	675	707
Average area (ha)	5.23	3.53	2.64	0.89
Costs US \$ year^{-1}	3701	4090	2782	361

[1] Considering 3 years of duration

[2] Estimate of labour involved in irrigation, fertilisation, repairing fences, providing drinking water and moving animals.

The productivity and the costs per kg milk (US \$ kg^{-1} milk) of the common Specialised and Semi-specialised dairy systems reported in Table 1 (see also Chapter 2) are used as a reference to evaluate the efficiency of the dairy system implemented in the FDPG. A comparison of the data in Table 1 with those in Table 2 reveals that the productivity per cow in the FDPG was 15% lower than in the Specialised Dairy System. Lower productivity of grazing cows when compared to that of housed cows receiving a total mixed ration, is a common feature (Moore, 1998). However, as stated by Moore (1998), it should be borne in mind that management should not be focused on maximising production per cow, per unit of labour or per unit of land: profit maximisation appears to be a more reasonable goal. This assessment by Moore (1998) concurs with the results of a simulation model reported by McCall and Clark (1999).

The costs per kg milk in the FDPG were lower than those in the other systems. A comparison of the data in Table 1 with those in Table 4 reveals that the reduction of the costs of feeding with 43% constituted the main difference. This result concurs with the assessment by Moore (1998) that the primary benefit of grass-based dairying is the reduction in the cost of feeding the cow herd. The reduction in feeding costs had three main components: i) almost all the forage consumed in the FDPG was produced on the farm (with the exception of 42% of the maize silage consumed), but that was not the case in many of the surveyed farms of the Specialised and Semi-specialised Dairy Systems, ii) grazing eliminated the costs of cutting, carrying and feeding the herbage and iii) the reduced use of supplementary feeding with concentrates, since the cost per Mcal Metabolisable Energy provided by commercial concentrates has been estimated to be approximately 7 times higher than that provided by grazed herbage (Améndola, 1997).

Conclusions

The dairy system implemented in the FDPG of Chapingo enabled milk production at lower costs than the dairy systems prevailing in the Plateau and the North of Mexico. This result was achieved by reducing feeding costs with 43%. The productivity of cows was 15% lower than the average of the Specialised Dairy System, but in economic terms this reduction was counteracted by the much lower production costs.

Feed availability was rather constant throughout the year. This was reflected in a uniform milk production pattern. Annual winter pastures increased the carrying capacity of the system during the winter. This effect counteracted their higher specific production costs. Supplementary feeding with maize silage also increased feed availability during the winter.

The average stocking rate in the FDPG was 3.04 cow-equivalents ha^{-1}. However, this stocking rate was lower than stocking rates attained with some treatments in experiments carried out at the FDPG. Therefore, there is scope for increasing stocking rate and hence profitability, because increases in stocking rate are usually linked with increases in the profit of dairy enterprises (Moore, 1998). In the experiments, increments of stocking rate and productivity per unit of land were linked to supplementary feeding with relatively high levels of maize silage and moderate levels of concentrates.

The conceptual model on which the system was based assumed four-year duration of alfalfa and orchard grass pastures. The results suggest that the duration of the phase of permanent pastures should not be longer than three years. Stocking rates attained in fourth-year pastures and in third-year re-established pastures (without previous crop rotation) were too low. Such a low carrying capacity does not concur with the high generic costs of herbage and forage production in this system. It also jeopardises a sustainable use of irrigation water. Considering a three-year duration of permanent pastures, the proportion of area sown to annual pastures and silage maize can be kept between 25% and 40%. The actual proportion will depend on the length of the annual pastures/silage maize phase (1 or 2 years). The proportion that maximises profit will depend on the cost:price ratio. Gómez and Jahn (1993) state that in order to maximise profits, the proportion of the farm sown to silage maize should increase with increments in the price of milk.

The reproductive performance of cows was lower than required for an efficient functioning of a dairy system. The average trend of changes in body weight during the lactation appeared to be within the normal range. Therefore, too high rumen degradable protein content of the diet and failures in the detection of heats were the factors most probably related to this poor performance.

The risks of bloat did not appear to jeopardise the sustainability of the system. The reduction of these risks is probably the result of the combination of using a preventive anti-foam agent and avoiding high initial herbage intake rates in alfalfa pastures due to supplementation.

The system was sensible to the sowing date of winter and summer annual pastures. Sowing in time of winter annual pastures is highly dependent on the amount of rain in late summer and early autumn. Alternative sowing methods of winter annual pastures with reduced tillage must be developed in order to overcome this dependence. Alternative management is needed to improve the efficiency of utilisation of summer annual pastures and to increase feed availability in the first half of the autumn. These topics will be dealt with in the General Discussion.

Chapter 8

General discussion

We undertook the task of developing a sustainable dairy system based on forages and grazing as an option to face the severe crisis of profitability that dairy production in Mexico had suffered during the 1980s. However, the situation of the international and the national dairy markets changed strongly during the 1990s. For that reason, we were concerned about the effect of these changes on the probable adoption of the alternative dairy system. From the review on Chapter 2 it can be concluded that dairy farming in Mexico, mainly relying on cut-and-carry forages and purchased concentrates, will surely require alternatives to reduce feeding costs. Due to favourable prices, the production in the dairy systems of the Plateau and North of Mexico grew steadily during the 1990s (Chapter 2). However, as agriculture is further integrated in a multilateral trading system, Mexican dairy farmers will face the challenge of an increased competition. Therefore –as stated by Harvey and Saunders (1993)- the strategy at farm level must be based on competitive free trade world prices. Under these conditions the price paid to Mexican farmers might approach the low prices paid in countries of the Southern Hemisphere (Australia, New Zealand, Argentina and Uruguay) that are becoming the market leaders. Prices paid to farmers in those countries are lower than feeding expenses in the Specialised and Semi-Specialised dairy systems of the Plateau and North of Mexico. If further growth of dairy production is to be expected in these systems, farmers will have to reduce feeding costs in order to remain competitive.

The results of two years of operation (1998 and 1999) of the Farmlet for Dairy Production Under Grazing (FDPG) of Chapingo University show that dairy systems based on forages and grazing are an alternative to reduce production costs. Feeding costs in this dairy system were 43% lower than the average feeding costs in prevailing dairy systems (Chapter 7). Feeding in this alternative dairy system was based on grazing of permanent and annual pastures and supplementary feeding with maize silage and relatively low amounts of concentrate as proposed in Chapter 1.

Raw milk lost its share on the Mexican dairy market and therefore dairy farmers must integrate to dairies (Chapter 2). The seasonal variation of production appears to be one of the main constraints for integration. Seasonal variation in the production originates in the low forage availability during the dry winter months. Avoiding seasonal variations in milk production while keeping the feeding costs low requires a uniform availability of forages throughout the year. The feed availability achieved with the pasture-crop rotation in the

FDPG was uniform throughout the year, which reflected in a milk production without seasonal variations (Chapter 7).

This dairy system is a first step in the development of a sustainable option. Though it is imperfect and requires many adjustments, it has already proven to be a viable alternative. Below, some components of the system will be discussed and some questions that require further research will be pointed out.

Persistence of alfalfa and orchard grass pastures

In the experiment reported in Chapter 3, third-year pastures with low proportions of alfalfa (57% of green herbage) had lower net herbage production (NHP) and average stocking rate (SR) than second- and third-year pastures with high proportions of alfalfa (71% of green herbage). The average SR and NHP of these latter pastures were in line with those attained two years later with first- and second-year pastures in the experiment reported in Chapter 5. These results concur with the fact that the productivity of alfalfa and orchard grass pastures depends mainly on the proportion of alfalfa. This effect of the proportion of alfalfa has been reported in Chapingo on first-year pastures (Ballesteros and Flores, 1994) as well as on third-year pastures (Julián, 1996). The decline in plant densities with age appears to be a normal situation in grazed alfalfa pastures (Lodge, 1991) and might therefore be considered as the main factor leading to the reduction in productivity. In this dairy system fourth-year pastures had lower average SR than second- and third-year pastures (Chapter 7). Other results (Julián, 1996, Paniagua, 1999; Amendola, unpublished) suggest that the difference in productivity and hence carrying capacity between young and old pastures is greater during winter than during spring and summer. The most probable reason for this seasonal effect relies on the fact that the decrease in productivity is coupled with a decrease in the proportion of alfalfa and an increase in the proportion of kikuyu, a C4 grass.

Based on results reported in Chapter 7 it can be estimated that the cost of year-round grazing on alfalfa and orchard grass pastures of 4-year duration was 0.78 US $ per cow-day, while those of grazing the same pastures of 3-year duration was 0.74 US $ per cow-day. This very simple economic evaluation demonstrates the unfeasibility of lengthening the permanent pasture phase to four years.

The discussion on persistence would probably need to involve information on plant densities. There is no universally accepted definition of persistence. The maintenance of adequate plant numbers appears to be the essential criterion. The term adequate should be interpreted as the density that achieves expectations in terms of economic productivity and environmental or cultural stability (Marten, 1989). No information was available on plant densities. However, the discussion on persistence in this thesis is based on the economic performance, which appears to be the proper background for making decisions.

Comparison between permanent and annual pastures

One of the problems that affected the sustainability of the initial dairy system based on grazing of alfalfa and orchard grass pastures was the lack of options for the problem of poor persistence of pastures (Chapter 1). We sought that option in a pasture-crop rotation in which annual pastures should play an important role by substituting old and degraded permanent pastures and attaining high rates of herbage production during the winter. In the experiments reported in Chapters 3 and 5 permanent and annual pastures were compared. In both experiments annual pastures were superior to permanent pastures. Considering the average of both experiments, the NHP of annual pastures (47 kg DM ha^{-1} d^{-1}) was much higher than that of permanent pastures (26 kg DM ha^{-1} d^{-1}). This difference was reflected in higher herbage intake on annual pastures at comparable levels of SR (Chapter 3) or higher SR on annual pastures at comparable levels of herbage intake (Chapter 5).

Considering a period of 7 months (October to April) and data on SR and production costs reported in Chapter 7, it was estimated that the cost of grazing annual winter pastures was 0.94 US $ per cow-day, while that of grazing of permanent pastures during the same period was 0.99 US $ per cow-day. The inclusion of winter annual pastures is therefore justified.

There were some additional benefits from including annual pastures in the rotation. Cows did not have to graze alfalfa and orchard grass pastures in the morning and that was one of the factors probably leading to the low incidence of bloat experienced in this system (Chapter 7). Herbage intake rates in annual pastures were higher than in permanent pastures (Chapters 3 and 5), which was probably due to a higher average bite weight. Taking into account the functional response (Ungar, 1996), a high herbage intake rate is expected to result in a high total daily herbage intake.

Supplementary feeding with maize silage and concentrates

It was assumed that the response to supplementation per hectare might be more closely affected by changes in SR than by changes in per cow production. Therefore, in order to evaluate the feasibility of supplementary feeding the economic analysis should include the potential effect on SR and hence on milk production per hectare. In order to estimate the effect on SR, a high and uniform degree of pasture utilisation was targeted in the experiments reported in Chapter 3 and 5, irrespective of the level of supplementary feeding. It was assumed that with this grazing management the effects of the levels of supplementary feeding and herbage availability would not be confounded. This assumption is based on the fact that, irrespective of the level of supplementary feeding, all cows would face the same average herbage mass, height and composition throughout the grazing sessions.

In both experiments this grazing management was suitable to detect the response of milk production per hectare to supplementary feeding. Milk production per hectare was more closely affected by changes in SR than by changes in production per cow. Supplementary feeding with maize silage up to 4.8 kg DM of silage cow^{-1} day^{-1} (Chapter 3) and 4 kg of concentrates cow^{-1} day^{-1} (Chapter 5) appeared to be economically feasible. Under the conditions of this dairy system, the right economic decision could not have been based on the response in milk production per cow to supplementary feeding. This result is not surprising since already in the 1950s McMeekan (1958) stated that the economy of milk production depended on full utilisation of the herbage grown and hence on the SR. Taking into account the scarcity of reports on the response of milk production per ha to supplementary feeding, our results support the assessment by Leaver (2000) on the need of research relating technology to farm financial return.

Crude protein content of herbage of alfalfa and orchard pastures in the experiment reported in Chapter 3 was high, which is in line with previous results (Sánchez *et al.*, 1996). Such a high crude protein content could affect the sustainability of the system (Chapter 1). However, the levels of milk urea nitrogen (MUN) reported in Chapter 4 were below the limit of MUN levels considered to affect reproductive performance (Butler, 1998). This result suggests that by combining the herbage of these pastures with herbage of oats and ryegrass pastures, maize silage and concentrates with relatively low contents of, the excess in rumen degradable protein in the diet could be reduced.

The effect of supplementary feeding on herbage intake

In the experiments reported in Chapters 3 and 5, herbage intake was measured in order to gain insight in the nature of the response of SR to supplementary feeding. Considering that making accurate estimates of intake of grazing animals presents real difficulties in most situations (Coates and Penning, 2000), in both experiments herbage intake was estimated in three ways: a) by means of herbage sampling, b) by means of faecal output and digestibility of the whole diet and c) through estimating intake needed to meet animal's requirements. In the experiment reported in Chapter 3 herbage intake of the unsupplemented cows was overestimated when based on herbage sampling. In the experiment reported in Chapter 5, double sampling techniques and a larger sampling unit improved the estimate of intake by means of herbage sampling. In that experiment there was a reasonable agreement between the three estimates of intake. However, relatively small differences in the estimates of intake by the three methods caused large differences between the estimates of substitution. This result suggests that even though substitution rates are the cause of the potential increase in SR when cows are supplementarily fed, the estimate of substitution rates is not suitable to estimate that potential increase. A comparison between the three methods of estimating intake was not intended. However, estimating intake by means of animal requirements appeared to be a low-cost method suitable for this type of experiments.

Increasing the level of supplementary feeding (Chapters 3 and 5) or using very low daily herbage allowance (Chapter 4) reduced herbage intake. The reduction in herbage intake was mainly caused by a decrease in active grazing time. In accordance with Rook *et al.* (1994a), differences in daily active grazing time in the experiments reported in Chapters 4 and 5 were mostly due to differences in night grazing. This result might be useful in practical situations, it suggests that after a change in management observing the response of night grazing might be a low-cost and fast method to predict the nature of the response of herbage intake.

In the experiment reported in Chapter 3, active grazing time appeared to be at least partially affected by reduced residence time in paddocks. Supplementary feeding with forages usually restricts the time that animals are on the pastures (Phillips, 1988). The intake rate of maize silage was between 35 and 39 g DM min^{-1} (Experiments 3, 4 and 5), which is much lower than the average intake rate of supplementary fed forages quoted by Leaver (1985). That is the probable reason for the relatively long sessions of supplementary feeding with maize silage in the current study. In the experiment reported in Chapter 4 it was observed that when cows were offered high herbage allowances they were reluctant to eat the maize silage and waited for herbage to be grazed. This result is in line with that reported by Valk (1994). In the experiment described in Chapter 5 mixing the maize silage with 4 or 6 kg of concentrates increased the acceptability of the silage, which gives a scope to reduce the length of the sessions of supplementary feeding. If supplements are supplied during the night to penned cows, grazing time might be less severely reduced (Phillips, 1988). However, the probable impact of this practice on the system efficiency might not be positive because even though it would reduce the average cost of the diet by increasing the proportion of grazed herbage, also negative effects are to be expected: i) if grazing time is less severely reduced, then the effect of supplementary feeding on stocking rate would be smaller, ii) the welfare of cows would be reduced because cows prefer to lie in grassland (Ketelaar-de Lauwere *et al.*, 1999), and iii) the proportion of urine and faeces excreted in the farmyard would increase with negative consequences for the operation costs (the removal of excreta from the farmyard is not mechanised).

Herbage allowance and ingestive behaviour

In the experiments reported in Chapters 3 and 5, we explored the effects of supplementary feeding on SR and productivity per ha using a uniform and high level of pasture utilisation. In the experiment reported in Chapter 4, we explored the levels of utilisation of the annual pastures likely to maximise production per unit of area using the average levels of supplementary feeding. The responses of herbage intake and composition of the ingested herbage to different levels of herbage allowance were used to identify the levels of stocking rate and height of residual herbage that maximised production per unit of area. The approach was suitable to translate experimental results into long-and short-term management recommendations.

According to the functional response (Ungar, 1996) biting rate is expected to increase with decreasing bite weight. That was the case when comparing annual and permanent pastures (Chapters 3 and 5). As expected, bite weight decreased as the grazing session progressed (Chapter 4). However, biting rate also decreased as the grazing session progressed (Chapters 3, 4 and 5). The results on biting rate are in line with those reported by Chilibroste (1999) and Soca *et al.* (1999), and therefore it might be assumed that this is the normal evolution of biting rate in this type of rotational stocking method with short grazing periods.

Bite weight decreased as the session progressed due to the effect that previously taken bites exerted on the attributes of the canopy (Chapter 4). The results of this experiment show that the number of bites taken per unit of area was an adequate variable to interpret the responses to herbage allowance. It enabled us to analyse the response of herbage intake to herbage allowance in terms of the state-rate functional response, which Ungar (1996) considered to be impossible. It was also useful to interpret the effect of herbage allowance on the preferential grazing of the cows. In general terms it allowed us to consider the interplay between daily intake per animal and intake per unit area, which has been stressed by Wade and Carvalho (2000).

Nitrogen fertilisation and irrigation of annual pastures

The results of the cutting trial reported in Chapter 6 show that N fertilisation between 50 and 100 kg N ha^{-1} per harvest might be economically feasible. However, the result should be tested in a grazing trial since lower responses to fertiliser N might be expected under grazing (Deenen, 1994). The average apparent effect of N fertilisation might be improved without affecting herbage production if low levels of N fertilisation are applied at the beginning of the growing season and N fertilisation is increased after the first harvest. This alternative deserves further research because: i) the value of the herbage produced by annual pastures decreases as the season progresses because the carrying capacity of permanent pasture increases (Chapter 7), ii) N present in the stubble might play a role in regrowth (Chapter 6), and iii) the level of N fertilisation affects the botanical composition (by improving the competitiveness of ryegrass for light) and hence might affect herbage accumulation rate in the following cycle. The rumen degradable protein content of herbage should also be considered as a response variable in further research because high levels of rumen degradable protein have a negative effect on the system efficiency.

Increasing the efficiency of irrigation water is an urgent need because the exhaustion of underground water used for irrigation jeopardises the sustainability of dairy production. Nitrogen fertilisation increased the efficiency of utilisation of irrigation water. The results suggest that keeping the level of irrigation low during the growth cycle of the first harvest and adjusting it slightly below the level of pan evaporation in the rest of the growth season might increase the efficiency of utilisation of irrigation water. The traditional fortnightly frequency of irrigation should be changed into a weekly one in order to increase that efficiency further.

Future research needs

Within this project we developed a dairy system that has already proven to be a viable alternative. However, the system is imperfect and requires many adjustments. Therefore, we conclude with the definition of the future research needs.

Further research should evaluate an alternative pasture-crop rotation. Lengthening the permanent pasture phase to four years is economically unfeasible. Furthermore, based on the differences in SR between permanent and annual pastures as reported in Chapter 7, it can be estimated that with 80% of the area sown to permanent pastures the carrying capacity of the system between October and April would be much lower than with 60% of the area sown to permanent pastures. Therefore, a rotation with 60% of the area sown to permanent pastures and the remainder 40% sown to annual pastures and silage maize appears to be more appropriate. Such a proportion can be achieved by keeping the length of the permanent pasture phase to 3 years, and the length of the annual pasture-silage maize phase to 2 years.

Cropping silage maize on approximately 50% of the area of the annual pastures-maize phase should produce all the maize silage consumed in the system (Chapter 3 and Chapter 7). The remainder 50% of that area should be sown to annual summer pastures and maize to be fed as green-chop. The cows should be supplementarily fed with maize silage between the end of October and the end of August. Excess of herbage can occur in June and July and feed deficits might take place in the autumn. These later deficits are coupled with the date of sowing of winter annual pastures. The use of maize green-chop might be an option to face those deficits (Moran, 1992). The hypothetical feed availability expected with this alternative rotation is depicted in Figure 1.

According to this proposal the issues that should be addressed by future research are:

1. Methods of minimum tillage for the establishment of annual winter pastures in order to reduce the probabilities of delaying sowing due to heavy rains (see Chapter 7).
2. Mixtures for summer annual pastures and grazing management of these pastures.
3. The delay until November of the utilisation of the herbage produced by permanent pastures during September and October. This requires special attention for the probable negative effects on the nutritional composition of the herbage and on the persistence of the pastures.
4. The use of maize green-chop as the main component of the diet during September and October.

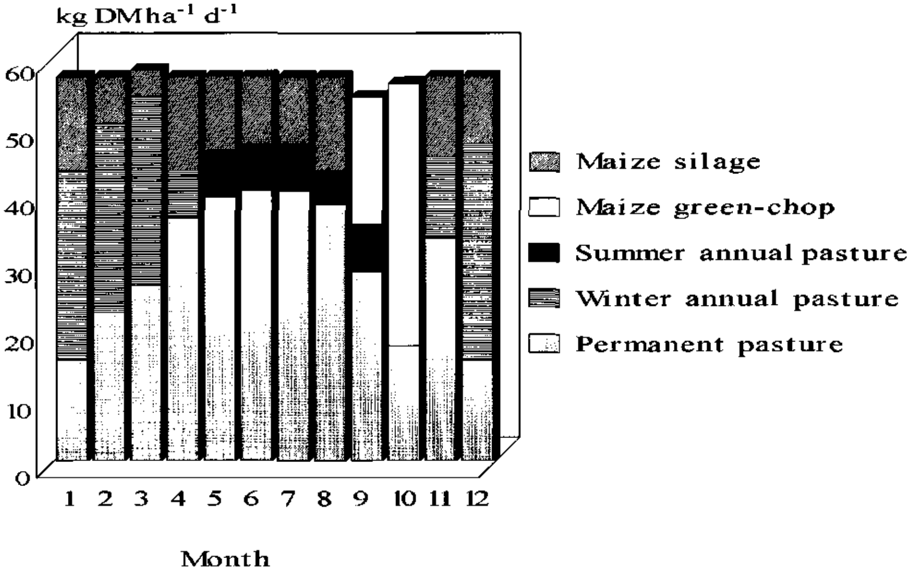

Figure 1. Hypothetical feed availability with the alternative pasture-crop rotation.

With this pasture-crop rotation, the highest levels of stocking rate and production per cow achieved in the experiments reported in Chapters 4 and 5 might be set as targets. Considering the area required for dry cows and replacements, the target SR is then 3.7 cows in milk per ha. The targeted production per cow is 22 kg milk cow^{-1} d^{-1} (Chapters 4 and 5) and the targeted productivity 29 Mg milk ha^{-1} $year^{-1}$. The targeted productivity is much higher than the results obtained during 1998 and 1999 (Chapter 7). However, it is reasonably in line with the results obtained by McCall and Clark (1999) using a linear programming model. The model predicts that with a milk price comparable to the one paid to the FDPG, the optimum inputs on New Zealand farms are i) 400 kg of N fertiliser ha^{-1} $year^{-1}$, ii) 6.7 Mg DM of purchased maize silage ha^{-1} $year^{-1}$ and iii) 198 kg of purchased supplemental grain ha^{-1} $year^{-1}$. With those levels of inputs McCall and Clark estimate a productivity of 27.4 Mg milk ha^{-1} $year^{-1}$ at a SR of 4.12 cows ha^{-1}. Therefore, our targeted productivity should be achievable.

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Summary

Dairy production in Mexico suffered a severe crisis of profitability during the 1980s. More than 70% of the milk is produced under temperate and semi-arid conditions in the Plateau and North of Mexico. Dairy systems in temperate Mexico will have to reduce feeding costs in order to remain competitive. This thesis describes the design of a dairy system based on forages and grazing as an alternative to reduce production costs in temperate Mexico. The designed dairy system is based on a sequential cropping system of permanent pastures of alfalfa and orchard grass, winter annual pastures of oats and annual ryegrass and silage maize. Between May and October the cows graze on permanent pastures and between November and April they graze both types of pastures. Between October and April the cows also receive supplementary feeding with maize silage. The cows are supplementarily fed with moderate amounts of concentrates during the lactation.

The situation of the international and the national dairy markets changed strongly during the 1990s. Taking into account that these changes could have a huge effect on the probable adoption of the alternative dairy system, in Chapter 2 a review of the dairy production sector in Mexico over the last 25 years is reported. The main objective was to update the characterisation of the sector and the outlines of its perspectives. Many factors that constitute the environment for dairy production were analysed in this review: i) the evolution of demand for dairy products, ii) dairy policies, including import of skim milk powder and definition of prices paid to farmers, iii) milk production of the different dairy systems including a brief description of these systems and their production costs, iv) the evolution of the world dairy market and v) changes in the national dairy market. Mexican dairy farmers will face in the near future the challenge of an increased competition and the strategy at farm level will have to be based on competitive free trade world prices. They will surely require alternatives to reduce feeding costs.

In Chapter 3 the responses of stocking rate and milk production per hectare to four levels of supplementary feeding with maize silage are reported. A high and uniform pasture utilisation was targeted irrespective of the level of supplementary feeding. Under this grazing management substitution rates were high leading to strong increments in stocking rate (0.32 cow ha^{-1} per kg dry matter of silage offered daily per cow). In spite of a slight negative effect on milk production per cow, milk production per hectare was increased with the level of supplementary feeding (0.79 kg per milk dry matter of silage offered daily per ha). Taking into account the price ratio between maize silage and milk, this increment justified

supplementary feeding up to the highest level used in this experiment (4.8 kg of dry matter of silage offered daily per cow).

In Chapter 4, the allowance - intake relationship for dairy cows grazing oats and annual ryegrass pastures is reported. The responses of herbage intake and composition of the ingested herbage to different levels of herbage allowance were used to identify the levels of stocking rate and height of residual herbage that maximised production per unit of area. The approach was suitable to translate experimental results into long- and short-term management recommendations. The results of this experiment show that the number of bites taken per unit of area is an adequate variable to interpret the responses to herbage allowance.

The experiment reported in Chapter 5 evaluated the response of stocking rate and milk production per hectare to four levels of supplementary feeding with concentrates. A high and uniform pasture utilisation was targeted irrespective of the level of supplementary feeding. A high response in milk production per cow was coupled to low levels of substitution. On the contrary, the increase in stocking rate was coupled to high levels of substitution. Milk production per hectare was mainly affected by the increase in stocking rate. The response to 2 kg of concentrates cow^{-1} d^{-1}was not economically feasible while that to 4 kg of concentrates was economically attractive and should be able to withstand deterioration in the price ratio between concentrates and milk. Basing the economic evaluation on the response of milk production per cow to supplementary feeding would have led to mistaken conclusions.

The effects of nitrogen fertilisation and irrigation on herbage and nitrogen yield of oats and ryegrass pastures were evaluated in the experiment reported in Chapter 6. Nitrogen fertilisation between 50 and 100 kg N ha^{-1} harvest^{-1} increased herbage production, reduced the cost of produced herbage and improved the efficiency of utilisation of irrigation water. Nitrogen fertilisation increased the proportion of ryegrass in the pastures by improving its competitiveness for light. Using a high level of irrigation (higher than the levels of pan evaporation) reduced the efficiency of utilisation of irrigation water and the recovery of fertilizer-N. However, increasing the frequency of irrigation increased the efficiency of use of absorbed N, probably through the improvement in radiation use efficiency.

The biophysical and economical results of two years of operation (1998 and 1999) of the Farmlet for Dairy Production Under Grazing of Chapingo University are reported in Chapter 7. The average stocking rate was 2.6 cows ha^{-1}, the average production per cow was 6200 kg milk per lactation and the average productivity was 16 Mg milk ha^{-1} year^{-1}. Feeding costs in this dairy system were 43% lower than the average feeding costs in prevailing dairy systems. The net revenues (1273 US \$ ha^{-1} year^{-1}) show that this dairy system is a feasible alternative.

In Chapter 8, the consequences of the results are reviewed in terms of the efficiency of the dairy system. Based on that analysis, an improved pasture-crop rotation is proposed and future research needs are outlined. The new targets are i) a stocking rate of 3.7 cows in milk ha^{-1} and ii) a production of 22 kg milk cow^{-1} d^{-1}. Even though the targeted productivity (29 Mg milk ha^{-1} $year^{-1}$) is much higher than the result obtained during 1998 and 1999, it appears to be achievable.

Samenvatting

De melkveesector in Mexico ondervond een ernstige rentabiliteitcrisis in de jaren 80. Meer dan 70% van de melk wordt op de Centrale Hoogvlakte en in het Noorden onder gematigde (halfdroge) omstandigheden geproduceerd. De melkproductiesystemen van gematigd Mexico zijn gedwongen hun veevoedingskosten te verminderen om hun concurrentievermogen te behouden. Dit proefschrift beschrijft het ontwerp van een melkproductiesystemen gebaseerd op groenvoeders en beweiding. Dit productiesysteem is ontworpen als een optie voor het verminderen van de productiekosten in gematigd Mexico. Het systeem is gebaseerd op meerjarig grasland (een mengsel van luzerne en kropaar), winter- kunstweiden (een mengsel van haver en Italiaans raaigras) en snijmaïskuil. De koeien weiden het hele jaar op het meerjarig grasland en tussen november en april tevens op de kunstweides. Tussen oktober en april worden de koeien bijgevoerd met snijmaïskuil. Tijdens de lactatieperiode worden de koeien bijgevoerd met geringe hoeveelheden krachtvoer.

In het afgelopen decennium zijn de Mexicaanse melkveesector en de wereldmarkt voor melkproducten aan veel veranderingen onderhevig geweest. In acht nemend dat deze veranderingen een negatieve werking op de mogelijke adoptie van dit systeem zouden kunnen uitoefenen, worden in Hoofstuk 2 de resultaten van een literatuuronderzoek naar de omstandigheden van de Mexicaanse melksector gedurende de afgelopen 25 jaar gerapporteerd. Het voornaamste doel van dit onderzoek was het in kaart brengen van de recente ontwikkelingen binnen de sector en het schetsen van toekomstverwachtingen voor het ontworpen systeem. Vele aspecten zijn hierbij meegenomen: i) het nationale beleid m.b.t. import van melkpoeder en het vaststellen van maximumprijzen, ii) het productieniveau van de verschillende productiesystemen in Mexico, iii) een beknopte beschrijving van deze systemen en de bijbehorende productiekosten, iv) de evolutie van de wereldmarkt voor zuivel en v) de veranderingen in de nationale melkveesector. De Mexicaanse boeren zullen binnenkort geconfronteerd worden met toenemende concurrentie en zij zullen hun strategie vooral op het verbeteren van hun concurrentiepositie tegenover de prijzen van de wereldmarkt moeten baseren. Hiervoor zullen zij beslist opties voor het verlagen van de veevoedingskosten in acht moeten nemen.

In Hoofdstuk 3 wordt de respons van de veedichtheid en de melkproductie per hectare op toenemende niveaus van bijvoeding met snijmaïskuil binnen het systeem beschreven. Het doel van de toegepaste beweidingmethode was het bereiken van efficiënte grasbenutting ongeacht het niveau van bijvoedering. De verdringing van vers gras door snijmaïskuil was hoog en dat leidde tot verhoging van de veebezetting (0.32 koe per hectare per kg dagelijks

aangeboden droge-stof snijmaïskuil per koe). Ondanks een gering negatief effect van het bijvoeren met snijmaïskuil op de melkproductie per koe nam de melkproductie per hectare significant toe met het niveau bij bijvoeding (0.79 kg melk per hectare per kg drogestof aangeboden snijmaïskuil per hectare). Rekening houdend met de prijsverhouding tussen snijmaïskuil en melk bleek de toename in de melkproductie per hectare door het bijvoeren met snijmaïskuil economisch aantrekkelijk tot en met het hoogste niveau (aanbod 4.8 kg drogestof snijmaïskuil per koe per dag).

In Hoofdstuk 4 wordt de relatie tussen grasaanbod en grasopname van weidende melkkoeien op kunstweides met haver en Italiaans raaigras kunstweiden gerapporteerd. De respons van de grasopname en de samenstelling van het opgenomen gras werden gebruikt voor het vaststellen van de niveaus van veebezetting en stoppelhoogte die de melkproductie per hectare maximaliseren. Deze benadering was geschikt om de proefresultaten om te zetten in beheersmaatregelen op de lange en korte termijn. Het aantal happen per vierkante meter bleek een geschikte variabele te zijn om de respons op toenemend grasaanbod te interpreteren.

In Hoofdstuk 5 wordt de respons van de veedichtheid en de melkproductie per hectare op toenemend niveaus van bijvoederen met krachtvoer gepresenteerd. Het doel van de toegepaste beweidingmethode was opnieuw het bereiken van een efficiënte grasbenutting bij alle niveaus van bijvoedering. Met een laag niveau van verdringing van gras door krachtvoer werd een forse respons van de melkproductie per koe geconstateerd. Daar tegenover staat dat de toename van de veebezetting gekoppeld was aan de lage niveaus van verdringing van gras door krachtvoer. De melkproductie per hectare werd voornamelijk door de veebezetting bepaald. De respons op 2 kg krachtvoer per koe per dag bleek niet rendabel te zijn, terwijl de respons op 4 kg krachtvoer per koe per dag wel economisch aantrekkelijk was en deze zou in staat moeten zijn om een eventuele verslechtering van de prijsverhouding tussen krachtvoer en melk te weerstaan. Het baseren van bedrijfseconomische conclusies op basis van de respons van de melkproductie per koe zou tot verkeerde conclusies geleid hebben.

De respons van de grasopbrengst en de stikstofopbrengst in kunstweiden van haver en Italiaans raaigras op toenemende niveaus van stikstofbemesting en irrigatie wordt in Hoofdstuk 6 gerapporteerd. Stikstofgiften tussen 50 en 100 kg stikstof per hectare per snede verhoogden de grasopbrengst, verlaagden de kosten van het geoogste gras en verbeterden de gebruiksefficiëntie van irrigatiewater. De stikstofbemesting verhoogde het aandeel Italiaans raaigras. Dit kwam hoogstwaarschijnlijk door een toename van zijn concurrentievermogen voor licht. Met het gebruik van een hoog niveau van irrigatie (hoger dan het niveau van de open pan verdamping) werden de stikstofopname, de gebruiksefficiëntie van irrigatiewater en de stikstofconcentratie in het gras verlaagd. Dit werd toegeschreven aan stikstofuitspoeling. Verhoging van de frequentie van irrigatie verhoogde de gebruiksefficiëntie van de opgenomen stikstof daarentegen wel, waarschijnlijk door een toename in de gebruiksefficiëntie van de onderschepte straling

De productiegegevens en de economische resultaten van de Proefboerderij voor Melkproductie onder Beweiding van Chapingo Universiteit zijn in Hoofdstuk 7 samengevat voor de jaren 1998 en 1999. De gemiddelde veebezetting was 2.6 koe per hectare, de gemiddelde productie per koe 6200 kg melk per lactatie en de gemiddelde productiviteit was 16 Mg melk per hectare per jaar. De voedingskosten binnen dit systeem waren 43% lager dan in de gangbare melkproductiesystemen in Mexico. De netto inkomsten bedroegen US$ 1273 per hectare per jaar. Hiermee bleek het ontworpen systeem een rendabele optie voor de toekomst om de productiekosten te verlagen.

In Hoofdstuk 8 zijn de verkregen resultaten aan een nadere analyse onderworpen om verdere efficiëntieverbeteringen door te kunnen voeren. Deze analyse resulteerde o.a. in een verbeterde gewasopvolging en concrete voorstellen voor nader onderzoek. De voorgestelde productiedoelen zijn een veebezetting van 3.7 koeien per hectare met een dagelijkse productie van 22 kg melk per koe. De bijbehorende productiviteit (29 Mg melk per hectare per jaar) is veel hoger dan de behaalde productie in 1998 en 1999, maar lijkt haalbaar.

Resumen

La producción de leche en México sufrió una severa crisis de rentabilidad durante la década de los ochenta. Más del 70% de la producción nacional proviene de sistemas lecheros ubicados en el Altiplano y Norte de México bajo condiciones templadas o semiáridas. Para conservar su competitividad, estos sistemas de producción deberán reducir sus costos de alimentación. En la presente Tesis se describe el diseño de un sistema de producción lechera basado en forrajes y pastoreo como una alternativa para reducir los costos de alimentación. El sistema diseñado se basa en una rotación de praderas permanentes de alfalfa con orchard, praderas anuales de invierno de avena con raigrás anual y maíz para ensilar. Entre los meses de mayo y octubre las vacas pastorean las praderas permanentes y entre los meses de noviembre y abril pastorean los dos tipos de praderas. Adicionalmente, entre los meses de octubre y abril las vacas reciben alimentación suplementaria con ensilado de maíz. Durante la lactancia, las vacas son suplementadas con cantidades modestas de concentrado.

Los mercados lecheros nacional e internacional cambiaron marcadamente durante la década de los noventa. Partiendo de la base que estos cambios podían afectar las posibilidades de adopción del sistema propuesto, en el Capítulo 2 se presentan los resultados de una revisión del sector productor de leche mexicano en los últimos 25 años. El objetivo de esta revisión fue actualizar la descripción del sector y definir sus perspectivas. En la revisión se analizan algunos de los factores que afectan el medio ambiente de la producción lechera: i) la evolución de la demanda de lácteos, ii) las políticas gubernamentales hacia el sector incluyendo la importación de lácteos y la definición de precios máximos al productor, iii) la producción aportada por los diferentes sistemas de producción, una breve descripción de éstos y sus correspondientes costos de producción, iv) la evolución del mercado internacional de lácteos y v) los cambios en el mercado nacional de lácteos. Los ganaderos lecheros mexicanos se verán expuestos en el futuro cercano a una intensa competencia. Para enfrentar esta competencia la estrategia en el ámbito de cada empresa deberá basarse en la competitividad frente a precios internacionales de libre mercado. Seguramente se requerirán opciones para reducir los costos de alimentación.

En el Capítulo 3 se reportan las respuestas de la carga animal y la producción de leche por hectárea a cuatro niveles de suplementación con ensilado de maíz. El manejo de pastoreo empleado tuvo como meta lograr un elevado nivel de utilización, independientemente del nivel de suplementación. Bajo este manejo del pastoreo, las tasas de sustitución fueron altas, permitiendo un fuerte aumento en la carga animal (0.32 vacas ha-1 por cada kg de materia seca de ensilado de maíz ofrecido diariamente por vaca). Si bien la producción individual

respondió negativamente a la suplementación, debido al aumento en la carga animal, la producción de leche por hectárea aumentó con el nivel de suplementación (0.79 kg de leche por cada kg de materia seca de ensilado de maíz ofrecido por hectárea). Tomando en cuenta la relación de precios entre el ensilado de maíz y la leche, este incremento justificó económicamente la suplementación con ensilado de maíz hasta el nivel más alto empleado en el experimento (4.8 kg de materia seca de ensilado de maíz ofrecido diariamente por vaca).

En el Capítulo 4 se reporta un estudio sobre la relación entre el consumo de forraje y la asignación diaria de forraje realizado con vacas lecheras en praderas de avena y raigrás anual. Se emplearon los resultados del consumo individual de forraje y la composición del forraje consumido, para definir los niveles de carga animal y altura de forraje residual que maximizaron la producción de leche por hectárea. El enfoque resultó adecuado para traducir los resultados experimentales en recomendaciones sobre medidas de manejo del pastoreo de corto y largo plazo. Los resultados de este experimento demostraron que la cantidad de bocados tomados por unidad de área es una variable muy útil para la interpretación de resultados de las respuestas a la asignación diaria de forraje.

En el experimento reportado en el Capítulo 5 se evaluó la respuesta de la carga animal y la producción de leche por hectárea a cuatro niveles de suplementación con concentrado. El manejo de pastoreo empleado tuvo como meta lograr un elevado nivel de utilización, independientemente del nivel de suplementación. Altas repuestas de la producción individual se asociaron con bajos niveles de sustitución. Por el contrario, los mayores incrementos en carga animal se asociaron con latos niveles de sustitución. La producción de leche por hectárea estuvo principalmente determinada por el incremento en la carga animal. La respuesta a 2 kg de concentrado vaca^{-1} día^{-1} no fue rentable, mientras que la respuesta a 4 kg de concentrado vaca^{-1} día^{-1} fue económicamente atractiva y debería estar en condiciones de soportar el deterioro de la relación de precios entre el concentrado y la leche. Si la evaluación económica se hubiese basado en la respuesta individual, se hubiese arribado a conclusiones equivocadas.

En el experimento que se reporta en el Capítulo 6 se evaluó la respuesta del rendimiento de forraje y la recuperación de nitrógeno a niveles crecientes de fertilización nitrogenada y riego. Niveles de fertilización nitrogenada entre 50 y 100 kg N ha^{-1} cosecha^{-1} incrementaron la producción de forraje, redujeron el costo del forraje cosechado y mejoraron la eficiencia del uso del agua de riego. Con la fertilización nitrogenada aumentó la proporción de raigrás probablemente debido a un aumento en su competitividad por luz. Al emplear un nivel alto de riego (mayor que la evaporación de tanque) se redujeron la eficiencia de utilización del agua de riego y la recuperación del N aplicado. Sin embargo, al aumentar la frecuencia de riegos se incrementó la eficiencia de utilización del N absorbido probablemente debido a un aumento en la eficiencia de uso de la radiación.

En el capítulo 7 se reportan los resultados biofísicos y económicos de dos ejercicios (1998 y 1999) del Módulo de Producción de Leche en Pastoreo de la Universidad Autónoma Chapingo. La carga animal promedio fue 2.6 vacas ha^{-1}, la producción individual promedio fue 6200 kg de leche por lactancia y la productividad promedio fue 16 toneladas de leche ha^{-1} $año^{-1}$. Los costos de alimentación en este sistema fueron 43% menores que los de los sistemas lecheros predominantes. El nivel de ingresos netos alcanzado (1273 US $ ha^{-1} $año^{-1}$) demuestra que este sistema constituye una alternativa rentable.

En el capítulo 8 se discuten las consecuencias de estos resultados en términos de la eficiencia de este sistema lechero. Sobre la base de este análisis se propone una rotación alternativa y se definen necesidades futuras de investigación. Las nuevas metas productivas son i) una carga animal de 3.7 vacas en leche ha^{-1} y ii) una producción individual de 22 kg de leche $vaca^{-1}$ $día^{-1}$. Aunque la meta propuesta de productividad (29 toneladas de leche ha^{-1} $año^{-1}$) es mucho mayor que los resultados obtenidos durante 1998 y 1999, parece ser alcanzable.

Curriculum Vitae

Ricardo Amendola was born in 1951, at Castillos, Rocha, Uruguay. After being reared in a mixed farm (cattle, sheep and crops) he thought -just like his older brother and sister- that no profession could fit him better than agronomist. In 1970 he started studying agronomy at the Agronomy Faculty of Uruguay. But then came the hard times of the military dictatorship, and in 1974 he had to stop studying. After spending two years in Argentina (1974-1976), in November 1976 he arrived as a refugee in The Netherlands. In 1977 he resumed studies in agronomy at the Landbouwhogeschool Wageningen. After carrying out his practical work in Mexico during 1980, he continued studying with Grassland Science as major subject and Soil Fertility and Theoretical Production Ecology as choice subjects. In 1984 he was awarded the Ir. degree with distinction. By that time he had become a Dutch citizen. Since then he has been working in topics related to grasslands at different universities: Universidad Autonoma Metropolitana, Mexico D.F. (1984-1985), Facultad de Agronomía, Uruguay (1986-1988) and Universidad Autónoma Chapingo, Mexico (1989- to the date).