A decision support system for *campesino* maize-cattle production systems of the Toluca Valley in Central Mexico.

By

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To Sara, Sofia and Octavio Jr.

Declaration

I hereby declare that this thesis has been composed by me and that all work presented in the thesis is my own unless specifically otherwise stated

July 1, 1999. **Octavio A. Castelán-Ortega**

Abstract

The viability of the *campesino* maize-cattle production system of Central Mexico is under stress by the North American Free Trade Agreement policies. To survive *Campesino* farmers are developing alternative production systems and more efficient uses of their land. The objective of this work was "to develop a "Decision-Support System" (DSS) in order to support *Campesino* farmers in this process. Two biological models, one socio-economic model and a survey database on the target farming system form the DSS. The CERES-Maize model simulated the yield response of three local land-races of maize to different management systems. The second biological model, a dynamic 'hybrid model', which predicts potential intake, digestion and animal performance of individual dairy cows, was used to simulate alternative feeding systems. A multi-period mathematical programming model integrated the outputs of the previous models with the survey database. This model was used to find the optimal combination of resources and technologies that maximised farmers' income. This model consists of 15,698 structural columns and 612 rows. The DSS was successful in reproducing the functioning of the main components of the farming system. More importantly it simulated the complex interactions observed between the farmers and their crops and cattle, including traditional maize management practices. The model simulated the resulting effects of these practices on the feeding systems for cattle and on the household's labour demand. The DSS selected on a monthly basis the forage type, concentrate type and supplementation level fed to all classes of cattle on the farm. Moreover, it was able to incorporate the seasonal effects on forage quality and availability.

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List of abbreviations

CA	*Criollo Amarillo* maize
CAB_m	CA grain bought in period m in kg
CAF	CA fed to the cattle herd
CAHV	CA harvested in kg
$CA_{o,k,a}$	Area planted with CA in ha for the different cultivation technologies
CAOV	CA opening balance in kg
CAS	CA maize Stover
CAS	CA (grain) sold in kg
CB	*Criollo Blanco* maize
CBF	CB fed to the cattle herd
CBHV	CB harvested in kg
$CB_{o,k,a}$	Area planted with CB in ha for the different cultivation technologies
CBOV	CB opening balance in kg
CBS	CB (grain) sold in kg
CFED	Concentrate type fed to cows
CICA	Centro de Investigación en Ciencias Agropecuarias
CM	Cow Model
CMN	Chicken Manure
CMNF	Chicken manure fed to the herd
CN	*Criollo Negro* maize
CNA	Comisión Nacional del Agua
CNCPS	Cornell Net Carbohydrate and Protein System
CNHV	CN harvested in kg
$CN_{o,k,a}$	Area planted with CN in ha for the different cultivation technologies
CON	Commercial Concentrate
CONF	Commercial concentrate fed to the herd
$COWS_{jlimqr}$	Variable name that defines feeding options for cows
CP	Crude Protein
CS	Case Studies
CHO	Carbohydrates
DCMM	DSSATv3 CERES-Maize model
DM	Decision Maker
DSS	Decision support system
dryfod	Input data table with forage composition for the dry season
feed	Input data table with concentrates composition
FFED	Forage type fed to cows
FMC	Labour required for the care of the family
FSR	Farming Systems Research
GCR	Ground corn
GDP	Gross Domestic Product

GMF	Green Maize Fodder
GR	Labour for grazing cattle and other livestock
HCFED	Concentrate type fed to Heifers
$HEIF_{jlmqr}$	Variable name that defines feeding options for heifers
HFFED	Forage type fed to heifers
HL	Hired labour in man days
HM	Household members
IERM	Institute of Ecology and Resource Management
IFSM	Integrated Farming System Model
IMLPS	Intercropped-Maize-Livestock Production Systems
IP	Amount of land planted with improved pastures in ha
LS	Labour required for other types of livestock
ME	Metabolisable Energy
MLK	Monthly milk production/herd in kg
MLK	Milk produced and sold in kg
MLPS	Maize-Livestock Production Systems
MP	Metabolisable Protein
MS	Maize Stover
MSIFED	Maize silage bought and fed to cattle
MSIL	Maize Stover Silage
Mz1c	Input data table with variable costs for maize production
NAFTA	North American Free Trade Agreement
NCULL	Number of culled cows/year
NDF	Neutral Detergent Fibre
NDFD	Neutral Detergent Fibre which is Degradable
NG	Amount of land occupied by native grass in ha
NSTEE	Fat steers sold per year
OC	Amount of land cultivated with other crops in ha
OCFED	Concentrate type fed to other cattle
OFFED	Forage type fed to other cattle
OG	Orchard Grass
OTHE	Variable name that defines feeding options for other cattle types
OWNDRY	Rainfed own land in ha
OWNIRR	Irrigated own land in ha
PRA	Participatory Rural Appraisal
PSE	Producer Subsidy Equivalent
RG	Rye Grass
RIGHTS	Communal land in native pasture in ha
RNTDRY	Number of ha of rainfed land rented
RNTIRR	Number of ha of irrigated land rented
RRA	Rapid Rural Appraisal
SAM	Sistema Alimentario Mexicano
SDSN	Small Holder Dairy Systems Network
SEM	Standard Error of the Mean
SM	Simulation Models

SS	Static Survey
STOBUYm	Stover bought in period *m* in kg
STOFEDm	Stover fed to the cattle herd
STOHV	Stover harvested in kg
STOSELL	Stover sold in kg
STOV	Stover opening balance in kg
tab1 to 4	Input data tables with the cow model´s output
UAEM	Universidad Autónoma del Estado de México
wetfod	Input data table with forage composition table
WDS	Weeds
WHB	Wheat Bran
WHBF	Wheat bran fed to the herd

Abbreviations in Italics are variables or input data files' names of the Integrated Farming system model

Chapter 1. Decision support for *campesino* maize-cattle production systems of the Toluca Valley.

1.1. Introduction

Mexico and its nearly one hundred million people, have an increasing demand for agricultural food products, which its agricultural sector has not been able to meet (de Janvry *et al.*, 1995a; de Ita, 1997; Tanyeri and Rosson, 1997). Most of the country's food production, particularly maize, depends on the small smallholder or *campesino* farming sector (Warman and Montañez, 1982; SARH, 1993a). However, campesino-farming systems have experienced dramatic changes over the last twenty years (Segarra *et al.*, 1992; de Janvry *et al.*, 1995a), moreover Mexico's membership to the North American Free Trade Agreement (NAFTA) has meant more changes, which have lead the sector to a crisis (Pesado, 1993; de Ita, 1997).

Substantial changes were introduced as part of the agreements signed by Mexico when joined the NAFTA, which implicated among other things two important changes to the agricultural and trade policies of the country. First, all support or subsidies to maize production will be eliminated over a period of fifteen years (Mexican government had traditionally subsidised and protected maize producers), and secondly, large quantities of cheap maize could be imported from the USA as part of an annual quota fixed in the agreement. Mexican imports of maize have dramatically increased after Mexico's incorporation to the NAFTA in 1994 (Pesado, 1993; de Ita, 1997).

To adapt to changes, *campesino* maize farmers are looking at different options or alternative systems of production and better uses of their land, which help them to adjust to new scenarios. There is also an urgent the need for scientists (in collaboration with farmers) to identify, and to develop viable technical options, which will serve an alternative systems of production and land uses. Such systems should be based on in-depth understanding of the local farming systems, be aware of the potential of local agroecosystems, the farmers' needs, and contribute to the solution of farmers problems. Probably more importantly they should help farmers in the process of decision making when deciding whether to adopt or reject a new technology. Mexican government and policy makers should also be provided with a decision support tool, which help them to predict the short and long term effects of new policies for agriculture, on the regions land and resource use, but probably more importantly on the farmers' economy and welfare.

To carry out experiments in research stations in order to test different technologies was a normal choice for many years. However, experience in many parts of the world has shown that some technologies successfully developed at research stations have been either rejected for reasons that seemed irrational to the scientists, or have produced poor results on farmers' holdings (Gryseels *et al.*, 1986; Kishindo, 1988). Further, these research methods traditionally have excluded clients from formulating the problems and contributing to their solution. They are highly technical, based on a reductionist approach involving a limited set of variables whose interrelationship are relatively easy to grasp, at least compared with the complexities faced by smallholder farmers. Conventional research methods are thus best applied to the conditions of more privileged farmers, who like scientists, have the capacity to control the natural environment (Sims and Leonard, 1990). Most researchers involved in this form of agricultural research neglected to recognise that the traditional farming systems used by smallholder and subsistence farmers are based in centuries of experience (Kanwar *et al.*, 1992). They were sceptic also about farmers' knowledge and practices, however they had rarely investigated the reasons and the possible scientific basis of peasant practices (Sims and Leonard, 1990).

More recently the farming system research and extension approach (FSR/E) has provided a more holistic and participatory approach, which allows to examine in an integral way the biological, economic and social aspects of a problem in agriculture (Hildebrand and Poey, 1985; Gryseels, *et al.*, 1989; Doyle, 1990; Baker and Norman, 1990). The holistic approach of FSR/E is stressed by Leaver (1994), who mentions that the nature of FSR/E is both holistic and participatory. The holism includes the interactions between these aspects at household, farm and community levels. The participation involves working closely with farmers in identifying constraints and research priorities and when necessary implementing on-farm research together with the farmer. Understanding of the needs and motivations of the farmer is essential in this approach.

However, it is argued that the use of experiments in research stations and under some circumstance on-farm research experiments may be very expensive and resource demanding, and it will be almost impossible to study a wide range of management possibilities, within the time scale, and budget normally allocated to these experiments. This is the case in most Mexican agricultural research centres where the research budget is normally very limited. In addition, no assessment can readily be made of how the technological package should be modified in different districts, or regions in response to different soils, and changing local climates (Dent and Thornton, 1988).

Simulation modelling, as part of the systems approach, has some potential for overcoming such problems, and also in speeding the transition from the design stage to the testing stage and beyond, however they need to be incorporated into a holistic framework for effective decision- support purposes (Dent, *et al.*, 1995). Moreover, Herrero *et al.*, (1996a) mentioned that increasing economic and environmental pressure on production systems have created the need to re-evaluate current management practices and to study new alternatives to ensure their sustainability. As a consequence, the demand for decision support systems (DSS) based on mathematical models has increased in the past years. This is the case of Mexico's *campesino* farming systems where new technologies and land use strategies need to be developed and tested.

1.1.1. Decision support for *campesino* maize-cattle production systems

In recent years important progress has been achieved in modelling biological processes. In the case of crop and livestock the nature of the processes represented has led to the construction, at different levels of aggregation, of very similar models throughout the world, resulting sometimes in overlapping and duplication of work in others. This overlapping has made model-building an expensive and time consuming activity because researchers often take on the enormous task of building new models rather than selecting and adapting the existing ones for their own purpose (Jones *et al.*, 1997; Herrero, *et al.,* 1997).

Tsuji *et al.*, (1994), Stoorvogel, (1995), and Herrero, *et al.* (1997) pioneered the development of decision support systems which integrate different simulation models in order to provide the decision maker with solutions to managerial problems for crop and pastoral ruminant production systems. Their work is inserted within a new approach in FSRE which attempts to address the problems associated with the traditional development and use of simulation models, described by Dent, *et al.*, (1994). This approach argues that the development of models that represents individual units or processes within a defined system, such as the animal, the plant, growth etc., are useful by themselves, but normally fail to provide solutions to real problems. It is suggested that this failure was partly due to the lack of consideration of socio-economic aspects by these kind of models. Therefore if biophysical models are to have any impact in rural development situations they must linked to socio-economic models in order to become holistic decision support system, which can represent the bio-physical and socio-economic aspects of any given farming system.

On the other hand, according to Jones *et al.,* (1997) most farm-scale models (mathematical programming models) have been developed with a bias towards economics and limited consideration of the biophysical components of the system. Few efforts have attempted to integrate biophysical models of crop and animal production with economic and environmental considerations at a whole-farm scale.

Moreover, some of the available models had have little application on real decision support and problem solving in smallholder and subsistence agriculture, even though their decision support ability was their main justification for their construction. Successful use and application of models for development situations has also been limited and no clear evidence has been found linking models with improving of farming systems or farmers livelihoods (Matthews, 1998-perssonal communication). Therefore there is the need to develop more effective and accurate DSS that can help to solve problems in the developing world agriculture. According to Fawcett *et al.*, (1998) socio-economic models must be built so that key decisions are explicit and readily translatable into actions.

Smallholder production systems are highly complex, with hundred of different activities interacting together to produce its current form, so to pretend to simulate them or to solve their problems using a single model or application is not possible, nor is it advisable to develop one for practical reasons. Therefore characterisation of the farming system followed by the identification of the system's main components and "bottle necks" should be the first steps. Thus simulation of these main components can be an adequate approach to simulate smallholder systems. Integration of models may be a solution, where limitations of some model may be compensated by others models, because each model has its merits and drawbacks with which users must cope and be aware. Moreover, extremely complex problems, which can not be handled by a single model, can be tackled by the integration procedure (Stoorvogel, 1995). This approach also permits a more accurate representation of the different components of a system, where technologies can be tested on individual components before being presented to a system model.

Model integration has also allowed us to pass from the traditional approach for the analysis and planning of agricultural land use based on techniques for land evaluation proposed by FAO, or on farming systems analysis (Beets, 1990, Stomph *et al.*, 1994), to a more holistic approach based on the development of methodologies for the analysis of land-use scenarios. The last defined as a set of hypothesized changes in the socio-economic and/or bio-physical environment, where the analysis is focused on the possible effect of these changes on crop, technology choice, or the whole farming system including the resulting consequences for the environment. The different scenarios are normally analysed by an optimisation model, which is in most cases a linear programming model. (Stoorvogel, 1995; Fawcett *et al.*, 1998).

DSS can be used for the analysis of "what if" questions of agricultural policies, and economic incentives (e.g. what will happen when credit become available in a region) frequently asked by policy makers. They can also serve to answer a farm management question asked by a farmer concerned with sustaining an economically sound and environmentally safe agriculture, without the cost, the time, the risk of failure, and in some cases the long term consequences, associated with the implementation of an unsuccessful policy (Tsuji *et al.*, 1994; Stoorvogel, 1995; Herrero, 1996a).

1.1.2. Factors limiting the use of models in developing countries

From what was said before it may seem clear that simulation models framed into a DSS could be a good option for the design of new systems or as reliable decision support tool for resource limited situations. However, there are still some problems accompanying the use of simulation models, particularly when they are applied to technology development for less developed regions in small experimental stations or research centres where resources are limited. For example, model calibration requires highly trained programmers/modellers using resources dedicated to the calibration and validation procedure if it is to achieve accurate predictions and scientific validity. However, this may not necessarily result in a robust model appropriate for use in development situations (Mbabaliye and Wojtkowski, 1994; Gajendra *et al.*, 1994).

Moreover, biological models' calibration often requires specially designed trials to test on-field or on-station model applicability. For large research stations, this may not represent a problem because most of the data to calibrate and validate the model would have been collected already so that the cost of making the model site operational compares favourably with the benefits received. For smaller research stations, where proportionally greater commitment of resources is needed, modelling may become a less favourable option (Mbabaliye and Wojtkowski, 1994).

The use of survey data collected from farmers' crop fields and from farmers' socio-economic environment through direct observation and measurement may reduce some of the problems associated with data needs for model calibration in small research stations. The use of robust models developed for multi-site applicability, associated with a deep knowledge of the target farming system, could also contribute to a more beneficial and relevant use of simulation models under resource limited conditions. However, this has not been tested before and there may be a large number of issues which have to be addressed.

It is in that sense that the main objective of this work is to develop a "Decision-Support System" based on the integration of three simulation models, with a detailed set of survey data on the *campesino* maize-cattle production systems of the Toluca Valley. It is intended that the DSS can be used to serve three broad areas. Firstly, to demonstrate the methodology used to calibrate and develop simulation models using survey data. Secondly, to illustrate the methodological approach used to integrate biological models to socio-economic models in order to develop a more holistic DSS. Finally to illustrate the use of the DSS in identifying and testing different technologies and management strategies and in finding the optimal combination of farm resources that maximises farmers' income.

The DSS has potential to be used to predict and evaluate the effect of the macroeconomic policies on the microenvironment of the *campesino* maize farmers, particularly those related with the NAFTA. However, this was not evaluated in this work.

1.2. Materials and methods

The methodology developed in this research comprised the following steps:

- Characterisation of the *Campesino* maize-cattle production systems of the Toluca Valley.
- Calibration of the **DSSAT v3 CERES-Maize** model (Tsuji *et al.*, 1994) and simulation of the *campesino* maize production systems.
- Calibration of a **Cow Model** (Herrero, 1997) and simulation of *campesino* cattle feeding systems.

- Construction of a generic **Integrated Farming System Model** (IFSM) and simulation of the dynamics of the *Campesino* farming system.

- Simulation of optimal combination of farm resources and technologies that maximise farmers' income.

The method proposed for this work uses a Farming Systems Research (FSR) approach, particularly the formal approach of the method proposed by Dent and Blackie (1979), Spedding (1988), McCown *et al.*, (1994), Dent (1995), and Fawcett *et al.*, (1998). This research proposal has two main components; one is concerned with the methodology for the characterisation of the farming systems of the study area. The second component refers to the development of the decision support system itself. Figure 1-1 shows the general framework used in this work, the different elements that constitute the decision support system are summarised in this figure too.

The FSR method described by the above authors and used in this work, consist of five phases or steps as follows: 1). Problem description and analysis, 2). Technology design and development, 3). Testing and verification, 4).Extension and 5). Monitoring, evaluation and feedback. For this particular work, only the first three steps of the method were used, because steps four and five require more time and could be part of a different work by themselves. Moreover the main objective of this work was the development and testing of a decision support system. The role of models in this method is not clearly defined in the steps mentioned above. The reason for this is that models are not a step of the method, but a tool of it, which allows one to carry out the technology design and development phase of the method (Dent and Thornton, 1988; Dent, 1995).

The DSS developed here consists of five sub-components shown in Figure 1-1, and described below:

1.2.1. Static survey

The static survey characterised the farming systems prevailing in the study area. This survey provided quantitative and qualitative information on the biophysical and the socio-economic components of the systems. The survey method consisted of a static survey combined with some techniques of the Rapid Rural Appraisal and Participatory Rural Appraisal methods (PRA). The static survey was based on some of the methods proposed by Kalton (1983), Nichols (1991), and Quijandria (1994). The elements of the Rapid Rural Appraisal method were taken from the methods proposed by Kumar (1993), Theis and Grady (1991), and The World Resources Institute (1990).

The survey was carried out in two communities where the farming systems are considered to be representative of the different farming systems that may be found in the Toluca Valley (Woodgate, 1997; Arriaga *et al.*, 1997a,b; González, 1997; Castelán *et al.*, 1997). Samples of soil, maize, forages and concentrates were collected and analysed at the laboratory to obtain the necessary quantitative data (parameters) to calibrate the biological models. The collected data was stored in a database.

The fieldwork was based at the *Centro de Investigación en Ciencias Agropecuarias* known as **CICA** (Research Centre in Agricultural Science) a small research centre part of the *Universidad Autónoma del Estado de México* (UAEM). CICA is a multidisciplinary research centre dedicated to the study of the *Campesino* farming systems of the state of Mexico (Rivera *et al.*, 1997). Over the last ten years CICA has produced valuable information on the characteristics and problems of these farming systems, which was very important in the development of this work (the author is a member of CICA's staff since 1993).

1.2.2. Case studies

Case studies were carried out in order to collect detailed data over a whole production cycle on farm management practices for maize and cattle, land use, resources allocation and maize and cattle growth and production performance. Case studies were also be used to validate the models used and developed as part of this work. The method proposed by Maxwell (1986) along with some elements of the same method proposed by Casley and Lury (1987) and Farrington and Martin (1988) were used to conduct the case studies.

1.2.3. Modelling campesino maize production

The Ceres-Maize model originally developed by Jones *et al.*, (1986a) and later improved and modified by the IBSNAT project (Ritchie and Crum, 1989; IBSNAT, 1990; Tsuji, *et al.*, 1994) was used in this work. The IBSNAT CERES-Maize model allows the quantitative determination of growth, development and yield of maize (Ritchie *et al.*, 1989; Tsuji *et al.*, 1994). The growth of the crop is simulated with a daily time step from sowing to maturity on the basis of physiological processes as determined by the crop's response to soil and aerial environmental conditions (Singh *et al.*, 1993; Jagtap *et al.*, 1993). The model can also simulate the effects of cultivar, planting date, planting density, N fertiliser dose, and irrigation on crop growth, development, and yield (Ritchie, 1986). For this particular work the CERES-maize model was used to simulate and identify respectively:

- Maize cultivation and production by *campesino* maize farmers from the Toluca Valley
- Alternative cultivation technologies based on different levels of inputs use
- Generation of maize production coefficients for the IFSM
- Identification of new research areas for maize production as in the Toluca Valley.

1.2.4. Modelling dairy cattle performance

The cow model developed and validated by Herrero (1997) was used to simulate local and alternative feeding systems for cattle. The model is designed to predict potential intake, digestion and animal performance of individual ruminants, in this case dairy cows, consuming forages, grains and other supplements. The rationale behind the model is that a ruminant of a given body size, in a known physiological state, and with a target production level, will have a potential forage intake determined by physical or metabolic constraints imposed both by plant and animal characteristics.

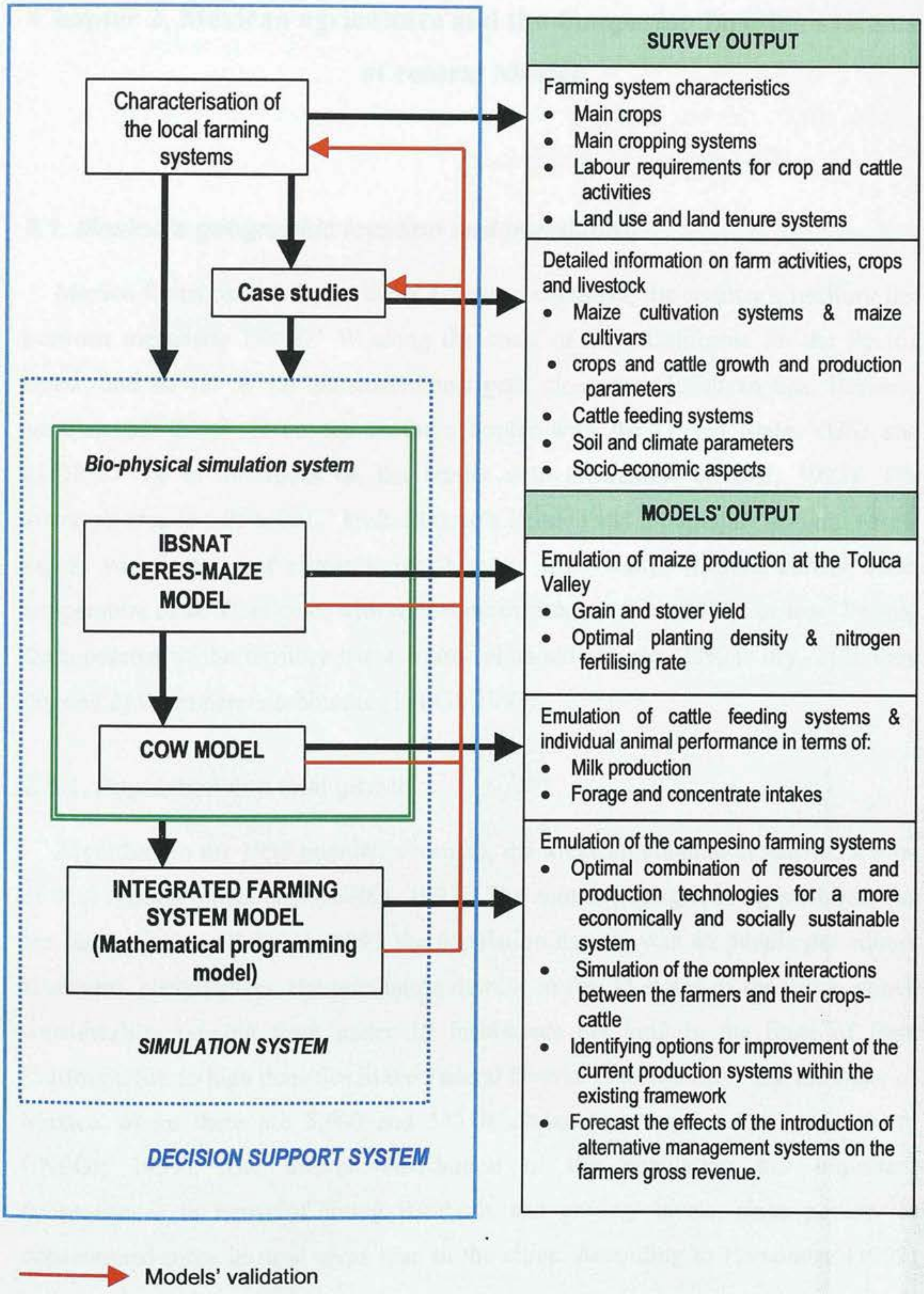
This model is largely based on the work of Illius and Gordon (1991), Sniffen *et al.* (1992) (Cornell Net Carbohydrate and Protein System, CNCPS) and AFRC (1993), and was validated for milk production systems of the highlands of Costa Rica. The ability of the model to simulate performance of cattle eating diets of relatively poor quality formed by a wide variety of ingredients constituted a hard test for the reliability of a model developed for cows eating better quality diets and under substantially better husbandry practices.

1.2.5. Integrated farming system model

A multi-period mathematical programming model was constructed; it integrated the outputs of the previous models with the survey database. This model consists of 15,884 structural columns and 602 rows. This model was used to

- Find the optimal combination of resources and technologies that maximised farmers' income.
- Simulate the complex interactions observed between the farmers and their crops and cattle, including traditional maize management practices.
- Simulate the resulting effects of these practices on the feeding systems for cattle and on the household's labour demand.
- Simulate seasonal effects on forage quality and availability.
- Identify options for improvement of the current production systems (for maize and cattle) within the existing framework
- Forecast the effects of the introduction of alternative management systems on the farmers' gross revenue.

Figure 1-1. A decision support for *campesino* maize-cattle production systems.



SURVEY OUTPUT

Farming system characteristics

- Main crops
- Main cropping systems
- Labour requirements for crop and cattle activities
- Land use and land tenure systems

Detailed information on farm activities, crops and livestock

- Maize cultivation systems & maize cultivars
- crops and cattle growth and production parameters
- Cattle feeding systems
- Soil and climate parameters
- Socio-economic aspects

MODELS' OUTPUT

Emulation of maize production at the Toluca Valley

- Grain and stover yield
- Optimal planting density & nitrogen fertilising rate

Emulation of cattle feeding systems & individual animal performance in terms of:

- Milk production
- Forage and concentrate intakes

Emulation of the campesino farming systems

- Optimal combination of resources and production technologies for a more economically and socially sustainable system
- Simulation of the complex interactions between the farmers and their crops-cattle
- Identifying options for improvement of the current production systems within the existing framework
- Forecast the effects of the introduction of alternative management systems on the farmers gross revenue.

Chapter 2. Mexican agriculture and the *Campesino* farming systems of central Mexico

2.1. Mexico's geographic location and population

Mexico forms part of the northern American continent, the country's territory lies between meridians 118°27' W along the coast of Baja California on the Pacific Coast, and 86°42' W on the easternmost part, along the Caribbean Sea. Between parallels 32°43'06" N on the northern border with the United States (US) and 14°32'27" N to the south on the border with Guatemala (INEGI, 1992). The country's area is 1 964, 381.7 km2. Mexico's latitude and topography account for its highly varied range of climates, which range from warm, with an annual mean temperature of 26°C, to cold, with annual mean temperatures of 10°C or less. Twenty three percent of the territory has a warm-subhumid climate, 28% is dry, 21% very dry and 21% temperate subhumid (INEGI, 1992).

2.1.1. Population and total growth

According to the 1995 population census, the Mexican population reached a total of 91.2 million inhabitants (INEGI, 1997). The annual demographic growth rate for the same year was 1.8%. In 1995 the population density was 46 people per square kilometre. Nevertheless, the population density in the 32 states of the union varies considerably, ranging from under 15 inhabitants per km2 in the State of Baja California Sur to high densities in the Federal District (Mexico City) and the State of Mexico where there are 5,660 and 545 inhabitants per square km, respectively (INEGI, 1997). The uneven distribution of the population has important consequences in terms of living standards and poverty levels, since poverty is concentrated more in rural areas than in the cities. According to Hernández (1992)

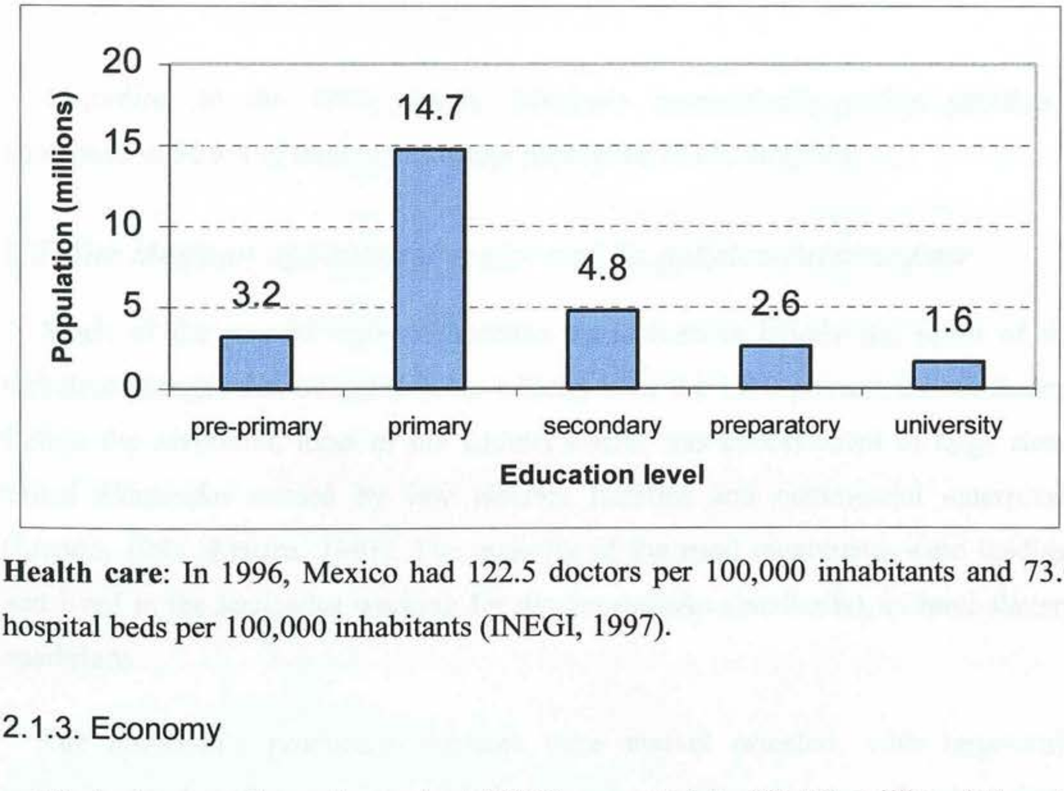
76% of rural population is in poverty while only 49% of urban population is in the same situation.

2.1.2. Access to services

Electricity and running water: According to the 1995 census, 85.6% of the population have running water and 93.2% have electricity (INEGI, 1997).

Education: In 1995, 10.6% of the population over 15 years of age was illiterate. Pre-primary and primary concentrate the largest amount of the population enrolled in the education system, and only a small proportion have access to higher levels of education such as high school or university as shown in Figure 2-1.

Figure 2-1. Population access to different education levels

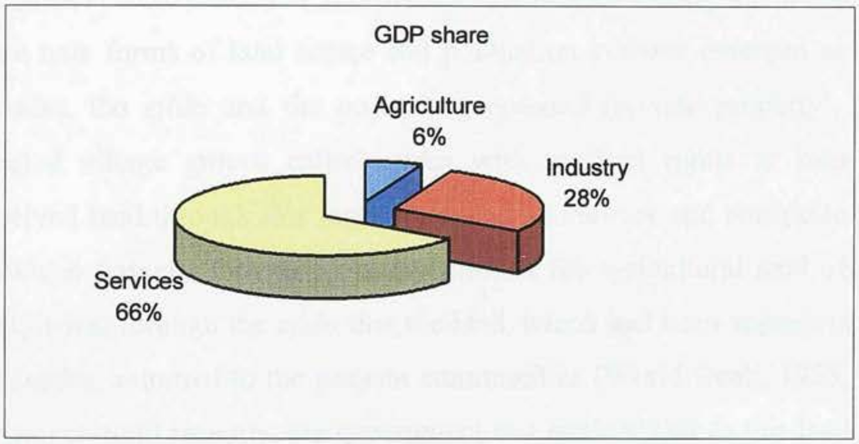


Health care: In 1996, Mexico had 122.5 doctors per 100,000 inhabitants and 73.0 hospital beds per 100,000 inhabitants (INEGI, 1997).

2.1.3. Economy

Mexico's gross domestic product (GDP) amounted to 402,541 million dollars in 1997, making it the 11th largest economy world-wide (INEGI-Web page). The share of GDP per economic sector is shown in Figure 2-2, manufacturing accounts 76.5% of the industrial sector, while 32.2% of the services sector is constituted by commerce and the tourism industry. Agriculture contributes with 6% of the GDP only.

Figure 2-2. Economic sector's share of the Mexican GDP



According to the 1995 census, Mexico's economically active population amounted to 54.9% of total working age population of 65, 302, 763.

2.2. The Mexican agricultural sector and its policies-An overview

Much of the present state of Mexican agriculture is largely the result of the turbulent changes that occurred in the country after the 1910 peasant-led revolution. Before the revolution most of the country's land was concentrated in large states called *Haciendas* owned by few wealthy families and commercial enterprises (Liendo, 1997; Krauze, 1997). The majority of the rural inhabitants were landless and lived in the haciendas working for the *hacendados* (landlords), in semi-slavery conditions.

The *hacienda*'s production systems were market oriented, with large-scale operation levels and strong links with the capital operators and international markets. As reported by Sanderson (1986), agriculture was the backbone of economic life in Mexico for much of the last century and during the *Porfiriato* (the dictatorial period before the Revolution), when agricultural capitalism blossomed in certain export enclaves, and the value of exports boomed. Agricultural exports represented almost half of total export value; a striking proportion, given the contemporaneous resurgence of mining.

The revolution and the agrarian reform that followed changed the status quo. The *Haciendas* were destroyed and the land distributed among the peasant communities. Two new forms of land tenure and production systems emerged as a result of this process, the *ejido* and the *pequeña propiedad* (private property). The first form created village groups called *ejidos* with usufruct rights to land. Farmers who received land through this form are called *ejidatarios* and constitute the majority of Mexican farmers; they also occupy most of the agricultural land of the country. In fact, it was through the *ejido* that the land, which had been appropriated by the large haciendas, returned to the peasant communities (World Bank, 1975; Liendo, 1997). However, until recently, the government had retained title to this land, so the wealthy could not regain control of it and the farmers could not sell it.

Most of the *ejidos* were formed in the late 1930s and have been operated on an individual rather than collective basis. The second form of land tenure is based on private rights; but the maximum size of the holding was reduced significantly to avoid the formation of new *haciendas*. The production systems practised by the *pequeños propietarios* (private owners of land) are in general more commercial and market oriented than the *ejidatarios*' production systems.

2.2.1. Importance of agriculture and its contribution to the economy

The importance of agriculture in the Mexican society has changed over the time from an important position to a less relevant one. Its importance can be evaluated in relation to its contribution to the nation's GDP and the number of persons employed in this sector over the last twenty years. The contribution of agriculture to the GDP has followed a declining trend since the early seventies, for example in the period of 1970 to 1976 it contributed with 11.5%, in 1990 with 8.9% and in 1991 with 7.5% of the GDP, see Table 2-1 (de Janvry *et al.*, 1995a). More recent figures indicate that in 1996 it contributed with only 6.0% to the GDP (INEGI, 1997).

However, consideration must be given to the possible bias of these figures, since 30% of the economically active population are employed by the agricultural sector, evidencing the importance of agriculture as an important source of occupation for the rural population (Levy, 1991). The small contribution of agriculture to the GDP and the large proportion of the population employed in this sector reveal a low productivity and probably increased poverty levels among Mexican farmers. In 1989, the average annual income in rural areas was only 26% of that in the urban centres (INEGI, 1994a, de Janvry, *et al.*, 1995a).

The proportion of the population employed in agriculture has also declined, by nearly 40% over the last twenty years. This drop is explained by the increased migration from the countryside to the urban centres in order to support Mexico's industrial conversion in the early seventies. In the following decade, the economic crisis explains much of the emigration to urban centres and to the United States and the consequent decline in the number of people employed in agriculture (de Janvry *et al.*, 1995a) (Table 2-1). Nevertheless, agriculture still employs an important segment of Mexico's population, even though it is not the most dynamic sector of the economy.

The growth of the agricultural sector has not been constant, but quite variable too. Between 1945 and 1965 it grew at a rate of 5.3% per year; in the period of 1966 to 1976 the growth decreased to 2% per year; 4% annual rate of growth was observed in the period of 1977-1981, followed by a drop to 1.7% in 1982-1985. Finally, a dramatic fall was observed after 1985, as shown in Table 2-1, when the effects of the country's economic crisis (motivated by a drop of international oil prices in the early eighties) were felt in the agricultural sector too (de Janvry *et al.*, 1995a, INEGI, 1994b). The 4% expansion observed in the period of 1977-1981 was linked to the implementation of a national programme whose main goal was to attain food production self-sufficiency. Under this programme, called *Sistema Alimentario Mexicano* (SAM), massive amounts of subsidised inputs and credits were directed towards the farming sector. In contrast, the decline of the positive growth observed in that period is associated with a reduction in the level of subsidies observed during the second half of the eighties (1982-85) in the first instance, and to changes in the policies for the sector more recently (de Janvry *et al.*, 1995b; de Janvry *et al.*, 1995a).

Table 2-1. Performance of the agricultural sector (average values for three periods and values for 1986 and 1990).

	1970-76	1977-81	1982-85	1986	1990
Agriculture participation in %					
GDP	11.5	9.3	8.2	8.5	8.9
Employment	32.2	28.2	27.4	27.5	27.6
Economically active population	39.4	28.8			20.5
Rural population	38.7	34.3	31.4	28.9	28.0
	Mean annual growth rate in %				
Total GDP	6.3	8.4	0.2	1.5	1.5
Agriculture	2.6	4.4	1.7	-1.5	-1.5
Cereals production	1.8	5.0	1.9	-2.0	*
Livestock production	3.6	2.8	1.6	-1.6	*

Taken from de Janvry *et al*., (1995a) * Data not available

2.2.2. Government policies for the agricultural sector-An overview of the last twenty years.

Before 1981, agricultural policies were committed to the provision of most of the sector's capital needs to carry out its production activities. The expansion observed in the sector between 1977 and 1981 was due to important flow of subsidies, credits and extension services financed mostly by the country's high revenues from oil exports. This pattern was observed throughout the seventies and early eighties. A key element of the government support programme for agriculture was the **guarantee price** policy for cereals, operated by the CONASUPO (the national basic food company) (de Janvry *et al.*, 1995a and b).

Through this program, domestic producer prices were kept stable and usually higher than the international prices, while the consumer prices were held down and closer to the border price in order to provide cheap food supply to the urban population. Thus, while the international cereal prices consistently dropped from 1965 to 1985 (except during 1973-1975 due to the world food crisis) at an annual rate of 1.7%, 3.1%, 1.5% and 1% for maize, sorghum, soya, and wheat respectively, local prices remained unchanged (de Janvry *et al.*, 1995a). In other words, the Mexican price policy for cereals effectively isolated the local cereals market from a declining and volatile external market; this was particularly the case of maize and beans. For example from 1977 to 1987 the price of maize was maintained constant, while the international price fell dramatically. At the end of this period maize had a nominal rate of protection of 64% (de Janvry *et al.*, 1995b).

Another important element of the government's policy was the significant increment of the irrigated area. From 1945 to 1985 the irrigated area rose from 1.1 to 5.3 million hectares (30% of the cultivable area) (SARH, 1993b). Access to credits also increased, particularly from 1977 to 1981, when a 15% annual increment was registered, although such increment was followed by a significant decline after 1982. Moreover, until 1988 the government banks provided 50% of all credits for agriculture at a reduced interest rate (23% less than the commercial banks). It is estimated that the total value of the subsidised credits provided by the government in 1986 was equivalent to the 0.54% of the GDP. Despite low interest rates the proportion of farmers who failed to repay their debts was high, 45% in 1987 and 65% in 1988 (de Janvry *et al.*, 1995a).

Probably the most notable government intervention in terms of subsidised inputs was with chemical fertiliser. It is estimated that at the end of the eighties, chemical fertilisers were used in 89% of the irrigated and 49% of the rainfed land. The distribution of fertilisers was monopolised by the state owned enterprise FERTIMEX, who distributed heavily subsidised fertilizer. Thus, in 1986 the prices of nitrogen and phosphorous were 50% cheaper than the international price for these products. The cost of the subsidised fertiliser reached 0.2% of the GDP the same year (de Janvry *et al.*, 1995a). The economic crisis suffered by Mexico in the early eighties caused a reduction in most of the subsidies and support programmes for the agricultural sector. The reduction in subsidies was followed by bold reforms initiated by Mexico in the late eighties, on many different fronts that had important effects on the social sector and particularly among maize producers.

According to de Janvry *et al.*, (1995b) these reforms included gradual privatisation of land in the social sector, restructuring and privatisation of the state apparatus that was used to channel massive subsidies to agriculture; extensive reorganisation of the financial sector with re-privatisation of commercial banks, elimination of credit subsidies, elimination of CONASUPO's monopoly over the marketing of the basic foods. It is estimated that the sum of all the government support to the sector was reduced by 76% in real terms between 1982 and 1987 (de Janvry *et al.*, 1995a). These reforms were followed by more radical changes related to Mexico's trade liberalisation program and the North American free trade agreement (NAFTA).

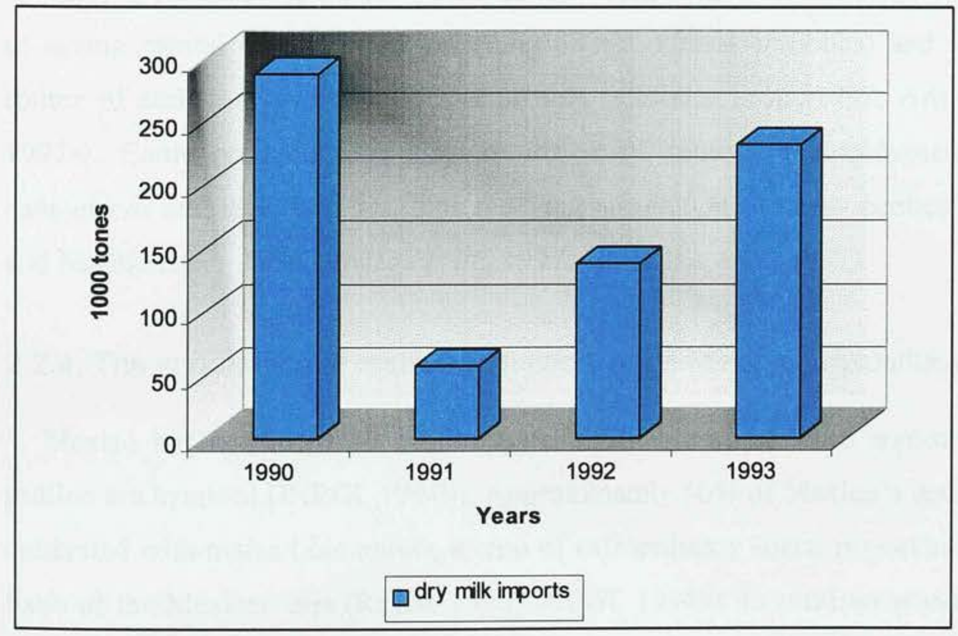
Thus, during the second half of the eighties agricultural production entered into a crisis, which had not an internal origin but was the reflection of that suffered by the system that had supported its development during the last two decades but was not able to maintain the subsidies system indefinitely. However, the guarantee price program and some subsidies were maintained for maize production due to its strategic importance for the country. In 1991, the nominal rate of protection was 77% and the producer subsidy equivalent (PSE), measured in percent of the value of production, was 44% (SARH, 1993b). This amounted to a PSE of US$ 92 per ton for white maize and US$71 for yellow maize, compared to US$28 in the United States and US$21 in Canada (de Janvry *et al.*, 1995b)

2.2.3. The crisis in Mexican agriculture

Mexican agriculture has suffered the effects of a prolonged economic crisis, which started when Mexico, as well as other Latin American countries, struggled during the 1980s with gross national product declining after 1981 and falling a massive 10 % in 1986. A large public deficit, together with declining oil prices, lower export revenues and lack of foreign financing lead to a triple digit inflation and drastically declining real incomes (Segarra, *et al.* 1992; Angel *et al.*, 1992). Both, the commercial and highly intensive and the less intensive agricultural sectors of Mexico, felt the negative effects of a crisis which began seventeen years ago and persist to the present day. Some of the most important Mexican agricultural enterprises disappeared. This scenario is particularly evident in the case of the intensive dairy industry that suffer a decrease of approximately 25% in the number of heads of cattle in the period of 1987 to 1989 only (Manrrubio and Pius, 1991; Simpson and Conrad, 1993, García, 1996).

The problems suffered by the cereal production sector and its trade deficit (1 US$ billion in 1990) attracted much of the government's attention, but hid the problems that affected the livestock and particularly the dairy sector. Milk and dairy products have registered an increasing demand over the last ten years, which the national industry has not been able to cover. This deficit was covered by large imports (see Figure 2-3), and by 1990 the trade deficit for these products was of US $692 million, quite similar to that of maize (de Janvry *et al.*, 1995a). Since then, Mexico has become the one of the world's largest importers of dairy products and the world's largest importer of non-fat dry milk. In 1993, milk and dairy products as a group were the principal food imports with a volume of 445 000 t and a value of US$626 million (García, 1996; Tanyeri and Rosson, 1997) (Figure 2-3).

Figure 2-3. Mexican imports of non-fat dry milk.



The effects of the crisis were felt in a differential way, being the intensive production systems the most affected because of their high dependency on imported inputs, which are more expensive to buy due to the continuous devaluation of the Mexican peso. *Campesino* farmers were less affected and have been able to survive the complex socio-economic and highly risky environment in which their production systems are inserted. The survival of the *campesino* farming systems can be attributed to the high level of integration observed between the crop and cattle production activities and an efficient use of the locally available resources, which made them less dependent on external inputs and a more sustainable form of production. Indeed the majority of Mexico's campesino farming systems are in fact, **mixed crop-livestock production systems**, where livestock, particularly cattle, play a key role in the maintenance and reproduction of the systems (Castelán *et al.,* 1997; Arriaga *et al*., 1997a; Zorrilla *et al*., 1997).

This integration is clearly observed in the ***campesino*** **maize-cattle production systems** of central Mexico, where maize production provides most of the forage and grain needs for cattle feeding, while cattle supplies large quantities of manure which is highly appreciated as fertiliser for maize production. Cattle also play both the role of saving capital (used for the financing of agricultural activities) and a constant source of cash flow through the sale of milk (Castelán *et al*, 1997; Arriaga *et al*., 1997a). Cattle production is also an important source of employment for the *campesinos* and their families, thus reducing emigration to urban centres (Castelán and Matthewman, 1996; Arriaga *et al*., 1997a; Castelán, *et.al*. 1997).

2.2.4. The importance of maize production in the Mexican agriculture

Mexico has a total of 20 million ha of arable land, of these approximately 6 million are irrigated (INEGI, 1994b). Approximately 50% of Mexico's arable land is cultivated with maize (*Zea mays*), a crop of extraordinary social importance and the basis of the Mexican diet (Reyes, 1990; INEGI, 1994a). In rural areas maize is the main food consumed by farmers; in urban areas is the main input into tortillas, a key component of urban worker's diets. Moreover, it is estimated that maize cultivation employs one out of three rural workers (Levy and Van Wijnbergen, 1992).

Most of the maize is produced in the states of Jalisco, Mexico, Chiapas, Puebla and Veracruz, in order of importance. Other crops, which also occupy an important proportion of the arable land in Mexico, include wheat, beans, sorghum, and soya, the area dedicated to each crop is illustrated in Table 2-2.

Table 2-2. Planted area and yields of the most important crops in Mexico.

Crop	1988	1989	1990	1991	1992	1993
Maize						
Cultivated area (m of ha)	6.5	6.4	7.3	6.9	7.2	7.4
Production (m of t)	10.6	10.9	14.6	14.2	16.9	18.0
Wheat						
Cultivated area (m of ha)	0.91	1.1	0.93	0.93	0.91	0.87
Production (m of t)	3.6	4.3	3.9	4.0	3.6	3.5
Soya						
Cultivated area (m of ha)	0.13	0.49	0.28	0.34	0.32	0.23
Production (m of t)	0.22	0.99	0.57	0.72	0.60	0.5
Sorghum						
Cultivated area (m of ha)	1.8	1.5	1.8	1.3	1.3	0.87
Production (m of t)	5.8	4.8	5.97	4.3	5.3	2.6
Beans						
Cultivated area (m of ha)	1.9	1.3	2.1	1.9	1.3	1.8
Production (m of t)	0.85	0.585	0.61	1.37	0.71	1.2

Source:INEGI (1994b) El sector alimentario en México. Comisión Nacional de Alimentación. Mexico.

According to González (1997) about 75% of the Mexican population obtain most of their energy requirements from maize, the *per capita* consumption of maize is four times bigger than that of the beans, ten times more than wheat, 22 times more than rice and fifty times more than beef. The national consumption of maize is also higher than those of any other crops, as shown in Figure 2-4. The second most important crop cereal in terms of its national consumption is wheat, but still its consumption is two to three times below maize, beans is the third most important crop. The consumption of maize has increased over the past six years in approximately 8 million tonnes, 33% more than the 1991 level (see Figure 2-5). The increased consumption is probably a response to the population growth, the increasing use of the grain as animal feed and the industrialisation of the crop into different products.

Despite the importance of maize, and the efforts of the Mexican government to increase production, Mexico is not self sufficient in maize production (de Janvry *et al*, 1995a; Enciso, 1999). The national consumption of the crop has increased over the past years, while the production has not increased in similar proportion to cover the demand; this fact is illustrated in Figure 2-5. The gap between production and consumption has increased from nearly zero in 1993 to more than five million tonnes in 1996, accentuating the food dependency problem of Mexico on a key staple food product (INEGI, 1994).

Figure 2-4. National annual consumption of maize and other crops (in millions of t)

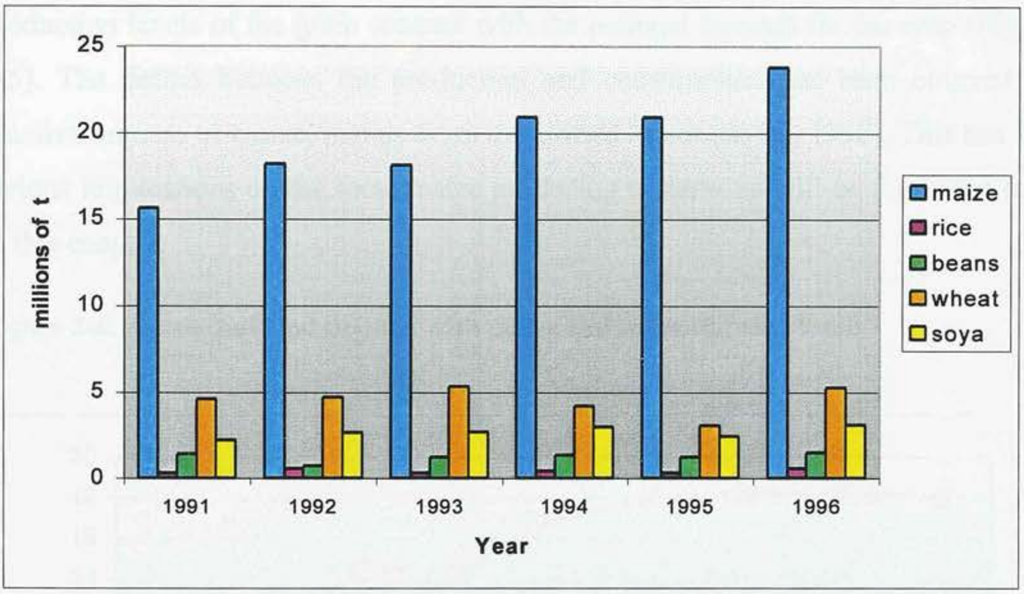
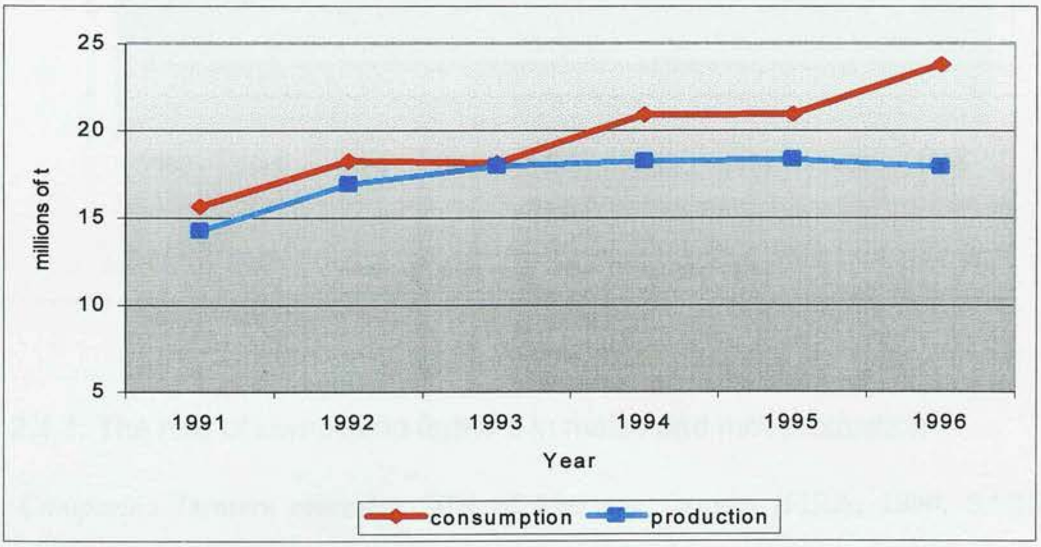
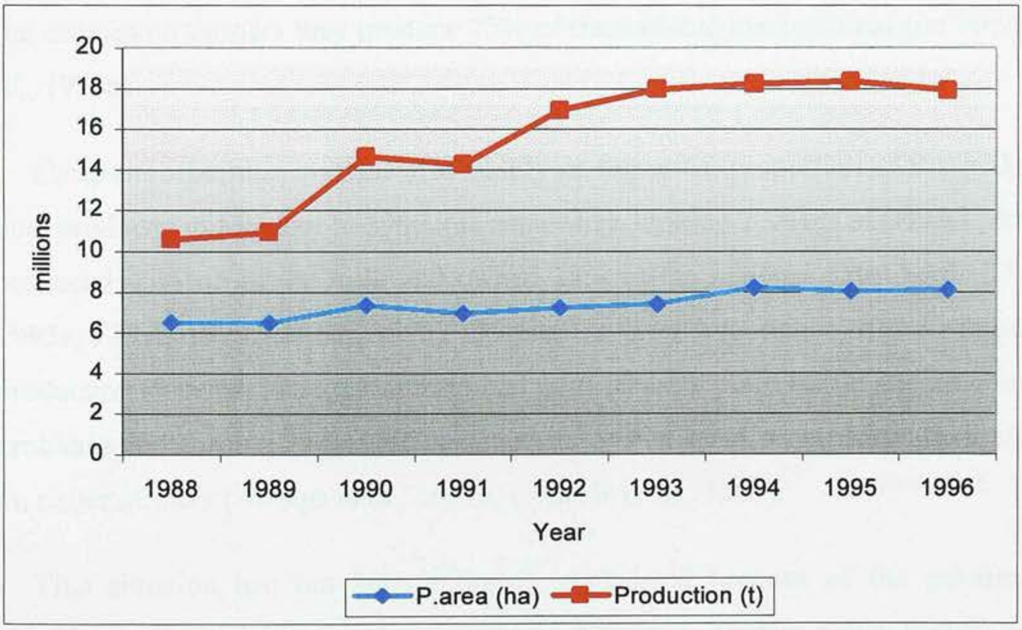


Figure 2-5. Annual production *vs.* consumption of maize in Mexico (in million of t)



In 1988, 6.5 million hectares were cultivated with maize, with a total production of over 10.6 million tonnes. Eight years later this area increased in 1.5 million ha and the production level rose to 17.9 million tonnes. Both the area cultivated with maize and the yield levels registered a modest increment over the last five years, maize yield per ha rose from 1.6 t/ha in 1988, to almost 2.5 t/ha in 1996 (INEGI, 1996) (Figure 2-6). The increments in the amount of land dedicated to maize and the production levels of the grain contrast with the national demand for the crop (Figure 2-5). The deficit between the production and consumption has been covered by massive imports of maize, mainly from the United States (de Ita, 1997). This has had serious implications on the local maize producing systems as will be discussed later in this chapter.

Figure 2-6. Amount of land planted with maize and its production levels



2.2.4.1. The role of *campesino* farmers in maize and milk production

Campesino farmers represent 80% of Mexican farmers (FIRA, 1990, SARH, 1993a) and produce most of the food consumed in the country, particularly maize (Warman and Montañez, 1982). According to de Janvry *et al.*, (1995b) in 1991 there were 2.4 million maize producers, representing 78% of Mexican farmers and some 12.5 million family members. Of these producers, 2.2 million has less than 5 ha planted in maize and the average maize area per producer was only 2.3 ha (SARH, 1991).

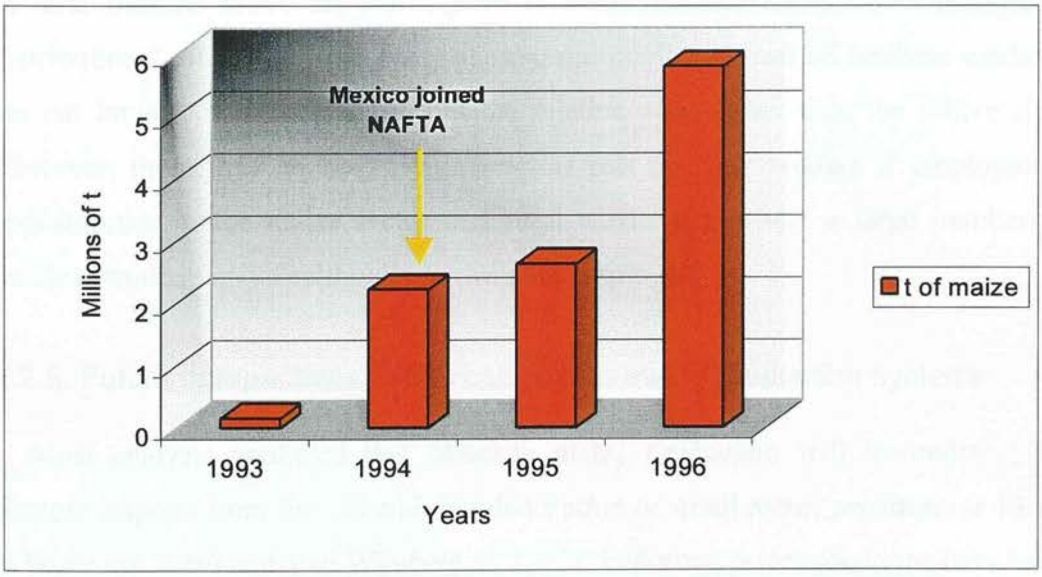
The majority of *campesinos*' land is under the *ejido* regime, according to the 1981 agricultural census, 52% of Mexico's arable land and 50% of its irrigated area are in the *ejido* sector (de Janvry *et al*, 1995b). The *ejido* sector is, however mainly endowed with rainfed land, much of which is of poor quality, and the land is highly fragmented (de Janvry *et al.*, 1995b). Moreover, 64% of the *ejidatarios* have farms less than 5 ha, which may be insufficient to maintain a family. This implies extensive participation by family members in the labour market and in seasonal migration (Levy and Van Wijnbergen, 1994). Only 9% have farms larger than 20 ha constituting a small sector of commercial farms. Despite the difficult conditions of the campesino farmers they produce 73% of the national maize output (de Janvry *et al.*, 1995b).

Campesino farming systems also supply an important proportion of the milk and beef produced in Mexico. In 1990, the campesino farming systems of central Mexico produced 45% of all the milk and owned 25% of the national dairy herd (SARH, 1993a, FIRA, 1990, García, 1996). Despite the clear importance of the *campesino* production systems, local researchers had until recently placed little attention on the problems and constraints that affect campesino systems and concentrated their efforts on richer farmers (Arriaga *et al.*, 1997b; Castelán *et al.*, 1997).

This situation had not been seriously considered because of the government subsidies and protection to maize producers. However, a major policy initiative was implemented in 1994 with the launch of a new programme called PROCAMPO, which meant substantially less benefits for farmers compared with the previous programmes. This change in the agricultural policy was introduced as part of the agreements signed by Mexico when joined the North American Free Trade Agreement (NAFTA). This implied two important changes to the agricultural and trade policies of the country. First, all support or subsidies to maize production will be eliminated over a period of fifteen years (including PROCAMPO), and second, large quantities of cheap maize could be imported from the USA as part of an annual quota fixed in the agreement. On the other hand, with the new programme the subsidy for maize production was paid per ha of land cultivated with maize whilst with the old programmes the subsidy was paid per ton of maize produced. Farmers estimated that with PROCAMPO they receive approximately 50% less subsidy than with the old programmes.

Mexican imports of maize have dramatically increased after Mexico's incorporation to the NAFTA in 1994 (Figure 2-7). In 1996 Mexico should allow the entrance of up to 2 652 250 ton of maize <u>in order to cover the deficit in this crop</u>, but by the end of the same year, 6 966 681 t were imported mainly from the USA (Pesado, 1993; de Ita, 1997). This was aggravated by the fact that the imported maize was cheaper than the local and so was creating a dumping effect on local maize markets and drop in the local price of maize (de Ita, 1997).

Figure 2-7. Mexican imports of maize since 1993 (in million of tonnes)



The application of the new policies has already shown negative effects on the local maize market. Lehman and Ritchie (1997) mentioned that the Mexican government has destroyed domestic markets for Mexican maize farmers by choosing to import maize under export subsidies from the U.S., instead of supporting Mexican production systems. de Ita (1997) stated that in 1996 the free trade agreement reached campesino farmers, who were launched into the world agricultural market without any comparative advantage, and with low government support, so they saw their price expectancies tackled by an unfair competition stimulated by maize imports. de Janvry *et al.*, (1995b) mentioned that Mexican maize producers would suffer the greatest losses due to more sizeable substitution rates to the US maize. Calva (1991) stated that in a country with over 2.4 million maize producers it should be expected social and economic disruption of considerable proportions.

On the other hand, de Janvry *et al.*, (1995b) mentioned that the effect of the new policies will be mainly limited to campesinos who are net maize sellers (approximately 50% of all maize farmers) and benefit those who are buyers, because in principle, nonsellers households would not be directly affected by a fall in the sale price of maize and net buyers would benefit from a drop in the local price of maize. Moreover, according to Levy and van Wijnbergen (1992) setting the price of maize in rural Mexico above the world price is inefficient and likely to have negative distributional effects because many subsistence producers, and all landless workers, are net buyers; in fact it screen out the relative poor rather than the reltive rich. However, there may be negative indirect effects on their welfare if employment opportunities in the maize sector and rural wages fall, where a large number of landless workers and smallholder farmers are employed.

2.2.5. Future perspectives for the campesino maize production systems

Most analysts predicted that Mexican maize production will be undercut by cheaper imports from the US and that dislocation of small maize producers is likely to be severe (Levi and Van Wijnbergen, 1992). Important price reductions have been observed, in 1996 the price of maize was between Mx$1 750 and 2000 per t, but in 1997 the price had fallen to Mx$1,200-1,270 per t of maize (de Ita, 1997). Calva (1991) asserted that 15 million family members would be displaced from agriculture as a resulted of the NAFTA. Koechlin and Larudee (1992) estimated a decline in

Mexican agricultural employment of up to 1.6 million. Levy and Van Wijnbergen (1992) are more conservative in their calculations, but still predict the displacement of 0.7 to 0.8 million workers as a consequence of a fall in the price of maize.

The Mexican government expected that increased employment in labour intensive fruit and vegetable production will offset much of the job losses in the maize sector. However, according to Rodríguez (1999), the export-oriented commercial farming sector is not linked to the rest of the agricultural sector, nor to the local and regional economies. Moreover, only 10% of the production units have access to the export market, and 1% of these concentrates more than 80% of the total exports. Therefore, although it is expected that the fruit and vegetable production may absorb some of the surplus labour, the theory that it will entirely solve the problem of displacement must be discounted.

The integration of maize and cattle observed in the campesino production systems of central Mexico is an option that has received little consideration for the improvement of these systems, and yet the possibilities of improvement are important for both maize and cattle (Castelán *et al.*, 1997; Arriaga *et al.*, 1997a; González, 1997). Improving the contribution of cattle to the livelihoods of campesino farmers and making maize production more efficient represent a more realistic solution to secure the future prosperity of maize growing communities in rural Mexico. A more efficient maize production means more forage available for cattle production, and more grain for family consumption and for selling. As mentioned previously, yields under rainfed conditions are half of those under irrigation, so increasing the irrigated area could be a viable option. The identification of the areas most suitable for this crop, the use of better cultivation systems and more efficient use of agrochemical inputs should lead to increased maize production (González, 1997).

Increasing milk production could also represent a viable option to reduce the negative effects of the government policies linked to the NAFTA (**provided that appropriate marketing mechanisms are developed**). It also offer the possibility of increasing the living standards of the campesino farmers and their families, through a higher income generated by the extra milk produced, which can be easily sold due to the high demand of the product. Increasing milk production will also contribute to reduce the high poverty levels observed in this sector already (Castelan and Matthewman, 1996; Castelán *et al.*, 1997; Arriaga *et al.*, 1997a; Zorrilla *et al.*, 1997; Tzintzun *et al.*, 1997; García, 1997).

Increasing milk production also offers the possibility to improve occupation levels among the rural communities, reducing the emigration to the urban centres. However, milk production in campesino farming systems is not efficient and the production levels are low. Low production is mainly associated with deficient nutrition of cattle (Castelán, 1996; Arriaga *et al.*, 1997a and b). Improving the nutritional status of the campesino farmer's dairy cattle should lead to higher milk yields.

Chapter 3. Characterisation of the *Campesino* farming systems of the Toluca Valley

3.1. Introduction

The main objective of this phase was to obtain detailed information on the characteristics and functioning of the *Campesino* maize-cattle farming systems of the Toluca Valley through a two stage survey in order to meet two important points. First, to generate the 'minimum data set' necessary to calibrate the biological models and to develop the integrated farming system model (IFSM) used in this work. Second, to improve the current knowledge on the systems and their problems in order to develop more adequate decision support tools. This included data on the region's natural resources, climate, soil, cropping and livestock production technologies as well as the socio-economic characteristics of farmers. Data from previous surveys carried out in the same area by the author (Castelán, 1996; Castelán *et al., 1997)* and by other CICA's researchers (González and Arriaga, 1996; Arriaga, *et al.*, 1997a; Arriaga *et al.*, 1997b; González, 1997; Vizcarra, 1997; Woodgate, 1997; Sánchez, 1997; Liendo, 1997) complemented the data obtained in the survey.

In fact these data constituted a valuable source of information because CICA's researchers have been working in the Toluca Valley and its highlands for more than ten years. Research carried out by these authors included the use farming systems research and participatory rural research approaches. The research areas include: characterisation of the campesino farming systems, genetic improvement of maize, design of alternative technologies to increase milk production, land use and land reform studies, gender distribution of labour in the campesino families and the role of women in the local farming system, and marketing studies (Rivera *et al.*, 1997).

Thus description and understanding of the farming system, was the first step in the decision support system construction process, since it was entirely based on this characterisation. It is suggested that no farm model construction is feasible without a good knowledge of the farming system in practice; otherwise many assumptions will have to be made, which may not resemble the actual processes that take place in the farmers' fields. The approach used here integrates some of the work carried out at CICA into a more complete research tool that could be used for both identifying new research areas and supporting farmers' decision making. This approach could be applicable to other research groups working with similar farming systems.

The method used to characterise the systems comprised the use of both formal and informal survey techniques described in the section that follows.

3.2. A framework for the characterisation of the Toluca Valley farming systems

The survey work was carried out over a period of 16 months, which was considered the minimum time necessary to capture the whole production cycle at the Toluca Valley. It was essential to monitor the whole cycle, because most of the systems' activities follow a seasonal pattern determined by the dry (7 months) and wet (5 months) seasons, which in turn determine maize production, the main agricultural activity in the Valley. The integrated farming system model described in Chapters 7 and 8, which is the final aim of this work, attempts to emulate this cycle.

3.2.1. Survey methods

A two tiered technique was used to characterise the production systems of the study area. It comprised a Static Survey (SS) followed by selection and monitoring of Case Studies (CS).

Static survey: The SS was carried out by the approaches for static surveys proposed by Kalton (1983) and Nichols (1991) and Quijandria (1994), which consist in the application of a formal questionnaire to a random sample of farmers. The questionnaire comprised 154 questions that covered most aspects of the farming system from socio-economic aspects to crop and cattle production technologies. These questions are synthesised in the following list.

a). Definition of the boundaries of the system

- total farm area
- topography
- soil type
- number of plots and location
- other farm assets

b). Determination of system's components

- area in each component (subsystem) and physical location
- type of crops and animals
- technologies employed and yields
- inputs and economic requirements
- evaluation over time of each of the productive activities
- seasonal demand for labour for each activity
- seasonal demand for inputs and cash flow

c). Determination of the social component

- age of farmers
- level of education
- family composition and size
- age and level of education of family members
- participation of each member in the production process
- use and distribution of family labour
- distribution over time of the demand for labour
- requirements for hired labour
- off-farm employment
- attitudes, motives and aspirations of farmers
- land tenure system

d). Determination of interactions among system components

- determination of the interactions between crops, between animals and between the two of them
- dynamics of interactions over time
- allocation of resources
- income distribution

e). Determination of system inflows

- input flows to each component of the system and to the household
- determination of average annual rainfall, temperature and radiation

- distribution, over time, of climatic events
- interactions between inflows and components

f). Determination of system outflows

- determination of the outflows for each component and for the family
- average annual sale of products, goods and services
- distribution over time of system outflows
- outflows per component and from the household
- interactions between inflows, components and outflows

Case studies: The methodology for conducting case studies proposed by Maxwell (1986), along with some elements of the same method stated by Casley and Lury (1987) and Farrington and Martin (1988) were applied in this work. This method was used to conduct farm management studies where the main cropping and livestock activities of the farming system were closely monitored along the whole production cycle. According with Casley and Lury (1987) the method's main objective is to collect data with a high order of accuracy to allow quantitative relationships to be formulated, in this case simulation of the farming system.

In both surveys the following techniques from the Rapid Rural Appraisal (RRA) and Participatory Rural Appraisal (PRA) methods (Chambers, 1981; Kumar, 1993; Theis and Grady, 1991; The World Resources Institute, 1990) were used: seasonal calendars, key informants, direct observation, group interviews, trend lines and farm sketches. It is suggested that a simple static survey by itself does not produce the quality of information and the level of understanding and knowledge of the system that may be produced by a PRA or RRA surveys. However, a PRA will not allow making valid inferences from the sampled units, because these are not randomly selected in this technique. On the other hand, Olsen (1992) has questioned the representativeness of the samples particularly in rural areas of developing countries. This author suggests that this method assumes that a clear boundary can be set for the study area. This may not always be possible because for example outlying hamlets can have an entirely different composition from central parts of villages. Second, in most cases you may only have one chance to do the survey, and your chosen locality may not be representative of the area.

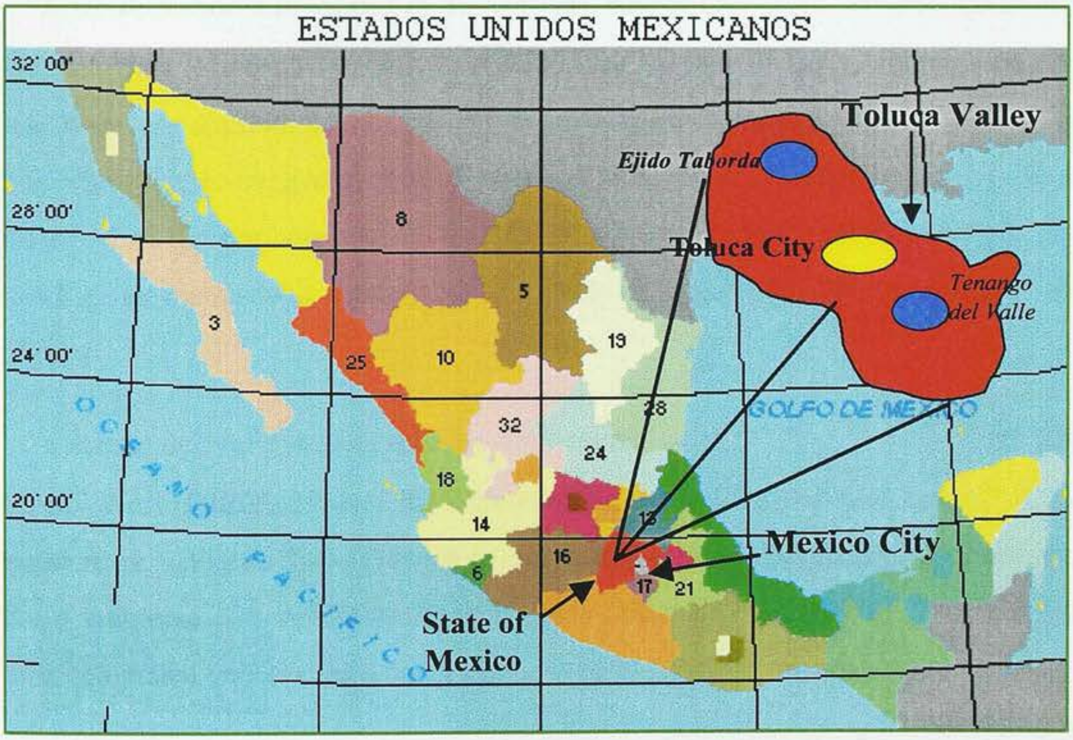
PRA surveys produce mostly qualitative data, and very little quantitative data, so little statistical data can be obtained from here. On the other hand a static survey produces little data about the farming systems as a whole, because this is only concentrated in few questions or variables, which are interesting for the researcher, but the rest of the system's components are not considered. It is suggested that direct participation of farmers and continuos interaction with them during the survey may help to reduce biases in identifying problems and constraints and allow better description of resources and resource use. Moreover PRA is a way of learning from, and with, community members to investigate, analyse, and evaluate constraints and opportunities, which affect local production systems (Chambers, 1981). In this work participatory techniques were very useful in getting a good knowledge of the farming systems and understanding the underlying principles behind some of the farmers' production technologies.

The main justification behind the use of the two-stage approach, SS and CS was that both types of surveys have particular strengths and weakness (Franzel, 1987). The SS allows a general understanding of the farming systems being studied, whereas the primary purposes of the CS surveys are to verify the findings of the SS, to get detailed information of their dynamics over time and to quantify some of the system's most important variables. Furthermore, in this study the CS survey generated a constant flow of information from the field, which served to calibrate and develop the models used. Case studies according with Maxwell (1986), and Farrington and Martin (1988) provide an optimal combination of time, cost, accuracy and coverage characteristics, which, are required in order to carry on to validation of modelling work.

3.2.2. Defining the sampling site, target population and sample size

Sampling site: The survey was carried out in two communities of the Toluca Valley called *Ejido* Taborda and Tenango del Valle, located at the northern and southern parts of the Valley respectively. The Toluca Valley is located in the State of Mexico in the central highlands of the country, 19° 27' North and 99° 38' west, 2360 m above sea level (INEGI, 1981). Figure 3-1 shows the location of the Valley. According to Espinoza (1993) the Toluca Valley has an approximate area of 1145 km2, and it occupies the agro-ecological zones 27 and 37 (the State of Mexico has 95 agro-ecological zones).

Figure 3-1. Location of the Toluca Valley



The Toluca Valley agro-ecological zones are characterised by a climate, *C (w2) (w),* the most humid of the temperate climates (García, 1988). Mean annual rainfall is 760.7 mm, the mean annual temperature is between 14 and 15 °C, with a range for the coldest month of -7 to 18 °C, and for the warmest month between 6.5 and 25

°C, frost is present from October to March or even April (SARH 1982; Garcia 1988). Vertisol pelico, Feozem aplico, Andosol humico and Andosol ocrico are the main soil types, while silty clay loam and clay loam are the most common soil textures (INEGI, 1981; Espinoza, 1993).

Toluca City is the capital of the state of Mexico and it occupies the central part of the valley (Figure 3-1). The eastern parts of the valley are dedicated to industrial activities. The northern and southern parts are dedicated to agriculture, which is where the project area is located. The main crop in the Valley is maize, according to INEGI (1994a) 16 739 ha of this crop are cultivated every year. Most of this land is irrigated in the north of the Valley, while in the south is rainfed.

Ejido de Taborda is located in the northern part of the valley, 19° 28' North and 99° 41' West (Figure 3-1) (INEGI, 1981). It has an area of approximately 1602 ha and there are approximately 200 smallholder farms. Although Taborda is a small community it is suggested that its farming systems are representative of those observed in the northern part of the Valley, where there are approximately 3 324 smallholder maize-cattle farms (INEGI, 1994a; Castelán *et al.*, 1997; Arriaga *et al.*, 1997a).

Tenango del Valle is located in the southern part of the Valley, 19° 06' North and 99°35' West (INEGI, 1981). This community is the head of the municipality of the same name (Figure 3-1). The whole municipality is approximately 181 km2 and there are some 579 smallholder maize-cattle farms (INEGI, 1994a). The sampled area comprised only the farm units, which were 10 km from the main town.

Target population: The target population comprised the *campesino* maize-cattle production units within these two communities. For this study only smallholder farmers with a farm size of less than 15 ha of land and 30±5 heads of cattle were considered. Bigger farmers were not considered because their production system and problems are different from those of the smallholders and because they were not of interest either to the researcher or to the research program on *campesino* cattle production systems of CICA (Castelan *et al.*, 1997; Arriaga *et al.*, 1997a).

Sample size: 30 farms from each community were sampled. A list of farmers was obtained from the *Comisario ejidal* (community leader in charge of land issues) from which a random sample was selected. The author is aware of the small size of the sample, however the reduced budget for the survey and the limited assistance to carry out it limited the size of the sample. However, according to Nichols, (1991), the cost and the money available for the sampling process are the main factor which determine the sample size. In addition, for exploratory or in-depth work, where the aim is to get a general idea of the farming system, there is no point in using a large sample, so sample sizes in the range of 30 to 50 are normally enough. For this work, as mentioned, time and money were the factors that limited the number of farmers sampled. However, data from previous surveys carried out by CICA's researchers were used throughout this work (Castelán, 1996; Castelán *et al., 1997;* González and Arriaga, 1996; Arriaga, *et al.*, 1997a; Arriaga *et al.*, 1997b; González, 1997; Vizcarra, 1997; Woodgate, 1997; Sánchez, 1997; Liendo, 1997), whereas most of the detailed data was obtained from the case studies.

Case studies: Five farmers were selected as case studies. The criteria for selecting them varied according with the needs of data to calibrate the models and the willingness of the farmers to participate. For example six farmers were selected to obtain the necessary data to calibrate the CERES-Maize model, the criteria for selecting them was their recognised experience in cultivating maize as explained in Chapter 4. In contrast three farmers were selected for the construction and validation of the IFSM. These farmers represented groups of farmers with different farm sizes as explained in Chapter 7, but particularly those with less than 5 ha since they are the majority of farmers in the region (SARH, 1991; INEGI, 1994a). The frequency of the visits to the case studies depended on the type of data that was collected from them, but in general every case study was visited every two weeks over a period of 14 months. Details of the type of data collected from the case studies is given in Chapters 4, 5, 6, 7 and 8, where models' data needs are described individually.

As Casley and Lury (1982) mentions " A case study is the detailed study of a small number of units, selected as representative of the group or groups relevant to the issue under consideration, but not necessarily representative of the population as a whole". The number of farmers/farms to be selected in each type will depend on the variability within the type, on the likelihood of drop-outs, on the range of the data to be collected, on the number of farm types to be covered and on the capacity of the researcher. According to Maxwell, (1986), two farms in each farm type is probably a minimum and five is probably a maximum. Moreover, he mentions that, whatever the number of farms in a particular category, case study programmes should have an overall limit of around ten.

The author is aware that there are other methods to select case studies such as cluster and discriminant analysis (Pielou, 1984). Cluster analysis allocates cases based on their characteristics, forming clusters or groups (Sierra-Bravo, 1987). However, this analysis was beyond the scope of this work since it can constitute a separate research on its own (Ferreira, 1997) and significantly more time would had been required to achieve this.

3.3. Characteristics and functioning of the farming system

Results presented here correspond to the static survey because the main objective of this section is to provide a general description of the farming systems of the Toluca Valley. Information collected from the case studies is described in detail in the chapters that described the modelling work. From the analysis of the survey data it is suggested that the *campesino* farming systems observed in the Toluca Valley during this survey could be classified into two types.

1. **Maize-livestock production system (MLPS)**

2. **Intercropped-maize-livestock production system (IMLPS)**

The Maize-livestock production system (MLPS) was the most commonly observed and was seen mainly in Taborda (100% of the surveyed farmers) although it can be found in Tenango too (33% of farmers). The average size of the farm is 4.2 ha with a minimum of 0.8 ha and a maximum of 12 ha. Maize is the main crop and the whole farming system revolves around it (see Table 3-1). Maize is harvested when the grain is dry and it is used within the farm for household consumption or fed to livestock and depending on yield levels, it can be sold. Dry stover constitutes the main source of forage for livestock particularly cattle and sheep. Livestock plays a very important role in the system because it represent a form of saving, provides a constant flow of cash, and is also a source of food for the household and an appreciated source of manure for the cropping activities. Farmers in this system may plant small areas with other crops like vegetables and small plots of improved pasture (Table 3-1). Farmers production of other crops apart from maize, is limited by the long growing season of maize and in Taborda the clayey soil texture of soil also limits cultivation of other crops (see Chapter 4).

Table 3-1. Main crops planted at the Toluca Valley

Main Crops	**Taborda (% of farmers)**	**Tenango del Valle (% of farmers)**
Maize (dry grain)	100	33.3
Maize (fresh corncob)	-	56.7
Dry grain+fresh corn	-	10
Other crops		
Vegetables	13	70*
Improved pastures	50	50
Number of farmers (*n*)	30	30

* Vegetables are normally intercropped to maize or planted after fresh corn is harvested (multicropping).

The **Intercropped-maize livestock production system** (IMLPS) was observed mainly in Tenango del Valle (approximately 70% of surveyed farmers in Tenango). This system is less common in the Valley, but in essence it is similar to the first one, except that in it maize is harvested fresh before the physiological maturity of the plant and sold as fresh corncob. The average size of the farm was 4.4 ha with a minimum of 0.5 ha and a maximum of 14 ha. A land race called *Cacahuazintle* is the most common maize variety planted in this community. Table 3-1 shows that nearly 57% of farmers in this community plant maize for fresh corncob production and 10% for both grain and corncob. The early harvest of maize in this system allows peas (*Pisum sativum*) intercropping, in this way two crops are produced in the same land area. Peas are planted after maize plants have reached approximately 1 m high. Fresh maize stover is fed as green fodder or ensilaged to feed cattle during the dry season, pea's straw is fed to cattle too.

It was observed that apart from peas, farmers in Tenango planted other crops like carrots (*Daucus carota*), lettuce (*Lactuca sativa*), cabbage (*Brassica oleracea*), spinach (*Spinacia oleracia*) and large beans (*Vicia faba*). The by-products of these vegetables are used to feed cattle too. Peas and large beans are normally intercropped to maize, while lettuce cabbage, carrots and spinach are planted after maize is harvested in July-August. Therefore it can be suggested that there is a more intensive use of the land in this system because more than one crop is produced in the same land area. This farming system is also more integrated to local markets than the first one. Unlike Taborda, the sandy texture of soils, the high water holding capacity and the rich content in organic matter and mineral such as K, CA and Mg facilitates vegetables production in Tenango del Valle (Villa, 1997).

However, both the MLPS and the IMLPS may be classified as smallholder farming systems, according to Ballantyne´s (1995) definition. Since they are more specialised systems, the crop yield levels are from medium to high, the use of external inputs like agrochemicals is high. Also most of the household's income comes from agriculture, and they have reasonable access to markets.

Results for Taborda are consistent to previous surveys carried out in the area (Castelán *et al., 1997;* González *et al*., 1996; Arriaga, *et al*., 1997b; Arriaga *et al*., 1997a; González, 1997). There are few works on Tenango del Valle that can be used to compare the results obtained in this work therefore they are not discussed further. Since the **Maize-livestock production system** that was observed in Taborda is the predominant farming system in the Valley; it was decided to base the description of the systems on it and only comment the main differences with respect to the IMLPS observed in Tenango del Valle. The "integrated farming system model" (IFSM) described in Chapters 7 and 8 was also based on this system because more powerful (and more integrated) biological models are required to simulate the multicropping and intercropping cultivation systems observed in Tenango del Valle While these models have started to become available, they required considerable more information to calibrate and most of them have never been tested with data from the tropics, making their applicability for the tropical countries unclear (Caldwell *et al*., 1996).

The author is aware of the fact that a more detailed description is required for the farming systems observed in Tenango del Valle. It is planned to expand the survey and the IFSM to cover this farming system in the near future.

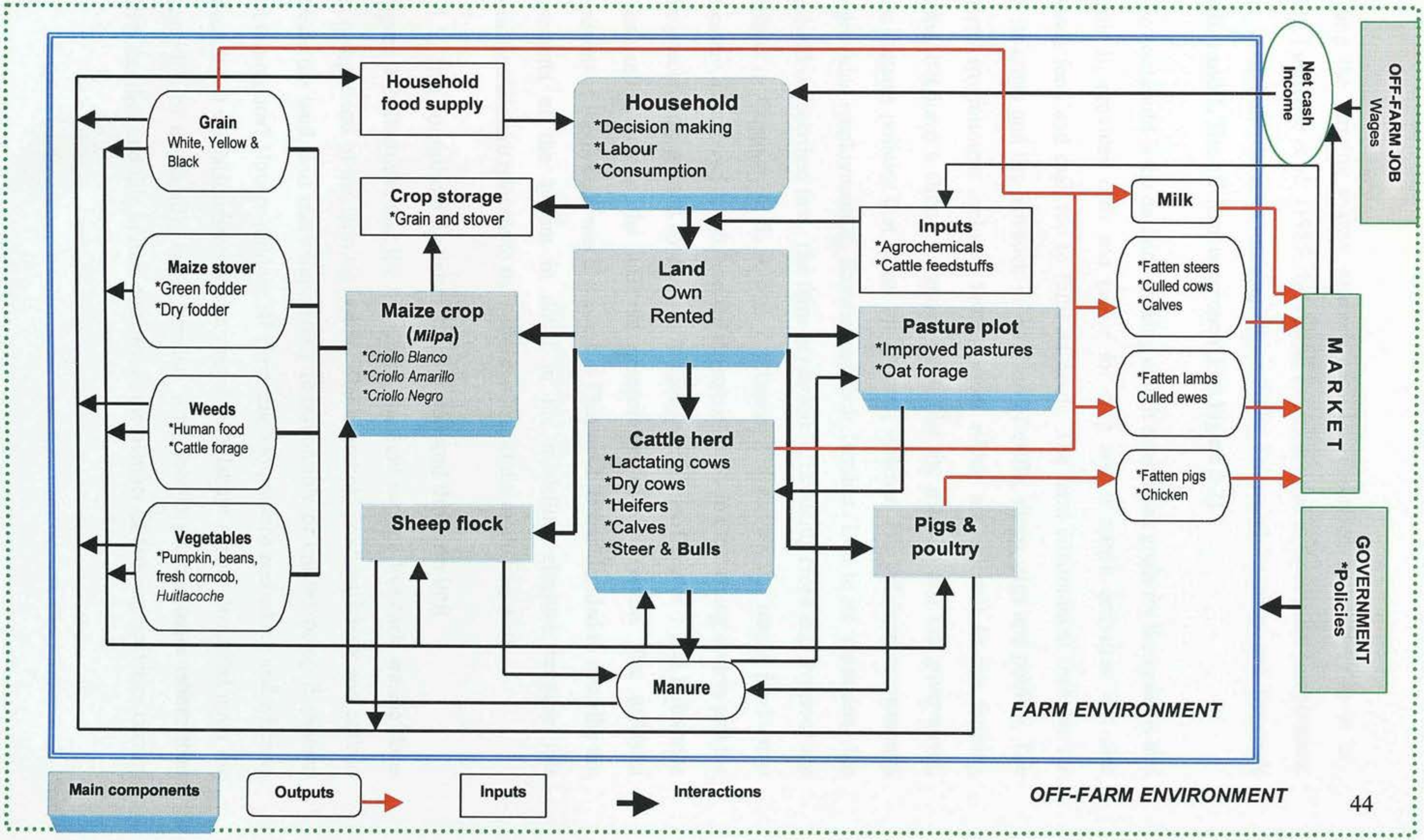
3.3.1. Maize-livestock production system

Figure 3-2, shows a diagram of the *campesino* maize-livestock production system. This diagram clearly illustrates the complexity of the farming system. This complexity is derived from an unpredictable environment and adverse economic scenarios (see Chapter 2). Moreover, it is complex because it reflects the multiple objectives of the farmers even when maize and livestock production are the only main farming activities in the system. A typical *campesino* farmer of the Toluca Valley produces at least three different varieties of maize with a specific purpose (see Chapter 4) (González, 1997; Chávez *et al*., 1998). Maize intercropping in the edges of the maize parcels is common, particularly in those close to the farmhouse. Small portions of the farm's land are also used for forage production (50% of farmers); such as improved pastures (Figure 3-2). This figure also illustrates the close association between livestock and crop production; for example, all sampled farmers have small cattle herds where milk and beef are produced, other livestock such as pigs, sheep and poultry, are also kept by farmers.

The MLPS moves around what is locally called *Milpa. Milpa* is a local word used to define a parcel of land planted with maize where other plants may grow along with maize in the same land. It was observed that all the plants that grow in the milpa were utilised by farmers for different purposes. These plants can be planted or not, those that are planted (apart from maize) included at least one of the following: pumpkins (*Cucurbita pepo*), beans (*Phaseolus vulgaris*) and large beans (*Vicia faba*) (these are normally planted in the edges of the *milpa*). Non planted plants are weeds which constitute an important source of forage for cattle and food for the household (see Figure 3-2). The main weed species and their use to feed cattle are described in Chapter 5.

The weeds used for human consumption, are called *Quelites* and are harvested at the beginning of the rain season. *Quelites* are a mix of different species of *Amaranthus sp* (Reyes, 1990). Apart from corn and weeds the *milpa* provides a type of fungus which parasitises the maize cobs and is edible too. The local name of this fungus is *Huitlacoche* (*Ustilago maydis*) and it is considered a delicacy, its price may be higher than those of the grain and the fresh corncob (if sold). These results suggest that farmers make a very intensive and integral use of all the resources that are produced in the *milpa* and not only the grain and stover as is normally assumed. These characteristics are entirely consistent to the description of the farming system given by González (1997), Arriaga *et al.*, (1997b); and Chávez *et al.,* (1998). The *milpa* system has also been reported in other parts of Mexico where maize is cultivated, particularly in smallholders and subsistence farming systems (Dzib, 1998; Aguilar, 1998).

Figure 3-2. The campesino maize-cattle production system of the Toluca Valley



Using the farming system research approach described in by Byerlee *et al.,* (1982); Lawrence *et al.,* (1985) the system can be divided in three main components: 1.The household decision making unit., 2.The farm and its crop and livestock activities and 3. The off-farm component (see Figure 3-2).

The household is the decision making unit, it establishes goals for the systems and controls it, provides cash and labour for crop and livestock activities, but also demands food and cash too to fulfil its needs. The farm environment includes the land, its crops and the livestock in the form of cattle, sheep, pigs and poultry. The off-farm environment includes those factors which are external to the farming systems, but have a strong influence on it, like the markets and the government, which dictates policies that affect the farming systems. The off-farm environment also provides employment to farmers and their families. Due to its importance the household is described first. The farm environment, including crops and livestock are described in Chapters 4, 5, 6, and 7. Chapter 4 describes the maize production component, Chapters 5 and 6 describe the role of cattle in the farming system and the feeding technologies used by farmers to feed their cattle. Chapter 7 and 8 describe the interaction among the different components of the system. The off-farm component of the system was discussed in Chapter 2. It was decided to describe the components of the system in detail in the modelling chapters because this information is more relevant to the understanding of the modelling work.

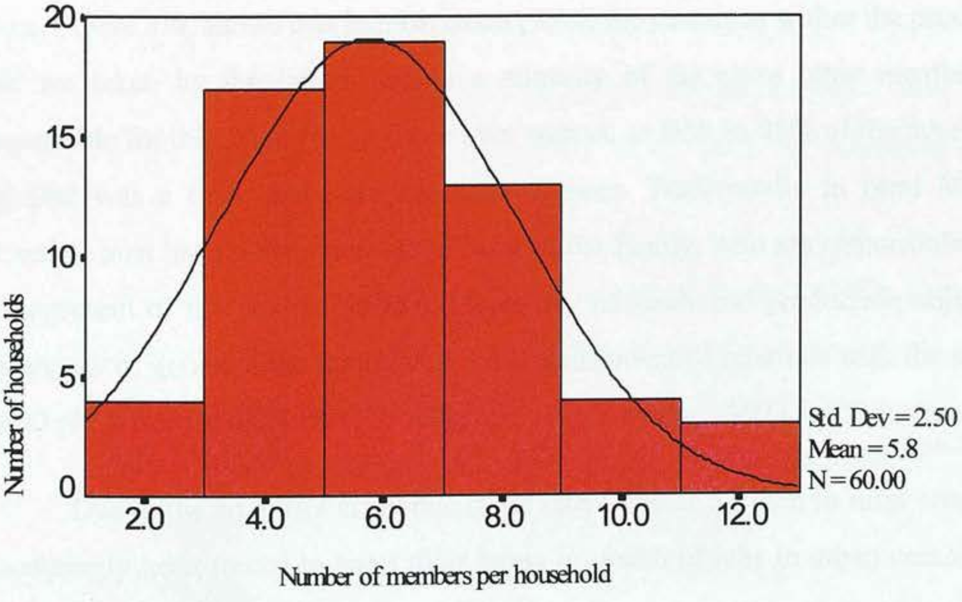
3.3.1.1. The household decision making unit and the farm unit

Figure 3-2 illustrates that the household, the land and the livestock are the three main components of the farming system. The household provides labour and cash to cultivate the land, and more importantly is responsible of the following decisions: What to produce? How to produce it? How much to produce and where and when to produce it?. It was also observed that household's labour supply depended upon the composition of the family, larger families were able to provide more labour than smaller families and this in turn determined the number of farming activities carried out by the household. Land is also an important component because it determines the scale of the farming enterprise and again the number of farming activities.

Average household size and composition In general (across the two systems) the average number of family members per household was 6, with a maximum of 10 and a minimum of 2. Figure 3-3 shows the distribution of the number of family members for the Toluca Valley, it can be seen that the majority of the household have between 4 and 8 members, these figures are entirely consistent to the ones observed in earlier studies (Castelán *et al.*, 1997). This is a common feature since rural families in Mexico tend to be large in number (de Janvry, 1995a; Vizcarra, 1997;).

Larger families in rural Mexican societies are partly explained by the labour demand imposed by the agricultural activities, since most of the labour needs in the *campesino* production systems are supplied by the family itself (Vizcarra, 1997). The household is composed of the decision-maker (normally the father), the spouse and the children. However, it was observed that 45% of the households have some other member apart from the ones mentioned. The extra member (s) is normally the grand parent, brother, or sister of the spouse or the husband. These may contribute to the labour supply too.

Figure 3-3. Average number of members per household



The average number of children per household was 3, with a maximum of 8 and a minimum of 0. The proportion of female and male children per family is similar, 50% of each gender. The results presented so far correspond to the averages obtained for both farming systems, but similar values were observed when the same variables were analysed for each system individually (see Table 3-2).

Table 3-2 . Average composition of the household.

Farming system	**MLPS**				**IMLPS**			
	Mean	S.D.	Max	Min	Mean	S.D.	Max	Min
No. of household members	6	2	10	2	6	3	12	2
Number children	3	2	7	0	3	2	8	0
No. of male children	2	1	4	0	2	1	4	0
No. of female children	2	1	7	0	1	1	4	0
Other members	1	-	-	-	1	-	-	-

SD= Standard deviation, Max= maximum number of household members, Min= minimum

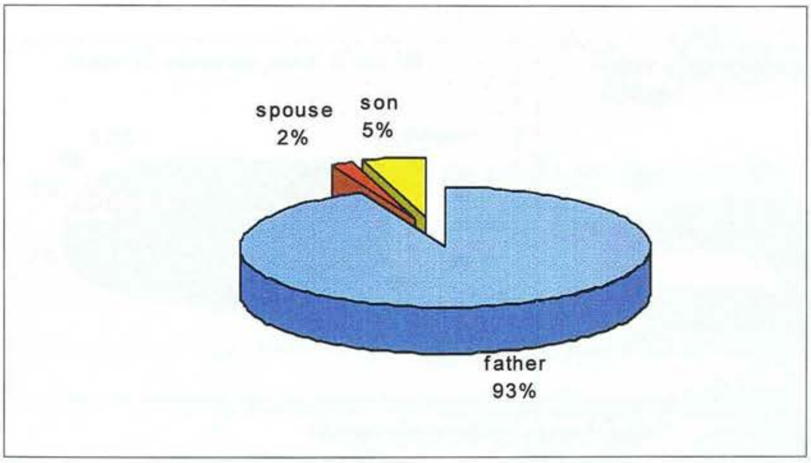
3.3.1.1.1. Characteristics of the Decision-Maker and the other members of the household.

It was observed that the decision-maker (DM) of the household was normally the father, but in his absence or when he is old, the spouse or the older son takes his place. Figure 3-4, shows that in most cases (93%) the decisions within the production unit are taken by the father, and in a minority of the cases other members are responsible for this. Men predominate over women as DM, in 98% of the households the DM was a man, and only 2% were women. Traditionally in rural Mexican societies, men have played the role of head of the family, who are responsible of the management of the production unit, the setting of goals and production objectives, the supply of goods to the family and the establishment of relations with the exterior world (de Janvry *et al.*, 1995a; Woodgate, 1997; Vizcarra, 1997).

Due to the country's economic crisis (see Chapter 2), men in rural areas have increasingly been forced to leave their farms in search of jobs in urban centres or in

Due to the country's economic crisis (see Chapter 2), men in rural areas have increasingly been forced to leave their farms in search of jobs in urban centres or in the United States (de Janvry *et al.*, 1995a). Women have taken over some of the responsibilities of the DM, but it was observed that men were still in charge of the main decision concerning crop and livestock activities. They normally come back to the farm when labour demand is high, such as the planting or the harvesting seasons. This results are consistent to those reported by Vizcarra, (1997).

Figure 3-4. Proportion of household members who are DM



Education level of DM and other household members. 100% of interviewed farmers declared to have access to basic services of education (primary and secondary) studies. Figure 3-5 shows the average number of education years of the different family members, except for the spouse, which were not registered during the survey.

Figure 3-5 shows that the majority of the members of the households have some years of basic education (1 to 6 years), the DM and the daughters being the ones with less education years than the male children. For example, the proportion of DM and female children without any education at all is larger than the proportion of male children (10% and 3% respectively). Figure 3-5 shows that 19% of male children have more that 13 years of education, which may involve some kind of university training. The proportion of females with 10-12 years of education is slightly larger than the males (11 and 7% respectively). This may be explained by the fact that farmers encourage their daughters to do some kind of technical training, which requires less years of education than a university degree, reserving the last option for the male children. This figure also illustrates that the education level has increased among generations, since the number of education years for the DM is lower than the children, which in general have more education years (Figure 3-5).

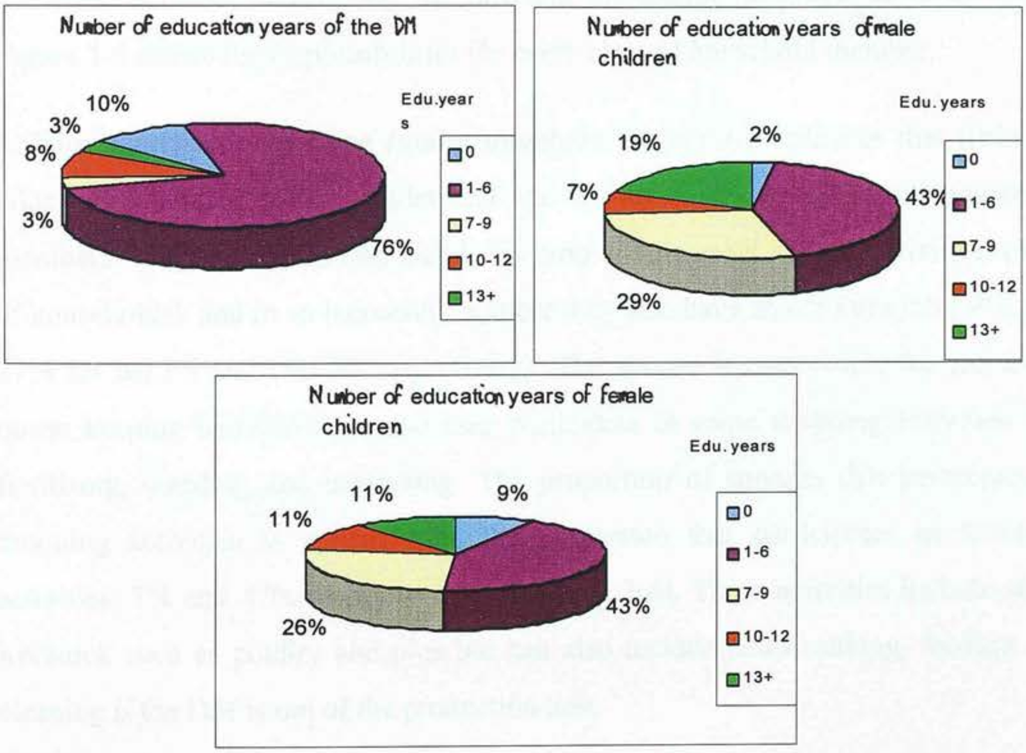


Figure 3-5. Number of education years of family members

Access to education has had a positive impact on the farming system. It was observed that farmers are open to learn and test new technologies, which is also reflected by a selective use of external inputs for agriculture such as chemical fertilizers, pesticides, and irrigation. On the other hand, farmers and their children workers, currently they may be employed as electricians, plumbers, nurses or even school teachers, which is a direct consequence of better access to education services (Arriaga *et al.*, 1997a).

3.3.1.1.2. Labour distribution among household members and labour demand for farm activities.

Because most of the labour supplied to the farming system comes from the household, it was considered important to describe it here as part of the household characteristics. Figure 3-6 shows how the labour associated to the different farm activities is distributed among the different household members. In other words Figure 3-6 shows the responsibilities for every class of household member.

Labour distribution among family members: Figure 3-6 indicates that labour is allocated according to the gender and age characteristics of individual household members. Thus the DM is responsible for crop and livestock related activities (92% of households), and in an increasing number they also have an off-farm job (30% and 27% for MLPS and IMLPS respectively). The spouse is responsible for the entire house keeping activities, but she may participate in some cropping activities like fertilising, weeding and harvesting. The proportion of spouses that participate in cropping activities is smaller than the proportion that participates in livestock activities, 7% and 47% respectively (see Figure 3-6). These activities include small livestock such as poultry and pigs but can also include cows milking, feeding and cleaning if the DM is out of the production unit.

The division of labour observed for the DM and the spouse was repeated for the children, which depending on their gender and age will perform similar activities as their parents. However, female children participate more extensive in crop and livestock activities, 22% and 51% respectively, than the spouse (Figure 3-6). These results may be explained by considering the fact that the spouse is the direct responsible of the family care, while the daughter only assist her and will have more time to cattle and crop activities.

responsible of the family care, while the daughter only assist her and will have more time to cattle and crop activities.

Figure 3-6 . Distribution of farm labour among the different household members

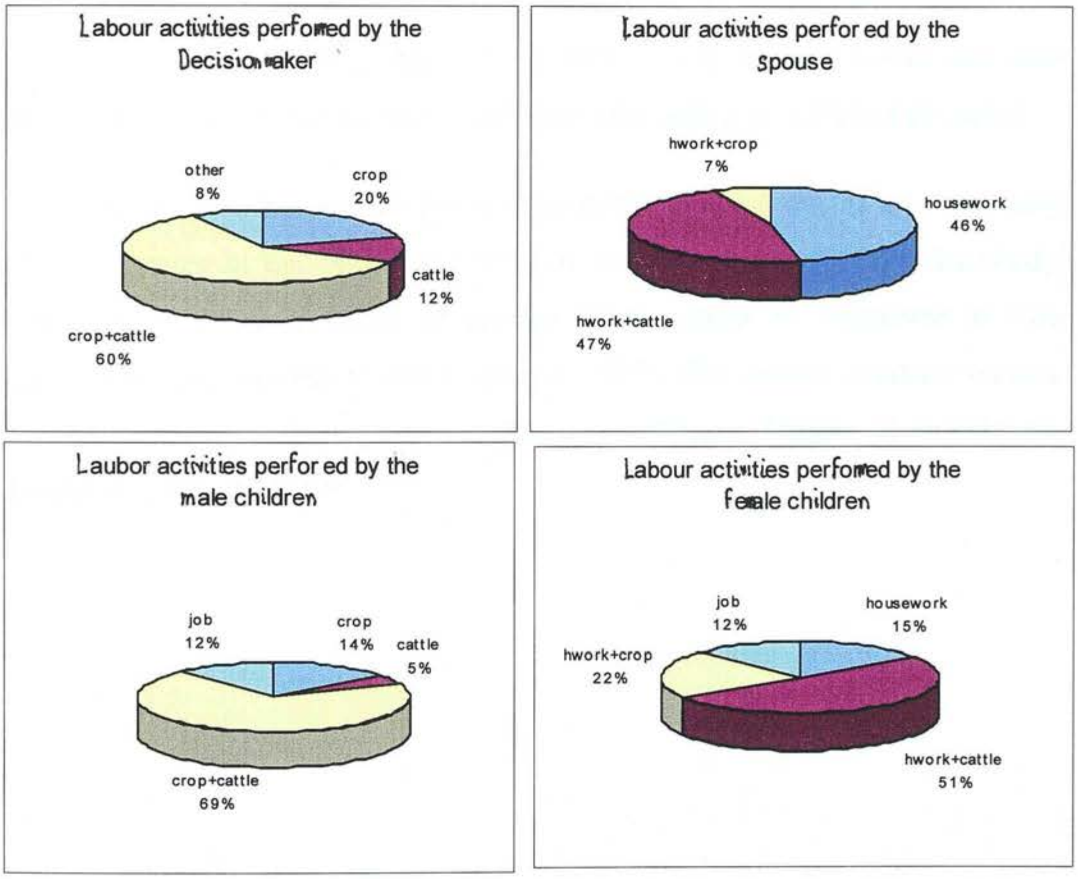


Figure 3-6 also indicates a strong gender division of labour. These results are consistent with those of Vizcarra (1997). This author mentions that labour distribution within *campesino* production units is gender distributed, so some activities are considered "men activities" and other "women activities". However woman will take part in men´s activities, while it was observed that the opposite is more difficult to occur. Women will participate very actively in the cultivation work

Off-farm jobs are important complement to the family income, 45.8% (n=59) of all sampled households declared to have at least one member of it working in off-farm activities, mainly wage labour. The proportion of households engaged in off-farm labour was larger in the case of the MLPS, 62% of the cases. While in the case of the IMLPS the proportion was lower only 30% of the cases. The reasons for these could be the higher labour requirements observed in the intercropping system and higher revenue associated to this system. Table 3-6 shows that female and male children have equal opportunities to work out of the farm unit (12% in both cases).

Despite the fact that households have members working out of the farm units, 67% of farmers in the MLPS and 93% of farmers in the IMLPS acknowledge agriculture as the main source of income. These results are consistent to those observed in a previous survey (Castelán *et al.*, 1997). The amount of labour supplied by every class of household member is described in Chapter 7 where this activity was also simulated by the IFSM.

Chapter 4. Simulating *Campesino* farmer maize production[1]

4.1. Introduction

This chapter describes a procedure used to calibrate the DSSATv3 CERES-Maize model and evaluates its performance in simulating growth and development of maize using input data collected from *Campesino* farmers and their cropping fields, instead of using data obtained from experiments in stations or from the literature. The problems encountered in the calibration process are also illustrated. Maize production in the intercropped maize livestock production system (IMLPS) was not simulated because the product is harvested before maturity and no intercropping model was used.

The viability of maize production in Central Mexico is under stress from the North American Free Trade Agreement with the USA and Canada (Lehman and Ritchie, 1997). To survive in the new scenarios, *campesino* maize farmers are developing alternative maize production systems and better and more efficient uses of their land. There is also an urgent need for scientists (working together with farmers) to identify and to develop viable maize production technologies, which will serve for alternative systems of production. Such systems should be based on an understanding of the local farming systems and awareness of the potential of local agroecosystems, and should contribute to the solution of farmers' problems.

The testing of different technologies could be very expensive and resource demanding, and it is almost impossible to study a wide range of management

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[1] *Based on: Evaluation of the CERES-Maize model in simulating Campesino farmer yields in the highlands of Central Mexico. Experimental Agriculture (in press).*

practices within the time scale and budget of field experiments. In addition, no assessment can readily be made of how the technologies should be modified in different regions in response to different conditions (Dent and Thornton, 1988).

Simulation modelling, as part of the systems approach, has some potential for overcoming such problem to speed the transition from the design stage to the testing stage and beyond, a holistic framework is needed for effective decision-support purposes (Dent *et al.,* 1995). Simulation models (SM) can be used to examine and identify the most promising cropping systems. However, there are some problems accompanying the use of SM when they are applied to technology development for less developed regions in small experimental stations where resources are limited. Model calibration requires both highly trained staff and specially designed trials to test on-station model applicability, if it is to achieve scientific validity. This may not necessarily result in a robust model appropriate for use in development situations (Mbabaliye and Wojtkowski, 1994).

The use of survey data collected from farmers and their fields through formal survey methods and participatory rural appraisal (PRA) techniques, plus a great deal of interaction with farmers may reduce some of the problems associated with data needs for model calibration in small research stations. The use of robust models (CERES-Maize model) developed for multi-site applicability, associated with an in-depth knowledge of the target farming system, could also contribute to a more beneficial use of simulation models under resource limited conditions. However this has not been done before, and there may be a large number of issues which have to be addressed: a small experimental area per farm in order to reduce disruption of the farmer's production system, and larger variability resulting from an even greater number of sources.

In this sense, the main objective of this work was to evaluate whether the DSSATv3-CERES-Maize (DCMM) model can be calibrated and used to simulate growth, development and yield of maize, using input data collected from *campesino* farmers and their cropping fields, instead of using data obtained from experiments at research stations, or from the literature.

4.2. Materials and methods

This work was carried out at the Research Centre in Agricultural Science (*Centro de Investigación en Ciencias Agropecuarias,* CICA) a small research centre part of the Autonomous University of the State of Mexico (UAEM). Most of the input data to calibrate the DCMM was collected from two maize fields, which belong to two different case study farmers from *ejido* Taborda. Recall that the case studies were selected from a larger sample of 60 *campesino* farmers from two communities, surveyed during the 1996 maize-growing cycle. Four more farmers and their maize fields were selected as case studies and monitored for the 1997 growing cycle, the data from this survey being used to validate the model once it was calibrated.

4.2.1. The model

The CERES-Maize model (CMM), was originally developed by Jones *et al.* (1986a) and later adopted and modified by the IBSNAT project (Jagtap *et al*., 1993; Tsuji *et al.*, 1994). It allows the quantitative determination of growth, development and yield of maize (Ritchie *et al.,* 1989). The growth of the crop is simulated with a daily time step from sowing to maturity on the basis of physiological processes as determined by the response of the crop to soil and aerial environmental conditions (Singh *et al.,* 1993; Jagtap *et al.,* 1993). The model can also simulate the effects of cultivar, planting date, planting density, N fertiliser dose, and irrigation on crop growth, development, and yield (Ritchie, 1986). The CMM does not simulate the phosphorous and potassium cycles in the soil or plant, nor, the effects of weeds, other pests and wind damage.

4.2.2. Selection of case studies

Because the DCMM is not sensitive to the effects of pests and limiting nutrients, it became necessary to select some of the best farmers where the maize plants were less likely to suffer from these stress sources, so the collected data could reflect plant growth and development under the best possible environmental and management conditions. Based on these criteria, two farmers from a larger sample of 60 were selected as case studies for the 1996 growing cycle.

The chosen farmers were recognised as good maize producers by other local farmers. One maize field from each farmer was selected. One field was approximately 11,500 m^2 and was planted with a local white maize variety "*Criollo Blanco*" (**CB**), while the other was 10,000 m^2 and was planted with a local yellow maize variety "*Criollo Amarillo*" (**CA**). Both fields were irrigated two weeks before sowing.

The objective of the research was explained to the farmers who were asked to cultivate the maize in their traditional way; no advice or recommendations were given by the researcher. The maize production cycle for these two farmers was closely monitored from land preparation to harvest. A careful recording was made of every cultivation activity, the type and amount of inputs used, and the occurrence of plant phenological events. The same procedure was repeated for the fields monitored in 1997 (two fields planted with CB and two with CA).

4.2.3. Model calibration

To calibrate the model a "Minimum set of data", defined by Ritchie *et al.*, (1986) and Singh *et al.*, (1993) as the necessary information to calibrate and run the CERES-Maize model, was collected both through direct measurement of the variables of interest in the case study fields and through the following PRA techniques: interviews, group discussions, cropping calendars, and direct observation (Kumar, 1993), that were applied to the case studies and all the surveyed farmers. The main elements of the minimum data set are listed in Table 4-1.

Table 4-1. Minimum data set collected to calibrate the CERES-Maize model.

Type of data	Description
Weather	Daily values of maximum and minimum air temperatures, rainfall and solar radiation.
Soil characteristics	Soil profile, and then for each layer: layer depth, pH, dry matter content, organic carbon content, bulk density, and volumetric moisture content.
Soil fertility	Soil fertility and soil water variables for each layer in the soil profile: nitrogen content (extractable ammonium N and nitrate N) phosphorous content, and volumetric soil water before the beginning of the growing season
Specific coefficient for each maize cultivar studied	Phenology and yield characteristics of the local maize plants, includes: Thermal time (base 8^{O}C) for the duration of the juvenile phase, and the duration of the silking to physiological maturity phase, maximum number of kernels per plant, individual kernel weight, number of kernels per squared meter and number of leaves per plant.
Crop cultivation practices	Cultivation practices used by local farmers which affect the final output of the model and includes: emerged plant population, row spacing, seeding depth, and harvest date.
Fertiliser management	Types of fertiliser applied, dates of application, amounts per application, method of incorporation, and placement of all fertiliser applications, and depth of placement.
Crop residue and manure application	Amounts of crop residues and animal's manures which are incorporated into the soil: Amount of residue, date of incorporation, and C:N ratio of the residue (or %N, and %P of residue)

4.2.3.1. Maize phenology and yield

All phenological events in Table 4-1 were determined according to the methods proposed by Reyes (1990), which basically consist in counting 10 plants to determine the number of plants out of the total where the event of interest has occurred already, for example 75% silking was determined when 7 or 8 plants out of ten were in silking stage. This procedure was repeated several times at random in different parts of the field to be sure that the event had already started in most of the plant population. Soil samples were collected in every field, and analysed at CICA´s laboratory.

Estimation of grain and straw yield were determined using two different methods. In the first method, which is recognised as a valid approach to estimate crop yields, the farmers were asked to record yields for grain and straw immediately after harvest (Casley and Kumar, 1988). For the second method, a more traditional approach was used, 18 rows of two meters each were selected at random in each of the surveyed fields, the total biomass above ground in each row was harvested, cobs were separated from leaves and stem, and were weighed and recorded separately. Samples from straw were collected and taken to the laboratory to determine moisture and nitrogen content. All the cobs were also taken to the laboratory to determine moisture content at harvest, grain weight per unit area, number of kernels per cob, weight per kernel and grain nitrogen content. Total grain and stalk yields obtained this way were compared with the yields reported by farmers after harvest, both methods reported similar results.

4.2.3.2. Weather data

Data on mean daily maximum (Tmax), and minimum (Tmin) air temperatures, and daily rainfall for 1996 and 1997 was obtained from the meteorological station of the Faculty of Agriculture of the UAEM, while data on solar radiation were provided by the National Water Commission (*Comisión Nacional del Agua, CAN*-personal communication) of the Ministry of Agriculture. Historical data for the last 30 years were obtained (mean monthly values only) from the Ministry of Agriculture (SARH, 1982, CNA 1996 personal communication). Weather data for 1996 and 1997 were used to calibrate the model, and historical data were used to simulate more years of weather data.

Daily weather data were imported to WEATHERMAN (Pickering *et al*., 1994) which is a DSSAT v3 programme, designed to automate some of the tasks associated with handling, analysing, and preparing weather data for using it with the DSSATv3 crop models (Tsuji *et al*., 1994). Weatherman was used to prepare the raw climate data into the right format and file type, so it could be read by DCMM. Daily weather variables were also simulated using SIMMITEO (Weatherman's weather generator that uses monthly means from a secondary data source to generate sequences of daily weather data), the climate variables simulated this way were photosynthetically active solar radiation in MJ m^{-2} d^{-1}, maximum and minimum daily air temperatures and daily rainfall in mm.

4.2.3.3. Calibration of genetic coefficients:

Once the data on climate, soil, and management were put into the model, and that the data on plant phenology and yield were available, the genetic coefficients for the local maize varieties were estimated (P1, P2, and P5 for phenology, and G2 and G5 for grain yield). P1, P2 and P5 were estimated by using the observed silking and maturity dates, while for G2 and G3 the observed number of kernels per ear was used for each of the varieties (Table 4-1). The coefficients were adjusted using "GENCALC" (Hunt *et al.,* 1993) until there was a match between the observed and simulated dates for silking and maturity, and between the observed and simulated yield variables.

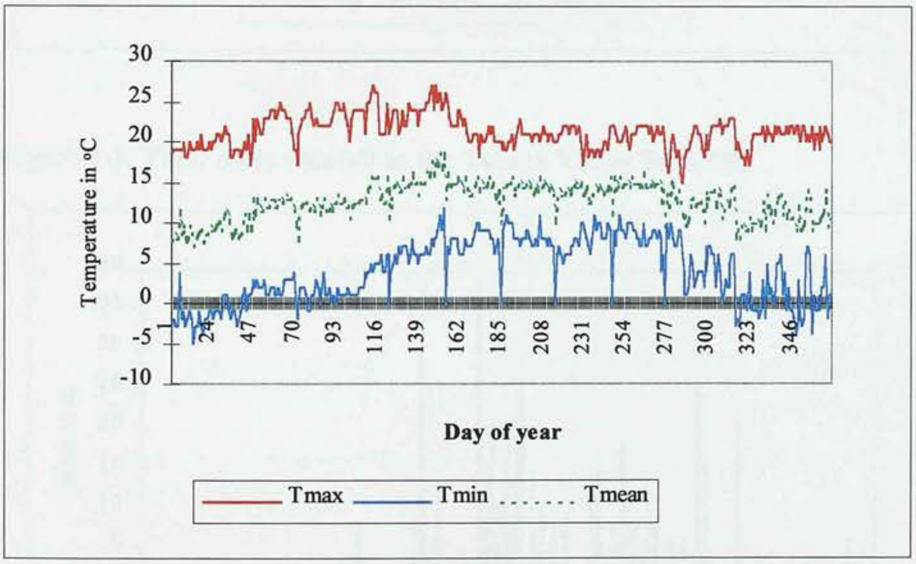
Model predictions were compared with measured data, and the difference was expressed in percentage and in standard error of the mean units (SEM). The calibrated model was validated against the data measured during the 1997 maize growing cycle. Simulated data were also regressed against observed data for grain and stalk yield only. Once the model was calibrated, it was run for different planting densities and different nitrogen application doses to find the optimal combination for these two inputs. It was also intended to run the model for different manure doses, however the model does not properly simulate manure utilisation and degradation, so the results were not included.

4.3. Simulating maize production

4.3.1. Weather characteristics

Temperature: Daily air temperatures registered in the Toluca Valley during 1996 are presented in Figure 4-1. There were large variations in between daily maximum and minimum temperatures. During the first three to four months of 1996, there were many days with temperatures below zero at night and reasonably warm (20 °C) during the day. Air temperatures for 1996 are within the range reported by García (1988) and SARH (1982). An analysis of the historical weather data for the period between 1966 to 1992 in the Toluca Valley (SARH, 1982) for the mean monthly maximum and minimum temperatures also revealed that the temperatures observed in the Valley during 1996 and 1997 lie within the average for the region (Figure 4-2); therefore these temperatures were used for the modelling work.

Figure 4-1. Daily maximum, minimum, and mean air temperatures in the Toluca Valley for 1996



Rainfall: Daily rainfall recorded at the Toluca Valley in 1996 is presented in Figure 4-3. The rainy season started in late May and ended in October, with a rainfall of 735 mm, within the range for the Valley (SARH, 1982).

Solar radiation: Solar radiation data was obtained from the local office of the CNA and the mean monthly values are presented in Figure 4-4.

Figure 4-2. Mean monthly maximum, minimum and mean temperatures in the Toluca Valley from 1966 to 1992.

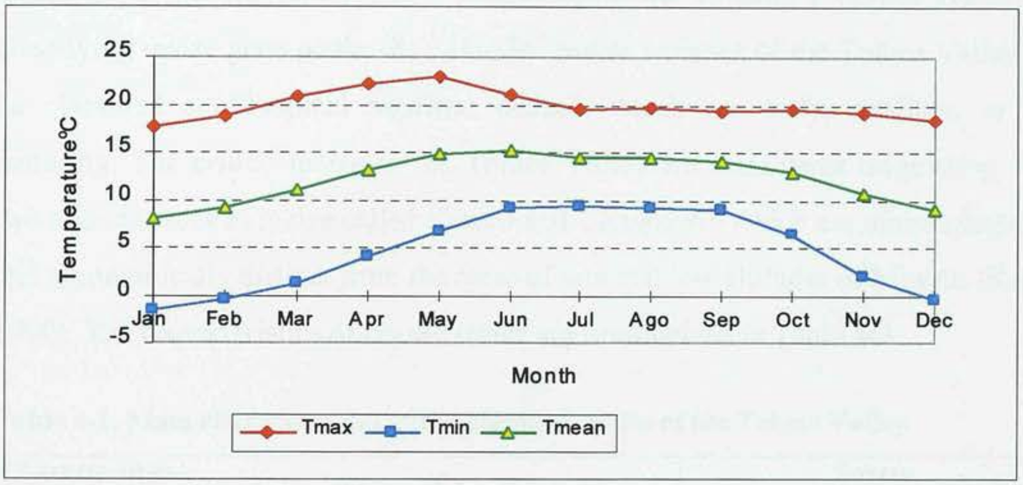


Figure 4-3. Total daily rainfall in the Toluca Valley for 1996

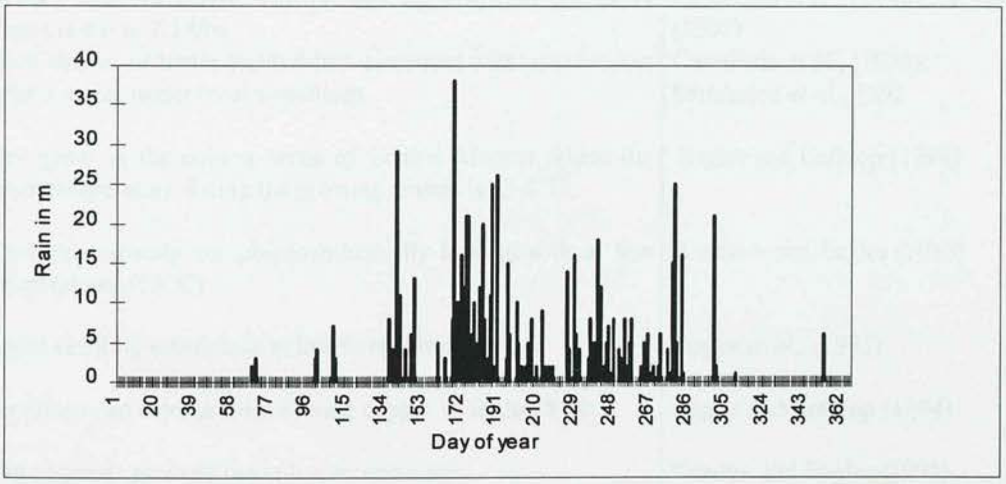
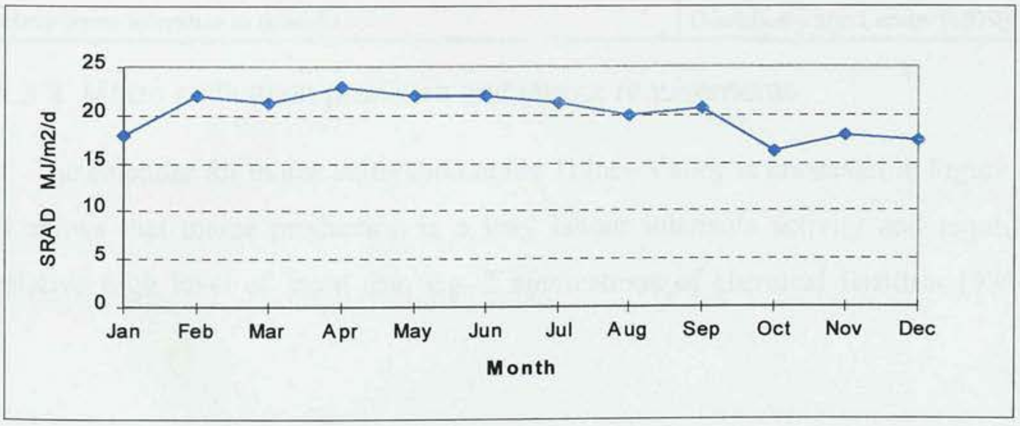


Figure 4-4. Mean monthly solar radiation in 1996



4.3.2. The *Criollo* maize of the Toluca Valley

Reyes (1990) reports that 707 types of *criollo* maize have been identified in the highlands of the State of Mexico. According to the CIMMYT (1980) system for classifying maize gene pools, the "*Criollo*" maize varieties of the Toluca Valley can be classified as "Tropical highland maize", which are early, medium, or late maturing. The c*riollo* maize of the Toluca Valley are semi-dents originating from two ancient races of maize called *Conico* and *Chalqueño*, which are morphologically and agronomically distinct from the races of mid and low altitudes of Mexico (Reyes, 1990). The characteristics of *criollo* maize are summarised in Table 4-2.

Table 4-2. Main characteristics of the highland maize of the Toluca Valley

Characteristics	**Source**
Require 160 to 180 days from sowing to maturity	Castañeda *et al*., (1996); Eagles and Lothrop (1994)
Require 98 to 123 days from sowing to silking	CIMMYT (1977); Castañeda *et al*., (1996)
Grain yield for maize with pre-sowing irrigation (*punta de riego*) is 4.0 to 7.5 t/ha	Castañeda *et al*., (1996); González, (1997)
Have similar or better yields when compared with improved or hybrid maize under local conditions	Castañeda *et al*., (1996); Fernández *et al*., 1992
Can grow in the coldest areas of Central Mexico where the mean temperature during the growing season is 13.4 ºC	Eagles and Lothrop (1994)
Have the capacity for photosynthetically base growth at low temperatures (13 ºC)	Hardacre and Eagles (1980)
Rapid seedling emergence at low temperatures	Eagles *et al*., (1983)
Seedlings can emerge from sowing depths of up to 25 cm	Eagles and Lothrop (1994)
Can continue grain filling at low temperatures	Newton and Eagles (1991)
Can survive light frosts	Eagles and Lothrop (1994)
Have some tolerance to drought	Castleberry and Lerette (1979)

4.3.3. Maize cultivation practices and labour requirements

The calendar for maize cultivation at the Toluca Valley is presented in Figure 4-5. It shows that maize production is a very labour intensive activity and requires a relative high level of input use, e.g. 2 applications of chemical fertiliser (93% of farmers use chemical fertilizer), manure application (85% of farmers) and mechanical and chemical weeding (93% of farmers use herbicides). Figure 4-5 also indicates the start and duration of both the rain and frost seasons in relation to the different cultivation activities, from which it is easy to appreciate that farmers have identified a "time window" (mid May to October) when conditions are appropriate to grow rainfed maize. Farmers who have access to water (% of farmers have access to irrigation), irrigate only once two weeks before sowing ("*punta de riego*" = irrigation lead), which allows sowing one month before the rainfed maize, enabling the growth of later maturing maize types over a longer period of time. Irrigation is a clear advantage over rainfed land, since grain yields for irrigated land are 2 or 3 tons higher than non-irrigated land.

These results indicate the existence of two main maize production technologies: irrigated and non-irrigated. However, since not all farmers have access to irrigation (82% have access to irrigation) and the farmers who have access to it, normally don't have sufficient water to irrigate all their land. It is very common to observe the use of both technologies in the same farm. The use of herbicide determines two more production technologies (which made four main production technologies in total): irrigated maize with herbicide application (**IH**), only irrigated (**I**), rainfed with herbicide application (**RH**) and rainfed only (**R**). The difference between these systems is clearly illustrated in Figure 4-5. In this chapter only irrigated maize was simulated.

Labour requirements: maize production requires significant quantities of labour allocated at very specific periods in the year. The growth and phenology of the crop (see Figure 4-5) determine these periods. The amount and timing of labour required to cultivate maize was investigated because of its implications in terms of simulating the crop itself and the system as a whole. Labour requirements and labour supply are two of the driving variables of the IFSM (see Chapter 7). Figure 4-5 shows the different cultivation works required for 1 ha of maize, the month when these take place, the amount of labour required for each work in man days per ha (MD/ha) and the members of the household who are responsible (or may participate) for carrying them out. The amount of hired labour is shown too. This figure also shows that most of the land cultivation is mechanised. Mechanised activities are under the heading "contractor". A “contractor system” was observed where farmers without tractors (64% of farmers in the MLPS) hire the services of farmers who own one. Table 4-3 also indicates the price paid to the contractors in Mexican pesos (Mx$) per work per ha of land. The use of draught animals is not common in the Valley, only 7% of farmers in MLPS and 17% in the IMLPS use draught animals. These results are in substantial agreement with those of Arriaga *et al.*, (1997b) and González (1997).

The use of contractors has allowed farmers to reduce the amount of labour they have to supply to cropping activities. However, there are some activities such as sowing, mechanical weeding and ridging, which are performed by the contractor, but still need the assistance of the farmer and his family or even hired labour (Figure 4-5). Notice that the total amount of labour required for cultivating maize in each main technology is different. For example, IH-maize requires less labour than I-maize. This is explained because in I-maize more labour is needed for weeding. Similarly rainfed maize requires less labour than irrigated because no labour is used to irrigate, and less time is spend in weeding.

Figure 4-5 also indicates the cultivation activities used by farmers to remove both weeds and green maize fodder during the rain season. **Hand weeding** takes place from June to October for irrigated maize and from August to October for rainfed maize. During these months weeds are cut and carried to feed cattle, early frosts in November kill all weeds and no weeding is performed after October. In the case of irrigated maize barren plants or plants with small cobs are thinned from August to September when it is evident to farmers which plants can be removed without compromising grain yield. Tops are scotched in October from all maize plants since the cobs reach maturity in this month. A similar pattern was observed for rainfed maize except that thinning takes place only in October and no scotching was observed.

Figure 4-5. Cultivation calendar and labour requirements to produce 1 ha of maize

Activity	Rainfall mm	Cultivation technology					Household labour						Hired
		Cont. cost (Mx$)	IH MD/ha	I MD/ha	RH MD/ha	R MD/ha	DM	SP	SON	DG	CH	OTH	labour
JAN	18												
Ploughing		300	0.5	0.5			+						
FEB	10												
Harrowing		160	0.5	0.5			+						
MAR	16												
Manuring		40	2	2			+		+				
Irrigation		150	2	2			+						
Plough		300			0.5	0.5	+						
Harrow		160			0.5	0.5	+						
APR	29												
2nd Harrowing		160	0.5	0.5			+						
Sowing+fertilizing		170	1	1			+	+					
MAY	71												
Mechanical-weeding		150	2	2			+		+	+			
2nd Harrowing		160			0.5	0.5	+						
sowing +fertilizing		170			1	1	+	+					
JUN	153												
Ridging		150	2	2			+		+	+			+
Hand weeding				1.25			+	+	+	+			
Mechanical weeding		150			2	2	+		+	+			
JUL	160												
Fertilizing			2	2			+		+	+			+
Spraying			1				+		+				+
Drain making			1	1			+		+				
Hand weeding				4			+		+				
Ridging		150			2	2							+
AUG	160												
H. weeding + thinning				3			+		+				
Fertilizing					2	2	+		+				+
Spraying					1		+		+				+
Draining					1	1	+		+				
Hand weeding						4.25	+		+				
SEP	129												
H. weeding+thinning				5			+		+				
h.weed						4	+		+				
OCT	74												
H. weed+ scottching				4									
h.weed+thinning						3							
NOV	24												
Harvesting			15	15			+	+	+	+			+
H. transport+storage		100	3	3			+		+	+			+
DEC	16												
Stover harvest&storage		120	14	14			+		+				+
Harvest					13	13	+		+				+
H. transport+storage		100			2	2	+		+				+
JAN													
Stover harvest&storage		120			10	10	+		+				+
Total labour			**46.5**	**60.75**	**35.5**	**45.75**							

IH=Irrigated maize+herbicide, I=Irrigated maize-no herbicide, RH=rainfed maize+herbicide, R=rainfed maize-no herbicide, DM=decision-maker, SP=spouse, DG=daughter, CH=children, OTH=other relatives, + =Indicates which household member takes part in the activity. All figures for labour represent man-days (MD) per ha.

4.3.4. Model predictions

In Tables 4-3 and 4-4 the output of the model is compared with the observed values, the differences between the measured and the calibrated (simulated) values for each of the cultivars are showed in percentages and in standard error of the mean units for most yield parameters. Appendix 1 shows the output of the DCMM for these two cultivars used to calibrate the model.

Table 4-3. A comparison between field measured and the model predicted yield figures for the *Criollo Blanco* and the *Criollo Amarillo* maize cultivars.

Maize Type	***CB*** **Measured**	***CB*** **Model Prediction**	**Difference**	***CA*** **Measured**	***CA*** **Model prediction**	**Difference**
YIELD ASPECTS DATA						
Biomass at harvest maturity (kg/ha)	14 480 (±562)	11 804	18.4 [4.7]	12 546 (±379)	11 097	11.5 [3.8]
Stalk at harvest maturity (kg/ha) dry	7987 (±603)	5 696	28.6 [3.8]	6801 (±531)	5 494	19.2 [2.4]
Harvest index (dry weight)	0.45	.51	13.3	0.46	0.50	8.7
Final leaf number	18	17.6	2.2	18	17.6	2.2
Grain yield (kg/ha) dry	6 493 (±680)	6108	6.0 [0.56]	5745 (±334)	5 604	2.4 [0.42]
Weight per grain (g/grain) dry	0.422 (±0.01)	0.390	7.5 [3]	0.370 (±0.01)	0.347	6.2 [2]
Grain number (grain/m2)	1632	1 566	4.0	1720	1613	6.2
Grain number / ear	340 (±21)	326.3	4.0 [0.65]	374 (±21)	350.5	6.3 [1.1]
Grain nitrogen (kg/ha)	108.1	104	3.8	90.7	95	4.7
Biomass nitrogen	184.3	139	25.0	141	130	7.8
Stalk nitrogen (kg/ha)	76.2	35	54.0	51	35	31.7
Seed nitrogen (%)	1.66	1.7	2.4	1.58	1.7	7.6
Stalk nitrogen (%)	0.95	0.61	35.8	0.75	0.63	16.0
Maximum leaf area index m^2/m^2	2.5	2.05	18.0	2.7	1.96	27.4
Grain moisture at harvest (%)	11.4	15	31.6	12.4	15	21.0

Figures in ( ) represents the standard error of the mean (SEM) for the variables measured in the field. Figures in [ ] represent the difference between the measured and the model simulated variables in SEM units. Figures without brackets represent the difference between measured and the model simulated variables in %. Stover includes stem and leaves.

Table 4-3 shows that the model gives good predictions for grain yield for both maize cultivars. In the case of CB the difference between the measured and simulated yield is only -0.5 SEM units, while for the CA is -0.4. Other grain yield related variables also produced good simulated results when compared to the observed values, e.g. grain number per ear (-0.65 SEM units for CB and -1.1 SEM units for CA), and weight per grain (-3 and -2 SEM units for the CB and CA respectively).

Model predictions for stalk yield were not very good in the case of the CB (-3.8 SEM units) which produced a large quantity of stover that the model was not able to simulate. Stover prediction for the cultivar CA was better, although still an important difference between the simulated and the measured value was observed (-2.4 SEM units). The partial failure of the model to produce better predictions for stover yield, affected other simulated variables which are calculated by the model using this figure, like biomass at harvest maturity, harvest index, and biomass nitrogen. The difference for these parameters is presented in SEM and percentage units in Table 4-3, where it can be observed that the difference for the cultivar CB (-4.7 SEM units, 13.3% and 25% respectively) are bigger than the cultivar CA (-3.8 SEM units, -8.7%, and 7.8%) for which in general the model produced better predictions.

Table 4-4 presents model predictions for the different growth stages of the two maize cultivars, which in general provided good predictions for the three phenological events that were measured in the field: emergence date, 75% silking date, and maturity date. In both cultivars the model predictions were below four days of difference between the measured and simulated dates. One important aspect is that farmers who have access to irrigation plant the maize seeds at depths of 14 to 16 cm to allow the seedling to have soil moisture for a longer period before the rainy season (Figures 4-3 and 4-5). As shown in Table 4-2 this does not represent a problem for local maize since it can emerge from deeper planting depths, but it is a problem for modelling, because the model took a long time to reach plant emergence. When the planting depth was reduced, the model produced better results, as is evidenced in Table 4-4. The model also overestimated the duration of the 75% silking to the start of the grain filling phase (XSTAGE=4, in the model), 27 days for both cultivars, when the normal value for this phase is no longer than 10 days.

Table 4-4. A comparison between the field measured and the model predicted figures for phenology of the *Criollo Blanco* and the *Criollo Amarillo* maize cultivars.

Maize Type	*CB* Measured	*CB* Model Prediction	Difference in %	*CA* Measured	*CA* Model prediction	Difference in %
PHENOLOGY						
Sowing date [a]	12/04/96	12/04/96		15/04/96	15/04/96	
Plant population at seeding (seeds/ha) [a]	52 380	-		48 648	-	
Plant population at emergence (plants/ha)	48 000	48 000		46 700	46 000	
Planting depth in cm. [a]	14-16	9.0		14-16	9.0	
Germination date (dap)	2 14/04/96	1		2 17/04/96	1	
Emergence date (dap)	12 24/04/96	14	16.6	13 28/04/96	14	7.7
75% silking phase (dap)	103 20/07/96	99	3.88	100 24/07/96	99	1.0
Beginning grain filling phase (dap)	109 30/07/96	126		111 04/08/96	126	
Maturity date (dap)	175 09/10/96	182	4.0	171 03/10/96	177	3.5
Harvest date (dap) [a]	252 20/12/96	207		224 25/11/96	202	

dap = Days after planting. [a] Not applicable because these factors were calibrated.

The model was validated with the data on maize growth and development collected during the 1997 growing cycle; the results are presented in Figures 4-6 and 4-7. It is not surprising to observe that the model performed better for grain yield where 81% of the variation in observed yields is explained by the model (see Figure 4- 6), while only 20% is explained in the case of stalk yield (Figure 4-7).

Figure 4-6 . Observed *vs* predicted grain yield for the CB and CA maize cultivars.

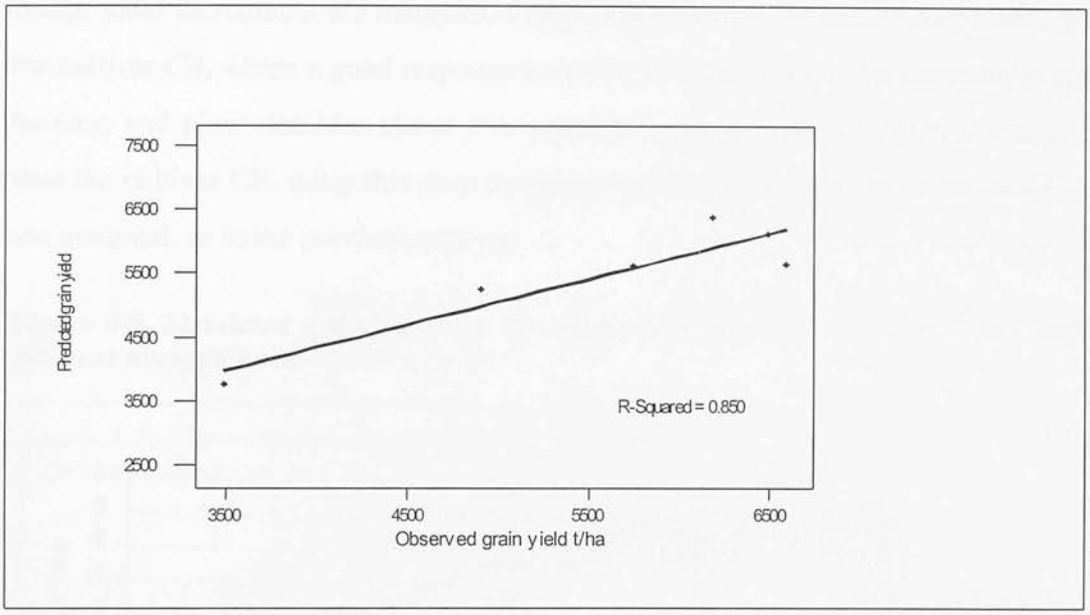


Figure 4-7. Observed *vs.* predicted stalk yield for the CB and CA maize cultivars

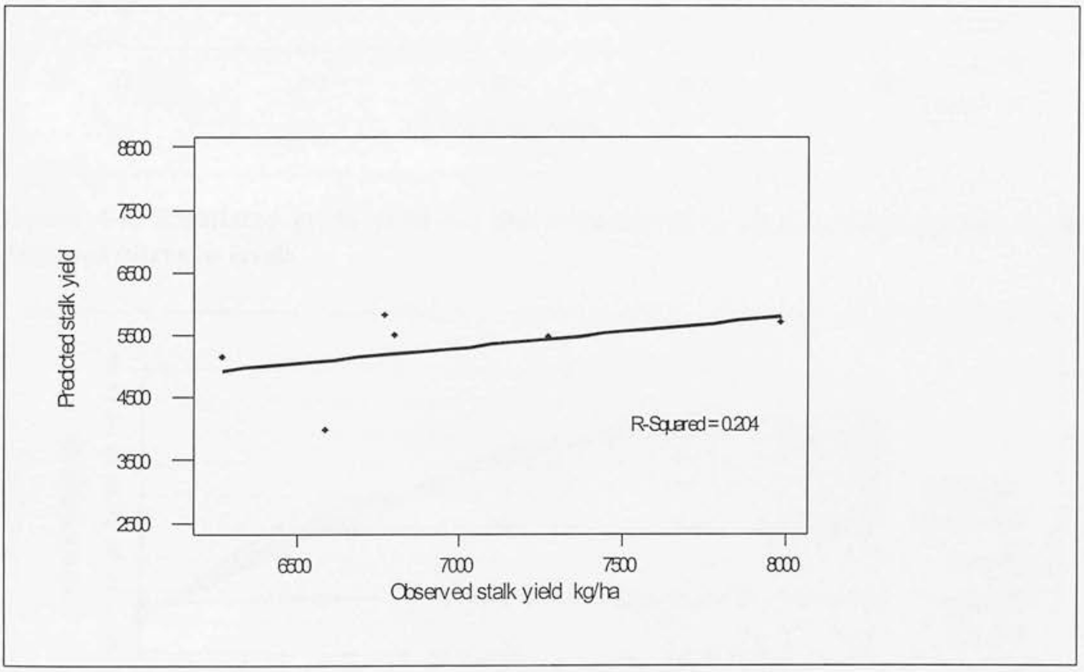


Figure 4-8 shows the model prediction for grain yield for the cultivar *CB* to different nitrogen application rates, and six planting densities. The model predicts the optimal combination of plant density and N fertiliser for higher yields with a density

density above five plants m^{-2} (7 to 9 plants/m^2), and 90 kg of nitrogen ha^{-1}, after which yield increments are marginal. Figure 4-9 presents the same comparison for the cultivar *CA*, where a good response is obtained at a dose of 60 kg of nitrogen per hectare, and plant densities above five plants/m^2, which mean 30 kg less nitrogen than the cultivar CB. After this dose the increments in grain yield per extra nitrogen are marginal, as in the previous cultivar.

Figure 4-8. Simulated grain yield for the cultivar CB to six planting densities with different nitrogen levels

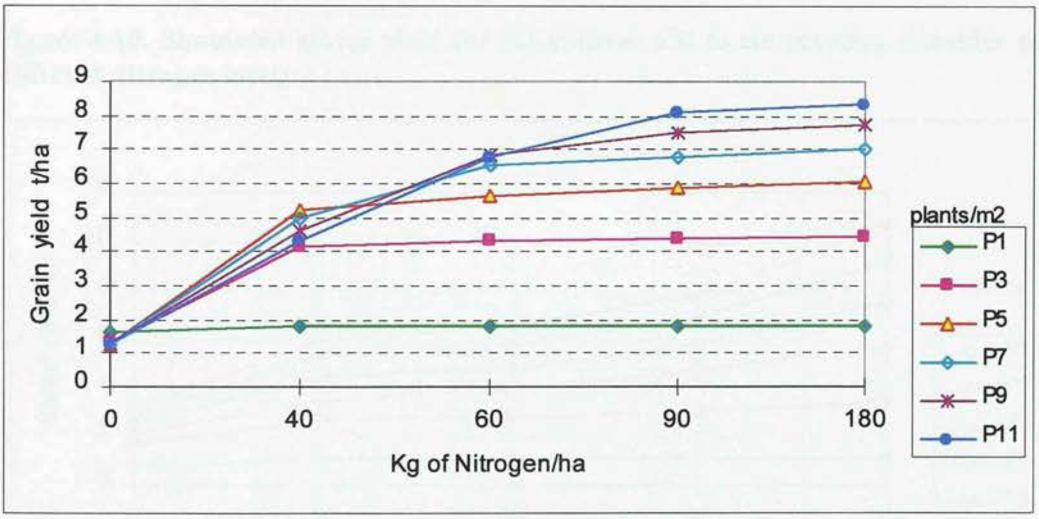
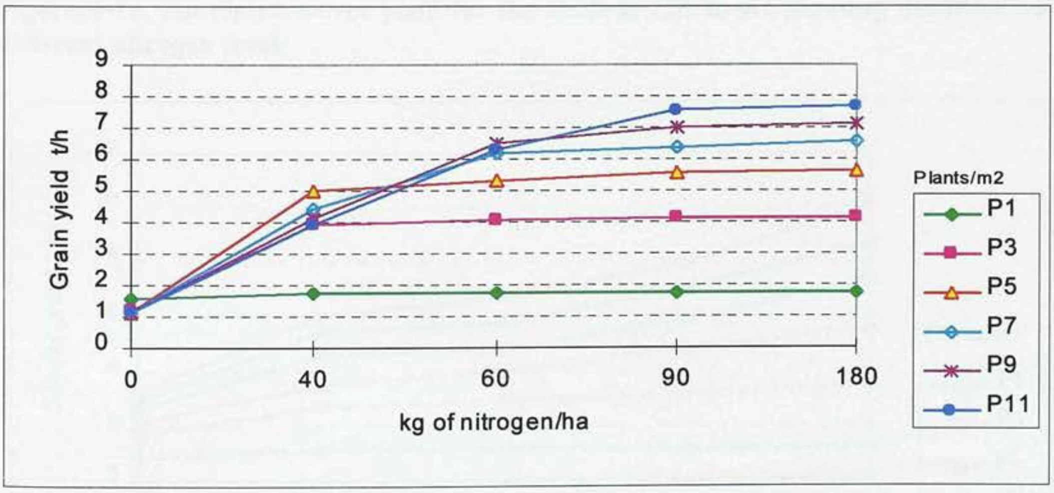


Figure 4-9. Simulated grain yield for the cultivar CA to six planting densities with different nitrogen levels



Figures 4-10 and 4-11 show the model response to the same nitrogen doses and plant densities as for grain yield, but for straw yield. The best response for straw production is reached at higher nitrogen doses than for grain yield. This is explained because when the nitrogen requirement for grain production is covered (in the model) the surplus nitrogen is used to produce more leaves and stems, and may suggest that what farmers are doing at the Toluca Valley is producing large quantities of straw in addition to grain at the expense of larger nitrogen doses, since both elements are very important to the system.

Figure 4-10. Simulated stover yield for the cultivar CB to six planting densities with different nitrogen levels

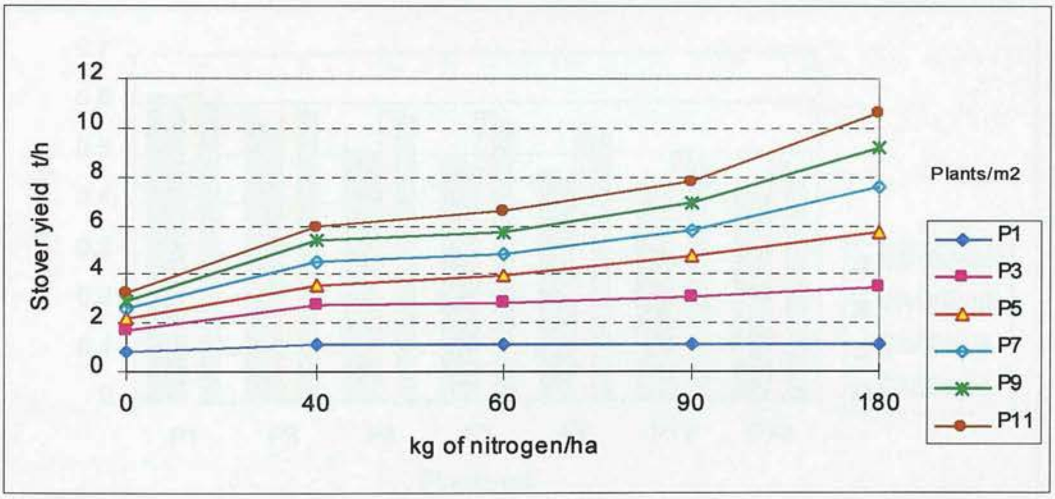


Figure 4-11. Simulated stover yield for the cultivar CA to six planting densities with different nitrogen levels

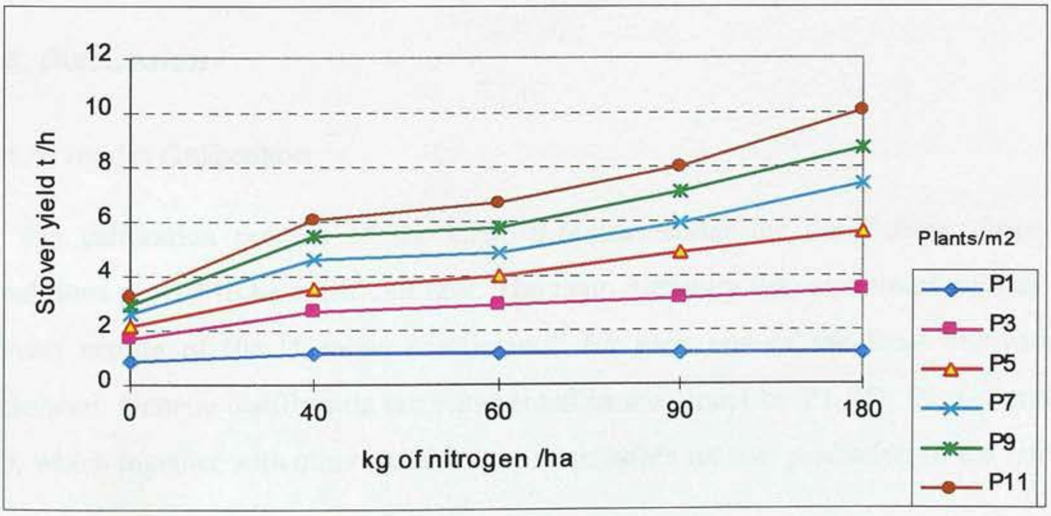
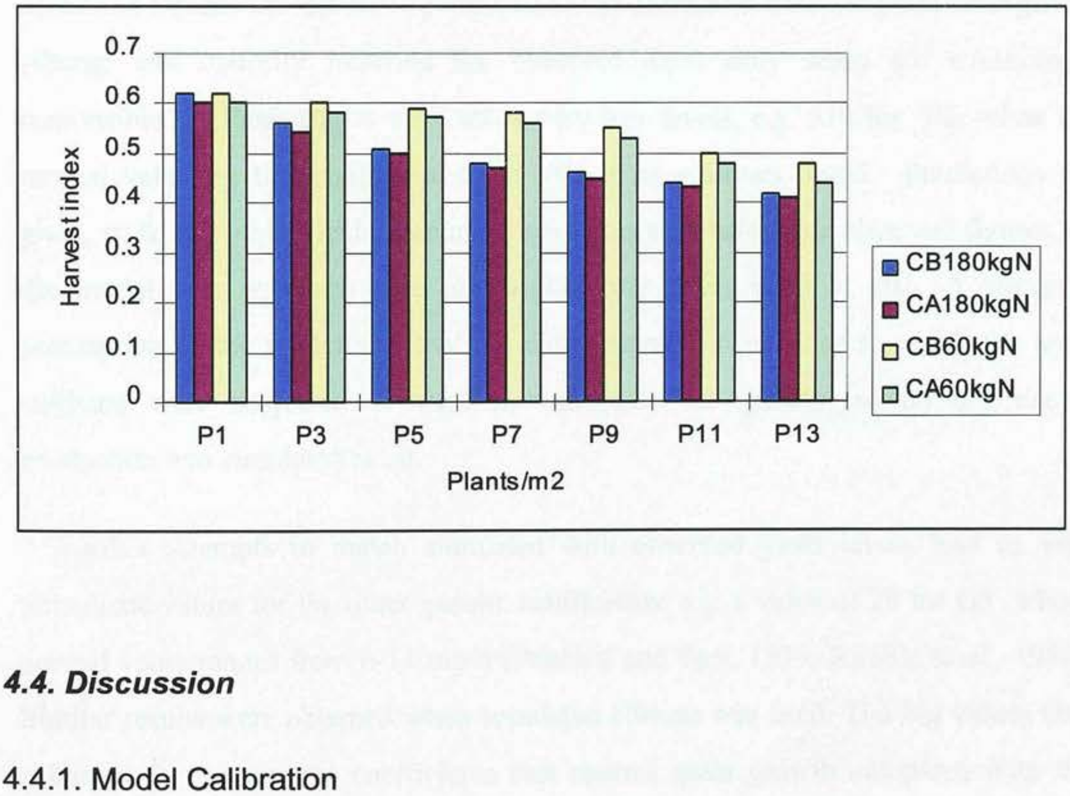


Figure 4-12, shows the model predictions for the harvest index (HI) of the simulated cultivars, from where it can be observed that in both cases the model tends to divert most of the dry matter produced towards grain production, leaving the rest for stalk formation (higher HI means that more assimilates are moved to grain). When a dose of 180 kg of N is used in both cultivars (CB and CA) the model predicts HIs similar to the measured ones only when high planting rates are used (9 plants/m^2), but when nitrogen is limiting most of the assimilates are moved towards grain production even at high planting rates.

Figure 4-12. Simulated harvest index for the CB and CA cultivars to two nitrogen levels and seven planting densities



4.4. Discussion

4.4.1. Model Calibration

The calibration process of the CERES-Maize model for the Toluca Valley conditions proved to be a difficult task. The main difficulty was associated with the correct setting of the "Genetic coefficients" for each one of the local cultivars simulated. Genetic coefficients are represented in the model by P1, P2, P5, G2 and G3, which together with other variables are responsible for the prediction of the rate of ontogeny of simulated maize cultivars. P1 and P5 represents the accumulation of growing degree days base $8^{o}C$ (GDD_8) during a particular growth stage, e.g. from seedling emergence to the end of the juvenile phase for P1, and from silking to physiological maturity for P5. P2 is a photoperiod sensitivity coefficient, which determines tassel initiation. G2 and G3 determine potential kernel number and potential kernel growth rate respectively (Ritchie *et al*., 1986).

After many attempts to set the genetic coefficients with the help of GENCALC (Hunt *et al*., 1993) for each of the two local maize cultivars, it was not possible to match the model simulated dates of phenological events and yield variables with the measured figures for the same parameters. The simulated dates of plant emergence, silking, and maturity matched the observed dates only when the coefficients responsible for these stages were set at very low levels, e.g. 510 for P5, when the normal value for this coefficient is 685 for most cultivars tested. Predictions for grain, stalk and other yield parameters were also well below the observed figures, or the model was not even able to simulate any grain yield at all. A common assumption of the model was that the environmental conditions to which the local cultivars were subjected to were not adequate for growth, so no dry matter production was simulated at all.

Further attempts to match simulated with observed yield levels lead to very unrealistic values for the other genetic coefficients, e.g. a value of 20 for G3 whose normal value ranges from 6-11 mg/d (Poneleit and Egli, 1979; Ritchie *et al.,* 1986). Similar results were obtained when simulated climate was used. The big values thus achieved for the genetic coefficients that control grain growth compared with the relatively small values of the coefficients that control plant phenology, suggested that the low temperatures, together with the large range between the daily air minimum and maximum temperatures to which maize plants are exposed at the Toluca Valley, may be responsible for the failure of the model to properly simulate maize growth under local conditions. In order to test this hypothesis the daily minimum temperature was increased by 1 ^{o}C for each day of the growing period. The performance of the model improved tremendously corroborating the previous assumption.

Temperature is one of the major driving variables of most crop models (Kiniry and Bonhome, 1991), as is the case of the CERES-Maize model (Jones *et al.*, 1986a), where temperature controls or influences important model subroutines which determine the occurrence of plant events in the model. For example, temperature is the driving variable in the subroutines "PHENOL" and "GROSUB": the first determines the occurrence of the different phenological events of a maize plant, while the second controls leaf area development, light interception, photosynthesis, and partitioning of biomass into various plant parts. The effect of air temperature on these processes is determined by the accumulation of thermal units or GDD_8 expressed as DTT in the model (Jones *et al.*, 1986b).

In the DCMM thermal units are calculated using the "remainder index procedure" which assumes a linear relationship between rate of plant development and temperature above a specific lower base, i.e., that temperature at the lower end of the temperature range, 8 °C for the CMM, which represents the highest temperature at which the rate of development is assumed to remain zero (Tollenaar et *al.,* 1979). This approach works fine for most cultivars that were used to develop the DCMM, or that have been used to test the model in different regions of the world. This has mainly involved hybrids of high yield levels and short growing season, cultivated in temperate regions or in lowland tropics where the Tmax and minimum Tmin are likely to stay within the range normally considered as the optimal for maize growth (Tmin= 8 and Tmax= 34 °C, with a optimum daily mean of 26 °C) (Tollenaar *et al.*, 1979; Warrington and Kanemasu, 1983; Kiniry and Jones, 1986).

However, the performance of the model in this work suggests that this approach may not work for cultivars which are grown in highland regions where the mean daily temperature is low (14 -15 °C) and there is a large variation among Tmax and Tmin. The Toluca Valley is a good example of this where the daily maximum and minimum temperatures may not exceed 25 and 8 ^{o}C respectively, during most of the maize growing season (Figure 4-1). An important consequence of this temperature pattern in terms of the modelling work, has to do with the low number of GDD_8 that will be accumulated in any particular growth stage of the plant (SUMDTT), and that long growing seasons are required to accumulate the necessary GDD_8 to successfully simulate maize growth. This is the case even if the model uses a correction factor for temperatures below the base temperature (8 ^{o}C), as the DCMM does (Jones *et al.*, 1986b).

For example, XSTAGE=4 is completed when SUMDTT= 170 GDD_8. In most conditions tested this period is completed within 10 days; however it took the model 27 days to reach this figure when normal air temperatures of the Toluca Valley were used. Moreover, the germination to emergence stage (ISTAGE=9) occurs when the SUMDTT is equal to P9, which is calculated by the equation P9 = 15. + 6. * SDEPTH, where SDEPTH= sowing depth in cm. So the deeper the seed is planted the larger number of GDD_8 will be needed to complete this growth stage. When the sowing depth used by farmers was input to the model, it took nearly 30 days for the seedlings to emerge, so a reduced depth was used as shown in Table 4-4.

It is apparent that highland cultivars (HC) of maize respond slightly different to temperature and have a different optimal temperature range than the temperate or lowland tropical cultivars (Hardacre and Eagles, 1980; Hardacre and Eagles, 1986; Ellis *et al.*, 1992; Eagles and Lothrop, 1994). It is generally agreed that the maximum growth response of maize to temperature will be found in temperatures from 25 to 34 ^{o}C and that less growth is expected at temperatures from 10 to 25 ^{o}C (Brown, 1977; Tollenaar *et al.*, 1979; Warrington and Kanemasu, 1983). On the other hand, the optimal temperature for maize growth also depends on its growth stage: Tollenaar *et al.* (1979) observed an almost linear relationship between rate of leaf appearance and temperature in a range of 12 to 26 ^{o}C with a maximum rate of development at 31 to 32 ^{o}C in an experiment with six maize hybrids.

Warrington and Kanemasu (1983) reported that both leaf-initiation rate and leaf-appearance rate showed near-linear increases as mean temperatures were increased from 15 to 28 °C, maximum rates occurred at 30 to 32 °C for two U.S. Corn Belt hybrid dents. Further, Brown (1977) reported optimum temperatures for the period of emergence to tassel initiation between 25 to 30 °C. The same authors also found a non-linear relationship between the temperature and the plant growth when plants grew under differential day/night temperatures, or when the mean temperature is below or above the base or the optimum for plant growth.

While temperatures above mentioned can be considered as optimal for temperate maize genotypes, there is some recent evidence that may suggest that some highland cultivars like H-32, ACROSS8201, *Criollo de Toluca* and others from CIMMYT pool 5, are less sensitive to temperature than other cultivars and that some of the observations determined for temperate maize may not apply to HC (Hardacre and Eagles 1980; Ellis *et al.*, 1992). Ellis *et al.* (1992) also found that the optimum temperatures for the rate of progress towards tassel initiation for the two highland cultivars evaluated by them are some 9 to 12 °C cooler than that for lowland tropical maize, and definitely cooler than the 30 to the 34 °C generally assumed for development in maize. Ellis *et al.* (1992) demonstrated that the relations between the rate of progress to tassel initiation and suboptimal temperatures are curvilinear with base temperatures of around 8 to 10 °C, in contrast with the common assumption for maize of linear relations above a temperature base, e.g. in the CERES-Maize Model.

Moreover, Hardacre and Eagles (1980) demonstrated that maize genotypes containing germplasm from the high altitude Peruvian races and genotypes from the CIMMYT´s Pool 5, predominantly "*Criollo de Toluca*" were capable of autotrophic growth at a mean daily temperature of 13 °C (constant), while the U.S. Corn Belt dent hybrids did not growth autotrophically at the same temperature. On the other hand, Warrington and Kanemasu (1983) observed that two corn hybrids (early and mid-season U.S. Corn Belt hybrid dents) grew and developed successfully under temperature regimes with cooler means (i.e., 16/6 and 16/11) or more rapidly under increased diurnal temperature variation with the same daily means (i.e., 23/9 compared to 16/6 °C). They concluded that the minimum temperatures that allows corn to grow normally, therefore, will be defined by the response limits to specific day and night temperatures and can not always be defined using mean daily temperature.

The findings of Warrington and Kanemasu (1983) could have important implications for the performance of the different crop models such as the DCMM (when used to simulate plant growth under extreme temperature conditions) that use the remainder index procedure and the mean daily temperature to calculate thermal units, because as was demonstrated by these authors, the limits of the maize plant's response to temperature are set by the day and night temperatures, rather than by the mean daily temperature, as in CERES-Maize.

Hardacre and Eagles (1989) and Ellis *et al.,* (1992) concluded that their results suggest that highland tropical maize germplasm may be characterised by an optimum temperature for development, as for dry matter production, that is significantly lower than that for temperate and lowland tropical germplasm, and that the relation between the rate of progress towards tassel initiation and wide ranges of suboptimal temperatures are curvilinear rather than linear.

The different response pattern to temperature of the highland cultivars may be responsible for the partial failure of the DCMM to simulate maize growth under the climate conditions of the Toluca Valley. In this work an increment in the minimum temperature resulted in better performance of the model, which suggests that at least in the case of the highland maize a different range of temperatures may be required in order to simulate growth and development of highland maize when using the DCMM. From the information reviewed in this work it is suggested that the temperature range should be set to 6 or 7 °C for the base temperature and 25 °C for Tmax. While a reduction in the base temperature is likely to produce better results for simulating phenology, the effects of low temperatures on the subroutine GROSUB, particularly on the estimation of Potential Dry Matter Production (PCARB), will require more review, since in this work the underprediction of stalk yield may be due also to the low temperature effect on PCARB, especially during the juvenile stage of the plant.

4.4.2. Model predictions for different management practices

There is no information in the literature reviewed on the performance of the model to simulate maize growth and development under smallholder's management, since most of the works reviewed involved the use of input data from field experiments (Kiniry and Jones, 1986; Jagtap *et al.*, 1993; Singh *et al.*, 1993); or from the literature (Mbabaliye and Wojtkowski, 1994) which were then used to calibrate the model.

Mostly the CERES-Maize model produced satisfactory predictions for the conditions that have been simulated. Here the model produced better predictions for grain yield, than for stover yield variables, which was not surprising, because of the effects of the low temperatures and because the DCMM is designed to translocate more assimilates towards grain than to straw production, as frequently occurs with hybrid maize cultivars. According to Pham *et al.* (1989), most of the genetic advances in crop yield have arisen not from increased photosynthetic rate but from changing distribution of assimilates to grain while crop biomass has remained the same at optimum plant densities and management conditions.

However, most local varieties of maize produce more stalk than grain; and therefore have a lower harvest index than the hybrids (Singh *et al.*, 1993). A similar performance was observed in the local maize of the Toluca Valley. The DCMM was able to simulate similar measured stalk yields only at high planting densities and high nitrogen rates, e.g. 9 plants/m^2, and 180 kg of N as shown in Figure 4-12, where it can also be observed that the extra nitrogen was used to produce more dry matter which was then allocated to stalk production, but only once grain requirements were covered. The same figure shows that, when a low nitrogen rate (60 kg/ha) was used for both cultivars most of the assimilate is moved towards grain production, despite high planting densities. The partition of assimilates in the model prioritises grain production above stalk production, since only when the daily dry matter increase calculated by the model is not used for grain production, is then partitioned equally between stems and roots (Jones *et al.*, 1986b).

The failure of the model to predict straw production for local maize could represent a problem in practical situations - if any recommendation to farmers about plant density management is going to be made - since straw is a key component for most smallholder *campesino* systems where cattle are present. Furthermore, there is clear evidence that farmers at the Toluca Valley manage the plants in order to cover their multiple objectives which include not only grain yield, but fodder supply and risk aversion. Consequently it is possible to say that farmers have the necessity to compromise between grain and fodder yields, when deciding the planting rate. Similar farmers' rationale was reported by Subedi and Dhital (1997) in maize farmers of the western hills of Nepal.

Moreover, the use of improved maize by local farmers is very limited: according to (Reyes, 1990) this type of maize is only cultivated by approximately 20% of the Mexican farmers. Recent evidence from work at CICA comprising a survey of 104 farmers from the highland valleys of the State of Mexico that had participated in a government programme to extend high yielding technology for maize production, showed that only 12.5% of farmers use improved high yielding varieties, while 87% rely on their *criollo* varieties (Arellano *et al.*, 1997).

The low rate of improved maize use by the *campesino* farmer may be explained because grain yield is not the main consideration in a small-scale farmer's decision about variety. Other factors include taste, cooking quality, grain colour, ease of shelling, and shelling percentage, forage yield, and resistance to pests (Pham *et al.*, 1989). Furthermore, according to CIMMYT (1997), one of the primary obstacles for the adoption of improved varieties is that in many highland areas, every valley or hillside is a unique ecological niche, making it difficult for breeders to develop broadly adapted maize that satisfies requirements over large target areas.

Information on the performance of the local maize under different doses of nitrogen fertiliser and planting densities under *campesinos'* management is limited. As Subedi and Dhital (1997) reported, "there are several published works on maize density studies in other parts of the world under experimental conditions, but not under farmers′ management". The lack of this piece of basic information makes it difficult to evaluate the model for the mentioned variables, and also evidences the need to collect these data from farmers, which will serve for future reference.

On the other hand, it was observed that the model tends to overpredict grain yield when planting densities above nine plants per m^2 are used, probably because the model does not consider the effects of other variables such as weeds, pests and wind that limit higher yields in real situations (Reyes, 1990). From the analysis of the survey data and from farmer's judgement, it is believed that the maximum planting rate used by local farmers is approximately 80 x 10^3 plants ha^{-1}. Farmers are aware that if higher planting rates are used grain yield is negatively affected, so it is quite probable that model predictions for major planting rates do not apply to local conditions. Normal plant populations at harvest recommended to farmers in Mexico range from 45 to 55 x 10^3 plants ha^{-1} (Reyes, 1990).

From the information discussed above, it is clear that more data on the growth and yield of maize cultivated by smallholder *campesino* farmers is needed in order to evaluate the DCMM performance for different management situations. On the other hand, it is also evident that the DCMM could have an important role in evaluating and predicting growth and production of improved maize varieties in the Toluca Valley and other regions of central Mexico, before they are presented to the farmers for evaluation, and possible adoption, reducing this way the associated risk of failure.

4.5. Conclusions and future research

The results obtained in this work suggest that the calibration of the DCMM using input data collected from farmers and their cropping fields instead of using experimental data, is possible and may be crucial in developing systems models, which can be applied both for experimental as for extension purposes. Data collection does not represent a problem as long as the appropriate survey techniques are used and a good level of continuous interaction with farmers can be achieved. Furthermore the model provided good predictions for grain yield and grain yield related parameters, which suggest it has some potential to be used for decision support purposes for grain yield forecast.

However, there are still some problems, which may limit the practical application of the DCMM for the development of alternative cropping systems for smallholders. Of particular relevance for this work is the partial failure of the model to simulate maize growth and development within the temperature range of the Toluca Valley and the incapacity to simulate stover yield of local maize cultivars. In both cases the DCMM did not produce satisfactory results. In the first case the model needs to be adjusted to cope with growth temperatures which are below the normally considered optimum range for maize growth. In the second case, the model also needs to be adjusted to allow more dry matter to be partitioned towards stalk production, which plays a key role in smallholder production systems. Otherwise it may be assumed that improved maize production will have to come only from the use of high yielding hybrids, which do not perform well under extreme climate situations where local maize cultivars perform better than improved maize cultivars.

The model also needs to be modified in order to simulate farmer-crop interaction such as thinning and scotching if it is to be used to support small holder farmer decision-making. It is suggested that once the model is adjusted to consider all the aspects mentioned an intensive validation should be carried out in order to validate predictions for different cultivation technologies, particularly different planting densities and nitrogen fertiliser rates.

Chapter 5. Cattle feeding systems and nutritional characterisations of the local forages

5.1. Introduction

Two sections form this chapter. The first section describes the cattle feeding systems used by local farmers during the wet and the dry seasons at the Toluca Valley. This section also includes a description of the most commonly used forages and concentrates and the seasonal variation in their availability and utilisation. The second part describes the nutritional characteristics of forages and concentrates based on their degradation kinetics as determined by the gas production technique. The nutritional characterisation was based on the feeding systems observed in Taborda (**MLPS**), but some characteristics of the feeding systems observed in Tenango del Valle (**IMLPS**) are also mentioned.

The second part of this chapter is fundamental because although some basic information has been collected by CICA researchers and other scientists from the Smallholder Dairy Systems Network[1] (SDSN), on the nutritional characteristics of the ingredients used by local farmers to feed cattle (Arriaga *et al.*, 1997a; Zorrilla *et al.*, 1997; Val *et al.*, 1997, Castelán *et a*l., 1997), the information available doesn't provide sufficient elements to evaluate these characteristics and the productive potential of local feedstuffs, nor is enough to design improved feeding systems or to simulate the prevailing ones. Much of the data available is based on the conventional system of proximate analysis and tables from NRC, (1989), and AFRC, (1993), but few on their dynamics of fermentation and degradation characteristics. However, it is

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[1] This network is formed by scientists from Mexican and British institutions interested in the Smallholder dairy systems of Central Mexico

suggested that some of these data may not be relevant to local conditions because there are forages that are native to central Mexico for which there is no information on such tables.

5.2. Seasonal cattle feeding systems used by campesino farmers

5.2.1. Dry season feeding systems

Cattle feeding systems of the Toluca Valley are based on the use of crop and industrial by-products, weeds, and native forages and in small proportion improved pastures. Maize production is the main source of cattle feed in the system, it provides grain and stover, which are the main ingredients of cattle diets throughout the year, but particularly during the dry season.

Table 5-1 shows the most common forages and concentrates fed to cattle during the dry season. In Taborda 93% of farmers fed dry maize stover during the seven months that last the dry season. In contrast, it was observed that in Tenango only 46% of farmers fed maize stover and 80% fed green maize stover silage, as the main forage in the dry season. This difference is explained by the fact that farmers in Tenango harvest most of their maize fresh (see Chapter 3), and the green stover left in the field has not reached its physiological maturity, so it is harvested and fed green in the wet season or made into silage to feed during the dry season. Despite the differences in the method of harvest and storage maize stover is the main source of forage fed to cattle during the dry season in both systems.

Table 5-1 . Forages and concentrates fed during the dry season

Forage	% of farmers *MLPS*	% of farmers *IMLPS*	**Concentrates**	% of farmers *MLPS*	% of farmers *IMLPS*
Maize stover	93	46	Maize	100	80
Maize silage	7	80	Chicken manure	50	-
Native pasture	75	17	Wheat bran	40	67
Rye grass or oat forage or alfalfa	50	50	Chopped maize stover*	30	0
			Coconut cake	21	67
			Commercial concentrate	26	70

*maize stover is also fed as concentrate

The amount of stover available to farmers will depend on the area planted with maize, the variety, the cultivation practices and the yield levels. Despite high stover yields (see Chapter 5) it was observed that farm production of it is normally not enough to feed cattle throughout the year. It was observed that most farmers (who own cattle) have to buy stover either at the beginning or end of the dry season. The intensive use of stover described here emphasises the assumption that the presence of cattle in the farming system is largely explained by stover production. Moreover, as quoted by Mr Luis González, *the increased productivity of cattle and the increment in the average numbers of heads per farm is explained by higher yields of maize and stover (particularly in irrigated maize) over the last twenty years.*

The key role of stover was observed in both small and large farmers as shown in Figures 5-1 and 5-2. Figure 5-1 shows Mr González's son (small farmer, <5 ha) harvesting stover, which was latter transported to the farmhouse and properly stored to prevent damage by weather. It was also noticed that little stover was left standing in the field, since most of it is collected or browsed by cattle.

Figure 5-1. Harvesting and storing stover by a small farmer

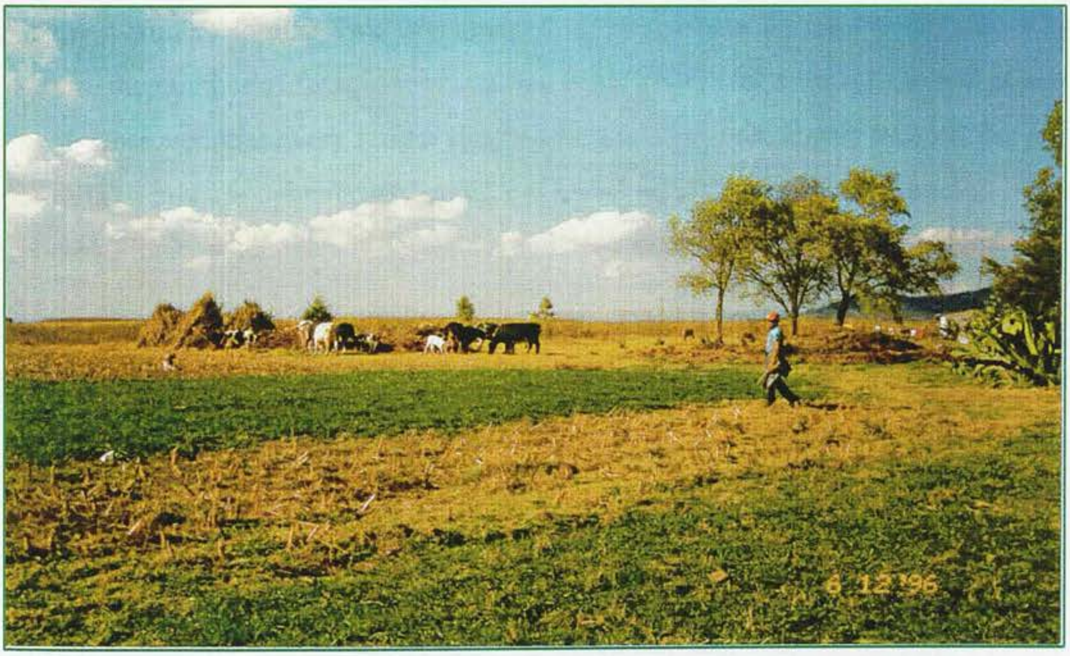
Figure 5-2, shows a larger farmer storing a substantially larger amount of stover. Notice the number of people and the machinery involved in this activity. Figure 5-2, also shows that stover is being chopped (a common practice) since <u>there is the knowledge among farmers that this practice improves forage intake and reduces waste of this resource</u>. It is well known that resistance to chewing rather than digestion is the main factor controlling voluntary intake of many forages and that any correlation between voluntary intake and digestibility is not causal but due to the association in most foods between resistance to chewing and digestibility (Laredo and Minson, 1973; Minson, 1998).

Figure 5-2. Stover storing by a larger farmer

The number of other forages available apart from stover is reduced mainly because of the prolonged duration of the dry season and the lack of water to produce forages under irrigation. Available water in the system is used to cultivate maize (see Chapter 4). Despite the shortage of water, it was observed that 50% of farmers in both surveyed communities allocate a small portion of their irrigated land to cultivate some kind of pasture, which in this work is called *improved pasture*. It is called improved pasture in order to differentiate it from the low quality pastures that constitute the largest proportion of cattle diets.

The average size of the area dedicated to improved pasture is 0.5 ha. The area allocated to pasture production is small because farmers normally plant the amount of land that they can afford to irrigate or they can afford not to plant with maize or other crops. Improved pasture types may include some of the following species: annual Rye grass, perennial Rye Grass (*Lollium perenne*), and occasionally alfalfa (*Medicago sativa*), or oat (*Avena sativa*). Figure 5-3 shows that this grass is planted in small plots between the maize fields and it offers the possibility of feeding a better quality pasture when everything else is dry. It is believed that there exists the knowledge among farmers that the inclusion of small amounts of improved pastures improves the overall nutritive value of the diet. Farmers who don't plant improved pastures may buy alfalfa or oat hays.

Figure 5-3. Improved pasture production (dry season)



Dry matter yield of improved grass species during this season is low. Based on the works of Arriaga *et al.*, (1997a); Espinoza and Martínez, (1989) and Castelán and Jaime (1990), it is possible to suggest that the annual dry matter yield of Rye grass at the Toluca Valley ranges from 11 to 14 t per ha and that approximately 70% are concentrated in the wet season. Farmers compensate dry season low yields by feeding only lactating cows with this forage, while the dry cows and the rest of the cattle are fed maize stover.

Table 5-1 also shows that 75% of farmers in the MLPS and 17% of farmers in the IMLPS feed native pasture during the dry season. Although most of the cattle feeding is based on a **cut and carry system**, it was observed that some farmers take their animals to graze in communal areas. However, this practice is limited because of the reduced number and size and of these areas and the low yields registered during the dry season. The walking distance was also a factor considered by farmers when deciding whether or not take their animals to graze.

Finally, it is important to mention that farmers normally feed cattle with two or three forages together. They prepare mixed-forage rations where they normally mix maize stover with a "better quality" forage (here called improved pastures) or other locally available forage. This practice was observed both during the dry and rainy season, the number of forages in the ration is obviously larger during the wet season. It was observed that every farmer (based on their own experience) uses his/her own formula to prepare their forage ration. Table 5-2 shows some of the common mixed forage rations, which were observed in some of the case studies.

Table 5-2. Common mixed-forage rations fed to cattle

	Dry season forage composition* Farmer			
Basic forage	**All farmers**	**V. Garcia**	**L. González**	**J. Valdez**
Maize stover (MS)	1	0.7	0.8	0.7
Improved pasture (IP)	0	0	0.2	0.3
Stover silage (MSIL)	0	0.3	0	0
	Wet season forage composition Farmer			
Basic forage	**L. Estrada**	**V. Garcia**	**L. González**	**J. Valdez**
Maize stover (MS)	0.2	0.2	0.2	0.4
Improved pasture (IP)	0	0	0	0.4
Weeds (WDS)	0.6	0.5	0.4	0.2
Green maize fodder (GMF)	0	0.3	0.4	0
Native grass (NG)	0.2	0	0	0

*Figures represent proportion of ingredients in each forage ration

Concentrates: All the interviewed farmers supplement their cattle with some type of concentrate. The most common ingredients are shown in Table 5-1. It was also observed that all of them fabricate their own concentrates, in fact it is possible to say that there are as many concentrate formulations as farmers in the communities. Every farmer uses the mix of ingredients (same as with forages), which they have available and according to their own experience produces the best response in terms of milk and beef production. Some farmers also use commercial concentrate, Table 5-1 shows that its use is more common in the IMLPS (70% of farmers) than in MLPS (26% of farmers). However, farmers who buy commercial concentrate may also make their own concentrates, since the first one is only fed to lactating cows. They may also use commercial concentrate as an ingredient of their own concentrates!

Farmers' concentrates are made with the ingredients shown in Table 5-1. Notice that almost all farmers in both communities use maize in their concentrates, also notice that 50% of farmers in the MLPS use chicken manure while none of the IMLPS farmers use this commodity. Table 5-3 shows some examples of the composition of concentrates used by some of the case study farmers. It is important to mention that concentrates composition does not change much between the rain and the wet season

Table 5-3. Concentrates composition

	Concentrates composition Farmer**					
Basic ingredient	L. González CONC-1(*I1*)*	V. García CONC-2(*I2*)	L. Estrada CONC-3(*I3*)	J. Valdez CONC-4(*I4*)	H. Estrada CONC-5(*I5*)	CONC6(*I6*)
Ground corn (GCR)	0.48	0.67	0.25	0.55	0.1	0
Chicken manure (CMN)	0.24	0	0.75	0	0.75	0
chopped stover (CMSR)	0.28	0	0	0	0	0
Wheat bran (WHB)	0	0.33	0	0.45	0.15	0
Commercial concentrate (CON)	0	0	0	0	0	1

* subscripts used in the Integrated farm model ** Figures represent proportion of ingredients in each concentrate

5.2.2. Rain season feeding practices

Wet season feeding practices are similar to those observed in the dry season, except that the number of forages available is bigger. Depending on the maize cultivation technologies and whether farmers decide to apply herbicide or not, green maize fodder (GMF) and weeds (WDS) may become available from the maize crop (see Chapter 4). Improved pastures are also available but in larger quantities due to the rainfall. Native pasture and oats were also observed, and for Tenango del Valle only, wasted vegetables which were not marketed including sweet corn, carrots (*Daucus carota*), lettuce (*Lactuca sativa*) and large beans (*Vicia faba*) were fed to cattle too.

WDS and GMF are used by 80% of farmers in the MLPS to feed their cattle during the wet season. Farmers have developed fine husbandry practices to harvest and utilise these resources. The development of the maize crop (phenology) and the onset of the rains determine the occurrence of these practices, which in turn determine the appearance of weeds too. The name and number of weed species that grow in the Toluca Valley were not identified in this work. However, according to Vibrans (1998) 317 species can be found as weeds in maize fields in the high Valley of Puebla and Tlaxcala, Mexico.

Since this Valley is located in the same geographic region as the Toluca Valley (100 km west) it can be assumed that the same weed species are found at this Valley too. The most abundant species reported by Vibrans (1998) included: *Bidens odorata, Amaranthus hybridus, Galinsoya parviflora Cav., Sanvitolia procumbens, Chenopodium barlandieri and Chenopodium graveolens willd.*

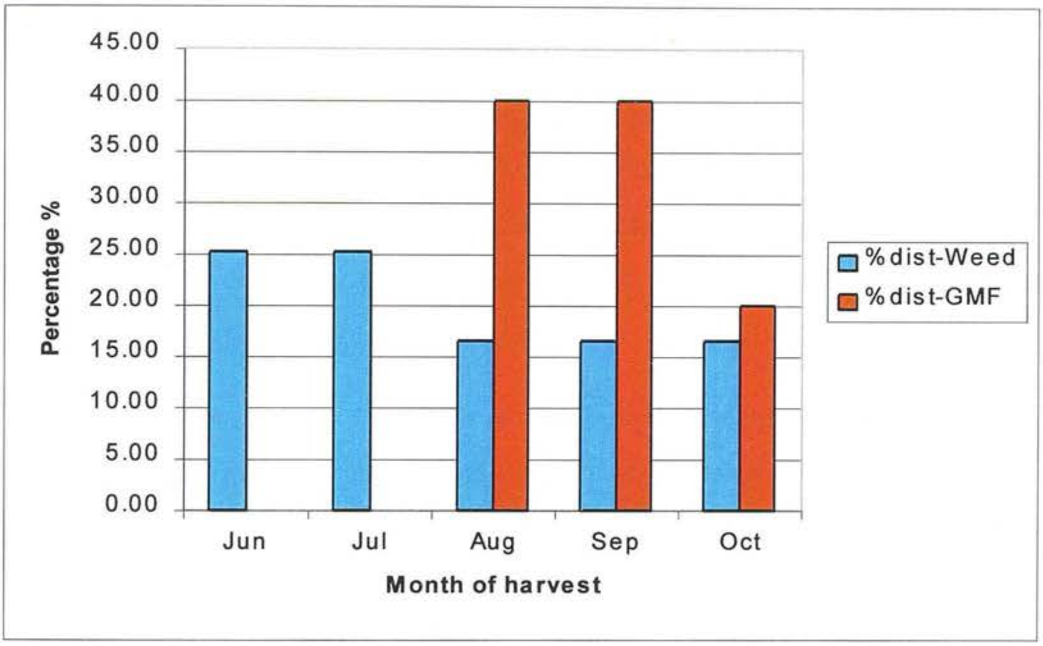
Due to the importance of GMF and WDS in local feeding systems, their utilisation practices were monitored in one of the case studies. One of the maize parcels from Mr Luis González's farm was followed for grain and stover yield to calibrate the maize model (Chapter 4), but at the same time data was gathered on weeds DM yield, and the amount of GMF removed from this parcel through thinning and scotching. This data was also used in Chapters 7 and 8 to simulate production and utilisation of these resources in the farm model. The associated husbandry practices for WDS and GMF are described in detail in Chapters 4 and 5. In this Chapter only the dry matter yields and the time when they become available are described.

The mean annual yield registered for weeds was 3085 ± 938 kg of dry matter/ha. Although the actual amount of GMF removed by this farmer from his field was not measured, he suggested that approximately 30% of the total stover biomass could be removed from irrigated maize, and that some 20% from rainfed maize. In other words because irrigated maize produces more stover; it is possible to harvest a larger proportion than in the case of rainfed maize.

Figure 5-4, shows the proportional distribution for the amount of weeds and green maize stover harvested each month from Mr Luis González's plot. This Figure shows that weeds are available from the start of the rainy season in June, and that most of the total DM yield was used over the first two months of it, On average 25% in June and 25% in July. The remaining 50% were harvested from August to October, at a rate of 16% per month.

Figure 5-4 also shows that GMF was harvested from August to October when it became evident to the farmer which plants were barren and could be removed without affecting grain yield. The larger proportion of this forage was harvested from August to September (80% of the total harvested), because it is in these months when stover thinning was carried out (more biomass was removed through this practice). The remaining 20% were harvested in October when only the tops of the plants were removed (maize scotching).

Figure 5-4. Proportional distribution of the use of weeds and GMF for irrigated maize



Weeds and green maize fodder are also harvested from the rainfed maize, except that in this case the amount harvested is lower than in irrigated maize. For example weeds are harvested from August to October and GMF only in October. Finally it is important to mention that all these forages are also fed mixed and some of the mixed forage rations fed during the wet season are shown in Table 5-2.

5.3. Nutritional characterisation of local forages based on the In Vitro *gas production technique and their degradation kinetics.*

The main objective of this section was to determine the degradation kinetics of the most commonly used forages and supplements through the use of the gas production technique. Much of the data available on the nutritional characteristics of tropical forages and crop residues is based on the conventional system of proximate analysis (Weende system), but few on their dynamics of fermentation and digestibility (Krishnamoorthy *et al.*, 1995). Recent works on nutritional characterisation of local foods and modelling of the smallholder dairy systems carried out by members of the SDSN have been based on nutritive values of foods taken from NRC (1989) or

AFRC (1993) tables (Domínguez, 1997; Val, 1998). While values in these tables may provide some valuable information and some assumptions can be drawn from them, it is suggested that some of the data may not be relevant to local conditions because there are some forage types and crop residues that are native to Central Mexico for which there is no information available in such tables. Therefore there is the need to generate information, which is more relevant to local systems and can be used in the development of improved feeding systems and to predict animal performance.

However, evaluation of feedstuffs for whole tract and ruminal digestion through feeding experiments is expensive and requires sophisticated laboratory and animal facilities which are not always available in developing countries (Krishnamoorthy *et al.*, 1995; Minson, 1998). *In vit*ro techniques developed by Tilley and Terry (1963) and Goering and van Soest (1970) promised to become an important tool for evaluation of ruminant feeds. However according to Aastveit and Marum (1991) and Murray (1993) cited by Herrero *et al.*, (1996b), some of these techniques have proved to be time-consuming, often expensive, and in some cases inaccurate.

More recently, the *in vitro* gas production technique, originally developed by Menke *et al.*, (1979) and Menke and Steingass, (1988), has been used to determine the nutritive value of feedstuffs. The underlying principle behind this technique is that the amount of gas, which is released when feedstuffs are incubated *in vitro* with rumen fluid is closely related to digestibility (substrate degradation) and therefore to the energetic feed value of feedstuffs for ruminants (Menke and Steingass, 1988; Blummel and ∅rskov, 1993; Theodorou *et al.*, 1998). In other words, the rate and extent of gas production must be related to the rate and extent of substrate degradation (NDF). The inclusion of crude protein, crude fat and N-free extracts in the evaluation makes the estimate more accurate than other methods, i.e. two-stage test (Tilley and Terry, 1963), cellulase method (Kellner and Kirchgessner, 1976) and estimation from chemical analysis (Van der Meer, 1983).

Herrero *et al.*, (1996b), suggested that this technique has provided better predictions of the *in vivo* digestibility and the energetic value of forages than other *in* *vitro* techniques and it can be used to represent the fermentation dynamics of the incubated samples. Moreover, according to Kibon and Ørskov, (1993) and Khazaal *et al.*, (1993) the importance of this technique lies in its relationship with dry matter degradation characteristics, forage intake, and animal performance. Gas production results have been used to estimate directly the ME energy content of foodstuffs and the digestibility of their organic matter through regression equations (Menke *et al.*, 1979, Menke and Steingass, 1988), while at the same time other scientists have looked at the relationship between *in vitro* gas production and voluntary intake (Minson, 1990). This technique also compares favourably with the dacron bag technique. For example Blummel and Ørskov (1993) and Khazaal *et al.*, (1993), reported that the gas production recorded at different time intervals fitted well (r=0.88 to 0.95) with the results of the nylon bag technique using cereal straws. However, prediction of animal performance was slightly more accurate in the nylon bag technique.

Furthermore, gas production data has been used to calculate parameters used in the development and validation of sophisticated ruminant simulation models (Illius and Gordon, 1991; Sniffen *et al.*, 1992; Herrero, 1997). According to Tamminga and Williams (1998), an area where *in vitro* methods have proven their value and no doubt will continue to do so is in combination with mechanistic modelling. However, according to these authors, the role of *in vitro* methods in the prediction of nutrient supply lies probably more in helping to elucidate the mechanisms underlying digestive processes than in giving straightforward predictions of nutrient supply.

The gas production technique has become more popular because it is a low cost, highly reproducible and easy method of obtaining a dynamic description of the nutritive value of a feedstuff while at the same time allowing more samples to be analysed. These characteristics makes it a useful tool to characterise foodstuffs under resource limited conditions as in developing countries. However, while the gas production technique has great potential and has become popular its results have to be taken cautiously. According to Theodorou *et al.*, (1998) the underlying processes that give rise to the gas in the first place are complex and not well understood. There is therefore concern about what is actually being measured in gas production studies and how this relates to the digestion process in the ruminant animal.

5.3.1. Description of feed fractions

The feed-stuffs fractionation approach used by Herrero *et al.*, (1998) was used in this work in order to analyse the results of the gas production test and to generate the parameters needed to calibrate the cow model developed by these authors and used in this work too. The separation of dry matter into its basic chemical entities is important because different feeds fractions of different forages have different degradation and passage rates and therefore have different digestibilities (Herrero *et al.*, 1998). Consequently they supply different amount of nutrients to the animal. These fractionations are also important into predicting effects of supplementation on the rate of cell wall digestion, modelling protein-energy interactions, and using recent standards of protein requirements. The basic fractionation approach is shown in Figure 5-5. This figure shows that the forage dry matter is composed of ash, carbohydrates (CHO), Nitrogen (N), and Fat. CHO and N fractions are further fractionated into a soluble fraction (**a** fraction), an insoluble but degradable fraction (**B**) and an undegradable fraction (**1-D**).

These fractions were determined by the gas production technique where the feed material is incubated in a sealed syringe with a mixture of strained rumen liquor and buffer solution, rumen micro-organisms ferment the feed material producing gas over time is measured. This *in vitro* gas production system simulates the rumen environment, producing a dynamic model of fermentation of a feed. The allocation of degradation parameters allows the total potential fermentation of a feed material and rate of fermentation to be determined, as well as the lag time when little or no gas is produced (Figure 5-5).

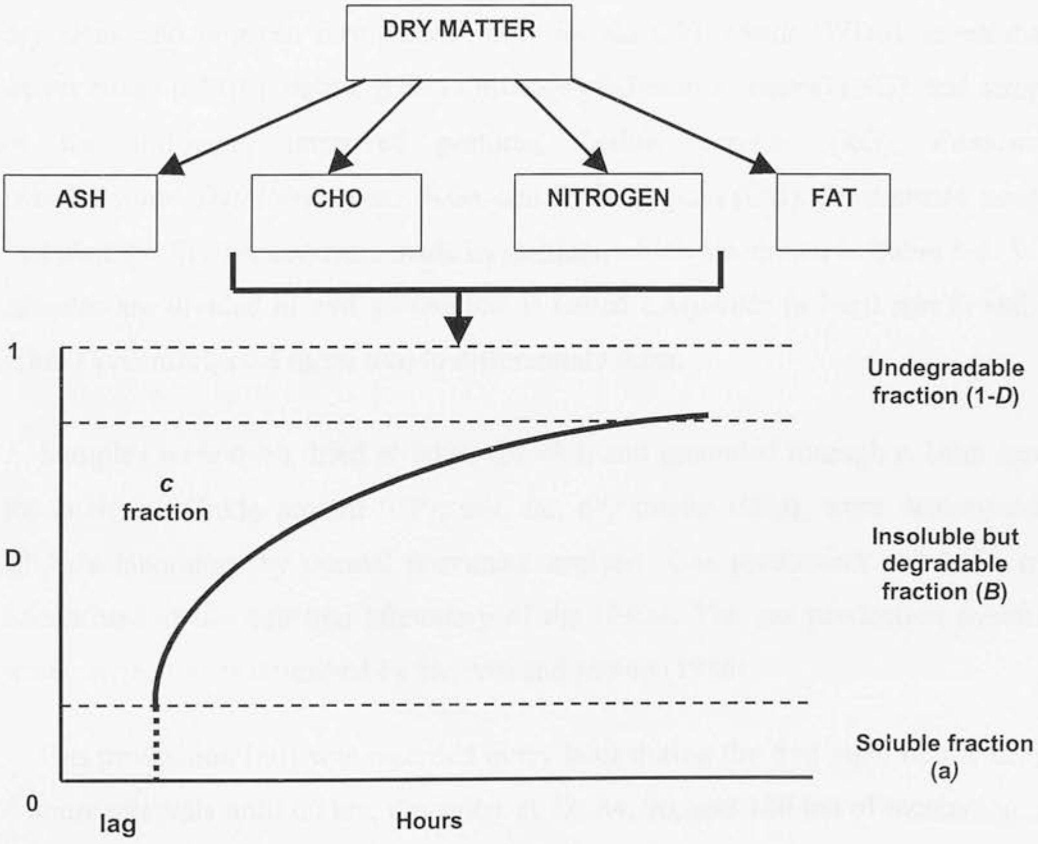
- The lag phase is the time (hrs) before gas is produced from insoluble material (or **B** fraction), microbes are attaching to and colonising the substrate material.

- The rate of gas production per hour, **c** (h^{-1})

- The asymptotic phase represent the volume of gas produced from the soluble fraction a (ml) and insoluble fraction **B** (ml) of a feed material. Total gas production **a** + **B** (ml).
- The **a** fraction is the soluble fraction, usually determined as the washing loss in degradation studies.

Sniffen *et al.*, (1992) consider that the nutritional description of the potentially degradable fractions of feed-stuffs requires yet further fractionations, e.g., the **a** fraction for CHO is fractionated into two more fractions, **a** (sugars) and **B1** (starch) fractions. However, Herrero *et al.*, (1998) suggest that it is doubtful that this will provide better predictions than simpler approaches.

Figure 5-5. Basic nutritional characterisation of forages.



Taken from Herrero *et al.*, (1998).

Finally, since the solubility of the roughage (**a** fraction), the insoluble but potentially fermentable fraction (**B**), its degradation rate (**c**), and their effect on the rumen outflow rate are key determinants of intake of crop residues and other low quality forages (Shem, *et al*, 1995). The estimation of these parameters is central to the design of improved feeding systems for ruminants. In this work only the degradation kinetics for the CHO fraction were determined, the N fractions were taken from the literature.

5.3.2. Materials and Methods

Forty samples of forages and 5 samples of concentrates originating from the case study farms at the Toluca Valley were collected during the survey work and used in this experiment. These samples represent the feedstuffs fed during the dry and wet seasons. They included maize stover from the three local varieties used throughout this work, *Criollo Blanco* (*CB*), *Criollo Amarillo* (*CA*) and *Criollo Negro* (*CN*) (in dry form, and in green form (GMF) only for the *CB*), weeds (WDS), green maize stover silage (MSIL), native grass (a mixture of Gramma grasses) (NG), and samples of the following improved pastures, *Lolium perenne* (RG), *Pennisetum clandestinum+Trifolium repens* (KG), and Orchard grass (OG). Concentrate samples included the five concentrates made by farmers, which are shown in Table 5-3. WDS samples are divided in two groups one is called *Chayotillo* (a local name) and the other *Cebadilla* (local name too) to differentiate them.

Samples were oven dried at 60^{o}C for 48 h and grounded through a 1mm screen for analyses. Crude protein (CP), ash, fat, dry matter (DM), were determined at CICA's laboratory by normal proximate analysis. Gas production and NDF were determined at the nutrition laboratory of the IERM. The gas production dynamics were carried out as described by Herrero and Jessop (1996).

Gas production (ml) was recorded every hour during the first eight hours, then at 4 hours intervals until 60 hrs, thereafter at 72, 84, 96, and 120 hrs of incubation. All samples were incubated in duplicate, but when the difference between the sample and its replicate (for NDF and gas production) were larger than 5%, the analysis was repeated for that sample. Three blank syringes containing only rumen liquor and buffer solution were included at spaced intervals in each run. These measured the gas production from fermentation of any material contained in the rumen fluid. Gas production from all the samples was corrected for gas produced in blank syringes.

Cumulative gas volumes were corrected for fermentation of soluble material (NDS) according to the method proposed by Jessop and Herrero, (1996). Prediction of NDF disappearance from gas production in forages can be improved if a correction is made to account for the gas produced from the early fermentation of NDS, which can be done by subtracting the volume of gas, produced up to 4 hrs from the cumulative gas volumes. Thus, a distinction can be made between gas production from soluble and insoluble fractions. Corrected gas volumes were fitted to the model developed by Krishnamoorthy *et al.*, (1995) and shown in Equation 5-1. The CURVEFIT command of *Grafit v3* was used for this purpose. The same approach was used to determine degradation kinetics of concentrate samples.

$$\mathbf{Y = B\ (1\text{-}exp^{-\ c(t\text{-}lag)})}$$

Equation 5-1. Krishnamoorthy model.

Where
Y = Cumulative gas production at a given time (ml)
B = Asymptote gas production from the fermentation of NDF after incubation for 120 hrs (ml),
c = Fractional rate of gas production (h^{-1}),
t = Time of fermentation and
lag= Lag phase before fermentation of NDF begins (h).

Neutral Detergent Fibre (NDF) was measured before and after the gas production by the method described by Pell and Schofield, (1993) in order to determine the indigestible fibre content of the forages, and the NDF lost during fermentation. Extraction of forage with a neutral (pH 7) solution of sodium lauryl sulphate and EDTA allows the preparation of a fiber residue that recovers the major cell wall components: lignin, cellulose and hemicellulose (Van Soest, 1994). All samples were grouped into 11 groups representing the different forage types. Means and standard error of the mean were calculated for all the degradation parameters and the proximal analyses results for all the groups of forages.

5.3.3. Results

Mean values of the gas production parameters, **b**, **c**, and **lag,** for all the analysed forages are in Table 5-4. This table also shows the mean NDF content and the degradability (in %) of the NDF. Table 5-5 shows the mean protein, fat, ash and dry matter content for the same forages. Figure 5-8 presents the degradation profiles for some of the concentrates and Table 6-3 in Chapter 6 provides the rest of the information on these concentrates.

Table 5-4. In vitro gas production dynamics of forages

		NDF	**NDFD**	**Gas production parameters**			
FORAGE	n	(g/kg DM)	%	**B**	c	lag	a*
Green maize fodder (GMF)	4	533.6 ± 22	0.63 ±0.01	44.2 ±1.0	0.052 ±0.003	4.3 ±0.4	277.5 ±34
CB Maize stover (CBS)	4	669.5 ± 32	0.60 ±0.03	44.1 ±2.3	0.045 ±0.007	4.4 ±0.2	201.7 ±29
CN Maize stover (CNS)	4	709.0 ± 16	0.60 ±0.02	45.1 ±2.2	0.045 ±0.005	4.7 ±0.08	149.6 ±17
CA Maize stover (CAS)	4	706.5 ± 18	0.64 ±0.01	48.0 ±1.8	0.045 ±0.006	4.6 ±0.3	150.7 ±20
Chayotillo Weed (CHY)	3	425.8 ± 10	0.52 ±0.03	29.7 ±2.5	0.077 ±0.005	3.4 ±0.4	294.7 ±35
Cebadilla Weed (CEB)	3	562.2 ± 67	0.63 ±0.03	38.4 ±1.8	0.056 ±0.004	3.6 ±0.3	269.2 ±38
Native grass (NG)	2	688.4 ± 45	0.61 ±0.04	45.4 ±1.7	0.040 ±0.001	4.6 ±0.8	134.2 ±20
M. stover silage (MSIL)	4	569.5 ± 42	0.57 ±0.006	40.7 ±2.0	0.046 ±0.005	4.9 ±0.2	250.7 ±27
Orchard grass (OG)	3	530.0 ± 40	0.70 ±0.03	40.5 ±1.6	0.064 ±0.005	4.8 ±0.3	203.5 ±18
Rye grass (RG)	7	445.8 ± 29	0.67 ±0.01	37.5 ±0.6	0.065 ±0.005	4.0 ±0.1	249.2 ±26
Kikuyu+white clover (KG)	2	360.3 ± 19	0.70 ±0.008	37.5 ±0.5	0.081 ±0.003	3.6 ±0.04	321.0 ±10

± = Standard error of the mean, * The values of **a** were not determined by the gas production technique

5.3.3.1. Gas production parameters

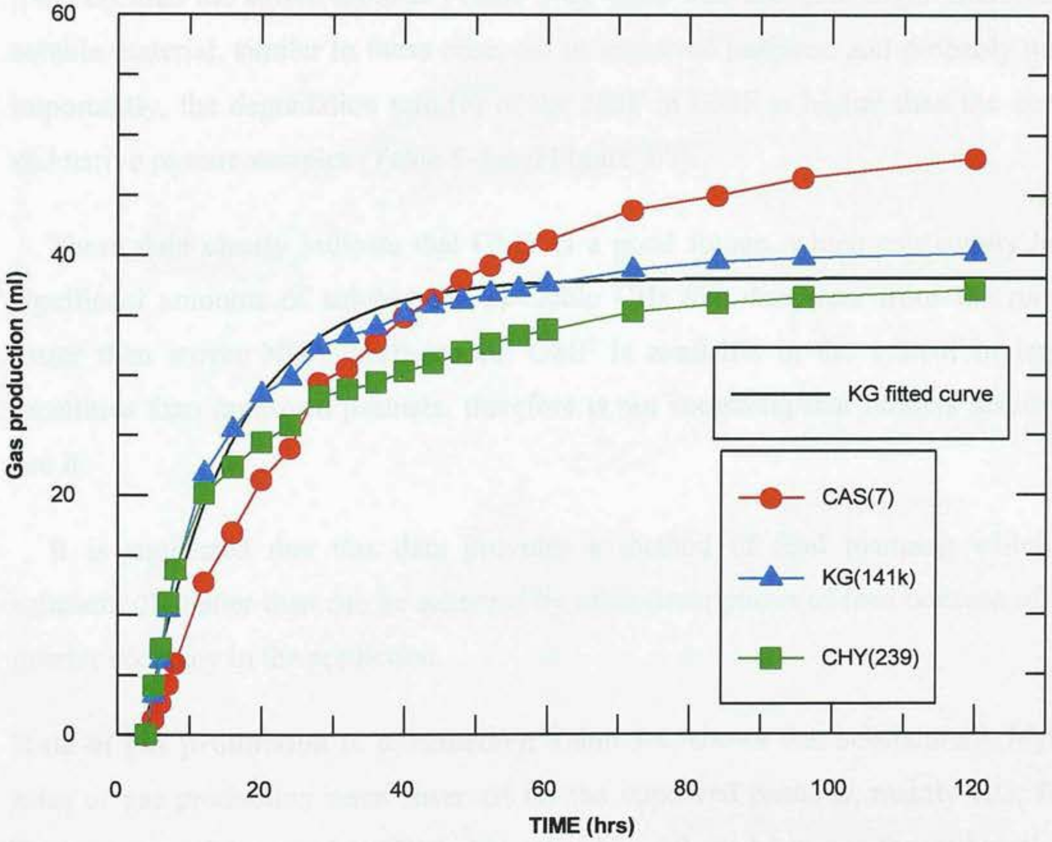
Cumulative gas production (B): Table 5-4 shows that the mean asymptotic gas volumes at 120 hrs of incubation, ranged between 29.7 ml (for CHY) to 48 ml (for CAS) for the different sampled forages. Stover samples CBS, CNS, CAS and the NG presented the highest asymptotic gas productions volumes while the lowest were measured in the weeds CHY and CEB and the improved pastures RG, OG and KG (also see Figure 5-6, which shows the shape of the gas production curves of samples of these three groups of forges). These results are consistent with the fact that the former forages have higher content of NFD than the weeds and the improved pastures, which may be contributing to higher production of gas. Recall that gas production is associated with the degradation of the substrate, which in this case is insoluble but potentially degradable NDF.

The NDF fraction is a good estimate of the cell wall components, and includes all the hemicellulose, cellulose, lignin, and other minor cell wall components including some protein, minerals and cuticle (Van Soest, 1994). NDF is lower in leaves than stems, temperate than tropical, and young than old grasses (Minson, 1990). So the high NDF content in these forages may indicate that they have a high content of complex structural carbohydrates, and a low content of digestible cell solubles (NDS), mainly because all are mature (old) forages. Table 5-4 shows that these forages have in general a lower content of soluble carbohydrates (**a** fraction) than the improved pastures and the weeds.

On the other hand, CHY, RG, OG and KG presented lower asymptote gas production, associated with an also low content of NDF, especially in the case of KG and CHY (Figure 5-6). In addition, notice that these forages have a higher content of soluble material (**a**) than the stover and native grass samples (Table 5-4). The low content of NDF and the high content of soluble material could explain low gas production in these forages as gas production is corrected for soluble material. However, despite low volumes of gas produced from the insoluble fraction, it is likely that the NDF of these forages is highly degradable as indicated by their high NDFD values (70%), suggesting higher intakes and nutrient supply to the animal.

These results are consistent with the fact that high cell wall contents are correlated with low digestibility and slow cell wall disappearance, while the opposite may be observe with low cell wall contents (Minson, 1990). This is particularly true in the case of the stover samples, because it is likely that the lignin content of the NDF is higher than the cellulose and hemicellulose content. Therefore the proportion of potentially degradable NDF (NDFD) is lower than the rest of the forages (Table 5-4).

Figure 5- 6. Gas production profiles of individual samples of CAS, KG, and CHY



According to Van Soest (1994), digestibility is dependent on both cell wall content and its availability to digestion as determined by lignification and other factors. Increasing the maturity of the pastures leads to a higher NDF content and lower digestibility due to an increased cell wall thickening and lower content of cell solubles (Wilson, 1994). Furthermore, the lignin content can affect the digestibility of the cellulose and hemicellulose (the other two main components of the NDF).

According to Minson (1972) the main factor limiting the digestibility of hemicellulose is the quantity of lignin protecting it from hydrolysis by bacterial hemicellulase.

Particular attention should be paid to the role of GMF in feeding because it is a forage that lies between the stover and the improved pasture samples in terms of its nutritional quality, as expressed by its degradation kinetics. This is illustrated in Figure 5-7. For example, GMF has less NDF and it is slightly more degradable (NDFD) than the stover samples (Table 5-4), GMF also contains larger amounts of soluble material, similar to those observed in improved pastures, and probably more importantly, the degradation rate (**c**) of the NDF in GMF is higher than the stover and native pasture samples (Table 5-4 and Figure 5-7).

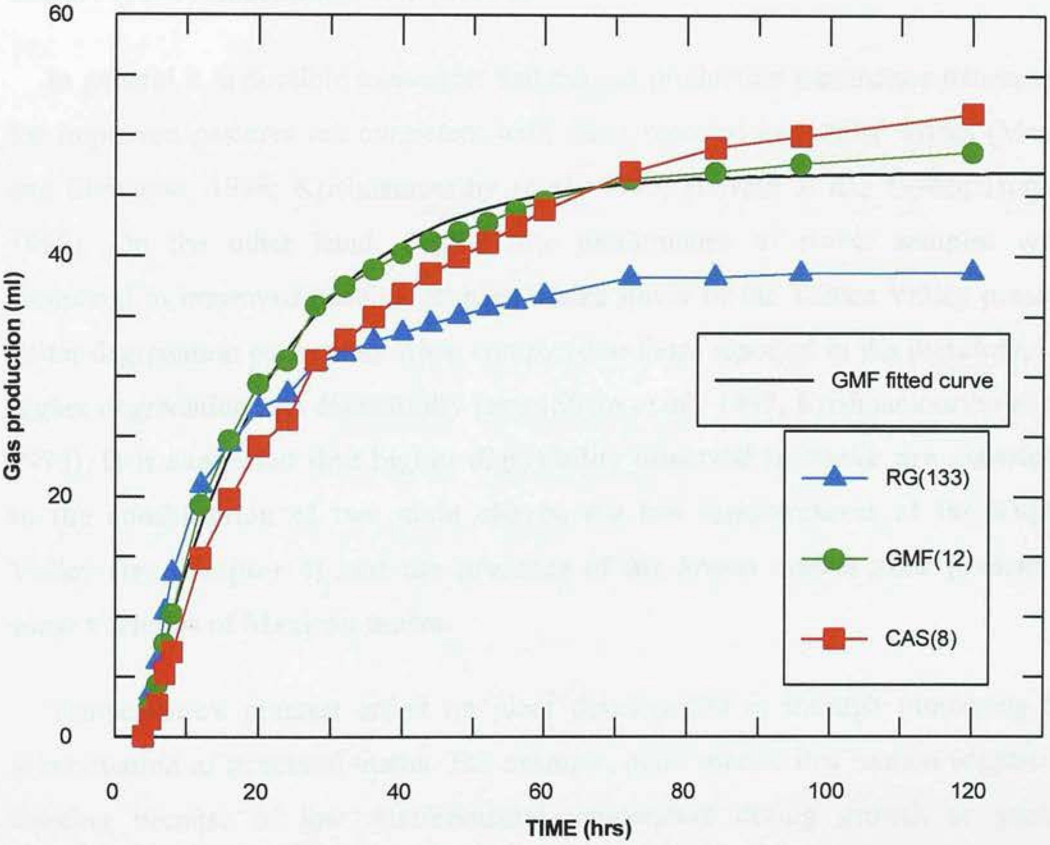
These data clearly indicate that GMF is a good forage, which can supply both significant amounts of soluble and insoluble CHs that disappear from the rumen faster than stover NDF. Furthermore, GMF is available in the system in larger quantities than improved pastures, therefore is not surprising that farmers decide to use it.

It is suggested that this data provides a method of feed planning which is substantially better than can be achieved by other descriptions of feed because of the greater accuracy in the prediction.

Rate of gas production (c parameter): Table 5-4, shows that substantially higher rates of gas production were observed for the improved pastures, mainly KG, RG, OG and one of the weeds (CHY). This may be explained because the cell walls of these forages may be lower in lignin and higher in cellulose and hemicellulose and therefore more easily accessible to the rumen microbes, which degraded them faster than the cell wall of the stover samples. Figure 5-6 illustrates this more clearly, it shows the gas production profiles of three different types of forages, CAS, KG, and CHY. CAS presents the highest volume of gas production after 120 hrs of incubation, but its substrate is degraded more slowly as indicated by its reduced rate of gas production, which as shown in Figure 5-6 is the slowest of the three forages.

For example after 24 hrs of incubation more than 75% of the potential gas production had occurred for KG and CHY and only 49% for CAS.

Figure 5-7. Gas production profiles for individual samples of RG, GMF and CAS



These results may have an important impact in terms of the amount of nutrients supplied to the animal by the different forages. For example, assuming a normal mean rumen retention time of 33 hrs for roughages, which is equivalent to a passage rate of 3% (Krishnamoorthy, 1991), it is possible to see that stover will supply less nutrients to the animal due to slow degradation rates and reduced intake (due to long retention time), while the opposite will be observed for the improved pastures. It is suggested that the CAS slow degradation rate illustrated by the long time required to achieve its asymptotic gas production level (see Figure 5-6 and 5-7), may be associated with the difficulty of the rumen microbes to degrade the cell wall of this forage, which may be rich in lignin. However, improved pastures and weeds are degraded faster, supplying more nutrients to the animal. Higher degradation rates are also associated to high forage intakes, since the rate of passage is also high due to the rapid disappearance of the forage from the rumen (Van Soest, 1994). For more information on the degradability of roughages and feed intake see Blummel and Ørskov (1993) and Khazaal *et al*., (1993).

In general it is possible to suggest that the gas production parameters determined for improved pastures are consistent with those reported in similar works (Menke and Steingass, 1988; Krishnamoorthy *et al*., 1995; Herrero *et al*., 1996b; Homan, 1996). On the other hand, despite low performance of stover samples when compared to improved pasture samples, maize stover of the Toluca Valley presents better degradation parameters when compared to those reported in the literature, i.e., higher degradation and digestibility rates (Shem *et al*., 1995, Krishnamoorthy *et al*., 1995). **It is suggested that higher digestibility observed in stover are associated to the combination of two main effects, the low temperatures at the Toluca Valley (see Chapter 4) and the presence of the *brown midrib gene* present in some varieties of Mexican maize.**

Temperature's greatest effect on plant development is through promoting the accumulation of structural matter. For example, plant species that remain vegetative, whether because of low environmental temperature during growth or genetic character, are always less lignified than plants that develop to the flowering stage under similar environmental conditions (Van Soest, 1994). Lower digestibility at higher temperatures is the result of the combination of two main effects, increased lignification of plant cell wall and a more rapid metabolic activity. Increased plant metabolism decreases the pool of metabolites in the cellular contents. Photosynthetic products are thus more rapidly converted to structural components. Results for stover indicate that low temperatures at the Toluca Valley may results in lower lignification of the plants and therefore higher digestibility.

According to Van Soest (1994), brown midrib was originally discovered in a collection of Mexican maize at Purdue University. The significance of soluble coloured matter in the midrib of leaves (the main reservoir of lignin in maize) was not appreciated until the character became associated with low lignin contents and high soluble polyphenolic matter. Because maize has been used primarily for its grain, "leaf and stalk quality" has been overlook particularly by commercial North American corn seed producers as discussed in Chapter 4. Moreover, plants bearing the gene appear to contain both less polymerised lignin and a considerable amount of soluble polyphenolic substances in the midribs that do not affect digestibility as normal lignin does. Cell walls are more digestible and ferment at a faster rate. See Barnes *et al.*, (1971), Cymbaluk *et al.*, (1973) and Gordon and Neudoerffer (1973), for a wider description of the effects of the *brown midrib gene* on stover digestibility.

5.3.3.2. Protein and other nutrients

The data presented so far clearly indicates that the different forages differ in the extent and rate of gas production, representing different amounts of fermentable material contained in the feedstuffs. Therefore one may be tempted to select forages on the basis of high degradability, which may increase feed intake and animal performance. However, this assumption must be taken cautiously because the *in vitro* gas production method only measured potential carbohydrate fermentation and when drawing conclusions as to the value of a pasture for animal production other factors must be taken into account. The protein content, its degradation kinetics, the dry matter yield, and the availability and suitability of the forage for the farming system are all important considerations.

The high nitrogen content of the buffer solution used in the gas production technique ensures that nitrogen supplied to the rumen microbes in not limiting. However, under farm conditions protein levels differ between forages and a low nitrogen content in the rumen may limit microbes' protein synthesis and therefore limit carbohydrate fermentation due to low microbial activity (AFRC, 1993). Table 5-5 shows the protein, fat, ash and dry matter content of the different forages used here. Data in this table show, as expected, that improved pastures have higher nitrogen content than the stover samples, but notice that CHY weed has also an important content of nitrogen. Also notice that the nitrogen content of GMF is considerably higher than dry stover. The data shown in Table 5-5 is consistent to nutrient content for the same forages reported by other authors, except for weeds for which no data was found.

Table 5-5 . Protein, fat and ash content of forages

FORAGE	C. Protein g/kg DM	Fat g/kg Dm	Ash g/kg DM	DM %
Green maize fodder (GMF)	87.50 ±5.91	32.75 ±0.63	57.78 ±8.93	30.50 ±1.23
CB Maize stover (CBS)	56.93 ±4.00	13.00 ±0.00	58.83 ±6.52	88.58 ±1.44
CN Maize stover (CNS)	48.60 ±13.06	11.40 ±3.37	55.12 ±13.79	65.40 ±18.77
CA Maize stover (CAS)	46.81 ±10.73	12.64 ±6.06	51.36 ±11.16	65.24 ±16.65
Chayotillo Weed (CHY)	123.03 ±7.87	16.00 ±0.00	140.43 ±29.29	16.67 ±0.89
Cebadilla Weed (CEB)	69.03 ±0.58	18.00 ±0.00	81.50 ±0.76	35.54 ±0.03
Native grass (NG)	113.00 ±2.45	18.00 ±0.00	88.15 ±0.12	93.20 ±1.47
Orchard grass (OG)	129.33 ±12.98	28.00 ±0.00	109.17 ±28.58	21.67 ±5.86
Rye grass (RG)	160.86 ±12.63	22.00 ±0.00	122.07 ±8.21	31.05 ±2.41
Kikuyu+white clover (KG)	186.00 ±14.00	26.00 ±0.00	106.65 ±22.35	47.25 ±27.25
Stover silage (MSIL)	80.90 ±6.96	29.25 ±4.27	69.53 ±7.78	30.40 ±30.40

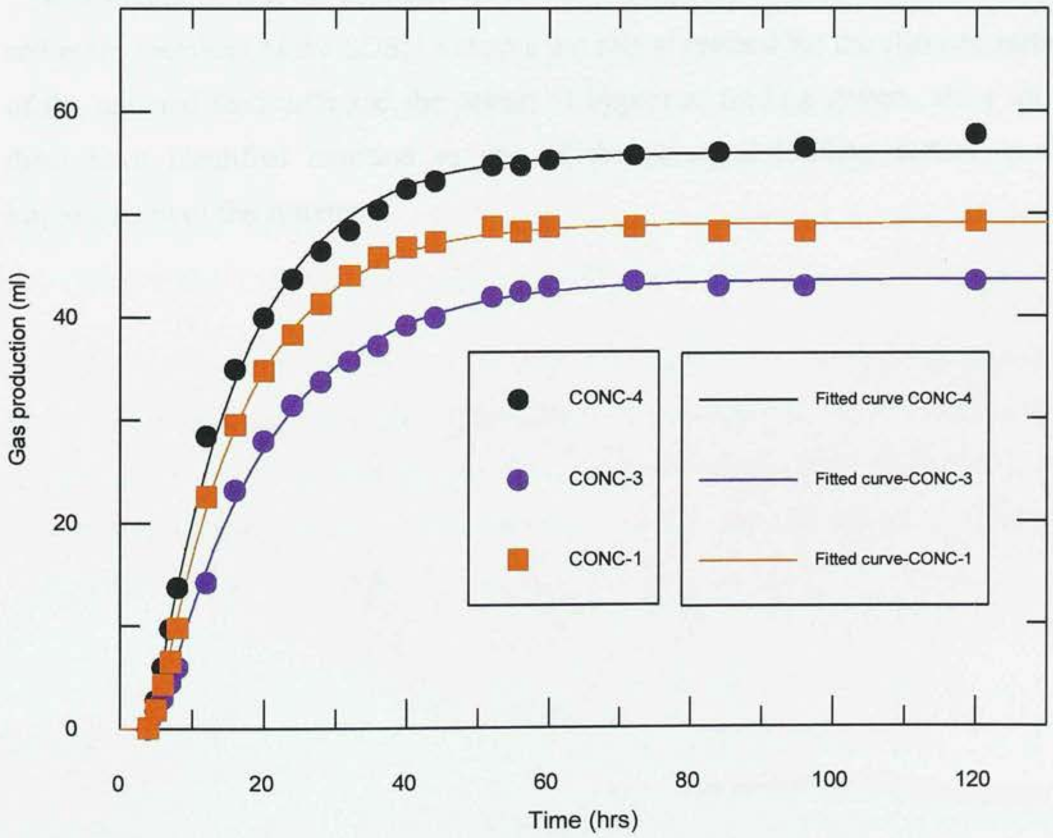
± = Standard error of the mean.

Based on all the results above described the forages sampled could ranked (for nutritional quality) as KG>OG>RG>GMF>Weeds>Stovers>NG. However, it is suggested that under some circumstances GMF could provide a larger quantity of nutrients than the improved pastures, especially during the rain when this forage supplies larger quantities of NDFD than the improved pastures.

5.3.3.3. Gas production profiles for concentrates

Figure 5-8 presents the gas production profiles and protein of some of the concentrates. This figure shows that the concentrate CONC-4 presented the higher volume of gas produced (at a high rate too) than the other two concentrates. This volume may be associated with a higher content of maize and wheat bran (see Table 5-3), which provides both NDF and soluble material. CONC-3 had the lower rate maybe due to its low content of grain, only 25% of maize. However, these results have to be taken cautiously because the gas production technique was developed for forages and it is possible that some of the gas produce comes from the soluble material of the concentrates rather than from their NDFD content. The results for the rest of the concentrates is shown in Table 6-3 in the next chapter, where these are more relevant to the discussion of the output of the Cow Model.

Figure 5-8. Gas production profiles for concentrates



5.3.4. Conclusions and future research

Finally, it can be concluded that the gas production technique generated relevant nutritional information about the forages and concentrates fed to cattle by farmers at the Toluca Valley. It can also be suggested that the forage degradation kinetics obtained from this technique provided a more accurate view of the nutritional quality of the feedstuffs in terms of the rate and extent of the degradation of their carbohydrate substrates. However, the author is aware of the fact that this technique only provided part of the information needed to properly characterise feedstuffs and that protein degradation kinetics may also be necessary in order to complete the picture. A larger number of samples are also required to obtain more accurate estimates of the mean value of the different parameters estimated here, in order to reduce the large standard error of the mean observed in some groups of forages. The method also needs a more extensive validation for local conditions.

It is suggested that the approach used in this work may offer researchers at CICA and other members of the SDSN a simple but robust method for the characterisation of the regional feedstuffs and the design of improved feeding system, since all of them have identified nutrition as one of the principal limiting factors to the improvement of the system.

Chapter 6. Simulating dairy cattle performance and Campesino cattle feeding systems

6.1. Introduction

This chapter is divided in two parts; the first part provides a description of the characteristics and functioning of the Cow Model (CM) used to simulate cattle performance under *campesino* feeding systems and the parameters needed to calibrate it. The second part, describes the approach and methods used to generate these parameters and the actual simulation process. This second phase integrates the knowledge of feeding systems with data on the nutritional characteristics of forages and concentrates described in Chapter 5. Parameters of the CM included average values for the productive and reproductive characteristics of local cattle, and potential milk yield estimated through a lactation curve. Potential milk yield is one of the driving variables of the CM, which together with liveweight and liveweight change are used to estimate energy and protein requirements and indirectly the animal's feeding level and passage rates, which in turn affect forage intake.

Animal performance in terms of milk production, forage and concentrate intake and concentrate-forage substitution rates were simulated for all the cows in the herd. For other animals in the herd, i.e., heifers, steers and young stock, only forage and concentrate intake were simulated, since the model did not predict live weight change associated with growth[1].

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[1] Silveira (1999) has since modified the model to predict live weight change in growing beef cattle.

Because the main objective of this simulation exercise was to emulate the local feeding systems for dairy cows and to test some alternatives for both the dry and the wet season, more effort was devoted to the practical application of the model. Readers are referred to Herrero (1997), Sniffen *et al.*, (1992) and Illius and Gordon (1991) for more information on the physiological and mathematical foundations of the model since only a brief description is given in the following section to facilitate the understanding of this work.

6.1.1. The role of modelling in designing improved feeding systems

Cattle play an important role in the farming system and provide a key element of the farmers' income generating strategies. It was observed that in addition to manure and soil fertility, cattle provide some of the cash needed to buy fertilisers, herbicide or to pay the contractor fees for maize production. Thus the income generated from cattle production can contribute significantly to improved maize production. Cattle also provide some of the "investment capital" needed to buy machinery (tractor) or even for the farmhouse improvement. The importance of cattle in mixed crop-livestock systems has been recognised in Mexico (Castelán, 1996; Zorrilla *et al.*, 1997; Barbabosa and García, 1997, Gómez and Pinto, 1997, Arriaga *et al.*, 1997b) and by other Latin American authors in countries where the role of cattle is acknowledged as the main form of income (subsistence) for resource-poor farmers (Bodisco and Abreu, 1981; Vaccaro, 1995; Quiroz *et al.*, 1997).

Most of these authors cite the main constraint to livestock production at smallholder level as deficient nutrition of cattle, which is based on the use of crop residues, native pastures and agricultural and industrial by-products (Vaccaro, 1995; Quiroz *et al.*, 1997; Arriaga *et al.*, 1997a and b). Improving the nutritional status of cattle will improve profitability of the local farming systems and hence the standard of living of farmers. For example, some members of the SDSN using participatory methods (Corro *et al.*, 1997; Arriaga *et al.*, 1997a) and in-station methods (Gutierrez and Martínez, 1997, Ortíz *et al*, 1997; Castelán and Jaime, 1990) have proposed a more extensive use of improved pastures and agricultural and industrial by products as a mean of improving the nutritional status of cattle in Central Mexico.

These methods have provided valuable information on different options to improve cattle nutrition and a better understanding of the *campesino* cattle feeding systems. However, only a limited number of options can be evaluated because of restrictions imposed by working with farmers on farm and the high costs associated with field experiments and laboratory analysis. There is the risk of affecting farmers livelihoods if the experiments fail to provide an appropriate solution, but more importantly only a limited number of feeding technologies can be tested because the researcher relies on both the willingness of farmers to participate and the amount of resources he/she can devote to the experiment. This limits the size of the experiment to a few replications (animals). Furthermore, it is difficult to study the underlying physiological processes, which govern animal response in the feeding systems under test, because of the lack of relevant nutritional data.

In recent works carried out by researchers of the SDSN (Castelán and Jaime, 1990; Domínguez, 1997; Val, 1998), animal response to traditional and alternative feeding systems had to be explained in relation to "standard methods for evaluating feeds" and "standard requirement systems" developed in industrialised countries (NRC, 1988). This is explained because of the lack of information on the nutritive characteristics of local feed resources. Although this approach has been used in education and training it may not provide adequate results to support decision-making at farm level.

According to Preston and Leng (1987) it has been apparent for many years that feeding standards based on assigned nutritive values (e.g. net energy) are misleading when unconventional feed resources are used, since the levels of production achieved may be considerably less than that predicted. More importantly, this often led to the rejection of locally available feed resources, which apparently were too low in digestible energy to supply the energy needed for production. Moreover, it encouraged researchers to copy feeding systems used in temperate countries, which are predictable, but require feed resources that are inappropriate in most tropical countries.

According to Herrero *et al*., (1998) "requirements systems" were not designed to predict intake but to assess the nutritional and productive consequences of different feedstuffs to the animal, once their intake was known. Therefore, a logical criticism is that the calculation of nutrient supply to the animal, and the prediction of animal performance, is dependent on the accuracy of the intake estimate used. The productivity of ruminants is influenced primarily by feed intake, which in turn is determined by the digestibility (degradability) of the feed and the capacity of the diet to supply the correct balance of nutrients required by animals in different productive states (Preston and Leng, 1987). The effect of alternative nutritional strategies on animal production and on the whole system can only be tested if forage intake and the subsequent responses to available nutrients by ruminants can be predicted (Herrero, *et al*., 1998).

Ruminant simulation models, like Herrero (1997) may help to overcome some of these limitations. Simulation models can be used to improve the understanding of the underlying principles of the nutritional management by *campesino* farmers and to test current technologies or to develop improved feeding systems. Whilst many efforts have been devoted to the construction of complex ruminant models which respond to very specific conditions (Baldwin, 1995; Danfaer 1990; Dijkstra, 1992) little has been done in developing adaptable models with easily obtainable parameters. The Herrero (1997) model offer this possibility because the main digestion and degradation processes of foodstuffs are accurately considered and it can be parameterised with easily obtainable parameters.

6.2. Characteristics of the Cow Model and parameters required for calibration

The model was largely derived from the work of Illius and Gordon (1991, 1992), Sniffen *et al*. (1992) (Cornell Net Carbohydrate and Protein System, CNCPS) and AFRC (1993). The outcome was a dynamic '*hybrid model*' based on a mechanistic platform but with site-specific parameters, and resulted from adapting approaches used in previously published models across a range of levels of aggregation. The model was designed to predict potential intake, digestion and animal performance of individual ruminants, in this case dairy cows, consuming forages, and supplements.

The rationale behind the model is that a ruminant of a given body size, in a known physiological state, and with a target production level, will have a potential forage intake determined by physical or metabolic constraints imposed both by plant and animal characteristics. Potential forage intake is defined as the intake achievable without the constraints imposed by herbage mass, sward characteristics, or behavioural limitations (Herrero, 1997).

The model assumes that the reticulo-rumen is the most important site controlling intake, and that intake can be estimated from the knowledge of degradation and passage of feeds through this organ (Illius and Gordon, 1991). It was originally implemented in SB-ModelMaker V2.0 (Zeton Tech, Nottingham, UK), (a newer version of the software was used here), and can be divided into two functional sections:

1). A dynamic section, which describes the flow and digestion of feeds through the gastrointestinal tract and its consequent nutrient supply to the animal. This section consists of a series of first-order differential equations estimating intake, the pool sizes of feed fractions in the rumen, small and large intestines of the animal, the pools of digested material and excretion of indigestible residues. This section runs on an hourly basis, but results are aggregated to a day (24 h) for an appropriate coupling to the static section of the model.

2). A static section, which estimates potential nutrient requirements of the animal, mainly on the basis of AFRC (1993). The difference with AFRC (1993), and the similarity with the CNCPS, is that the model predicts animal performance on a daily basis from the estimates of intake and nutrient supply obtained from the dynamic section of the model. According to Herrero, (1997), this is a major step from requirements systems (i.e. INRA, 1989; NRC, 1989, 1996; AFRC, 1993), where animal performance is predicted from digestible of metabolisable energy estimates of feeds and intake 'predictions' are obtained from linear or multiple regressions (i.e.

NRC, 1989, 1996; SCA, 1990; AFRC, 1993). The model of Sniffen *et al.* (1992), estimates nutrient supply from a dynamic model of digestion, but they still use regression equations for intake prediction.

Two pathways control intake in the model. The first one is the physical constraint on intake caused primarily by low digestibilities; while the second one is a metabolic constraint. If the supply of nutrients equalled the requirements of the animal, the animal stopped eating. The model uses the feed fractionation determined in Chapter 5, which includes the 4 main constituents of feedstuffs: ash, fat, carbohydrate and protein. The dynamic section of the model focuses on the carbohydrate and protein fractions, which are further sub divided into soluble (**a** fraction), insoluble but potentially digestible (**B** fraction) and indigestible (**1-D** fraction) (Ørskov and McDonald, 1979; AFRC, 1993).

The protein fractions used by the CM are the same as those estimated in the metabolisable protein (MP) system proposed by AFRC (1993), with the difference that their representation in this model is dynamic. For example, the pools of soluble protein, degradable protein and undegraded protein represent the terms quickly (QDP) and slowly (SDP) degraded crude protein, and undegraded (UDP) crude protein of the AFRC (1993) MP system. For more information on the characteristics and functioning of the model readers are referred to Herrero (1997), Illius and Gordon (1991, 1992), and Sniffen *et al.* (1992).

A description of parameters used in this work to calibrate the CM is shown in Table 6-1 below. Parameters were divided into three main groups, the first group describes the protein fractions of the different feedstuffs, the second group the carbohydrate fractions, and the third group contains the animal related variables.

Table 6-1. Parameters required to calibrate the Cow Model

Parameter name	Description
Protein fractions	
Cpconcentrate	Crude Protein concentrate (g/kg)
aCPconcentrate	Soluble CP-Concentrate
aCPforage	Soluble CP-Forage (g/kg)
bCPconcentrate	Potentially degradable CP(g/kg)-Concentrate
bCPforage	Potentially degradable CP(g/kg)-Forage
undegCPconcent	Undegradable N as a proportion of N-Concentrate
undegCPforage	Undegradable N as a proportion of N-Forage
k9concentrate	Degradation rate of soluble N in the rumen-Concentrate
k9forage	Degradation rate of soluble N in the rumen-Forage
k10concentrate	Degradation rate of degradable N in rumen-Concentrate
k10forage	Degradation rate of degradable N in rumen-Forage
k14concentrate	Degradation of soluble N in LI-Concentrate
k14forage	Degradation of soluble N in LI-Forage
Carbohydrate fractions	
CCforage	Cell contents or **a** fraction-Forage (g/kg)
cforage	Forage cell wall degradation rate/h (**c** rate)
K2concentrate	cell wall degradation rate/h for concentrate (**c** rate)
DCWconcentrate	Digestible cell wall (g/kg) for concentrate-NDFD
DCWforage	Digestible cell wall (g/kg) for forage-NDFD
FATconcentrate	FAT Concentrate
NDFconcentrate	Neutral detergent fibre (NDF)-Concentrate g/kg
NDFforage	Neutral detergent fibre(NDF)-Forage g/kg
starch	Proportion of Non-structural carbohydrates as Starch-Conc
Animal Variables	
BW	Body weight (kg)
bwgain	Body weight gain (kg/d)
bwloss	Body weight loss (kg/d)
Milk_fat	Milk fat (g/kg)
Milk_lactose	Milk lactose (g/kg)
Milk_prot	Milk protein (g/kg)
conc_intake	Kg concentrate/12 hrs
potential_milk	Potential milk yield in kg/d
protper	Protein % in milk (%)

6.3. Materials and methods used to estimate model parameters

6.3.1. Protein fractions

The crude protein content of the different feedstuffs used was determined through standard laboratory techniques (Khjedal) The different fractions of the protein and their degradation rates were taken from the literature. Appendix 2 shows the values for the protein fractions, their corresponding degradation rates and published source.

6.3.2. Carbohydrate fractions

The approach used to generate this information was described in detail in Chapter 5. Starch content of the soluble fraction for the concentrates was also taken from the literature, see Appendix 2 for values and source.

6.3.3. Defining mixed-forage rations

Farmers in the Toluca Valley normally feed cattle with diets, which contain more than one forage at a time. The proportion of each forage in the basal forage diet will depend upon availability as influenced by cropping practices of individual farmers. Because it will be very difficult to simulate all of them, it was decided to simulate some of the mixed-forage rations observed in the case study farms. Forage rations shown in Table 5-2 together with the farmers' concentrates shown in Table 5-3 (Chapter 5), were used to simulate *campesino* feeding systems.

A modified version of Table 5-2 is presented here on Table 6-2, this table shows that the proportional contribution of IP to forage-mixed ration 4W of the wet season was increased from 0.4 to 0.6. This change permitted the evaluation of the effect of increasing the consumption of this forage and compares it in relation to the other wet season forage rations. Since an important part of the research on *campesino* farming systems at CICA is based on the introduction of improved pastures (Arriaga *et al.*, 1997a), it was considered important to evaluate this technology through the cow model. Note that all the basic forages described in Chapter 5 were included in the forage-mixed rations in order to reflect the different forage produced and used during the dry and wet seasons.

The author is aware that only a small number of forage rations and concentrates were simulated and that more need to be tested. However, the main idea behind this exercise was to demonstrate the methodology, it is suggested that a more extensive forage characterisation needs be carried out and more simulation studies must be part of future work.

Table 6-2. Dry and wet season mixed-forage ration composition

	Dry season composition (*dryfod**)			
Basic forage	**D1**(*j=1***)	**D2**(*j=2*)	**D3**(*j=3*)	**D4**(*j=4*)
Maize stover (MS)	1	0.7	0.8	0.7
Improved pasture (IP)	0	0	0.2	0.3
Stover silage (MSIL)	0	0.3	0	0

	Wet season composition (*wetfod**)			
Basic forage	**W1**(*j=1*)	**W2**(*j=2*)	**W3**(*j=3*)	**W4**(*j=4*)
Maize stover (MS)	0.2	0.2	0.2	0.2
Improved pasture (IP)	0	0	0	0.6
Weeds (WDS)	0.6	0.5	0.4	0.2
Green maize fodder (GMF)	0	0.3	0.4	0
Native grass (NG)	0.2	0	0	0

D(j=1:4)=dry season forages, W(j=1:4)=wet season forages, *=Table names used in the farm model (Chapter 7), **forages subscripts used in the farm model.

Forage parameters for mixed-forage rations: The fact that farmers feed simultaneously more than one forage represented a problem since the CM only simulates the intake and digestion of only one forage and concentrate at the time. In order to solve this problem a standard approach of ration formulation (AFRC, 1993) was used, where weighted means were calculated in order to reflect the proportional contribution of the individual basic forages to the each of the mixed-forage rations.

The different forage types shown in Table 5-4 were grouped into five "basic forage groups". Stovers were grouped because farmers make no distinction in term of the maize variety where the stover comes from. They normally feed the stover which is available, so from a practical point of view there was no reason (apart from the scientific interest of knowing nutritional characteristics of individual varieties) to keep them as separate forages. The same occurs with weeds because they are fed mixed, and no differentiation is made for a particular variety.

Means were calculated for all the nutritional parameters in every basic group of forages. These means were used to calculate the weighted means, which were finally used as parameters of the cow model. Mean values for the basic forages and weighted means for all the forage-mixed ration are shown in Table 6-3. Values in Table 6-3 suggest that despite the mean calculation the differences in the nutritional quality between the forage basic groups were preserved, as is shown in the result section. No weighted means were calculated for concentrates and their original values shown in Table 6-3 were used directly in the CM.

6.3.4. Defining animal parameters

6.3.4.1. Cattle herd

It was considered important to simulate all the animal classes in the herd in any given farm, because all of them contribute to the farm income, but also require labour and feedstuffs resources. Therefore every cattle class had to be simulated individually in the CM in order to provide relevant data on animal performance. In this way a better representation of the role of cattle in the farm could be obtained. This data was used as technical coefficients to the Integrated Farm Model (Chapters 7 and 8).

The average herd composition was defined first in order to simulate all classes of animals in a typical *campesino* herd. A typical herd is composed of cows (which can be lactating or dry), heifers (pregnant and non-pregnant), calves, steers and bull. It was assumed that three main variables, lactation number and lactation stage, plus the dry period describe the cows in the herd. The number of lactation, considered were from 1,2 and 3 or more lactations, and three stages of lactation, early, mid and late, so the cows in any given herd can be in 12 possible states:

COWS $_{iq}$

Where,
$i$max = 3., 1= first calving, 2=second calving, 3=three or more calving

$q$max = 4., 1= early, 2= mid, 3= late lactation, 4= dry period

Table 6-3. Weighted means for the CH fractions and CP, ash and fat content of the basic forages and mixed-forage rations

	NDF	NonD-NDF	NDFD	NDFD	Gas Production parameters			C. P	Fat	Ash	Soluble CH (a)	DM
BASIC FORAGE	g/kg DM	g/kgDM	%	g/kg	**B**	**c**	**lag**	g/kg DM	g/kg DM	g/kg DM	g/kg	%
GMFG	533.6	201.5	0.63	345.0	44.2	0.052	4.3	87.5	32.7	57.7	277.5	30.5
MS	695.0	265.3	0.62	429.7	45.7	0.041	4.6	59.3	13.2	65.0	167.3	85.8
WDS	494.0	203.0	0.58	291.0	34.0	0.066	3.5	96.0	17.0	110.9	281.9	26.1
NG	618.0	270.5	0.56	347.4	43.7	0.038	3.8	116.0	18.0	88.0	159.9	95.0
IP	452.6	143.8	0.68	308.8	38.3	0.067	4.1	157.1	24.1	116.2	249.7	31.4
MSIL	569.5	242.5	0.57	327.0	40.7	0.046	4.9	80.9	29.2	69.5	250.7	
MIXED-FORAGE RATIONS												
FORAGE-D1	695.0	265.3	0.62	429.7	45.7	0.041	4.6	59.3	13.2	65.0	167.3	85.8
FORAGE-D2	657.4	258.4	0.60	398.9	44.2	0.042	4.7	65.7	18.0	66.3	192.3	60.0
FORAGE-D3	646.5	241.0	0.63	405.5	44.2	0.046	4.5	78.8	15.4	75.2	183.8	74.9
FORAGE-D4	622.3	228.8	0.64	393.4	43.5	0.049	4.4	88.6	16.5	80.3	192.0	69.4
FORAGE-W1	559.0	228.9	0.58	330.0	38.3	0.056	3.7	92.6	16.4	97.1	234.6	51.8
FORAGE-W2	546.1	215.0	0.60	334.9	39.4	0.057	3.9	86.1	20.9	85.8	257.7	39.3
FORAGE-W3	550.1	214.8	0.60	340.3	40.4	0.055	4.0	85.2	22.5	80.0	257.2	39.8
FORAGE-W4	509.4	179.9	0.65	329.4	38.9	0.062	4.0	125.3	20.5	105.0	239.7	41.2
CONCENTRATES												
CONC-1(*I1*)	230.8	80.4	0.65	150.4	49.0	0.081	4.9	187.8	38.7	83.7	458.9	99.8
CONC-2(*I2*)	201.0	94.9	0.52	106.0	59.2	0.068	4.0	129.6	46.2	23.6	599.6	91.5
CONC-3 (*I3*)	212.4	102.2	0.52	110.2	43.5	0.066	5.3	284.3	40.3	102.2	360.7	92.2
CONC-4(*I4*)	250.9	96.7	0.61	154.2	55.9	0.080	4.3	148.8	40.0	34.0	526.2	90.6
CONC-5(*I5*)	240.1	110.1	0.54	130.0	44.4	0.042	4.1	264.4	38.0	104.3	353.1	92.1
CONC-6(*I6*)	120.0	-	-	100.0	-	0.08	-	140.0	30.0	-	660.0	92.0

Values for concentrates are not weighted means.

The cows were divided into lactation number since it is generally agree that that the calving number is one of the most important factors, which determine milk yield levels (Wiktorsson, 1979). The length of the lactation, dry period length, days to conception and other parameters needed to determine the cows' production cycle were also taken from the survey work.

Table 6-4 shows a summary of these parameters, which were also used to mark the progression of cows' classes over time in the IFSM. Liveweight was not measured in this work, but was taken from Arriaga *et al.*, (1997a) who have measured it in cows from the *Ejido* San Cristobal also in the Toluca Valley. It was assumed that cows lose 5% of their body weight during the first part of their lactation, no weight was lost during the second part, and the weight loss was regained over late lactation and dry period.

This conservative approach to liveweight change during lactation was used because we were dealing with a very heterogeneous population, where there are animals of different production potential, different levels of improved blood, and different feeding and management systems. The amount of information on the subject is also very limited. Liveweight change of similar magnitude has been reported by Salas *et al.*, (1997) in cows of smallholder farming system in the State of Michoacán, Mexico.

No distinction was made for genetic potential, since there was not sufficient information on the subject and monitoring information on the local herds is limited, and it is not a practice amongst these farmers to keep records of their animals. The lack of this basic information strengthens the need to investigate more about cattle productive and reproductive characteristics and to establish a herd monitoring system in order to get the relevant data on cattle performance in the Toluca Valley.

Table 6-4. Productive parameters for cows and heifers

Parameter	Value
COWS	
Age at first calving	854 days (28 months)
Lactation length	305 days (adjusted)
Dry period length	61 days
Days to conception after calving	91 days
Average number of calves/cow (productive life)	5-6
Calving interval	366 days
Potential milk yield at first calving (kg/lactation)*	1966
Potential milk yield at second calving (kg/lactation)	2809
Potential milk yield at third calving (kg /lactation)	4160
Body weight at second calving (kg)	521
Body weight at third calving (kg)	547
Body weight change throughout lactation (in %)	5
HEIFERS	
Age at first service	579 days (20 months)
Approximate weight at first service	350 kg
Age at first calving	854 days (28 months)
Approximate weight at first calving	450 kg

*Potential milk yield was determined according to the method described in section 6.3.4.2.

Heifers (*HEIF*) are described by their physiological stage, as pregnant and non-pregnant. A non-pregnant is a heifer which age is between 13 and 19 months; it was assumed that all heifers are serviced at approximately 20 months of age, and that the pregnancy lasts 275±5 days, therefore calving occurs at 28 months of age.

HEIF $_q$

Where,
$q$max = 2., 1= non-pregnant heifers, 2= pregnant heifer

Other stock (*OTHE*) was classified into three classes calves, steers, and bulls. Calves were divided in two categories according to their age in months, 0-6 months and 7 to 12 months. It was decided to divide calves because forage intake is different between these two groups, and because calves constitute an important number within the herd. Therefore forage intake by this group could be significant.

CALFq

Where:
q = 2., 1= 0-6 months and 2= 7-12 months of age.

Steers were considered as all those male stock, which are older than 12 months and that are fatted for a period of over 6 months and sold afterwards.

STEE*q*

Where:
q=3., 3 =13-18+ months male stock

Bulls (BULL) were considered as male stock that is kept for reproductive purposes and is older than 18 months.

BULL*q*

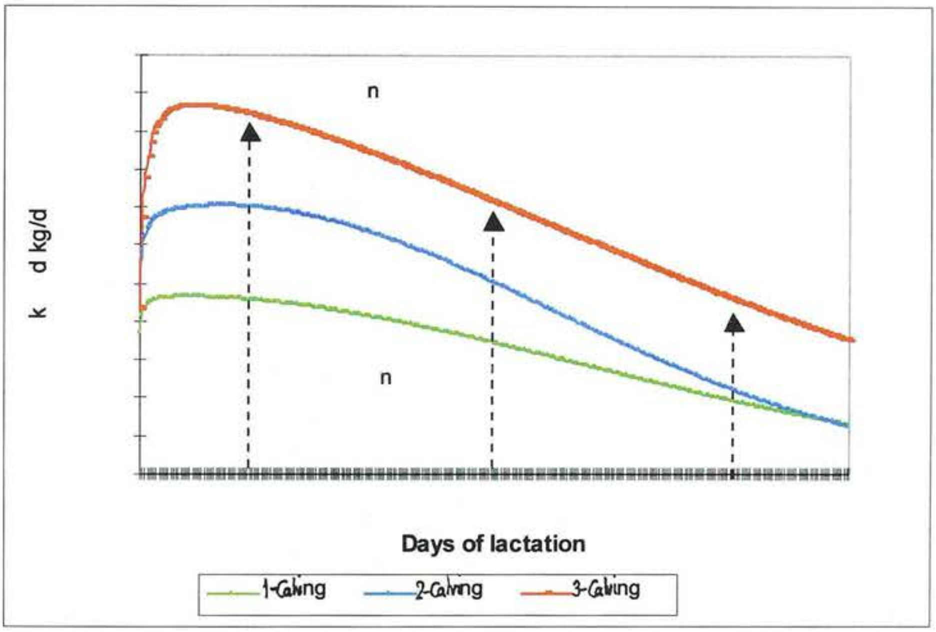
Where:
q=4., 4 = male stock older than 18 months

6.3.4.2. Calculating potential milk yield

Lactations of 24 cows were monitored in order to obtain an estimate of the potential milk yield of cows at the Toluca Valley. Milk yield was measured every two weeks from one week after calving until the end of the lactation in every cow. The data was fitted to the model of Morant and Gnanasakthy (1989), and from the adjusted curves the potential milk yield for every lactation number and stage was taken. The lactation model of Morant and Gnanasakthy (1989) was used because it has proved to produce a better fit than other lactation models (AFRC, 1993). In this work the r^2 value for model predicted vs observed values was in the range of 0.8 and the average mean prediction error was 7%. Figure 6-1 shows the shape of the lactation curves for the three groups of cows, the arrows indicate the point in the lactation curve used as a parameter in the CM.

Notice that the curves for first and second calvers are almost linear and that in none of the curves a proper lactation peak was observed. This may be explained by the fact that the nutrition in these cows did not allow them to reach a lactation peak or if it was achieved persistency was very short, as in the third calver cows. Similar shapes have been reported for cows in similar production systems (Madalena *et al.*, 1979).

Figure 6-1. Fitted lactation curves



Weight and weight change in other cattle: Because no data was available on the growth curve for animals from birth to calving which could be used as parameters for heifers and other cattle, it was decided to use the Gompertz model for growth (Gill and Oldham, 1993) in order to simulate body weight change over time, and then use this information as an estimated body weight to input to the cow model. The Gompertz growth model was used to predict live weight and live weight gain for heifers and other cattle. Two points in the growth curve for HEIF were simulated in the CM, pregnant and non-pregnant heifers. The same approach was used for calves and bulls, where two points of the growth curve were simulated for calves and only one for steers and bulls. Initial growth parameters were taken from Vera (1991) and modified in order to achieve the live weights shown in Table 6-4.

6.3. 5. Simulating feeding strategies

Two factorial experiments were designed to simulate dry and wet season feeding strategies for all the cattle classes in the herd. The mixed-forage rations and farmer's concentrates in Table 6-3 were used in the factorial experiments. One more concentrate was included in both experiments, a commercial concentrate (Conc-6), in order to compare farmers' concentrates against a typical commercial one. Nutritional parameters for this concentrate were taken from Herrero (1997). Table 6-5 shows the experiment for the dry season where 976 strategies were simulated. Table 6-6 shows the wet season experiment where 992 strategies were simulated.

More feeding strategies were simulated in the wet season because two forages were tested for calves, steers and bulls as opposite to the dry season where only one forage was tested. It was observed that despite that there are more forage types available during the wet season, the forage diet for these cattle classes is still based on stover. Therefore it was considered important to simulate the inclusion of better quality forage for this cattle too, in this case forage 3 (3W) of the wet season.

Table 6-5. Factorial experiment with dry season feeding strategies

<table>
<tr><th colspan="2">Animal Class
$i=1:3$</th><th>Subcategory
$q=1:4$</th><th>Forage Dry season $j=1:4$</th><th>Concentrate Type $l=1:6$</th><th>Supplement rate $r=1:4$</th><th>Total</th></tr>
<tr><td colspan="2">COWS
i=1(1^{st} calving)
i=2(2^{nd} calving)
i=3(3^{rd} +calving)</td><td>q=1(early lactation)
q =2(mid lactation)
q =3(late lactation)
q =4(dry cow)*</td><td>j=1(forage D1)
j=2(forage D2)
j =3(forageD3)
j=4(forage D4)</td><td>Conc-1
Conc-2
Conc-3
Conc-4
Conc-5
Conc-6</td><td>$r=1$(0 kg/d)
$r=2$(2 kg/d)
$r=3$(4 kg/d)
$r=4$(6 kg/d)</td><td>936</td></tr>
<tr><td colspan="2">HEIF</td><td>q=1(non pregnant)
q =2(pregnant)</td><td>j=1(forage D1)</td><td>Conc-1
Conc-6</td><td>$r=1$(0 kg/d
$r=2$(2 kg/d
$r=3$(4 kg/d</td><td>24</td></tr>
<tr><td rowspan="3">OTHE</td><td>CALF</td><td>q =1(6 months)
q =2(6-12 month)</td><td>j=1(forage D1)</td><td>Conc-1
Conc-6</td><td>$r=1$(0 kg/d
$r=2$(1 kg/d</td><td>8</td></tr>
<tr><td>STEE</td><td>q =3(>12 months)</td><td>j=1(forage D1)</td><td>Conc-1
Conc-6</td><td>$r=1$(4 kg/d
$r=2$(6 kg/d</td><td>4</td></tr>
<tr><td>BULL</td><td>q =4(> 2 years)</td><td>j=1(forage D1)</td><td>Conc-1
Conc-6</td><td>$r=1$(2 kg/d
$r=2$(4 kg/d</td><td>4</td></tr>
</table>

*Dry cows across all forages and concentrates were tested at a fixed supplementation rate (r=3).

For feeding strategies for dry cows (i=1:3, q=4) in both seasons only concentrate supplementation rate 3 was tested, since it was observed that cows in this state normally don't receive more than 4kg per day. Since the model does not predict live weight gain associated to pregnancy, it was decided to simulate forage intake across all the forages and concentrates types at a fixed supplementation rate in order to reduce the computer time required to run the model for the whole experiment.

Table 6-6. Factorial experiment with wet season feeding strategies

Animal Category $i=1:3$		Subcategory $q=1:4$	Forage Rain season $j=1:4$	Concentrate Type $l=1:6$	Supplement rate $r=1:4$	Total
COWS		q=1(early lactation)	j=1(forage W1)	Conc-1	$r=1$(0 kg/d)	
i=1(1st calving)		q =2(mid lactation)	j=2(forage W2)	Conc-2	$r=2$(2 kg/d)	
i=2(2nd calving)		q =3(late lactation)	j =3(forage W3)	Conc-3	$r=3$(4 kg/d)	
i=3(3rd + calving)		q =4(dry cow)*	j= 4(forage W4)	Conc-4	$r=4$(6 kg/d)	
				Conc-5		
				Conc-6		936
HEIF		q=1(non pregnant)	j=1(forage W3)	Conc-1	$r=1$(0 kg/d)	
		q =2(pregnant)		Conc-6	$r=2$(2 kg/d)	
					$r=3$(4 kg/d)	24
OTHE	**CALF**	q =1(6 months)	j=1(forage D1**)	Conc-1	$r=1$(0 kg/d)	
		q =2(6-12 month)	j=1(forage W3)	Conc-6	$r=2$(1 kg/d)	16
	STEE	q =3(>12 months)	j=1(forage D1**)	Conc-1	$r=1$(4 kg/d)	
			j=1(forage W3)	Conc-6	$r=2$(6 kg/d)	8
	BULL	q =4(> 2 years)	j=1(forage D1**)	Conc-1	$r=1$(2 kg/d)	
			j=1(forage W3)	Conc-6	$r=2$(4 kg/d)	8

*Dry cows across all forages and concentrates were tested at a fixed supplementation rate (r=3). ** Forage D1 of the dry season was tested because it is the main forage fed to these classes of cattle even during the wet season.

6.4. Model predictions

Because forage intake was not measured during the fieldwork it was difficult to validate the CM in the way the other two models used in this work were validated. Since forage intake is the driving variable of the model and is responsible for the amount of nutrients supplied to the animal for maintenance and production activities it would had been incorrect to validate the model using only milk yield observations measured during the fieldwork. Herrero (1997) validated the model for forage intake against 23 tropical and temperate forages, and reported that the model explained 65% of the variation in observed intakes with a mean prediction error of 5%. From the analysis of the results it is suggested that model predictions for milk yield for the different feeding strategies simulated are within the range of the milk yields observed in the field and those reported by Arriaga *et al.*, (1997a) and Castelán *et al.*, (1997).

6.4.1. Model predictions for Dry Season feeding strategies

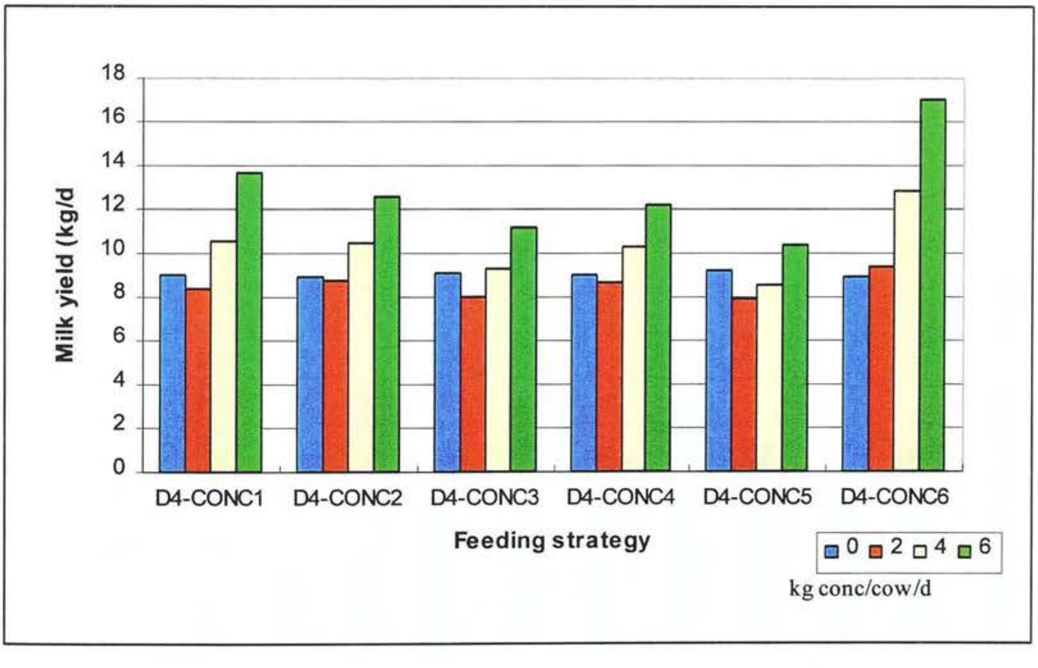
Due to the large number of feeding strategies simulated and the size of the output, the results presented in this section correspond only to the cows in their third lactation (i=3) and early lactation stage (q=1). Model predictions for milk yield and forage intake that were observed in the first and second calving cows are similar to those observed in this group of cows. Appendix 3 shows the CM predictions for all the cow classes simulated. Model predictions for HEIF and OTHE cattle are presented in Appendix 3 too. Due to the size of the output file, only a summary of the output for both the dry and the wet season is presented.

The dry season feeding strategy which produced the highest response in terms of milk production (17kg of milk) was forage D4 supplemented with the concentrate Conc-6, at a rate of 6 kg of concentrate per animal per day (r=3). Figure 6-2, shows predicted milk yields for forage D4 supplemented with all concentrates. It is observed that Conc-6 produced the highest response across all the supplementation rates (2, 4 and 6 kg/d/cow) when compared with the other five concentrates tested. Concentrate number one produced the second highest response (13.6 kg), followed by concentrates number 2 and 4 (12.6 and 12.2 kg respectively), which have similar composition (see Table 5-3). Concentrate 3 and 5, presented the lowest predicted milk yields when were fed with forage D4 (11.1 and 10.4 kg respectively).

It is suggested that these results are consistent with the nutritional characteristics of the mixed-forage rations and concentrates shown in Table 6-3 and with their composition in terms of their basic ingredients (Tables 5-3 and 5-2). For example, Conc-6 is high in soluble material and low in NDF and its degradation rate is among the highest in all concentrates (see Table 6-3). Forage D4 has 30% of improved pasture; its NDF is more degradable and its degradation rate is slightly higher than the rest of the dry season forages. These factors probably resulted in more nutrients being supplied to the animal due to increased degradation and outflows rates, particularly in the concentrate, and possible increased forage intakes. Therefore, it was not surprising that higher milk yields were observed in this feeding strategy when compared to the other dry season feeding strategies. Despite important differences in the predictions for concentrates, the differences between forages are not so important, as is described later in this section.

Particular attention should be paid to the fact that concentrates 1 to 5 when supplemented at a rate of 2 kg per day depressed milk yield (Figure 6-2). Concentrate 5 produces the same effect when supplemented at 4 kg per day and only returned to the initial intake level (only forage) when the supplementation rate is increased to 6 kg/d. Concentrate 6 is the only concentrate that did not depress milk production when supplemented at the lower rate. These results can be explained by higher substitution effect produced by concentrates 1 to 5 associated with the lower nutritional quality, particularly high levels of NDF. The substitution effect of the different concentrates is explained in section 6.4.1.2. of this chapter.

Figure 6-2. Predicted milk yield for 3rd calving cows in their early lactation (i=3, q=1) fed forage D4 and concentrates 1 to 6



The commercial concentrate, Conc-6, also produced the highest response in terms of milk yield when it was supplemented to the rest of the forage rations tested for the dry season. For example, Figures 6-3 and 6-4 show that when CONC-6 is supplemented to forage D1 and D3 the same response pattern described for forage

D4 above is repeated with these forages too. Figure 6-3 and 6-4 also show that concentrate number Conc-1 produced again the second highest milk yield, followed by concentrates 2 and 4, while the concentrates 3 and 5 produced the lowest milk yields. In addition, notice that forages D3 and D4 presented slightly higher milk yields (0.44 and 0.8 kg/d respectively) than forage D1, particularly when supplemented by Conc-6. This could be explained by the content of improved pasture in these mixed forage rations.

Figure 6-2 shows that the difference between milk yields predicted by supplementing Conc-1 and Conc-6 at a rate of 6 kg/cow/d to forage D4 was of 3.4 kg of milk/d; this difference is increased to 5.8 kg when Conc-6 is compared to Conc-3, which is a lower quality concentrate. Figures 6-3 and 6-4 show that a response of similar magnitude was observed when Conc-6 was compared with the rest of the dry season forage rations.

Figure 6-3. Predicted milk yield for 3rd calving cows in their early lactation (*i*=3, *q*=1) fed forage D1 and concentrates 1-6

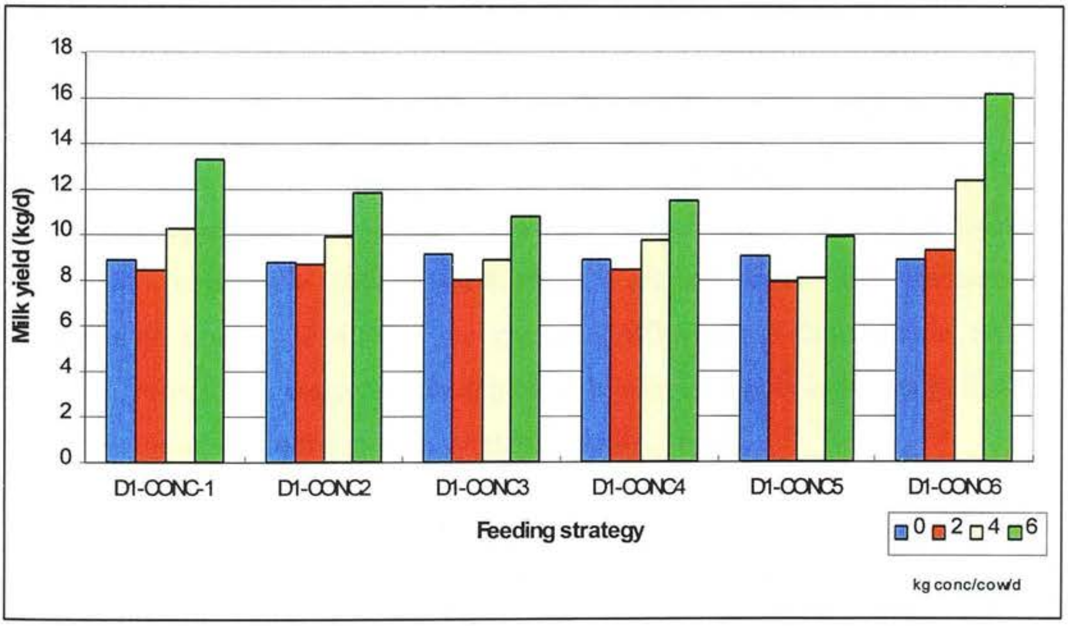
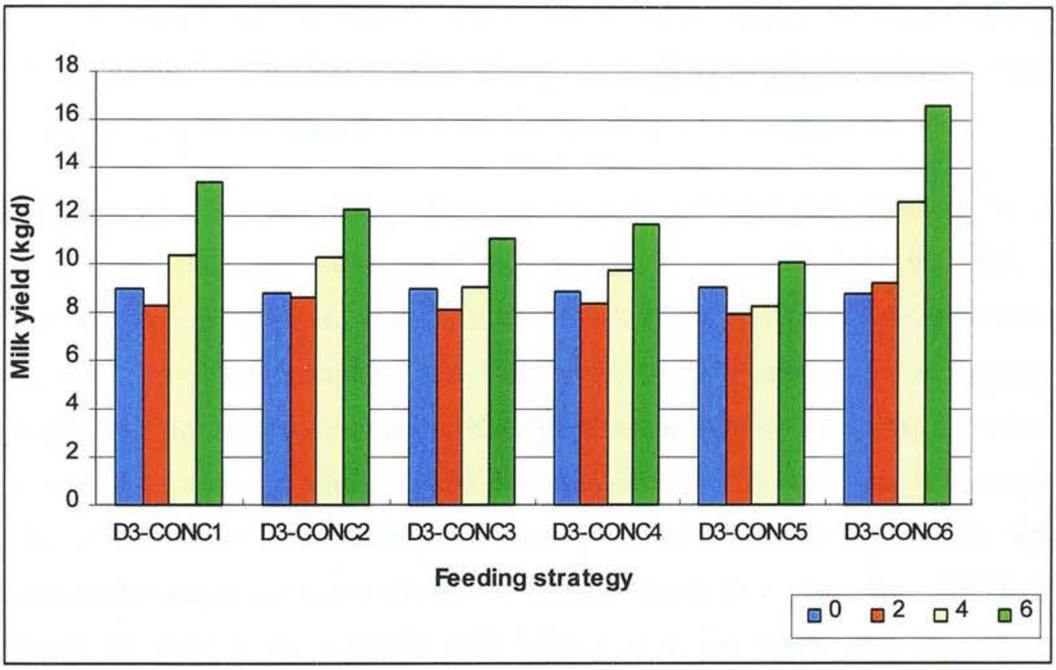


Figure 6-4. Predicted milk yield for 3rd calving cows in their early lactation (*i*=3, *q*=1) fed forage D3 and concentrates 1-6



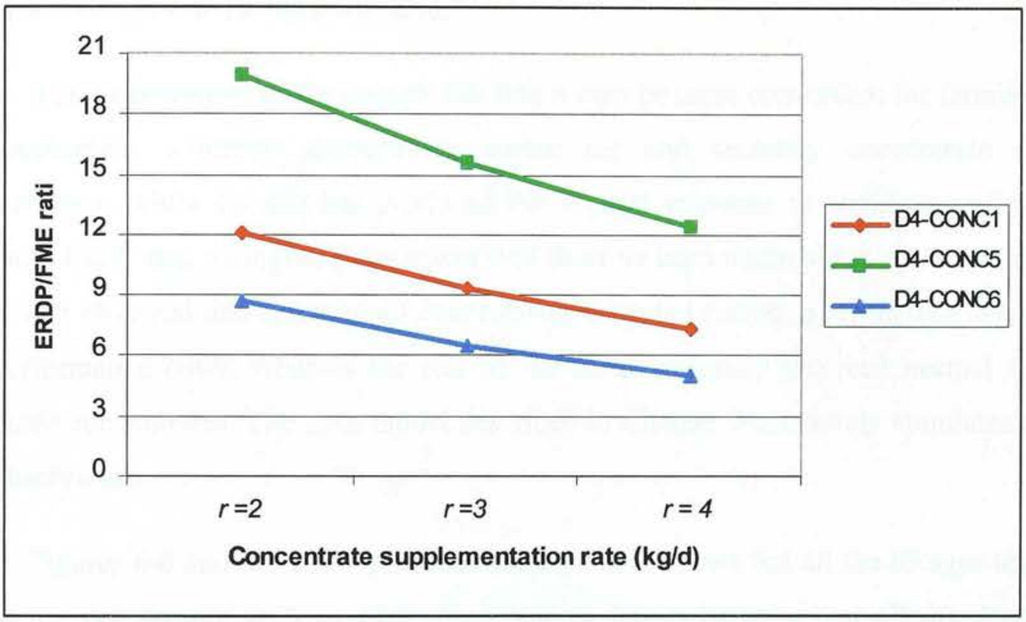
Low milk yield predicted for Conc-3 and Conc-5 are consistent with the fact that these concentrates have the lowest nutritional quality among all the concentrates since they are formed by more than 70% of chicken manure, high content of NDF with a low proportion of NDFD (0.52 to 0.54%), and low quantity of soluble C.H. due to small proportion of grains or other sources of energy (Tables 5-3 and 6-3). Therefore, if supplemented to cattle they will supply reduced amounts of nutrients to the animal, particularly soluble CHs, which are converted into Fermentable Metabolisable Energy (FME) in the rumen. FME plays a fundamental role in microbial growth and rumen functioning because energy supply is normally the first limiting factor on microbial protein synthesis (AFRC, 1993).

FME is the Metabolisable Energy (ME) content of a feed or diet as MJ/kg DM, less the ME content present as total oils and fats and the ME contribution of fermentation acids. Because concentrates Conc-3 and 5 are rich in chicken manure it is quite likely that energy will be the main limiting nutrient for correct microbial growth and rumen functioning. Chicken manure is a cheap source of non-protein nitrogen in the form of urea (Preston and Leng, 1987), so it is likely that rumen microbes do not suffer from lack of protein. Under ideal conditions the effective rumen degradable protein (ERDP) supply should exactly match the supply of FME supply (AFRC, 1993). The ERDP/FME energy ratio threshold for adequate rumen environment is 9:1 for maintenance and low yielding cows (Oldham, 1984).

ERDP (g/d) is a measure of the total nitrogen x 6.25 supply captured by the microbes, whether as non-protein N and/or intact soluble protein in the QDP, or degraded protein moieties, SDP (Webster, 1992; AFRC, 1993). Model predictions indicated that supplementation with Conc-3 and Conc-5 across all the simulated forages does not meet the required ERDP/FME relation mainly due to the low energy content of the diet as a whole. Figure 6-5, demonstrates this more clearly where the ERDP/FME ratios were calculated from the output of the model for three concentrates supplemented to forage D4. Conc-1 represents a case where energy and protein are close to the adequate ratio, Conc-6 is a case where there is sufficient energy but there is not enough ERDP to support adequate microbial growth. Conc-5 represents a case where there is not sufficient energy to support microbial growth, but there is plenty of ERDP since the ratio is quite far from the required threshold which is 9.

This type of information is very valuable because it allows evaluation of current feeds and the formulation of better ones, thus the decision support is more effective. For example, although the feeding strategy D4+Conc-6 produced the highest response it still requires some ERDP protein to achieve optimum protein-energy ratio, so supplementation with urea or chicken manure could improve the nutritive value of this ration. D4+Conc-5 requires the opposite: more energy which allows the use of the surplus N in the rumen. Moreover, results in Figure 6-5 indicate that too much non-protein nitrogen is being fed which could be toxic to the animal.

Figure 6-5. ERDP/FME ratio for CONC-1, 5 & 6, supplemented to forage D4



Since the effects of energy and protein, <u>at ruminal level</u>, are adequately represented by the CM, it is not surprising then that Conc-6 and 1 presented the highest response, and CONC-2 and 5 the lowest. Results in Figure 6-5 suggest that Conc-1 presented a better balance of energy and protein given by a substantially larger amount of grain (48%) and lower chicken manure content (28%) which together with maize stover were responsible for a reasonable high milk yield. In fact it can be suggested that Conc-1 presented the best response among all farmers' concentrates.

However, these results have to be taken cautiously since the model is more sensitive to the energy content of the diet than to the protein content. Because while the protein-energy interactions are properly accounted for at ruminal level (dynamic section), it does not occur at the static section where the animal requirements for protein and energy are calculated.

For example, the CM does not consider metabolisable protein requirements-supply for lactation when calculating milk yield, and only ME requirements are used.

Therefore, the model is more sensitive to the energy content of the diet than to the protein when calculating milk yield.

Results presented so far suggest that that it may be more convenient for farmers to supplement primarily concentrate number six and secondly concentrate one. However, while Conc-6 has produced the highest response to supplementation it quite likely that its higher price prices will limit its used under some circumstances. It was observed that commercial concentrates were fed (when used) mainly to high-performance cows, whereas the rest of the cattle normally received normal farm made concentrates. The farm model described in Chapter 7 accurately simulates this observation.

Figures 6-6 and 6-7 show predicted milk yield for cows fed all the forages tested in the dry season, with concentrates 1 and 6. It can be seen that all the forages presented very similar milk yields when fed alone without any concentrate. However, when the concentrates were added to the diet, only a small difference is observed among the different feeding strategies. This difference is mainly between forage D1 and forages D3 and D4. These figures also show that forage D2 presented the lowest response when fed alone, probably because of the low quality of the silage used by farmers. The small difference observed between the forages may suggest that the use of improved pasture is having a limited effect particularly when is fed without any concentrate.

These results suggest that the inclusion of relative low quantities of improve forage, as in forage D3 and D4, has a small effect milk yield when compared with those cows which are fed with maize straw alone, as in forage D1. However, only a limited number of strategies were tested and different rates of IP inclusion may need to be tested.

Figure 6-6. Predicted milk yield for 3rd calving cows (i=3,q=1) fed all dry season forages and concentrate 1.

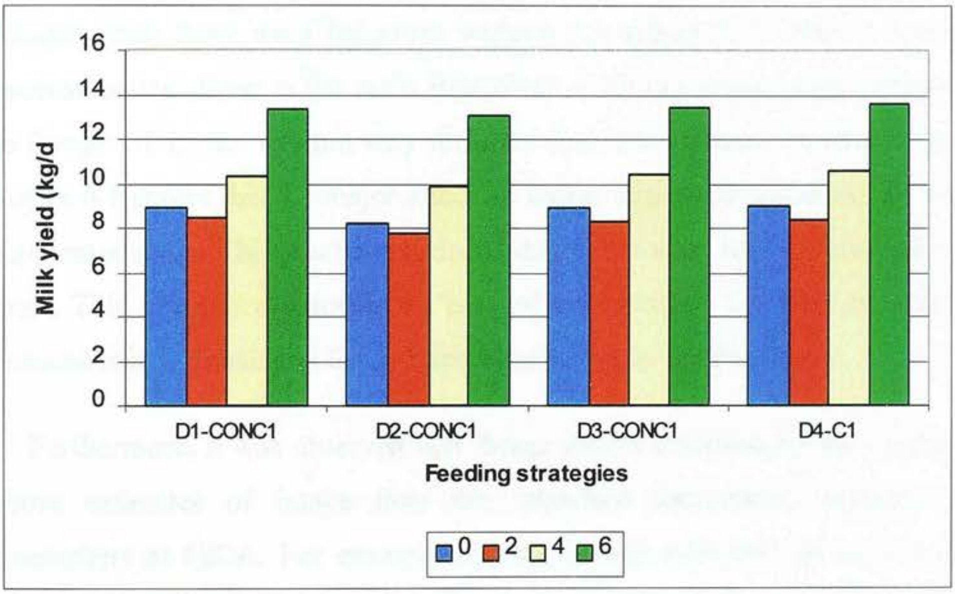
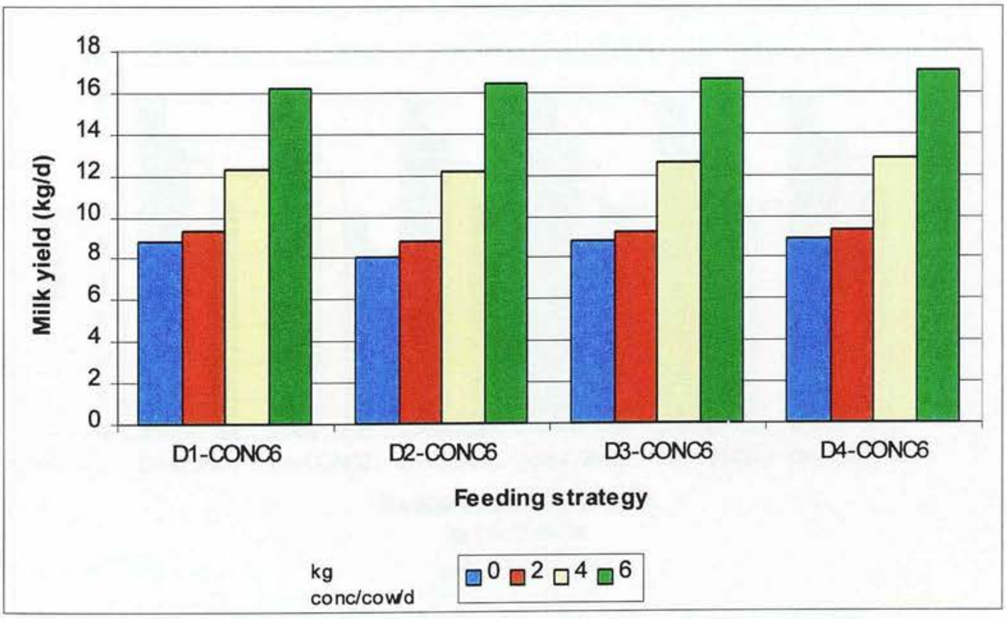


Figure 6-7.Predicted milk yield for 3rd calving cows (i=3,q=1) fed all dry season forages and concentrate 6.

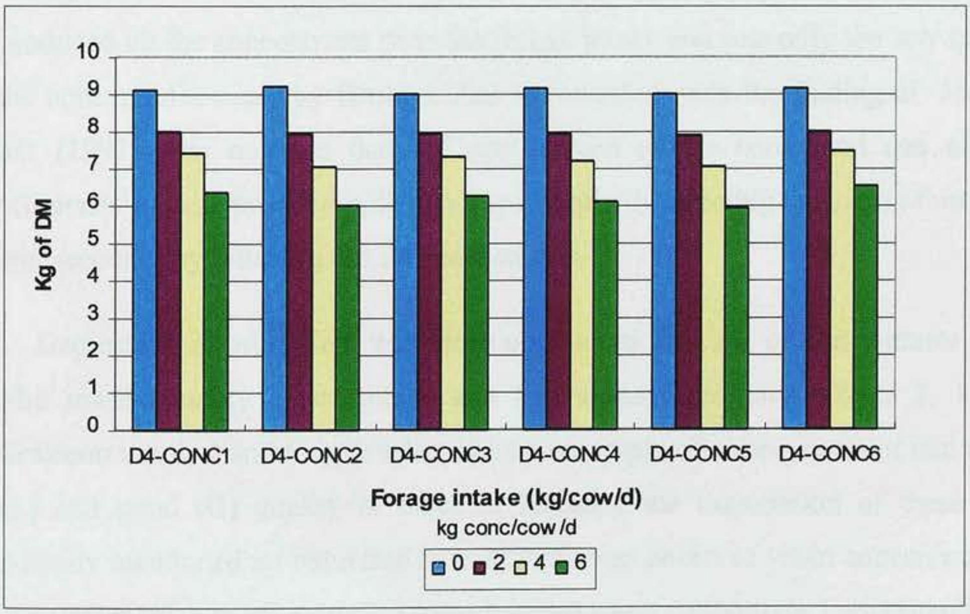


6.4.1.1. Forage intake

It was observed that predicted forage intake was similar for all the dry season forages when these were fed alone without any concentrate. This is not surprising because maize stover is the main ingredient of all dry season mixed-forage rations, so forage D1 intake was not very different from the intakes of forages D2, 3 and 4. Figure 6-8 shows that the major effect on forage intake was produced by concentrate supplementation. This practice produced different forage intakes, particularly at high rates. This is more evident in the case of concentrates 1, 5 and 6, where Conc-5 reduced forage intake and Conc-1 and 6 increased it, see Figure 6-8.

Furthermore, it was observed that forage intake predicted by the model provided better estimates of intake than the "standard formulation systems" used by researchers at CICA. For example Arriaga (1996) estimated an intake of 8 kg of maize stover DM for a cow of similar characteristics to the one used in Figure 6-8, while the model estimated an intake of more than 9kg of DM.

Figure 6-8.. Predicted forage intake for D4-CONC1-6 feeding strategy (in kg of DM/cow/d).



This author used the MAFF (1984) simple regression model to calculate potential dry matter intake (DMI), where DMI= $0.025W + 0.1Y$ (in Arriaga, 1996). MAFF

(1984) model only uses animal factors to calculate intake such as liveweight (W) and milk yield (Y), but it does not include food factors. Food factors such as the solubility of the roughage, the insoluble but potentially fermentable fraction, its degradation rate, and their effects on the rumen outflow rate are key determinants of intake of crop residues and other low quality forages (Shem *et al.*, 1995). However, most simple and multiple regression models for predicting intake do not include these factors (Lønne, 1994). Considering that food and animal factors are represented in the **CM** we can be sure that predictions for forage intake are more accurate than those calculated by Arriaga (1996) using standard formulation systems.

6.4.1.2. Forage-concentrate substitution rate

It was observed that all the concentrates made by farmers (CONC-1 to CONC-5) produced a reduction in milk yield when supplemented at low doses instead of producing an increment in yield as it normally occurs when supplementing concentrates, for example Figures 6-2, 6-3 and 6-4 show that 2 kg of concentrates 1 to 5 resulted in lower milk yielded than when not concentrate was supplemented. These results can be explained by two main factors, firstly the substitution effect produced by the concentrates over the forage intake and secondly the low quality of the concentrates made by farmers. This is consistent with the finding of Jackson *et al.*, (1991) who mention that the composition of the compound can affect the efficiency of milk production in two ways, firstly by affecting the yield of milk solids and secondly by affecting the substitution rate.

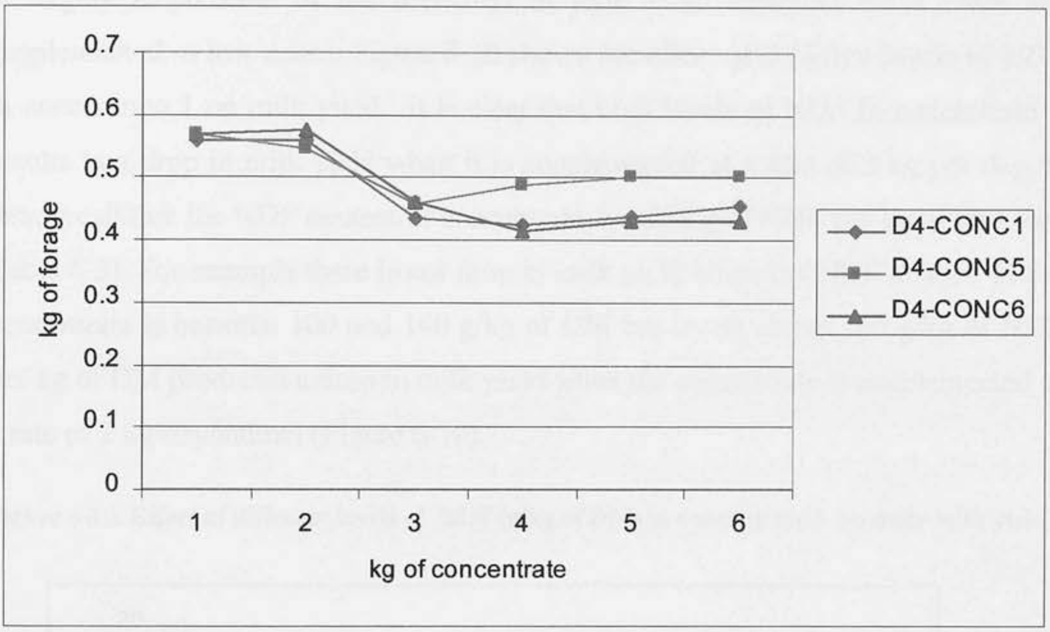
Depression in milk yield was more obvious in the case of concentrates 3 and 5 (the lowest quality concentrates) and less evident for concentrates 2, 1 and 4. Concentrates 5, 1 and 6 were selected as an example of concentrates of bad (B), low (L) and good (G) quality in order to facilitate the explanation of these effects. Already mentioned no reduction in milk yield was observed when concentrate 6 was supplemented, a small reduction was observed when concentrate 1 was supplemented and the higher reduction was observed when concentrate 5 was supplemented (see Figures 6-2, 6-3 and 6-4).

Substitution effect: Figure 6-9 shows the forage-concentrate substitution rates for the forage D4 and concentrate 1, 5 and 6. Concentrates 5 produced the highest substitution rates over this forage but also across all the forages tested for the dry season, concentrate 1 produced a lower substitution rate and concentrate 6 produced the lowest substitution rate. These results are consistent with the model prediction for milk yield, where concentrate 5 produced the highest reduction in milk yield and concentrate 6 produced an increment in milk yield. According to Broster and Thomas (1981) when forage is given *ad libitum* the addition of a concentrate supplement depresses forage intake but increases total intake. The depression in the intake of the forage (unit of forage ΔF) produced by a unit of change in the intake of a concentrate (ΔC) is termed the "substitution rate". The type of concentrate, the level of concentrate and the digestibility of the forage (Broster and Thomas, 1981; Leaver, 1988) can influence substitution rate.

In the case of concentrate 5 the higher substitution rate is produced by its high content of NDF (240 g/kg of DM), the low degradability of its NDFD (0.54%) and the very low degradation rate of the NDF (0.042) of this concentrate (see Table 6-3 for values). In fact, the degradation rate for concentrate 5 is quite similar to the degradation rates of the forages. Therefore, forage and concentrate are competing for space in the rumen since both are degraded at similar rates, a normal concentrate is quickly degraded and eliminated from the rumen but this does not occurs in the case of this concentrate which takes longer to be eliminated from the rumen.

Results in Figure 6-9 are in close agreement with the degradation characteristics of the concentrates. The better quality concentrates such as 6 and 1 are degraded faster and spend less time in the rumen than the bad quality one, mainly due to higher outflow rates. Thus these concentrates produce smaller substitution rates. Increased degradation and outflow rates mean that these concentrates leave the rumen faster than the other concentrates therefore forage intake is less affected (Preston and Leng, 1987; AFRC, 1993). It is also important to mention that substitution is a competition between passage and degradation in the rumen and this is a non-linear process as shown in Figure 6-9.

Figure 6- 9.Forage-concentrate substitution rate



A similar situation occurs in the case of concentrate 1 that is also high in NDF (231 g/kg of DM) although its degradation rate is higher than the previous concentrate and similar to the concentrate 6 which explains the lower substitution rate observed in this concentrate and the lower reduction in milk yield than in concentrate 5. Both concentrates are low in soluble CH due to their low content of grains i.e. concentrate 5 has 10% of ground maize and concentrate 1 has 48% of ground maize (see Tables 5-3 and 6-3).

Moreover concentrate 1 has 28% of chopped stover, whilst concentrate 5 has 75% of chicken manure which is also an important source of fibre because of its content of stover. Stover is used as bedding for broilers, therefore, the chicken manure used by farmers at the Toluca Valley is in fact a mixture of chicken droppings and stover. Concentrates made by farmers are quite different from the traditional dairy compounds which are based on cereals which provide an energy source in the form of starch. Starch is readily available to the rumen microbes however, when large amounts are ingested a fall in pH together with a decrease in the ratio of acetic to propionic acids is observed in the rumen liquor (Jackson *et al.*, 1991).

It is suggested that the high content of NDF in the concentrates made by farmers is largely responsible of the reduction in milk yield observed when these are supplemented at low doses. Figure 6-10 shows the effect of different levels of NDF in concentrate 1 on milk yield. It is clear that high levels of NDF in concentrate 1 results in a drop in milk yield when it is supplemented at a rate of 2 kg per day or less, recall that the NDF content of concentrate 1 is 230 g of NDF per kg of DM (see Table 6-3). For example there is not drop in milk yield when the NDF content of the concentrate is between 100 and 140 g/kg of DM but levels above 160 g/kg of NDF per kg of DM produced a drop in milk yield when the concentrate is supplemented at a rate of 2 kg/day/animal (Figure 6-10).

Figure 6-10. Effect of different levels of NDF (g/kg of DM) in concentrate 1 on daily milk yield

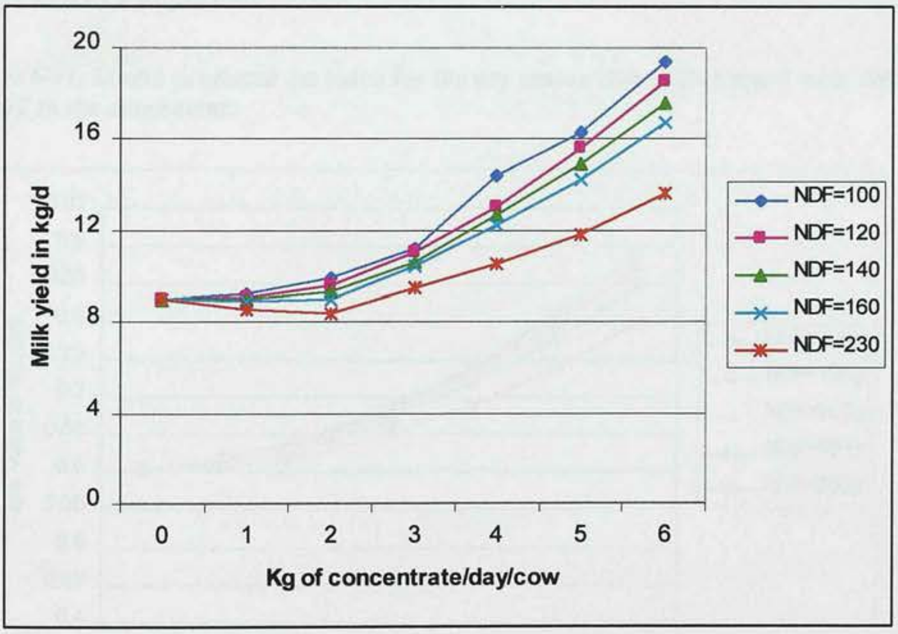
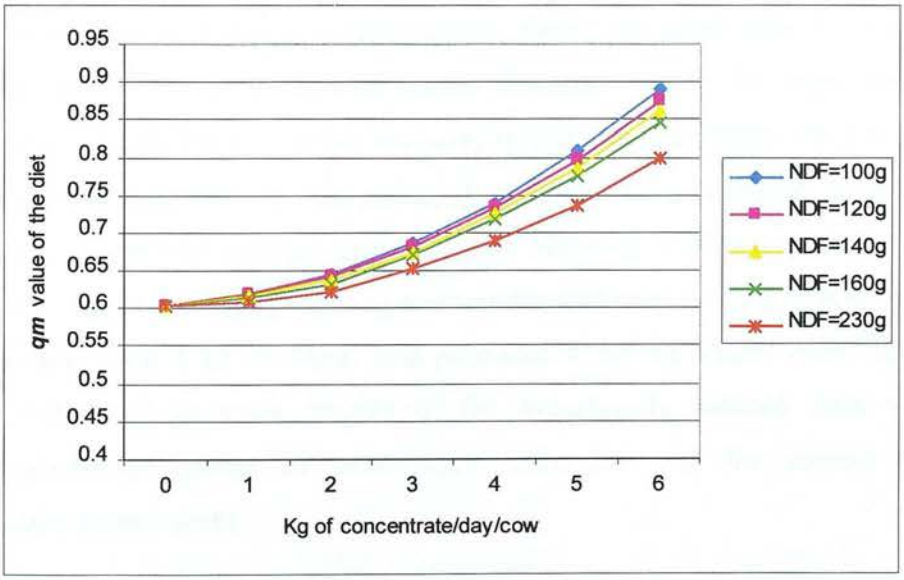


Figure 6-10 also shows that rates of concentrate supplementation higher than 3 kg/d resulted in an increment in the milk yield even at the highest content of NDF in concentrate 1. This increment in yield is produced by the higher energetic value of the ration as a whole (forage+concentrate) achieved at higher supplementation rates. Figure 6-11 indicates how the *qm* value of the diet increases as the supplementation rate also increases, also notice that higher *qm* values were predicted at lower NDF contents of the concentrate. Higher supplementation rates increase the energetic value of the diet or *qm* value, this in turn makes the efficiency of utilisation of the energy for the different physiological process more efficient. In other words, the higher the *qm* value of the diet, the more efficient is the utilisation of the metabolisable energy by the animal. For example, at higher *qm* values the efficiency of utilisation of the energy for lactation is higher (AFRC, 1993) therefore an increment in milk yield is observed.

This can explain the increment in milk yield observed at supplementation rates above 3 kg of concentrate per day, however it is suggested that the increment in the metabolisability of the diet at two kg of concentrate per day is not sufficient to increase milk yield and that the substitution effect of the concentrate over the forage intake is more important.

Figure 6-11. Model predicted *qm* value for the dry season diet F4D+Conc-1 with different levels of NDF in the concentrate



The response to increasing amount of concentrates is well documented and it varies with the amount of concentrate but consist primarily of a reduction in forage intake but increases in total DM and digestible energy intakes, milk yield and milk protein concentration with variable effects on milk fat concentration (Sutton *et al.*, 1994). Due to the characteristics of the concentrates made by farmers is likely that the response predicted by the model differs from the one observed by these authors particularly in milk yield.

Changing *qm* values in the total diet also affect the ME requirements of the animal because the ME requirement are not constant for a given animal but are a product of animal/feed interactions as shown in Figure 6-11 (AFRC, 1993). For example at high supplementation rates the *qm* value of the diet as a whole also increases therefore less ME energy is required by the animal because the efficiency of utilisation is higher. Changes in the *qm* value of the diet also affect the passage rates since the passage rates are scaled according to feeding level on multiples of ME above maintenance. Therefore if ME requirements are changed the passage rates also change because these are not constant (Herrero, 1997). This dynamic functioning of the system also explains the variable substitution rates, which depends on the amounts of feed given to the animal, observed in Figure 6-9.

It is suggested that the observations above described must be validated with experiments involving cows of similar characteristics of the ones simulated here. However, exist some evidence that suggest that supplementing cow with low quality concentrates produces a high substitution effect and a reduction in milk yield and forage intake. For example Espinoza and Martínez (1989) and Jaime and Castelán (1990) found that supplementing cows under continuos grazing of Rye grass (*Lolium perenne*) with 4 kg of wheat bran produced a not significant effect on milk yield (P>0.05) and in some months of the experiments reduced milk yield in the supplemented groups of cows when compared with the control cows (non-supplemented cows).

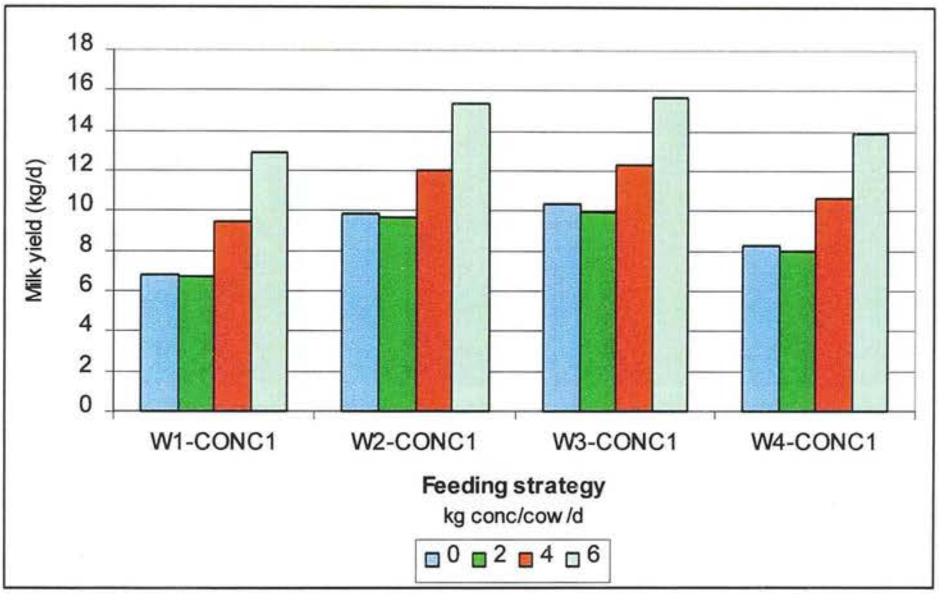
Finally, the fact that protein-energy interactions of feedstuffs at ruminal level, the response to concentrate supplementation and forage-concentrate substitution rates and their effects on milk yield can be evaluated through the CM represents a real improvement compared to the traditional system of feed formulation. Moreover, two of the fundamental variables in designing improved feeding systems, 1) The amount and balance of nutrients required for production and, maintenance and 2) The quantitative availability (solubility) of nutrients from the diet, can be evaluated through the CM. It is possible to suggest that the development of model like the one used here offers a great potential to both designing improved feeding systems and as a decision support tool. For example, results in Figure 6-9 suggest that supplementing cows with 2 kg of farm-made concentrate could actually reduce milk yield, so it may be worthwhile for farmers to feed higher rates of concentrate in order to obtain a better response.

6.4.2. Model predictions for wet season feeding strategies

Because of the larger number of forages available during the wet season and the greater difference in their nutritional characteristics it is not surprising that bigger differences in terms of milk yield and forage intake, either when fed alone or supplemented with concentrates, were predicted by the CM. Figure 6-12 displays the model's prediction for all the mixed-forage rations supplemented with concentrate CONC-1. This figure clearly indicates that the CM was able to capture the differences in the degradation characteristics among the forage rations shown in Table 6-3. For example, the highest milk yields were achieved when forages W3 and W2 were fed (15.6 and 15.4 kg of milk/cow/d respectively), followed by forages W4 and W1 (13.9 and 12.9 kg of milk/cow/d respectively). Milk yield predictions for this season are in close agreement to the yield levels registered during the fieldwork and those reported by Arriaga *et al.*, (1997a) and Castelán *et al.*, (1997).

Recall that mixed forage rations W2 and W3 contain 30% and 40% of green maize fodder (GMF), which as mentioned in Chapter 6 provides important quantities of soluble and insoluble but degradable CHs. It is suggested that the high content of these nutrients was responsible for higher milk yields because the CM is particularly sensitive to the energetic content of the foodstuff as a whole. Results illustrated in Figure 6-12 justifies the fact that farmers prefer to used this forage and are willing to allocate important amounts of labour for its harvest and transport.

Figure 6-12. Predicted milk yield for 3rd calving cows in their early lactation (i=3, q=1) fed all the forages and CONC-1



Moreover, notice that the mixed forage ration 4W, which contains an important proportion of improved pastures, produced less milk than the forage rations that contain GMF. Although improved pastures are in general better quality forages, it was observed that as a whole they supply less CH to the animal than GMF and this may explain model predictions for these particular forages.

Figures 6-13 shows that model prediction for the same forages but supplemented with concentrate Conc-6 resulted in a similar response pattern to that described for Conc-1. However, notice that even higher milk yields were predicted for these feeding strategies. These results are consistent to the predictions observed for the dry season, where the highest milk yields were observed when this concentrate was supplemented. In the same way, Figure 6-14 shows model's predictions for all the forages supplemented with Conc-5. Again it can be observed that supplementation with a low quality concentrate such as Cconc-5 resulted in low milk yields even for wet season forage rations.

Figure 6-13.Predicted milk yield for 3rd calving cows in their early lactation (i=3, q=1) fed all the forages and Conc-6

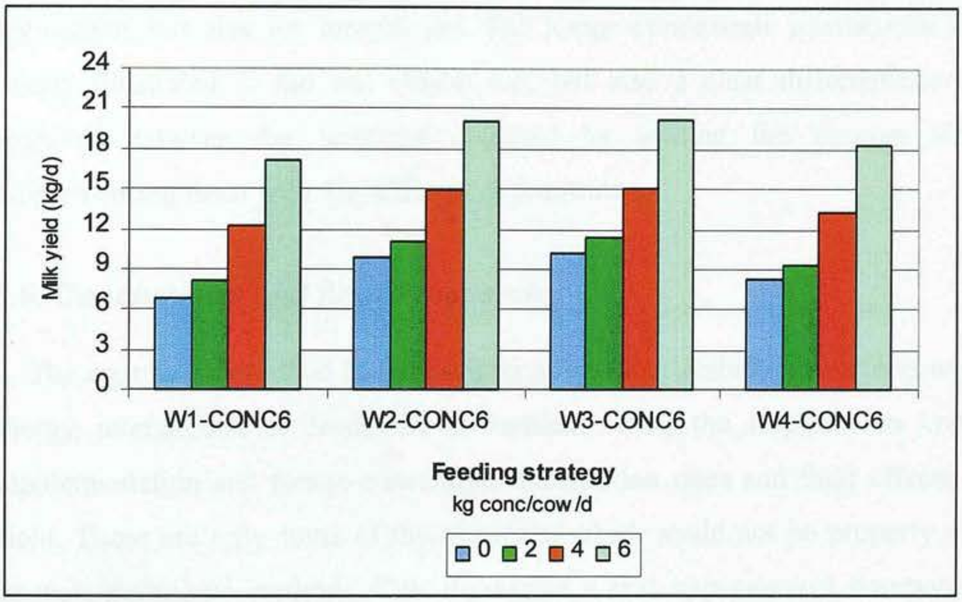
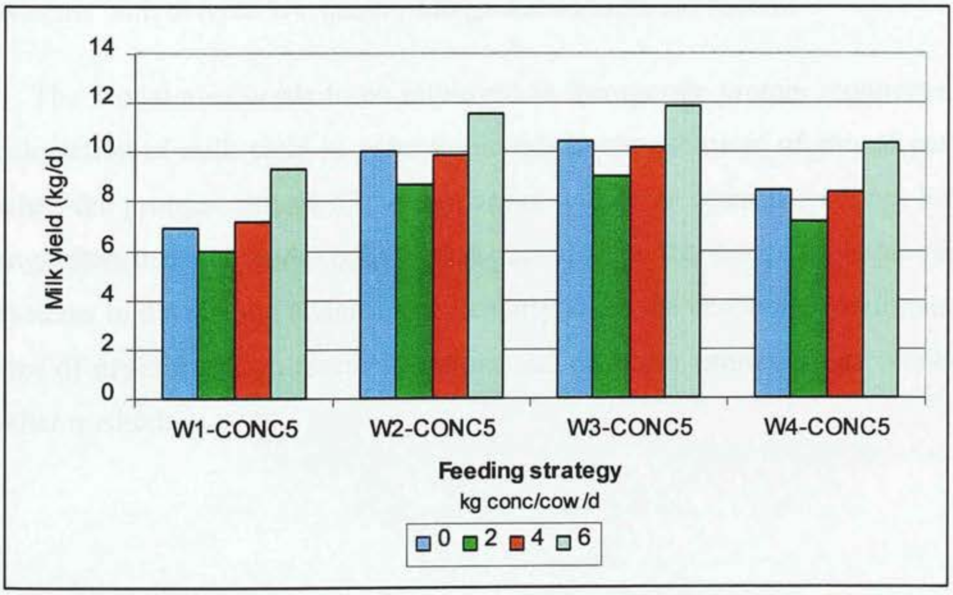


Figure 6-14. Predicted milk yield for 3rd calving cows in their early lactation (i=3, q=1) fed all the forages and CONC-5



Finally it is possible to suggest that model predictions for the rainy season presented a wider range of response not only for concentrates as it occurred in the dry season, but also for forages too. The forage-concentrate interactions are more clearly illustrated in the wet season too, but also a clear differentiation can be observed between the response obtained by feeding the forages alone and supplementing them with the different concentrates.

6.5. Conclusions and future research

The approach described in this chapter allowed to evaluate the effects of protein-energy interactions of feedstuffs at ruminal level, the response to concentrate supplementation and forage-concentrate substitution rates and their effects on milk yield. These are only some of the elements, which could not be properly evaluated through traditional methods. This represents a real improvement compared to the traditional system of feed formulation. Moreover, the fact that thousands of different feeding strategies can be simultaneously evaluated represent a facility not easily available at any research station. However, it is suggested that the model needs to be extensively validated against field data particularly for feed intake from feeding systems with diverse low quality forage and concentrate source.

The model also needs to be improved to incorporate protein requirements in the calculation of milk yield in order to provide better estimates of animal performance when the protein content of the diet varies widely or when is limiting. Finally it is suggested that the model offers great potential for the design of improved feeding systems in developing countries particularly when the economic conditions limit the size of experiments in research stations and no better estimates can be obtained by other methods.

Chapter 7. Integrated farming system model

7.1. Introduction

This chapter describes the characteristics and functioning of the Decision Support System, which in effect is an *Integrated Farming System Model* (IFSM) because it integrates all the other elements of this work into one model. The IFSM was designed to emulate the typical *campesino* maize-cattle production system of the northern region of the Toluca Valley (MLPS), and to support the decision making process of farmers in this system. The structure of the model is flexible to accommodate the multicropping system observed in Tenango del Valle (IMLPS).

In essence, the household, maize production and cattle production are the key components in both systems. It was considered important to develop a generic model that includes these three activities while it can be extended to incorporate more cropping activities. It is acknowledged that while the structure of the IFSM can be modified to simulate the farming systems observed in the southern part of the Valley (Tenango del Valle), more integrated biological models are required to simulate the multicropping and intercropping cultivation systems observed in this region. Such models have been created but they required considerable more information to calibrate and most of them have never been tested with data from the tropics, making their applicability for the tropical countries unclear (Caldwell *et al.*, 1996).

The construction of the IFSM was based on detailed data on the characteristics and functioning of the target farming system, its natural and economic resources, as well as the social characteristics of the farmers, obtained during the survey work described in Chapter 3. Data from other surveys carried out in the same area by CICA's researchers was also included in the farm system modelling exercise (Arriaga *et al.*, 1997b; González, 1997; Vizcarra, 1997; Woodgate, 1997; Castelán *et al.*, 1997).

This knowledge was the key factor in developing an IFSM that could be used to emulate the *campesino* maize-cattle production systems in a practical and realistic manner. Understanding of the farming system was the first step in the construction process. Several authors have recognised the importance of accurate knowledge of the farming system in the development of decision support tools. Sharifi and Van Keulen (1994) proposed that the development of such tools requires an understanding of the system, its constituent processes and their impact on system behaviour. Moreover they mention that understanding the agricultural system requires synthesis of important biological, managerial and economic processes of the system, and, for actual operational planning, an integrated model that combines all these interrelated processes is needed.

The IFSM has the potential to be used as a decision support tool for both *campesinos* and policy planners. In the first case *campesino* farmers are frequently faced with operational decision problems with respect to land use, such as what commodities to produce, on which tract of land, by what method, in which seasonal time period, and in what quantities. In the second case the effects of some policies for this particular farming system could be evaluated before their application. In both cases, decision-makers need tools to analyse a variety of information in such a way that the consequences of various strategies or options can examined before their implementation.

The IFSM reproduces the functioning of the main components of the farming system: the household, maize and cattle production activities. More importantly it simulates the interactions among them and how these are influenced by the non-biological parts of system, such as the climate. This representation was possible due the interaction of the two biological simulation models used in this work with the IFSM. The maize model simulated 744 different technologies to cultivate three varieties of local maize under rainfed or irrigated conditions. The cow model simulated 1872 feeding strategies for lactating cows alone.

The model was refined to the point of making it simulate complex interactions observed between the farmers and their maize crops. Traditional management practices for this crop include different planting population, thinning and scotching of the green maize stover and the cut and carry of the weeds that grow in the maize fields (see Chapters 4 and 5 for description). The model simulated the effects of these practices on the feeding systems for cattle and on the household's labour demand. The IFSM also determines on a monthly basis the most efficient use of the different products generated within the system, such as grain, stover, and other forages.

The IFSM selects from the cattle feeding systems generated by the cow model (see Figure 7-1) the best option for the different classes of animals within the farm herd. A normal output of the model includes a monthly statement with the forage type, concentrate type and supplementation level fed to all animal classes in the herd. Moreover, it differentiates between the dry and wet seasons, and allocates the best strategy month by month of each season and decides whether or not it is worth feeding concentrate supplements.

The information considered by the model in the selection of the feeding strategies included: the availability of the different forages, as influenced by their growing season, the type and yield of the maize variety(s) cultivated, and the milk yield attained by feeding the different diets. The model is therefore able to incorporate seasonal variation and cropping patterns effects on the type, amount and quality of the different forages produced in the farm to fed cattle. This is an option not seen in similar models (Brockington *et al.*, 1983; Nicholson *et al.*, 1994; Mainland, 1994). On the other hand, the IFSM can not select any other feeding strategy than those tested in the cow model nor can interpolate or extrapolate elements between diets because it does not simulate the animal's response and the diet formulation is done in the cow model (see Chapter 6). The IFSM only selects the best feeding strategy from those presented by the cow model as an input file to the IFSM.

The model's objective function defines the optimal combination of activities, which maximizes the farm's gross revenue *(optimisation model)*. The author is aware that this approach may have some limitations, since the objective function may not be a satisfactory representation of all the farmers' priorities. Other issues may be required to be addressed in the objective function, such as reduction of risk associated with the adoption of a new technologies, minimisation of labour or even the social status within in the community (Romero and Rehman, 1989; Maino *et al.*, 1993; Delforce, 1994).

However, on the one hand, it is believed that a satisfactory level of accuracy was achieved with this model, probably because farmers are optimisers as well. And on the other hand, a multi-objective programming model approaches goes beyond the scope of this work, since more data and time are required to completed this task. Finally, a better assessment on the success or failure of this model to simulate the target farming system must be carried out in conjunction with the farmers who are the final beneficiaries of the technologies developed and tested by the model.

7.2. Materials and methods

There are many possible combinations of cropping and livestock production patterns, and different levels of inputs and natural resources use, there are as many as farmers in the region. Therefore, it was decided to develop a ***generic model*** that could be applied to different farmers within the region (using similar farming systems), with only minor changes in relevant coefficients and subscripts of the state variables. Mr. Luis González's farm served as case study farm on which the model construction was based. Once completed, the model was tested on two more case study farms.

The farms of Mr Luis González, Mrs. Lidia Estrada and Mr. Juan Valdez were monitored throughout 1996. The data gathered was used in the different Chapters of this thesis to calibrate the maize (Mr González's and Mr Valdez's farms were also monitored in 1997 to gather data to validate the maize model) and the cow models and to develop and test the IFSM described here. All the farms are located in the community of Taborda. The case studies represent the range of farmers that can be found in the northern part of the Toluca Valley.

According to SARH (1991); de Janvry *et al.* (1995a); and INEGI (1994a) the size of the holding determines the main differences among campesino farmers in Mexico where more than 90% of *campesinos* have less than 5 ha of land (see Chapter 2).

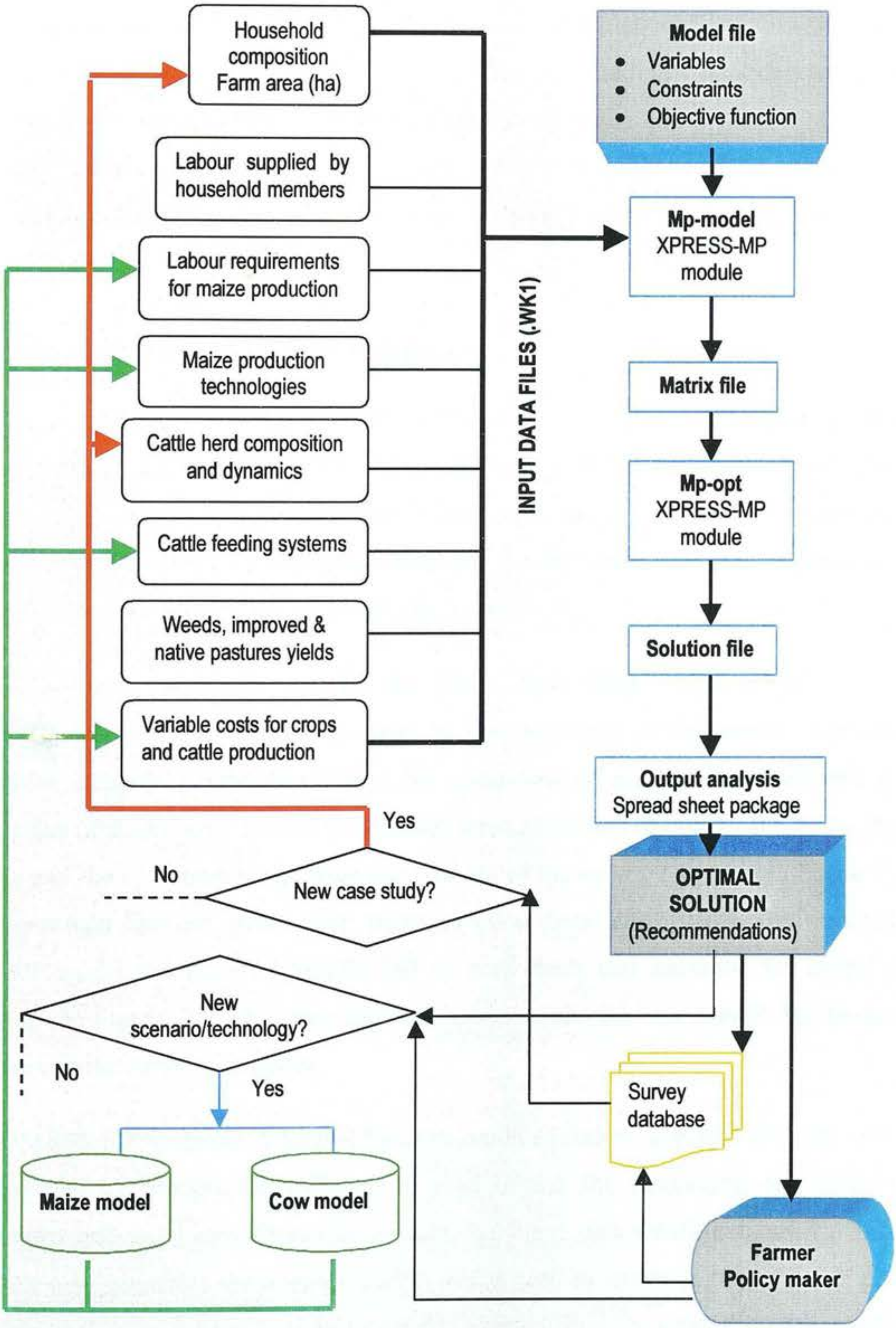
Farm size influences the number of activities and the size of the enterprises that individual farmers can carry out. Based on these criteria the case studies for the construction and validation of the IFSM were selected. Mrs. Lidia Estrada and Mr Luis González represent the group of farmers with less than 5 ha, while Mr Juan Valdez the group of farmers with more than 5 ha of land. It is suggested that by using this approach the main groups of farmers are represented in the simulation process and at the same time the generic nature of the model was validated too.

7.2.1. Model definition

The integrated farming system model is a multi-period mathematical programming model, in which the main aim is to find the optimal combination of resources that satisfy the model constraints and maximises the objective function. The essential characteristics of this model are the same as any other LP model: There is a single linear expression to be maximised or minimised. There are a series of *constraints* in the form of linear expressions which must not exceed (≤) some specified value. Linear programming constraints can also be of the form ≥ and =, indicating that the values of certain linear expressions must not fall below a specified value or must exactly equal a specified value. Finally there is set of variables which describe the system's *activities* and technical coefficients representing the variables' productive response (Dent *et al.*, 1986; Williams, 1991; Winston, 1995).

In this model, the objective function is to maximise the household's annual gross cash income (gross revenue). The model consisted of 15,698 structural columns, representing the model's **activities** and 612 rows that represent the **constraints** to the activities. It was developed using **XPRESS-MP** a mathematical programming software, which provided a powerful language for describing the problem (model) in the form of linear equations, so it was not necessary to construct a model matrix since the software generated it from the equations (XPRESS-MP, 1997). XPRESS-MP also allowed gathering the model's input data from spread sheet files, this facility permitted the incorporation of the output of the two biological simulation models used in this work, and the database from the survey work, into the model's routines (Figure 7-1).

Figure 7-1. File structure and functioning of the Integrated Farming System model



The model runs in monthly periods (***m***) of 30.5 days, 12 of these periods (*m=12*) represent a complete production cycle (one-year) at the Toluca Valley. The Valley presents a marked seasonal variation given by the dry and the wet seasons, both determine the occurrence of the different cropping activities, and the quantity and quality of forages available for cattle feeding. The use of monthly periods permitted the capture of this variation, especially in the case of maize production, where the different cultivation tasks are determined by the monthly climate conditions (Chapter 4). Seasonal variation effects on household's labour demand are also represented.

7.2.2. Files structure and model functioning

The structure of the IFSM is shown in Figure 7-1. The model is formed by five main components, the first component, is the "Model's Equations File" (the mathematical programming model itself), that comprises a set of linear equations, representing the **variables**, **the constraints** and the **objective function**. A complete version of the equations' file is presented in Appendix 4.

The second component includes the **Input Data Files** which contain those variables whose value is not calculated by the equations of the model, and the variables' technical coefficients used in the calculation of the their optimum values. The value of these variables and coefficients were calculated out of the IFSM, by the *maize* and the *cow* models and from the analysis of the survey's database (Figure 7-1). Input data files are spread sheet tables saved as *Lotus* files (wk1). This enabled the *MP-model* module of XPRESS-MP to read them and generate the model's matrix, see Figure 7-1. The other three components are the **cow model**, the **maize model** and the survey's database.

XPRESS-MP software is formed by three modules shown in Figure 7-1, the *MP-Model* module enables the software to read in the file containing the model's equations and the Lotus files, that contain the input data (.wk1 extension). This module also generates the model's matrix that is read in and solved by the *Mp-opt* module of XPRESS-MP. The third module is responsible for generating the output file (solution), which in this model was approximately 300 pages long, too big for its practical analysis.

To facilitate the sensitivity analysis the model's output was exported to a spreadsheet file (see Figure 7-1) where the variables for which an optimal solution was found were filtered out from those without an optimum value. Through this process an efficient method was developed to visualise the model's optimal solution, from which recommendations to the farmers can be drawn more easily. Other outputs generated by the model were also analysed through this method. These included the activities' ***reduced cost*** and the ***shadow prices***.

The ***reduced cost*** of a variable shows the amount by which the per-unit profitability must increase, before it would become worthwhile including the activity not selected by the model. A zero activity and zero reduced cost implies that there are alternative solutions with identical objective function values.

The ***shadow price*** represents the marginal value product of a binding or limiting resource. It indicates change to the total gross margin if one unit of the resource (positive) were added or if one unit of the resource (negative) were withdrawn.

The approach shown in Figure 7-1 enabled the development of a powerful Decision Support System where the output of two deterministic biological models interacted together with a mathematical programming model and a survey database. The decision support system (IFSM) can be used to simultaneously evaluate hundreds of different maize and cattle production technologies, in different case studies with only minor changes in the model's state variables and in the input data files, without the need to change the equations of the model.

For example, if the IFSM is run for a new case study, it is only necessary to change the household composition, the farm area, and the cattle herd structure as shown in Figure 7-1. If the decision maker wants to test a new technology or a different scenario, then the user has to run the biological models to test the new technology and the output presented to the IFSM in the form of input data files.

Some minor changes to the input file for the variable costs will be required too, particularly in the case of new economic scenarios.

In this section of the method only the mathematical programming model's equations and the Input data files will be described since the other components of the IFSM were described in previous chapters.

7.2.3. Structure and functioning of the model equations

As in similar models, **activities** were considered processes that produce or consume resources of the farm. **Constraints** represented the amount of resources (resource restriction) that are available for the farm activities, like available land, labour and personal requirements or targets. Restrictions also determined the level of those activities representing a productive process (operational and limits of the activities), they normally express the logical statement what is used (demanded) must be less than or equal to what is supplied (Fawcett *et al.*, 1998; Rehman and Romero, 1993). The **Objective Function** is the expression of the purpose of the model, which is maximising farmers' gross revenue.

Figure 7-2, shows the general structure of the model's equations, the main groups of variables and the relationships between them and between the input data tables. The arrows represent the restrictions to the variables, since the restrictions determined the use of farm resources and the value of the variables. Figure 7-2 also provides a clear representation of the Activities producing resources and those using them. The variables' technical coefficients (input data tables) are shown too, since they establish the variables levels. Figure 7-2 shows how the farm resources flow from one activity to the other and how the decisions on the model's driving variables such as land use are made.

It is important to mention that the main purpose of Figure 7-2 is to describe the model functioning, and not the sequence in which the model is solved. Because all the equations in the model are solved simultaneously, they do not follow the sequence shown in Figure 7-2.

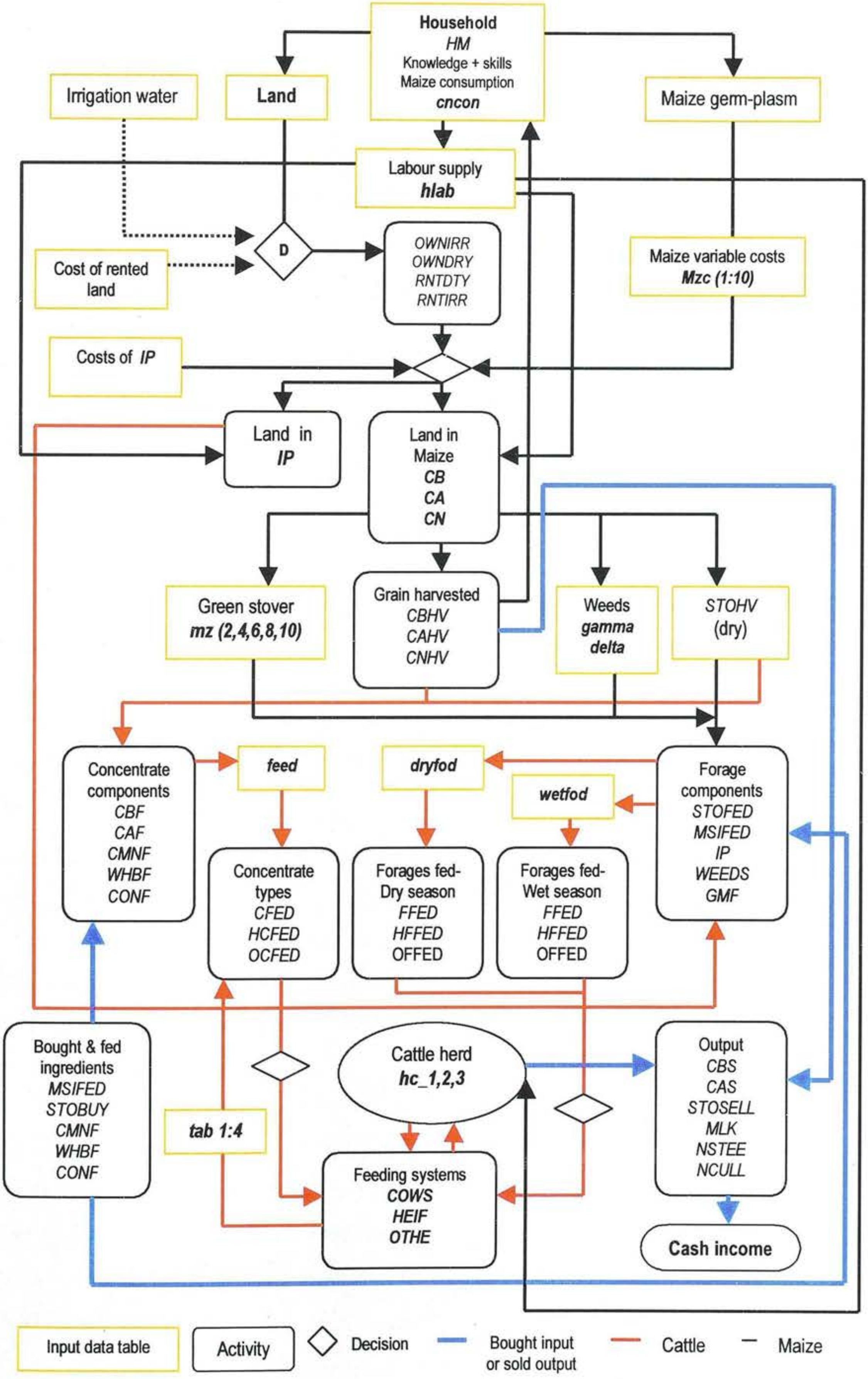
Activities and their associated constraints are described first in order to explain the farming activities simulated by the model. Due to the large number of constraints in the model only the *generic constraints* are described. Generic constraints are groups of equations that share a similar structure and restrict the values of variables within a group of similar activities, but have different subscripts levels. For example, the constraints that define the optimum value for the variables in the *Grain harvested module* in Figure 7-2, are restricted by a group of equations which share the same basic structure. Except that the name of the variables and the level of their subscripts are adjusted accordingly with the activity simulated and the technology used. Equations 7-3 and 7-4 are a clear example of the Generic Constraints equations used here. The input data tables, which are part of the equations too, also change following the same criteria. The objective function and the approach used to simulate labour supply and utilisation within the farming system are described at the end of the method.

7.2.4. Activities

Figure 7-2 allows visualising more easily the role of each farming activity, and the complex interactions between the activities and the farm resources utilisation dynamics simulated by the model. Figure 7-2, shows that the household members ***HMn*** provide the skills (expert knowledge), the labour (***hlab***), the different resources such as the land, the crop genetic resources (Maize germ-plasm, *CA, CB* & *CN*), and the money (***Mzc1:10, Ipcosts***) to cultivate the farm's land. The household also owns the cattle (***hc_1 to hc_3***) and uses it to produce milk (***MLK***) and beef (***NSTE***E & ***NCULL***), both important elements of the farming system.

Figure 7-2, illustrates how the generated resources are utilised by the different activities in order to come up with the optimal solution. For example, the land allocated to maize production (***CB, CA,*** & ***CN***) will produce, depending on the maize variety and the cultivation technology selected, grain (***CBHV***, ***CAHV*** & ***CNHV***), stover (green ***mz2,4,6,8,10*** and dry ***mz1 to 10***) and weeds, which in turn could be fed to the family (***cncon***), or to the cattle (***COWS, HEIF***, & **OTHE**) or could be sold (***CBS***, ***CAS***, ***STOSELL***).

Figure 7-2. Model functioning



The level of most of the activities in the model is determined by their associated constraints. However, there are some activities whose value was fixed and not determined by the constraints. These activities included the household composition and the cattle herd inventory, the reason behind this decision is explained later in this section. All the simulated activities were classified into 6 groups, to facilitate their description, representing the main farming activities of the system as follows:

- Activities whose optimum value is not selected by the model
- Maize production activities
- Cattle production activities
- Household related activities
- Improved Pasture and other crops activities
- Buying and selling activities

The Activities whose optimum value is not selected by the model are described first, because of their implicit importance and because they exert an important influence over the rest of the model's variables.

7.2.4.1. Activities whose optimum value is not selected by the model

Household composition activities: Every household's members was allocated into seven different categories and every category was treated as a different activity. The household composition activities in terms of the number, age and gender of the different individuals were not calculated by the model because it is a particular trait of every individual household. It will be wrong to allow the model to calculate the optimal family composition; therefore the family composition activities were supplied in the form of an input file (see Figures 7-1 and 7-2). These activities played a fundamental role in the model because from the family composition depends the amount of labour supplied to the different farming activities. The household members were classified into seven categories as shown in Table 7-1. The variable ***HM(maxn)***, represents the number of household members in the *n*th category, where: ***maxn***=1:7, is the maximum number of household members categories.

Table 7-1. Household composition activities

Member category	Variable name
Decision maker	HM_1
Spouse	HM_2
In-farm sons	HM_3
Daughters	HM_4
Children	HM_5
Old	HM_6
Off-farm sons	HM_7

The household size and composition for every case study simulated was mapped in the model by Equation 7-1 below (see Appendix 4).

Equation 7-1. Mapping household members

homb (n=1:maxn): HM(n) = hmem(n)

Where:

homb is the constraint's name which restricts the household members activities ***HM(n)*** to the values in the input data table ***hmem(n)***.

The approach above described illustrates the generic nature of the IFSM, because two tables with the composition of the household and cattle herd is all what is needed to run the model for a new case study (Figure 7-1). As described in chapter 5, most household members fall in the categories shown in Table 7-1. Moreover, by using this approach the amount of labour supplied by every individual was properly differentiated and accounted for their gender, age and activity. Details of the amount of labour supplied by every individual are described at the end of the method section.

Although this is a multi-period model, it was assumed that the household composition remained constant throughout the 12 monthly periods of the simulation since it is unlikely that major changes in the household composition (deaths or births) occur over such a short period of time. The composition of each case study simulated here is shown in Table 8-1 (Chapter 8).

Cattle herd inventory activities: The same animal categories defined in Chapter 6 for the average cattle herd in the study area were used here to simulate the **Cattle Herd Inventory Activities** and other cattle related activities, such as milk production, and forage and concentrated intakes. The same approach used for household members was used for the cattle herd composition. Every animal was treated as an individual therefore; the number of animals in each category in the ***m***th period is defined as the Cattle Herd Inventory Activities, for that period.

The cattle herd of Mr Luis González was used in the development of the IFSM, the size, age and sex composition of the herd was registered during the fieldwork. Its initial structure is presented in Table 8-1 together with the herd structure of the other two case studies (Chapter 8). Because of the reduced number of animals in the herds (X=12 heads of cattle for the MLPS), each animal within the herd was accounted for on an individual basis, rather than as a percentage of a population. The contribution of every animal to the farmers' livelihoods is so important that the disappearance of only one could have important implications to the whole system. For purposes of simulating the dynamics of every individual within the various cattle categories, it was assumed that the set of productive and reproductive parameters, shown in Table 6-4 and Figure 6-1, determined the current physiological state and productive performance of each individual animal over the time.

Because the IFSM is a multi-period model, the natural progression of the different animals (within each category) between categories over the different ***m*** periods had to be taken into account, since it has important implications for other simulated farm activities such as forage consumption, milk production and labour requirements. Thus the progression of every individual from one productive stage or from one reproductive state to the following was mapped in, and presented to the model as an input data file (Table 7-2). For example in Table 7-2, there is in January one first calving cow, which is in its dry period, (***i=1, q=4***), the following month the same cow calved and started to produce milk, therefore it became a second calving cow in its early lactation (***i*=2, *q*=1**). As a result in of this change, now there are two cows in

February (there was one ***i=2, q=1*** cow before) that are second calving cows in their early lactation.

The implications of this simple change are accounted for in the model, because the cow which passed from i=1,q=4 to i=2,q=1 will require a better quality diet, but it will also be producing milk, and require more labour too. The herd structure and dynamics were calculated out of the model, because it was not intended that the model select the optimal combination of animal inventory as is normally done in similar works (Chudleigh, 1977; Nicholson *et al.*, 1994). It is believed that in smallholder systems, the herd composition is a trait that is determined by farmers and their own circumstances, so even if the model finds an optimal composition, such change will take several years.

It is believed that approach used here is flexible enough to allow replicating some replacement policies used by the farmers. For example if the farmer decides to buy a new cow or heifers, it only has to be included in the corresponding cattle class in the month when it was purchased. The model will then produce a new optimal solution for the new herd structure.

The cattle herd is contained in three tables as shown in Table 7-2. Table ***hc_1***, contains the technical coefficients for the number of cows, in the ***i***th category, in the ***m***th period and the ***q***th subcategory. Table ***hc_2*** represents the number of heifers in the ***m***th period and the ***q***th subcategory. Table ***hc_3*** represents the other cattle categories in the herd (calves, steers and bulls) in the ***m***th period and the ***q***th subcategory. Again, using this approach permitted running the model for the different case studies by only changing the corresponding cattle input data table (Figure 7-1). Equation 7-2 was used to map into the model the cattle table for the cows and at the same time define the feeding options open to them; similar equations were used to map in the rest of the animal categories in the herd.

Equation 7-2. Mapping the cattle herd in the model

$$hdc1(i=1:\max i, m=1:12, q=1:\max q): \sum_{j} \sum_{l} \sum_{r} COWS_{j\,l\,i\,m\,q\,r} = hc\_1_{imq}$$

Where:

COWS =Number of cows
hdc1 =is the constraint name that controls the feeding options for cows
i = Cow category
q = Cow subcategory
m = Monthly period
j = Forage type
l = Concentrate type
r = Concentrate supplementation rate

The cattle feeding options and the role of the variable *COWS* are described in detail in Table 7-6 in section 7.2.4.3., below.

Table 7-2. Cattle herd inventory and dynamics for Mr. Luis González's herd

Dimension **Month**	**Cattle category(*i*) Subcategory (*q*)**																			
Period m=12	First calvers i=1 and q=1:4				Second calvers i=2 and q=1:4				Third calvers i=3 and q=1:4				Heifers q=1:2		Calves q=1:2		Other q=3:4			
Month	1,1	1,2	1,3	1,4	2,1	2,2	2,3	2,4	3,1	3,2	3,3	3,4	4,1	4,2	5,1	5,2	5,3	5,4		
Jan				1	1				1				3	3	2	4	0	0		
Feb					2					1			2	4	3	4	0	0		
Mar					2					1			2	4	3	4	0	0		
Apr	1				2					1			2	3	3	3	2	0		
May	2				1	1					1		2	2	4	1	4	0		
Jun	2					2					1		2	2	4	1	4	0		
Jul	2					2					1		1	3	3	2	4	0		
Aug	1	1				1	1					1		4	2	3	4	0		
Sep		2					2					1		4	2	3	4	0		
Oct	1	2					2		1					3	3	3	3	0		
Nov	2	1	1				1	1	1					2	3	4	1	0		
Dec	2		2					1	1					2	3	4	1	0		
Table name	*hc_1*												*hc_2*		*hc_3*					

7.2.4.2. Maize production activities

Table 7-3 summarises the variables and their dimensions that represent the simulated activities associated with maize production in a typical *campesino* farmer production unit. These variables represent the varieties and the range of technological options that are used by local farmers to cultivate maize; they also express some of the complexity associated with maize cultivation in the Toluca Valley, like the crop-farmers interaction and their effects on the whole farming system. The two land races simulated by the CERES-Maize model were used here, *Criollo Blanco* (***CN***) and *Criollo Amarillo* (***CA***) (Chapter 4). A third variety called *Criollo Negro* (***CN***) was simulated with the maize model. Since this variety has similar yield and growth characteristics as *CA* the same coefficients were used. Most farmers plant at least three maize varieties in any given year, as part of their normal production strategies. Each variety has a specific purpose within the farming system, in this model ***CB*** is cultivated for sale to generate cash income, but may be fed to cattle. ***CA*** is cultivated to fed cattle but it may be sold too, while the last variety **CN**, is cultivated and used only for household consumption (its taste is preferred above the other two).

Table 7-3. Maize production variables

Variable Name	Description	Units	Dimension		
			1	2	3
CB	Area planted with CB	Ha	Main treatments, o=1:4	Fertiliser level, k=1:7	Planting level, a=1:12
CA	Area planted with CA	Ha	Main treatments, o=1:4	Fertiliser level, k=1:7	Planting level, a=1:12
CN	Area planted with CN	Ha	Main treatments, o=1:2	Fertiliser level, k=1:7	Planting level, a=1:12
CBHV	CB harvested	Kg	Month, m=1:12		
CAHV	CB harvested	Kg	Month, m=1:12		
CNHV	CN harvested	Kg	Month, m=1:12		
CBOV	CB opening balance	Kg	Month, m=1:13		
CAOV	CA opening balance	Kg	Month, m=1:13		
STOHV	Stover harvested	Kg	Month, m=1:12		
STOV	Stover opening balance	Kg	Month, m=1:13		

In order to simulate irrigated and rainfed maize production (the two main systems of cultivation) and the interaction between the farmers and their maize crops, a factorial experiment was designed. The experiment was run in the CERES-Maize model, and its output constitutes the technical coefficients from which the model selected the optimal value for each one of the Maize Variables simulated (Figure 7-1). Table 7-4 shows the factorial experiment used, it includes three maize varieties and four main treatments (***o***=1:4), in addition for every ***o*** treatment, 7 fertilizer application rates (***k=1:7***) and 12 planting levels (***a=1:12***) were tested. The levels of the ***k***th and ***a***th treatments are shown in Table 7-4 below.

Table 7-4 . Factorial experiment simulated with the CERES-Maize model

Maize variety	Main treatment o=1:4	Fertilizer level Kg of Nitrogen/ha		Planting level Plants/ha
	Irrigated maize			
CB	o =1 Irrigated with herbicide applied (IH)	k=1 0kg	k=5 70kg	a =1 10,000
CA	o =2 Only irrigated	k=2 40kg	k=6 90kg	.
CN		k=3 50kg	k=7 180 kg	.
		k=4 60kg		a=12 120,000
	Rainfed maize	k=1 0kg	k=5 70kg	a =1 10,000
CB	o =3 Rainfed with herbicide applied	k=2 40kg	k=6 90kg	.
CA	o =4 Only rainfed maize	k=3 50kg		.
		k=4 60kg		a=10 100, 000

Main treatments included irrigated maize (*punta de riego,* see Chapter 4 for definition) with herbicide o=1, and irrigated maize without herbicide, o=2, rainfed maize with herbicide, o=3, and rainfed maize without herbicide, o=4 (Table 7-4). Farmers normally do not apply herbicide to some maize plots and use different planting densities in order to have the opportunity to harvest weeds and green maize stover (before the crop has reached its physiological maturity). Green stover is used together with the weeds to feed cattle. Treatments o=2 and o=4 permitted to simulate these practices and therefore to simulate the different uses of the maize crop biomass by local farmers. Crop husbandry practices such as stover thinning and scotching and cut and carry of weeds were included in the IFSM too.

A total of 504 technologies for maize production under irrigated conditions (*punta de riego)* and 240 technologies under rainfed conditions were simulated through the factorial experiment. The output of the maize model was inputted to the IFSM in ten tables (Figure 7-1 and 7-2), which contain the grain and stover yields for the maize production technologies simulated. The name and dimensions of each table is presented in Table 7-5. Simulating these technologies was fundamental, because they are the backbone of the crop-cattle farming system since the use of irrigation determines the yield performance of both grain and stover. On the other hand, the application of herbicide in some maize plots determines the future availability of forages, like weeds, green and dry stover.

Table 7-4, shows that for rainfed maize only six levels of fertilizer and 10 levels of planting population were simulated. Since farmers know that the performance of local maize under rainfed conditions is lower than the rainfed maize they normally allocate fewer resources than for the irrigated maize. Therefore it was considered unnecessary to simulate a higher allocation of resources, which in real life will be an unrealistic approach. Because the IFSM is a multi-period model, it was more easy to simulate the dynamics of maize production in the Toluca Valley, for example irrigated maize is harvested in November (*m=11*), while rainfed maize is harvested in December (*m=12*) (see Chapter 4). The effects of different harvest dates are important in terms of the attained yields, the amount of labour required and the availability of forages and grain to fed cattle, as will be discussed later.

Table 7-5. Input data tables with the CERES-Maize model's predictions for different cultivation technologies

Data Table	**Description**	**Dimension** 1	2	3	4
mz1	Predicted grain & stover yields for *CB*, ***o***=1	Fert. level, *k*=1:7	Planting level, *a*=1:12	Grain yield kg/ha (**1**)	Stover yield kg/ha (**2**)
mz2	Predicted grain & stover yields for *CB*, ***o***=2	Fert. level, *k*=1:7	Planting level, *a*=1:12	"	"
mz3	Predicted grain & stover yields for *CA*, ***o***=1	Fert. level, *k*=1:7	Planting level, *a*=1:12	"	"
mz4	Predicted grain & stover yields for *CA*, ***o***=2	Fert. level, *k*=1:7	Planting level, *a*=1:12	"	"
mz5	Predicted grain & stover yields for *CN*, ***o***=1	Fert. level, *k*=1:7	Planting level, *a*=1:12	"	"
mz6	Predicted grain & stover yields for *CN*, ***o***=2	Fert. level, *k*=1:7	Planting level, *a*=1:12	"	"
mz7	Predicted grain & stover yields for *CB*, ***o***=3	Fert. level, *k*=1:6	Planting level, *a*=1:10	"	"
mz8	Predicted grain & stover yields for *CB*, ***o***=4	Fert. level, *k*=1:6	Planting level, *a*=1:10	"	"
mz9	Predicted grain & stover yields for *CA*, ***o***=3	Fert. level, *k*=1:6	Planting level, *a*=1:10	"	"
mz10	Predicted grain & stover yields for *CA*, ***o***=4	Fert. level, *k*=1:6	Planting level, *a*=1:10	"	"

Figure 7-2 shows the information flow on which the model decides which type of land to use for cultivation, whether irrigated or rainfed (***OWNIRR*** or ***OWDRY***), own or rented (***RNTDRY*** or ***RNTIRR***), and the amount of land allocated for maize production or for improved pasture production (***IP***) or both (see Table 7-8). Next the model can select the best technology for maize production, which maximises yield and income return. For example, if the variable **CB_{oka}**, is selected, then the area of land defined by the model will be planted with the variety *CB*, with main treatment ***o***, and the sub-treatments ***k*** and ***a*** (Table 7-4). Equations 7-3 and 7-4 describe the constraints that define how the maize technology is selected for *CB* under both irrigated and rainfed conditions respectively. Equation 7-3 and 7-4, also define the amount of CB that is harvest (***CBHV***) from using the selected technology. Similar equations were used to define the land area to be planted with the other two simulated cultivars.

$$NOVBL: -\sum_{k}\sum_{a} 0.9 * mz1_{k,a,1} * CB_{1,k,a} - \sum_{k}\sum_{a} 0.9 * mz2_{ka1} * CB_{2ka} + CBHV_{11} < 0$$

Equation 7-3. Constraint for selecting maize technology in irrigated land

Because Equation 7-3 refers to irrigated maize, input data tables ***mz1*** and ***mz2*** are used (see Table 7-5), the ***CB*** variable uses ***o****=1* and *2* subscripts and the maximum fertilising and planting rates are used, ***k=1:maxk*** and ***a=1:maxa*** (see Tables 7-3 and 9-4). The column number one, of both tables, containing the grain yield for each production technology simulated for the variety CB under irrigated conditions multiplies the variable *CB*. Multiplying the grain yield values of column one by 0.9 allows the model to consider grain losses due to harvest and the moisture content of the grain (Kumar, 1993). Constraint ***NOVBL*** also defines the amount of grain, which is harvested from the *CB* variety in the selected technology, since what is produced cannot be more than what is harvested. Therefore, the amount of grain harvested in November is defined by the variable **$CBHV_{11}$** in Equation 7-3 above.

$$DECBL: -\sum_{k=1:6}\sum_{a=1:10} 0.9 * mz7_{k,a,1} * CB_{3,k,a} - \sum_{k=1:6}\sum_{a=1:10} 0.9 * mz8_{ka1} * CB_{4ka} + CBHV_{12} < 0$$

Equation 7-4. Constraint for selecting maize technology in rainfed land

Equation 7-4, follows the same principles as Equation 7-3, except that the variable ***CB*** uses the ***o***=3 and 4 subscripts which refers to rainfed maize (Table 7-4). Therefore ***k =1:6*** and ***a=1:10***, which reflect a lower use of inputs. Column one of Tables *mz7* and *mz8* contains grain yield figures for *CB* rainfed maize (Table 7-5). The amount of stover that is harvested (***STOHV***) from the area planted with maize under the selected technologies is defined by the constraints in Equation 7-5. In the case of stover no differentiation is made in terms of the variety, because from a practical standpoint, all the stover is fed to cattle regardless the maize variety produced. However the model does differentiate between the stover produced by rainfed or irrigated maize because stover production from rainfed maize is lower than for irrigated maize. The model also considered whether herbicide was applied or not, because if no herbicide is applied, then green maize stover is harvested from August to October. Therefore the amount of dry stover harvested in December and January should be lower than if no green maize stover is removed. Equation 7-5 determines the amount of stover harvested in December for irrigated maize, with and without herbicide. Therefore:

$$
\begin{aligned}
&DECSTV\ :-\sum_{k}\sum_{a} 0.85 * mz1_{ka2} * CB_{1ka} - \sum_{k}\sum_{a} 0.595 * mz2_{ka2} * CB_{2ka}\ \& \\
&-\sum_{k}\sum_{a} 0.85 * mz3_{ka2} * CA_{1ka} - \sum_{k}\sum_{a} 0.595 * mz4_{ka2} * CA_{2ka}\ \& \\
&-\sum_{k}\sum_{a} 0.85 * mz5_{ka2} * CN_{1ka} - \sum_{k}\sum_{a} 0.595 * mz6_{ka2} * CN_{2ka}\ \& \\
&+ STOHV_{12} < 0
\end{aligned}
$$

Equation 7-5. Amount of stover harvested from the land planted with maize

The values of the variables ***CB, CA*** and ***CN*** are multiplied by the second column of the tables in Equation 7-5, containing the stover yields, to determine the amount of stover harvested from all the selected varieties under irrigated conditions and for all the selected cultivation technologies. When ***o***=1, the values of the second column in tables ***mz1, 2*** and ***3*** (see Table 7-5) are multiplied by 0.85, since it was observed that approximately 15% of the biological yield of stover is left in the field and therefore not used to feed cattle or sold. When $\boldsymbol{o}=2$, (no herbicide applied) values of second column of tables ***mz2, 4*** and ***6***, are multiplied by 0.595, since it was observed that approximately 30% of the stover biomass is removed as green stover and again approximately 15% of what is left standing after grain harvest (dry stover) is lost during the stover harvest process. A similar approach was applied for the ***JANSTV*** restriction that controls the stover harvested from rainfed maize $\boldsymbol{STOHV_1}$ in January (see Appendix 4).

It is important to mention here that farmers harvest the green stover and weeds only from those fields where herbicide is not applied ($\boldsymbol{o}=2$ and ***4***). These fields are normally close to the farmhouse, which facilitates the transport of the forage, while the fields where herbicide is applied are normally far from it. As mentioned in Chapter 5, not all the farmers' land is close to their houses, therefore it will be impractical for them to travel long distances to cut and then carry the forage back to the farmhouse. The application of herbicide offers them a solution to this problem. It is believed that the approach above described, represents an appropriate description of the irrigation and herbicide application practices used by local farmers. Moreover, it allowed the incorporation of the effects of these practices on the whole farming systems (Figure 7-2), as will be shown in the results section of this chapter.

Finally, since the IFSM is a dynamic model, where decisions over the use of the produced grain and stover are made in more than one point in time (***m***th period), grain and stover balance equations (which control the monthly allocation of grain and stover to the different activities that use them), were developed too. Equation 9-6, is the grain balance equations for *CB*, it restricts the amount of the *CB* used every month by the different activities shown in Table 7-3 to the amount of *CB* harvested above ($\boldsymbol{CBHV_m}$). In other words no more *CB* grain can be fed to cattle or sold than what is harvested. Equation 7-7 is a closed inventory loop equation that makes sure that the opening balance of *CB* in period $\boldsymbol{m=1}$, $\boldsymbol{CBOV_1}$ (amount of *CB* available in January) is equal or less than what is available in period $\boldsymbol{m=13}$ $\boldsymbol{(m+1)}$ (January next year). In other words, since the model simulates a whole year, and the *CBHV* is used every month, Equation 7-6 makes sure that the amount of *CB* in January is equal or less than what is available in January next year, since grain is harvested at the end of the year.

$$CBOB_{m=1:12} : CBOV_m + CBS_m + CBF_m - CBHV_m + CBOV_{m+1} < 0$$

Equation 7-6. Balance equation for CB grain

$$CBOB : CBOV_1 - CBOV_{13} < 0$$

Equation 7-7. Closed inventory loop equation for CB.

A similar approach was used for the balance equations of *CA* and stover, there is no balance equation for *CN* since it is only used for household consumption.

7.2.4.3. Cattle production activities

The IFS model was further improved to simulate the effects of maize cultivation technologies and the interaction between farmers and their crops on the seasonal availability and quality of forage. Based on the traditional cultivation practices and its association with the seasonal production and utilisation of forages, the factorial experiments shown in Table 6-5 and 6-6 (Chapter 6) were designed and ran in the ***Cow*** model. The output of the factorial experiments constituted the technical coefficients of the cattle production variables shown in Table 7-6 (see Figure 7-2). 936 feeding strategies were simulated for dairy cows in the dry season and a similar number of strategies for cows in the wet season. On the other hand, 24, 8, 4 and 4 different feeding strategies were simulated for heifers, calves, steers and bulls respectively. The output of the cow model was captured in four tables shown in Table 7-7. The simulated year was divided into a 7-month **dry season** (November to May) and 5-month **rain season** (June to October). This approach permitted the model to simultaneously allocate farm-produced forages and purchased feeds among the different cattle categories (see Figure 7-2 and Table 7-6), for every month of each season. It is suggested that an important contribution of this model is that it selects the optimum feeding strategies for both dry and the wet seasons as a response to the different forage availability and quality as determined by the cropping system. The model is therefore able to incorporate seasonal variations in the type, amount and quality of the different forages fed to cattle. This is a facility not seen in other smallholder farm system models (Brockington *et al.*, 1983; Nicholson *et al.*, 1994).

Table 7-6. Cattle production variables

Variable name	Description	Units	Dimension					
			1	2	3	4	5	6
COWS	Define feeding options for cows	Heads	Forage type j=1:4	Concentrate type, l=1:6	Cow category i=1:3	Month, m=1:12	Subcategory q=1:4	Concent level, r=1:4
HEIF	Define feeding options for cows	Heads	Forage type j=1:2	Concentrate type, l=1:2	Month, m=1:12	Subcategory, q=1:2	Concentrate level, r=1:2	
OTHE	Define feeding options for other cattle types	Heads	Forage type j=1:2	Concentrate type, l=1:2	Month, m=1:12	Subcategory, q=1:4	Concentrate level, r=1:2	
FFED	Forage type fed to cows	Kg DM	Month	Forage type j=1:2				
STOFED	Stover fed to the cattle herd	Kg DM	Month					
MSIFED	Maize silage bought and fed	Kg DM	Month					
CFED	Concentrate type fed to cows	Kg DM	Month					
CBF	CB fed to the cattle herd	Kg DM	Month					
CAF	CA fed to the cattle herd	Kg DM	Month					
CMNF	Chicken manure fed to the herd	Kg DM	Month					
WHBF	Wheat bran fed to the herd	Kg DM	Month					
CONF	Commercial concentrate fed to the herd	Kg DM	Month					
MLK	Monthly milk production/herd	Kg DM	Month					
HCFED	Concentrate type fed to Heifers	Kg DM	Month	Concentrate type, l=6				
HFFED	Forage type fed to heifers	Kg DM	Month	Forage type j=4				
OCFED	Concentrate type fed to other cattle	Kg DM	Month	Concentrate type, l=6				
OFFED	Forage type fed to other cattle	Kg DM	Month	Forage type j=4				
NCULL	Culled cow	Heads	Year					
NSTEE	Fat steers sold	Heads	Year					

The factorial experiments in Chapter 6 (Tables 6-5 and 6-6) restricted the number and composition of the forages and concentrates used for each simulated season. However, it is believed the forages and concentrates types used in this work are a reasonable representation of the cattle feeding systems in the Toluca Valley (Castelán *et al.*, 1996; Arriaga *et al.*, 1997a; Castelán *et al.*, 1997). The number of forages and concentrates can be easily increased to test more feeding strategies, however it goes beyond the scope of this work, since more data is required on the degradation dynamics of local ingredients which on its own constitutes a separate research.

Special emphasis was put on modelling nutritional characteristics of the system because there is important evidence that suggest that nutrition represents one of the main limitations to increased productivity and profit in the system (Castelán *et al.*, 1996; Arriaga *et al.*, 1997a; Castelán *et al.*, 1997). Rather than use feed and animal nutrients requirements developed for temperate regions, a complete feeding system was developed based on the degradability dynamics of the most common forages and concentrates used at the Toluca Valley. Thus the simulated feeding strategies are more relevant to the region's conditions.

The cattle herd inventory variables are fixed, and supplied as an input data file. The cattle herd of a any given case study is mapped into the model by Equation 9-2, this equation also controls the feeding options for all the cows in the herd, by making table ***hc_1*** equal to the variables COWS shown in Table 7-2. Therefore, for feeding purposes $\boldsymbol{COWS_{jlimqr}}$ represent the number of cows fed with the ***jth*** forage, the ***lth*** concentrate, in its ***ith*** calving number, in the ***mth*** period, in the ***qth*** lactation stage and fed concentrate at the ***rth*** rate. The type and amount of concentrate fed to cows in the dry season are then restrained by Equation 7-8, below.

$$cc1d(m=1:5, l=1:\max l): \sum_{j}\sum_{i}\sum_{q}\sum_{r} tab1_{jlqr1} * 30.5 * COWS_{j\lim qr} - CFED_{ml} < 0$$

Equation 7-8 . Concentrate type fed to cows during the dry season

Where the restriction *ccld(m=1:5,1=1:maxl)* is controlling the season, in this case, the first five months of the dry season (January to May), and the concentrate type ***l***. The values of column one from table ***tab1*** (see Table 7-7) (which contains concentrate intakes/d/cow) are multiplied by a 30.5 factor, which is the number of days in any given ***m*** period. The equation is then balanced against the variable ***CFED*** (see Table 7-6 and Figure 7-2). Equation 7-9 uses the same approach to define the amount of forage fed to cows during the dry season, except that the values of column two (forage intake/d/cow) from table ***tab1*** are used instead (see Table 7-7). The equation is then balanced against the variable ***FFED*** since no more forage can be fed than what is available in any given month (Table 7-6).

$$fc1d(m=1:5, j=1:\max j): \sum_{l} \sum_{i} \sum_{q} \sum_{r} tab1_{jlqr2} * 30.5 * COWS_{j\lim qr} - FFED_{ml} < 0$$

Equation 7-9. Forage type fed to cows during the dry season

Table 7-7. Input data tables with the Cow model's output for the different feeding systems

Data Table	**Description**	**Dimension** **1**	**2**	**3**	**4**	**5**	**6**
tab1	Dry season systems for feeding cows	Forage type j=1:4	Concentrate type, l=1:6	Cow category, i=1:3	Subcategory, q=1:4	Concentrate level, r=1:4	Data items u=3, 1=conc,2= forag, 3= mlk
tab2	Wet season systems for feeding cows	Forage type j=1:4	Concentrate type, l=1:6	Cow category, i=1:3	Subcategory, q=1:4	Concentrate level, r=1:4	Data items u=3
tab3	Dry and wet season systems for feeding heifers	Forage type j=1:2	Subcategory q=1:2	Concentrate type, l=1:2	Concentrate level, r=1:3	Data items, u=1:2	
tab4	Dry and wet seasons systems for feeding other animals	Forage type j=1:2	Subcategory q=1:4	Concentrate type, l=1:2	Concentrate level, r=1:2	Data items, u=1:2	
feed	Concentrates composition	Commodity	Concentrate type, l=1:6				
dryfod	Forage composition Dry season	Commodity	Forage type, j=1:4				
wetfod	Forage composition Wet season	Commodity	Forage type, j=1:4				

Similar equations were used to define the type and amount of forage fed to cows during the rainy season. The ***m*** subscript is used throughout the model to control the season, when its values go from *m=1:5* and *m=11:12*, it is referring to the months of the dry season, and when its values go from *m=6:10*, it is referring to the wet season. The whole approach used above is used to simulate the concentrate and forage allocation for the other categories of cattle ***HEIF*** and ***OTHE*** (see Appendix 4).

The amount of milk supplied monthly by the lactating cows during the dry season is calculated by Equation 7-10 bellow. The variable *COWS* multiplies the values of column three in ***tab1*** (milk yield in kg/d/cow), in order to obtain the monthly milk yield from all the lactating cows from the herd. Notice that the subscript ***i*** only goes from ***i =1:3***, which represents lactating cows only, since ***i =4*** are dry cows. The equation is balanced against variable ***MLK*** shown in Table 7-6. A similar approach is used for milk production during the rain season, except that ***m=6:10***.

$$mc1d(m=1:5): \sum_{j} \sum_{l} \sum_{i} \sum_{q=1:3} \sum_{r} tab1_{jlqr3} * 30.5 * COWS_{j\lim qr} - MLK_{m} < 0$$

Equation 7-10. Monthly milk supplied by lactating cows (dry season).

Because most forages and concentrates are in fact mixes of separate ingredients (see Chapters 5 and 6), which are supplied by maize and improved pasture activities, supply equations were developed to simulate the allocation process. Supply equations are a clear example of the approach used to simulate the flow of resources from the activities that produce them to the activities that make use of the resources (Figure 7-2). Equation 7-11 determines the amount of *CA* and *CB* that is supplied and fed (***CAF*** and ***CBF***) in the form of concentrate to all the animal categories every month. Therefore the amount of *CB* and *CA* in the ***lth*** concentrate fed to all the cattle categories in every ***m*** period is determined by the values in table $\boldsymbol{feed_{1l}}$ (see Table 7-7), times *CFED*, *HCFED* and *CFED*, in Equation 7-11. Where 1 (one) is the row number in the table, $\boldsymbol{feed_{1l}}$ which, contains the maize commodity and ***l*** is the concentrate type. The equation is then balanced against ***CAF*** and ***CBF*** since no more maize can be fed in concentrates than what is available for cattle feeding.

Subscript ***m*** in ***gcrs*** goes from 1 to 12 since the same concentrates are fed through the year, and no differentiation is made for season as in the case of forages. In this way a very efficient method was developed by which different concentrates (of different composition) can be tested by just changing the values in table $\boldsymbol{feed_{1l}}$.

$$gcrs(m=1:12): -CAF_m - CBF_m + \sum_l feed_{1l} * CFED_{ml} + \sum_l feed_{1l} * HCFED_{ml} \ \& \\ \sum_l feed_{1l} * OCFED_{ml} < 0$$

Equation 7-11. Supply equation for maize grain

Similar supply equations were used for the other concentrate ingredients used here (Appendix 4). It was assumed that the commodities that are not produced in the farm were purchased, this is the case for variables ***CMNF, WHBF, CONF*** (Table 7-6 and Figure 7-2). In this way farmers can obtain a prediction for the amount of each ingredient that needs to be bought.

Supply equations for the farm forage use a similar approach as for concentrates, except that the seasonal effect on forage availability is considered. Equation 7-12 shows the supply equation for maize stover supplied over the first part of the dry season. Again in Equation 7-12 is the subscript ***m*** that controls the season where maize stover is supplied. Because maize stover is used throughout the year, there are two more equations controlling stover supply, where ***m=6:10*** for the wet season and ***m=11:12*** for the second part of the dry season (Appendix 4). Table ***dryfod*** (Table 7-7) in Equation 7-12 defined the composition of every simulated forage, therefore the amount of stover in *FFED*, *HFFED* and *OFFED* determined row one in table ***dryfod***.

$$sfd(m=1:5): -STOFED_{m} + \sum_{j} dryfod_{1j} * FFED_{mj} + \sum_{j} dryfod_{1j} * HFFED_{mj} \ \&$$
$$\sum_{j} dryfod_{1l} * OFFED_{mj} < 0$$

Equation 7-12. Dry stover (forage 1) supply equation for dry season

7.2.4.4. Other household activities

This group of activities represents the land use for the different farm activities and the type of land that the farmers in the Toluca Valley have access to (see Figure 7-1 and Table 7-8). These variables were included in this section because the farmer (decision maker) is who decides whether he uses all his own irrigated land ***OWNIRR*** or his own dry land ***OWNDRY***. He or she decides what to plant and how to plant it. However, because renting land is a common practice and some farmers have the option to rent a limited amount of extra land, which can be irrigated or not irrigated ***RNTIRR***, ***RNTIRR*** , it was included in land use equations too (Figure 7-2). In this work both cases were simulated, farmers who have the opportunity to rent extra land and farmers who do not have that chance. The amount of rented land was restricted to the maximum registered for each case study; however, the amount of land can be increased or reduced depending on the case study or the scenario that is tested. Equation 7-13 shows the land use equation for own and rented irrigated land. Where the different possible uses of the farm's irrigated land (with their associated technologies) are represented by the variables ***CB, CA, CN*** and ***IP*** . Note that the subscript ***o*** goes from 1 to 2 for all the maize varieties under irrigation.

$$irr: \sum_{o=1:2} \sum_{k=1:\max k} \sum_{a=1:\max a} CB_{oka} + \sum_{o=1:2} \sum_{k=1:\max k} \sum_{a=1:\max a} CA_{oka} + \sum_{o=1:2} \sum_{k=1:\max k} \sum_{a=1:\max a} CA_{oka} \ \&$$
$$+ IP - RNTIRR < ownirr$$

Equation 7-13 . Land use equation for irrigated land

Equation 7-13 is balanced against ***ownirr*** which is a constraint defining the irrigated land owned by the farmer in ha, since no more land can be cultivated than what is available in the farm. ***RNTIRR*** is also a constraint, which defines the area in ha that the farmer can rent. It is believed that Equation 7-13 is a reasonable representation of the farmers' decision over their land use. The same approach was utilised for the non-irrigated land as described in Appendix 4. The buy and sale activities are described in the objective function while the role of the rest of the activities shown in Table 7-8 can be easily understood from the equations file in Appendix 4.

Table 7-8. Other farm activities variables

Variable Name	Description	Units	Dimension 1
	Other household activities		
OWNIRR	Irrigated own land	Ha	
OWNDRY	Rainfed own land	Ha	
RIGHTS	Communal land in native pasture	Ha	
RNTDRY	Number of ha of rainfed land rented	Ha	
RNTIRR	Number of ha of irrigated land rented	Ha	
FMC	Labour required for the care of the family	MD	
GR	Labour for grazing cattle and other livestock	MD	
	Improved pasture and other crops activities		
IP	Amount of land planted with improved pastures	Ha	
NG	Amount of land occupied by native grass	Ha	
OC	Amount of land cultivated with other crops	Ha	
LS	Labour required for other types of livestock	MD	
	Buy and sale activities	Kg	Month, *m*=12
CAB	CA grain bought in period *m*		
STOBUY	Stover bought in period *m*	Kg	Month, *m*=12
HL	Hired labour	MD	Month, *m*=12
STOSELL	Stover sold in kg	Kg	Month, *m*=12
CBS	CB (grain) sold	Kg	Month, *m*=12
CAS	CA (grain) sold	Kg	Month *m*=12
MLK	Milk produced and sold	kg	Month *m=12*
NCULL	Number of culled cows	Head	Year
NSTEE	Number of steers sold	Head	Year

7.2.5. Objective function

The LP model maximises gross revenue defined as sales from milk, animals, maize and stover , less the variable costs for hired labour, purchased maize inputs, cattle feeds and the cost of renting land. Farm assets other than cattle (land, buildings, equipment, etc) were treated as predetermined over the one-year model horizon; costs associated with farm assets are treated as fixed costs. These costs are thus omitted from the objective function. As in other optimisation models, the price of farm inputs and outputs have the strongest influence on the behaviour of the model and in the strategy selection. All the prices used here were obtained from the farmers, and correspond to 1996, when the survey work was carried out. Prices are expressed in Mexican pesos (Mx$), where £1.00 pound sterling is equivalent to approximately Mx$ 12.00 pesos.

The variable costs for the different technologies used to cultivate maize were calculated and input to the model in ten tables shown in Table 7-9. These costs included the contractor costs (tractor hire) paid to cultivate the land, fertiliser, herbicide, seeds and water costs. The prices of livestock were expressed on a per animal basis, the prices for crops, concentrates and milk are in Mx$ per kg and the price for the hired labour is in pesos per Man/day. The equation for the objective function is shown in Appendix 4.

Table 7-9. Variable costs for maize production under the simulated technologies

Data Table	**Description**	**Dimension**		
		1	**2**	**3**
mz1c	Variable costs for *CB*, *o*=1	Fertiliser level, *k*=1:7	Planting level, *a*=1:12	Costs in Mx $/ha
mz2c	Variable cost for *CB*, *o*=2	Fertiliser level, *k*=1:7	“	"
mz3c	Variable costs for *CA*, *o*=1	“	“	"
mz4c	Variable costs for *CA*, *o*=2	“	“	"
mz5c	Variable cost for *CN*, *o*=1	“	“	"
mz6c	Variable costs for *CN*, *o*=2	“	“	"
mz7c	Variable costs for *CB*, *o*=3	Fertiliser level, *k*=1:6	Planting level, *a*=10	"
mz8c	Variable costs for *CB*, *o*=4	“	“	"
mz9c	Variable costs for *CA*, *o*=3	“	“	"
mz10c	Variable costs for *CA*, *o*=4	“	“	"

Table 7-10 is an example of the tables shown in Table 7-9 above. This table is a summary of the variable costs of the inputs used to cultivated 1 ha of irrigated *CB* maize with herbicide application under the different fertilising and planting rates (o=1), the name of the table is *mz1c*. Note that the costs considered are those of the herbicide, irrigation, contractor, fertiliser and seed for every maize production technology tested in the model (the cost shown in Table 7-10 are only for two planting rates since the main idea is to illustrate the procedure used). The contractor costs in Table 7-10 are aggregated but individual costs of the different contractor activities were considered to calculate this figure.

Table 7-10. Example of the variable costs of one ha. cultivated with irrigated *CB* maize

Technology			Inputs costs in Mx$/ha					Total cost/ha
o=1	k=1:7	a=1:12	Herbicide	Irrigation	Contractor	Fertiliser	Seeds	mz1c
1.0	1.0	1.0	100.0	50.0	1500	0	8.3	1658.3
1.0	1.0	12.0	100.0	50.0	1500	0	100	1750
1.0	2.0	1.0	100.0	50.0	1500	400	8.3	2058.3
1.0	2.0	12.0	100.0	50.0	1500	400	100	2150
1.0	3.0	1.0	100.0	50.0	1500	411.6	8.3	2069.9
1.0	3.0	12.0	100.0	50.0	1500	411.6	100	2161.6
1.0	4.0	1.0	100.0	50.0	1500	476.4	8.3	2134.7
1.0	4.0	12.0	100.0	50.0	1500	476.4	100	2226.4
1.0	5.0	1.0	100.0	50.0	1500	550	8.3	2208.3
1.0	5.0	12.0	100.0	50.0	1500	550	100	2300
1.0	6.0	1.0	100.0	50.0	1500	680	8.3	2338.3
1.0	6.0	12.0	100.0	50.0	1500	680	100	2430
1.0	7.0	1.0	100.0	50.0	1500	1168	8.3	2826.3
1.0	7.0	12.0	100.0	50.0	1500	1168	100	2918

Table 7-11. Monthly prices of some farm products

	Selling price for 1996 in Mx$/kg				Buying price in Mx$/kg	
Month	***CA* grain**	***CB* grain**	**Stover**	**Milk**	**CA grain**	**Stover**
JAN	1.2834	1.426	0.05	2.5	1.7	0.210
FEB	1.323	1.47	0.05	2.5	1.7	0.210
MAR	1.3644	1.516	0.05	2.5	1.7	0.317
APR	1.5156	1.684	0.08	2.5	1.7	0.317
MAY	1.5165	1.685	0.08	2.5	1.7	0.317
JUN	1.5174	1.686	0.08	2	1.7	0.317
JUL	1.5174	1.686	0.08	2	1.9	0.317
AUG	1.5174	1.686	0.08	2	1.9	0.317
SEP	1.5174	1.686	0.08	2	1.9	0.317
OCT	1.5174	1.686	0.08	2	1.9	0.317
NOV	1.5174	1.686	0.08	2.5	1.9	0.317
DEC	1.5174	1.686	0.08	2.5	1.9	0.317

Table 7-11 shows the selling and buying prices of some of the farm products but especially the prices of maize and stover. Note that monthly price of maize and stover changes depending upon the season, maize and stover are cheaper after the harvest season and more expensive during the rainy season. On the other hand, the milk price is lower during the rainy season due to excess in the offer of this product during this season. This data indicate that seasonal fluctuation in the prices of the farm products and inputs were considered in the model. The selling and buying prices were included because farmers sell their farm products but they also have to buy in when the farm produced is not sufficient to cover internal needs, like in the case of stover.

7.2.6. Simulating labour supply and demand in the system

This section describes the approach used to simulate the amount of labour supplied by the different members of the household. It also describes the approach used to calculate the labour requirements for the cattle production activities. The labour requirements for maize production were described in Chapter 4.

7.2.6.1Calculating labour supplied by individual household members

The average amount of labour supplied by every individual member of the household per year was calculated using the information provided by the family members of the case studies and through direct observation of their daily activities.

The amount of labour provided by each member of the household is expressed as "Adult man days" (*MD*). It is considered that one man-day is the equivalent to approximately 8 hours of work performed by an adult man. This figure is also based on the amount of time that a hired worker works per day; a normal working day starts approximately at 7 a.m. and ends at 3 p.m., making a total of 8 hrs per day. It was observed that the amount of labour in MD provided by each individual of the household depended on its age, gender and position in the household. Based on these observations the following simple rules were developed to calculate the household labour supply.

Adult men and the DMs (included females who are DM) who work "full time" in the farm supply on average 1.5 MD per day. It was observed that this group normally works more than 8 hours per day. A normal working day starts at 5 or 6 am and ends twelve hours later (normally the last activity in the day is feeding and milking of cows). So this group supplies approximately 12 hours of labour per day, it was observed that their working week goes from Monday to Saturday. Sunday is considered as rest day, and little work is done, therefore it was not included in the calculations of labour supply.

For adult women (spouse and daughters) the working day is 4 hours less than the DM, and it was considered to be equivalent to 1 AMD (indeed women works as hard as men). They supply on average 1 AMD per day and Sunday is also their rest day. Older members of the household supply a small part of the labour needs of the farm; it was observed that the amount of labour that they provide is approximately a quarter of an AMD per day. It was observed too that they also work from Monday to Saturday.

Adult men or women (son or daughter) that have an off-farm job may contribute to the labour supply, if their working place is close to the community, such as Toluca City. They can normally supply some labour very early in the morning or late in the evening. It was observed that they contribute with approximately a quarter of an MD per six days per week. It was also observed that during the harvest time, they could supply approximately 5 to 10 full man-days.

Using the simple rules above described; the total labour supplied per year per household member in MD was calculated as follows.

Since all the members of the household work from Monday to Saturday, the total number of possible working days (*WDY*) per year is shown in Equation 7-14.

$$WDY = DY - Sun$$

Equation 7-14 . Working day in a year

Where *DY* is the number of days in a year, in 1996 there were 366. *Sun*=52, which is the number of Sundays in a year, so the total number of working days was 314. The number of holy days (***HD***) where most people in the households do not work was also considered in the calculation of labour supply, and subtracted from ***WDY***. In Taborda and Tenango, the number of holidays is approximately 6 per year.

The number of days that every household member takes as vacation (***VD***) per year is included in the calculation of the labour supply too, it was observed that in average every member takes 5 to 10 ***VD*** per year. Vacation days are used mostly to visit religious places such as shrines or churches. Based on this information, the total number of adult man-days supplied by the different household members per year for the different cropping and cattle activities was calculated using the following simple equations:

$$MD_{DM} \leq 1.5 * WDY-(HD+VD)$$

Equation 7-15. Labour supplied by the DM

Where MD_{DM} is the number of an adult man-days supplied by the DM, whether it be the father, adult son or a female DM (in the case of the households where there is no male DM or adult son). The amount of labour supplied by the spouse was calculated as shown in Equation bellow.

$$AMD_{SP} \leq 1 * WDY-(HD+VD)$$

Equation 7-16. Labour supply by the Spouse

Where MD_{SP} is the number of MD supplied by the spouse, the same equation applies for the adult daughters working full time in the farm. The number of MD supplied by the adult sons or daughter who have an off-farm employment was calculated as shown in Equation 7-17.

$$AMD_{OFF\text{-}FS} \leq (0.25 * WDY1 - (HD+VD)) + FTFD$$

Equation 7-17. Labour supplied by off-farm employed children

Where $MD_{OFF\text{-}FS}$ is the number of MD supplied per year by the adult sons or daughters, $WDY1$ is the number of working days in a year in which the off-farm members supply part time farm labour, and is $WDY\text{-}10$. $FTFD$ is the number of days in which they work full time in the farm, which can be 5 to 10 per year.

The number of MD supplied by the elder members of the household was calculated using Equation 7-18 below

$$AMD_{OLD} \leq 0.25 * WDY\text{-}(HD+VD*2)$$

Equation 7- 18. Labour supplied by old members of the household

Where AMD_{OLD} is the number of MD supplied by the older members of the household, which in general is the grandfather, since it was observed that the grandmother contributes little to the labour supply. Vacation days in this group is twice as many as in other groups since they normally require more off-work days than the rest of the household members. The monthly labour supply by the household members was input to the model in an input data table named $hlab_{n12}$.

The labour requirements for the different activities shown in Table 7-12, were subtracted from what is supplied, the deficit was supplied by hired labour (see Appendix 4 for the labour balance equation **LAB**)

Table 7-12. Input data tables and their dimensions for labour supply and demand

Data Table	Description	Dimension 1	2
hlab	Monthly labour supplied by the household	Category	Month, m=1:12
lcb	Labour required to cultivate CB maize	Month	Main treatment, o=1:4
lca	Labour required to cultivate CA maize	Month	Main treatment, o=1:4
lcn	Labour required to cultivate CN maize	Month	Main treatment, o=1:2
lip	Labour required to cultivate IP	Month	
loc	Labour required for other crops	Month	
lgr	Labour required for grazing	Month	
lol	Labour required for other livestock	Month	

7.2.6.2. Labour requirements for cattle activities

The amount of labour required to feed and clean the farm's cattle is dependent upon the composition of the herd in terms of the number of animals of the different classes, since more time will be spent in feeding a cow than a calf or a heifer. The activities that consume more time are the feeding, cleaning and milking of the animals. The time required to cut and carry forage also consumes an important amount of the household's labour, but it was included in the labour budget for maize cultivation, as manual weeding. Cut and carry forage occurs only during the rainy season because it is in this season when green forage is available for cutting.

Using the information provided by the farmers on the amount of time that they spent in feeding, cleaning and milking their cattle, two linear regression models were developed to calculate the amount of labour required to perform these activities. The output of the models is expressed in MD per month for the different simulated categories of cattle.

The first model calculates the labour needed to milk the cows, in MD/month (t_{milk}), which are in milk in any given monthly period of the year. The second model calculates the labour needed to feed and clean the cattle in MD/month ($t_{fed\text{-}clean}$) in all categories. In the second model the number of cattle heads per herd were scaled to livestock units (LSU) in order to differentiate the time farmers spent in feeding the different categories of cattle. A cow represented 1 LSU, heifer, steers and bulls were considered as 0.65*1LSU and calves 0.34*1LSU.

Approximately 90% ($r^2=0.9$) of the total variation in the time required for milking the cows is explained by the regression model shown in Equation 7-19 below, which suggests that it can be used to calculate the time needed to milk all the cows in a herd ($p<0.01$).

$$t_{milk} = 0.304 + 0.584 * N$$

Equation 7-19. Model for labour required to milk cows

Where t_{milk} is the labour needed to milk all the cows in a herd, expressed as MD per monthly period of 30.5 days and N is the number of cows that are being milked in any monthly period. The model used to calculate the time required for feeding and cleaning the cattle, shown in Equation 7-20, also explains a large proportion of the variation (76.3%). It provides strong evidence ($p<0.01$) that suggests it can be used to predict the time required to feed and clean all the animals classes in the herd.

$$t_{fed\&clean} = 2.516 + 1.3 * LSU$$

Equation 7-20. Model for labour required to feed and milk cows

Where $t_{fed\&clean}$ is the time needed to feed and clean up the cattle, expressed as MD per monthly period of 30.5 days and, LUS is the number of the different cattle categories in the herd scaled to livestock units.

Equations 7-19 and 7-20 permitted development of the set of coefficients used in Equation 7-21, to simulate the dynamics of labour requirements for cattle production over the simulated periods. Equation 7-21 calculates the amount of labour required for cleaning feeding and milking the entire herd. It can be seen that the model is able to predict how the monthly labour requirements change with the time, since the herd structure also changes. This enabled the model to consider the different herd sizes and structures for the different case studies simulated, stressing the generic characteristic of the model.

$$catlab_{m=1:12} \sum_{q} \sum_{i} e * hc\_1_{imq} + \sum_{q=1:2} g * hc\_2_{mq} + \sum_{q=1:2} f * hc\_3_{mq} \, \&$$

$$+ \sum_{q=3:4} g * hc\_3_{mq} + h$$

Equation 7-21. Equation for labour requirements of the herd

Where ***e*** is equal to 1.88, which is the sum of the regression coefficients from Equations 7-19 and 7-20, for cows in all classes for milking-feeding and cleaning times LSU (0.584 and 1.3 respectively). Since heifers, steers and bulls are not milked, they are only feed and cleaned, the coefficient associated with labour required for milking cows is not used. Therefore, *g*=1.3*0.65 (where 1 heifer =0.65LSU) and *f*=1.3*0.34 for calves (where 1 calf=0.34LSU). Finally h=0.304+2.516.

Chapter 8. Simulating the *campesino* maize-cattle production system of the Toluca Valley

8.1. Introduction

This chapter describes the performance of the IFSM in emulating the *campesino* maize-cattle production system. Results illustrate the production dynamics of a complete production cycle at the Toluca Valley (13 months). The model solutions for land use, dynamics in farm resources use and gross revenue are compared to the survey data for each of the simulated case studies. Special attention was paid in describing the ability of the model to represent the complex interactions observed between farmers, crops and cattle. Model solutions for maize and milk production are described in relation to the technologies selected and land use. Seasonal variation in cattle feeding systems is also described especially the capacity of the model to select the best feeding strategies using available resources. The generic nature of the model is stressed by describing model solutions for every case study.

A description of the main characteristics of the case studies is presented first in order to facilitate the comparison between the case studies and the model predictions. This description is followed by discussion on the model's accuracy in reproducing the farming system dynamics. Due to the size of the output a summary of the main results is presented.

8.2. Characteristics of the case studies simulated

The main characteristics of the three case studies are presented in Table 8-1, and described below.

Mr Luis González's farm: This farm is located in a small community called Allende, which is part of the *ejido* Taborda. His father was one of the original recipients of land when the local haciendas were divided; and the *ejido* founded in

1936. His farm is 4.0 ha from which 0.5 ha are occupied by the farmhouse and the cattle barn. The rest is used to cultivate maize, and some improved pasture (annual Rye grass), the land use pattern for his farm is shown in Table 8-1. Improved pasture is normally located amongst the maize fields that are close to the farmhouse. Two and a half hectares of Mr González's are irrigated and one ha is rainfed only (Table 8-1). He also rents two extra hectares of irrigated land from a neighbour farm, which he plants with maize too. Mr González cultivates his own varieties of *Criollo Blanco*, *Criollo Amarillo* and *Criollo Negro* maize. Normally he does not apply herbicide to his maize fields, since he uses all the forage available to feed his cattle. Depending on yield levels he may sell some or use all to feed his animals.

Mr González reckons that the main objective of keeping cattle is milk production, however it was observed that beef production was also a very important activity for him. All the male calves are kept in the farm and sold once fat, no female calves are sold since all are kept as replacements. Most of the milk produced is sold to the local middleman; in fact milk sales constitute his main daily cash income source. Beef animals also supply an important amount of cash, although the income is less frequent and is seen more as a saving activity. He has other livestock including sheep, pigs, donkeys and poultry. The cattle herd structure and the type and number of other livestock is summarised in Table 8-1.

Mr Luis González is the decision-maker in his farm; he is 58 years old, and his wife 52. The number and gender of his children are shown in Table 8-1. Two of his sons have an off-farm job in the industrial zone near the Toluca City, but they contribute with some labour to the farm. His son Tirzo (25) works full time in the farm; he has a technical career (12 years of education). Tirzo worked in a factory but he decided to quit, he believes he can make more money working in his father's farm. Mr González's spouse and daughter are in charge of the housekeeping, but they are also responsible for the small livestock. If needed, they may also contribute to some of the cultivation and major livestock related activities. Mr González has no tractor; he has to pay the contractor to do all the cultivation activities that require it. He has no permanent workers, but he does hire extra labour during the harvest season.

Table 8-1. Main characteristics of the case study farms.

	Case study farmers		
Household composition	Mrs Lidia Estrada	Mr Luis González	Mr Juan Valdez
Decision maker	1	1	1
Spouse	0	1	0
In-farm son	0	1	0
Daughter	1	1	0
Children	0	2	2
Old	0	0	2
Off-farm son	0	2	1
Community	Taborda-Las Lomas	Taborda-Allende	Taborda
Farm size in ha.	1.5	4.0	7.0
Own arable land			
Irrigated	1.25	2.5	6.0
Rainfed	0	1.0	0
Rented land in ha			
Irrigated	0	2.0	3.0
Rainfed	0	0	2.0
Land in farmhouse & livestock housing in ha.	0.25	0.5	1.0
Crops	Maize	Maize	Maize
Other crops	Pumpkins*	Pumpkins, large* beans	Pumpkins, large beans
Land in crops in ha.	1.0	5.39	10.0
Pastures	Annual Rye grass	Annual Rye grass	Rye grass
Land in pastures in ha.	0.25	0.110	1.0
Livestock			
Lactating cows	5	5	9
Dry cows	1	0	0
Pregnant heifers	1	2	5
Non-pregnant heifers	1	2	2
Calves	2	5	9
Steers	0	4	6
Bulls	1	0	1
Total	11	18	32
Sheep	0	8	0
Pigs	0	2	0
Poultry	10	30	35
Donkeys	1	2	0
Machinery			
Tractor	No	No	Yes

***Pumpkins and large beans are intercropped with maize**

Mrs Lidia Estrada's Farm: Mrs Estrada's farm is located in Las Lomas, a community that is also part of the *ejido* Taborda. Mrs Estrada is a widow and she inherited her land from her husband who died ten years ago, since then she has lived from milk and maize production. Her farm is 1.5 ha from which 1.25 ha are of farming land and 0.25 ha is occupied by her house and the cattle barn. All her land is irrigated; she plants 1 ha with *Criollo Amarillo* maize and the rest with annual Rye grass (Table 8-1). Mrs Estrada does not rent extra land since she acknowledges that she can not afford to cultivate more land, and it will be difficult for a widow to have access to land for renting. She does not apply herbicide to her maize because all the forage is used to feed her cows, and she does not sell any maize or stover.

Milk production is the main objective of keeping cattle in the case of Mrs Estrada, and all the milk is sold to the local middleman too. All the calves are sold when they are 6 months old or less, because she does not have enough forage and maize to keep them. Again no heifers are sold, and milk is her main source of income. Mrs Estrada does not have any other large livestock, only chickens and turkey. Most part of the dry season she feeds her cattle with maize stover, small amounts of improved pasture and a concentrate that she makes. The concentrate is made of chicken manure and ground corn (Conc-3). She has access to a communal grassland area from which she takes advantage to take her animals to graze. During the rainy season, she feeds her cattle weeds, green stover and dry stover; she uses the same concentrate as in the dry season, although she may include some wheat bran in it (concentrate 5). Mrs Estrada has to buy large amounts of stover since what she produces is not enough to feed her animals, 18 heads of cattle in average per year. She reckons that feeding expenses are among the largest in her production costs.

Mrs Estrada who is 50 years old has a daughter (18) who works full time with her; both manage to provide all the labour required to look after her cattle. However she needs to hire people at some points of the maize growing season to help her with the cultivation activities. She has no tractor too.

Mr Juan Valdez's farm: Mr Valdez's farm is located in the Taborda community. He represents the segment of wealthier farmers in the region (approximately 10%). He is 75 years old, and is also one of the initial dwellers of the *ejido* Taborda. Mr Valdez's farm is 7 ha; the farmhouse and the cattle barn occupy one hectare, and the rest is arable land. All his land is irrigated from which he plants 5 ha with maize and 1 ha with Rye grass (*Lollium perenne*). Mr Valdez normally rents an extra 5 ha of land;

three of which are irrigated and the other two are not, all this extra land is planted with maize too (Table 8-1). Mr Juan Valdez plants his own varieties of *Criollo Blanco, Amarillo* and *Negro*; he normally applies herbicide to all his maize plots, except in 2 plots close to the farmhouse. He cuts and carries forage to feed his cattle during the rain season from these plots. Due to the relatively large area planted with maize he normally has a surplus of grain and sometimes stover that, depending on the market conditions, he may sell or feed them to his cattle.

Mr Valdez has the largest herd from all the case studies; 32 animals in total (see Table 8-1). He reckons that his main interest in keeping cattle is milk production, his cows have higher yields than the average in the community, however it was observed that beef production plays an important role in his production strategies. All the male calves are kept and sold once fatted. All the milk is sold to his older son who is a local milk middleman. Again no heifers are sold, but used as replacements, notice the large proportion of heifers in the herd shown in Table 8-1. During the dry season he feeds his cattle with maize stover, some improved pasture, and a better quality concentrates, made from wheat bran, maize, and chicken manure (Conc-1 and 2). If the price is low he may also use some commercial concentrate. For most part of the rainy season he feeds his cattle with maize stover, improved pasture, weeds and green maize stover, and he uses the same concentrates.

Due to Mr Juan Valdez's old age, his son Juan (28) is in charge of the farm and in many aspects he is the decision-maker or shares the key decisions with his father. Mr Valdez's wife is in charge of the housekeeping and does not participate in the cultivation or cattle activities. Due to the large size of the farm, Mr Juan Valdez has a permanent worker (sometimes two workers) in his farm, in charge of feeding and cleaning cattle. He also hires some extra labour to carry out most of the cultivation activities, particularly during the harvest season. Mr Valdez is the only one of the case study farmers who owns a tractor.

8.3. Model predictions for maximum gross revenue and household dynamics.

8.3.1. Maximum gross revenue

Model predictions for annual gross revenue and land uses are presented in Table 8-2. The size and structure of the simulated households is also shown to facilitate the description of the output. This table shows that as expected Mr Juan Valdez's farm obtains the highest gross revenue, followed by Mr González's and Mrs Estrada's farms. These results are consistent with the fact that Mr Valdez owns more land than the other two case study farmers do. Therefore he plants more maize and can afford to have more cattle, which at the end generates him more profit. Gross revenue predicted for Mr Luis González is also in line with what was observed in the field since this farmer is visibly better-off than Lidia Estrada, who represents the group of less wealthy farmers, mostly due to the small size of her holding. Note that the maximum gross revenue predicted for her is not substantially different from that of Mr González. This is probably explained because of the dairy cattle contribution to her gross annual income since she has a similar number of cows as Mr González (Table 8-1).

Although the actual gross revenue for every case study was not calculated during the survey, the farmers were asked to give an estimate of their annual gross revenues. It was observed that the maximum gross revenues predicted by the model are some 20% higher than the average annual profit reported by the case study farmers. However, farmers mentioned that in good agricultural years, when weather conditions are good (no early frosts and good rainfall) and the maize plants do not suffer from water or nutrients stress, similar profit levels to those reported by the model may be achieved.

Moreover, when the gross revenue from one hectare cultivated with irrigated maize was calculated using the survey data, it was observed that for an average yield of 4.5 t of grain and 4 t of stover, the gross revenue was of Mx$ 4900/ha. This figure is quite similar to the Mx$ 5461 **dual value** (is a measure of what an additional unit of a resource is worth) predicted by the model for an extra hectare of irrigated land used to cultivate maize or improved pasture (***irr***). These observations suggest that the model predictions for gross revenue generated from 1 ha of land cultivated with maize are consistent with those observed in the field.

Table 8-2. Model predictions for gross revenue and land use

				Case study					
	Luis González			**Lidia Estrada**			**Juan Valdez**		
Variable name and dimension	**Techno-logy**	**Value**	**Input Cost**	**Techno-Logy**	**Value**	**Input Cost**	**Techno-logy**	**Value**	**Input cost**
Gross revenue (Mx$/year)		64 152.5			42 389			116 310	
Household									
HM 01		1	0		1	0		1	0
HM 02		1	10		0	0		0	0
HM 03		1	0		0	0		0	0
HM 04		1	0		1	0		0	0
HM 06		0	0		0	0		2	0
HM 07		2	0		0	0		1	0
Land use									
	o, k, a			***o, k, a***			***o, k, a***		
CB (ha)	2,5,04	2.19	-2133	-	-	-	1,6,04	6.42	-2363
CB "	1,6,04	1.84	-2363	2,6,04	0.82	-2263	2,6,04	1.80	-2263
CB "	3,6,04	1	-1950	-	-	-	3,6,04	1.56	-1950
CB "	-	-	-	-	-	-	4,6,04	0.43	-1850
CN "	1,7,08	0.159	-2404	2,7,08	0.053	-2792	2,7,08	0.09	-2792
*CA** "	1,6,04	0	-2354	2,6,04	0	-2254	2,6,04	0	-2254
*CA ** "	3,6,04	0	-1924		0	0	3,6,04	0	-1924
IP "		0.311	-2000		0.381	-2000		0.70	-2000
RNTDRY (ha)	-	-	-	-	-	-		2	-1839
RNTIRR "		2	-2777	-	-	-		3	-2777
*ownirr*** "		2.5			1.25			6.0	
*owndry*** "		1.0			0			0	
Gross margin/ha		11 664			42 389			10 573	
Gross margin/cow		12 380			14 129			11 631	
Household lab return/day		43.0			60.5			216.0	

Variables not selected by the model which reduced cost is equal to 0, **Arable land in ha/farm are restrictions.** Key:HM***=household members, ***RNTDRY***=rented rainfed land, ***RNTIRR***=rented irrigated land, ***ownirr***=own irrigated land, ***owndry***=own non-irrigated land, ***IP***=improved pastures

Dickson (1997), in a more simple model of the campesino maize-cattle production systems of the Toluca Valley, predicted an annual gross revenue of Mx$ 73,270 for a farm with nine cows and 4 ha of land planted with maize, which is similar to Mr González's farm. It is possible to use the model to simulate maize production under different climate conditions such as those observed in crop failure or low yields situations. The model predictions shown in Table 8-2 reflect maize and improved pasture growth and production under reasonable good climate conditions (see Chapter 4), which also explains the profit levels predicted by the model.

Gross revenue predicted by the model are higher than those reported by Arriaga *et al.*, (1997a), for campesino farmers of the Toluca Valley. The difference may be explained by the fact that these authors considered the family labour as part of the variable cost, as well as the cost of rearing heifers for replacements. On the other hand, they made general assumptions regarding the yield level for maize, stover, weeds, and other farm products, and do not deal with the dynamics of the farming system over the time. For example, crops and forage yields are not the same every year, the structure of the cattle herds changes throughout the year too. Therefore, it will be wrong to use fixed values for these parameters since they are constantly changing in response to the environment and farmers' interventions.

In this work family labour was not considered as variable cost, since it was considered more important to differentiate its cost from the cost of hired labour. For example, the shadow price of family labour predicted by the model is higher than the normal cost of hired labour. This may be explained by the fact that family members normally supply more labour than a hired worker does, thus it may be more convenient to allow the model to calculate the cost of family labour instead of giving it a fixed value. For example, the shadow price of the labour supplied by the decision-maker and the adult son is Mx$ 40/day, Mx$ 27/day for the spouse and daughter, while the cost of hired labour is Mx$ 25 (Table 8-3).

The cost of rearing replacements were not considered as variable costs, because replacements are produced within the farm and reared using stover and grain which are produced in the farm, and their costs were accounted for in the maize production costs. The predicted gross revenue is also the result of selecting the optimum (predicted) technologies available to produce milk and maize, for example in the case of the dairy cows only the best diets and concentrates allocation strategies were selected by the model. For the rainy season, all the lactating cows were fed with concentrate CONC-6 that is the concentrate which produced the highest milk yield response among all the concentrates tested (see Chapter 6, section 6.4.1). Although farmers sometimes administrate commercial concentrate, it is not a normal practice to supplement all the cows with it during the wet season. The model found that it is worthwhile to supplement this concentrate to all lactating cows during the whole duration of the rainy season when better response is obtained.

On the other hand, cattle diet selection during the dry season did not included commercial concentrate because the model found more convenient to utilise only those concentrates which maximise milk yield but are less expensive than the commercial one (farm-made concentrates). Also recall that during the dry season response to concentrate is lower than during the rainy season due to the low quality of the forages, that is probably why the model did not selected commercial concentrates for this season. This diet selection pattern selected by the model for the dry season is more similar to the feeding systems used by farmers.

Higher gross revenue predicted by the model can also be explained by the reasonable high grain yield predicted by the maize model. As explained before the CERES-Maize model predictions for grain yield are in close agreement to those observed in the field, however these observations are for good years when climate conditions are appropriate for maize growth and there is no damage by frost, pests or diseases as will be explained later in the following section.

Table 8-2 also shows the gross margin per ha and per cow and the return to household's labour per day of work. These data suggest that Mrs Lidia Estrada is the most efficient farmer among the three case studies. Despite she only has one ha of land she makes the most efficient use of it getting the higher gross revenue per hectare of land. It is suggested that milk production contributed to a larger extent to this results since by producing maize alone she will not be able to get this level of revenue. Mr Juan Valdez obtains the highest return for one day of household's labour but this is probably due to the size of his holding, however in general it is possible to say that all farmers get higher wages from working in their farms than the average wage rate they could get working for someone else.

Finally, it is acknowledged that farmers normally operate over the optimum for most production technologies, it is believed that the model was able to find some space for potential improvement, which resulted in higher gross revenue, as will be discussed later.

8.3.2. Household dynamics

Although the model did not explicitly determine the household size and composition, the model was successful in incorporating the household composition of the simulated case studies into the model's dynamics. Table 8-2 shows that the household size and composition used by the model to calculate labour supply and maize consumption for all the case studies is the same as the one presented in Table 8-1. Every member was properly accounted for in the model, this approach permitted to run the model for different case studies regardless the size and composition of the household. This is clearly shown in the cases of Mrs Lidia Estrada and Mr Luis González whose households represent the extremes in term of household composition and size, two and six members respectively (Table 8-1).

Moreover, results in Table 8-2 suggest that the model was able to reflect the effects of individual household composition in terms of family labour supply, and preferences on maize consumption and production which at the end determines the farm production strategies. Already mentioned the IFMS is free to select which maize variety to produce for sell and cattle feeding, however in the case of the household's maize consumption it was constrained to produce *Criollo Negro* in order to cover the households' needs. This was done because it was observed that campesino families normally plant small areas with *CN* maize, which is preferred for human consumption above the other varieties.

It is believed that the approach used here also contributes to a certain extent to incorporating socio-economic aspects of the farming system in the modelling process. It is well known that traditionally, models aimed at simulating one component of the farm system, be that either the food production or ecological systems, have tended to ignore the social component of the farm system (Dent *et al.*, 1995; Jones *et al.*, 1997). This is quite unfortunate because the responses of the people to their economic and social environment is what ultimately determines the other outputs of agricultural systems.

The generic nature of the model is based on the assumption that there exists some degree of commonality between the behaviour and production practices of individual farmers of the Toluca Valley. So rather than attempt to simulate the unique behaviour of individuals, it was decided to develop a model which assumes some degree of commonality in the behaviour of individuals, but also recognises that the characteristics of the individual households will influence the specific uses of the land and production responses. This goal was achieved by identifying the production practices that are common to most farmers in the study area and reproduce them in the model. The model therefore acts as an expert system, because it attempts to emulate some of the decision-making process of human experts (Luger and Stubblefield, 1989). In this case, the experts are the campesino farmers of the Toluca Valley, and the model attempts to emulate their behaviour, from the standpoint of their farming practices.

8.4. Simulating land use

Model prediction for land use was consistent to the land use pattern observed in the field for every simulated case study. For example in the case of Mr Luis González the model utilised all the land to which the farmer has access to, as normally occurs with Mr González (Tables 8-1 and 8-2). The model selected to cultivate two varieties of maize, 5.03 ha of *CB* and 0.016 ha of *CN*. *Criollo Blanco* was selected because it generates the highest income (has a higher sale price than *CA*). However, the variety *CA* could also be used without significantly affecting the final value of the objective function. Table 8-2 shows that the variety *CA* (using a similar cultivation technology to that use for *CB*) could effectively be included in the land use strategy and produce the same final result, because its *reduced cost* is zero. Therefore, there is no objective function loss by producing some of this variety. These results showed that the model didn't ignore the diversity on the use of local maize varieties, since it could use simultaneously all the maize varieties without affecting the final gross revenue.

The model was remarkably accurate in reproducing the maize production technologies used by the farmer at the Toluca Valley. For example Table 8-2 shows that in the case of Mr González, the model selected both to cultivate irrigated and non-irrigated maize (*o=1:2 and o=3:4*, respectively). Moreover, it was able to reproduce the differential application of herbicide; it selected to apply herbicide in nearly 3 ha, and not to apply it in 2.19 ha of maize. The extra forage produced by not applying herbicide (weeds and green maize fodder) was used by the model to feed cattle, as is shown later in this section.

On the other hand, it was observed that the area predicted by the model for herbicide application is different from the area determined by farmers. For example, Mr González only applies herbicide in 1 ha; in contrast the model decided to apply herbicide in nearly three hectares of maize. This may be explained by the fact that the model decided to feed cows with the highest rate of commercial concentrate (better quality) during most part of the wet season. Reducing the amount of forage needed during this season, which is the same weeds and green maize stover produced by not applying herbicide. Moreover, model predictions for Mr González suggest that it may be more convenient for this farmer to save more stover for the dry season (not cutting it as green stover) when more stover is required, thus reducing purchase of it during this season. It is believed that in the end, the model was successful in capturing the interactions between the crops and the cattle and the compromise between the need to produce grain, but also to produce forage from the same maize plots.

The model also allocated some of the farm's land to produce improved pasture. This is remarkable because there is not a constraint that forces the model to allocate land to this activity. Table 8-2 shows that the model used 0.311 hectares to produce improved pastures, in contrast Table 8-1, indicates that Mr González uses only 0.11 ha to produce improved pasture. The model suggests that it may be more profitable for this farmer to allocate slightly more land to this activity. The model prediction for this variable also suggests that such change should not produce significant effects on the land use pattern and maize production (since the extra area dedicated to this activity is very small).

Model predictions for Mrs Lidia Estrada are also consistent to what was observed in the field for this farmer. The model allocated 0.87 ha for maize production (irrigated) while the farmer normally allocates 1.0 ha. The model assigned 0.38 ha for improved pasture while the farmer uses 0.25 ha for this activity (Tables 8-1 and 8-2). The results for Mrs Estrada also show that the model selected to produce *CB* maize without herbicide, because weeds and green maize fodder are used to feed cattle during the wet season. It was observed that this is a common practice used by the farmer, who due to the small size of her farm makes use of all the forage resources that she has access to.

The land use pattern predicted for the third case study is also similar to that observed in the field, and to the other two case studies. The model decided to cultivate both irrigated and non-irrigated maize, and allocate most of the farm's land for this activity (10.3 ha). The model also decided not to apply herbicide in 1.8 ha cultivated with irrigated *CB* and 0.43 ha of non-irrigated *CB* (Table 8-2). The herbicide application regime predicted by the model is also consistent to what was observed in the field for this farmer. It was observed that Mr Valdez does not apply herbicide in 3 ha of his maize crop. The model allocated 0.7 ha for improved pasture production, while the farmer uses 1 ha for this purpose. These results suggest that the model prediction for this variable and other land use variables are in close agreement with the farmer land use practices observed in the field.

Notice that for this farmer the model decided to cultivate only *CB* maize too. However, *CA* can also be cultivated without significant effect on the final value of the objective function as indicated by the 0 value assigned to the *reduced cost* for these variables. In other words, it will cost nothing (or lose nothing) to the farm income to include in the land use plan the *CA* variety (using similar cultivation technologies as for *CB*).

In all the case studies the model selected the fertilizer levels 5 and 6 (*k=5* and *6*), 70 and 90 kg of N /ha, respectively (see Tables 7-4 and 8-2). These results indicate that it may be more economically viable for farmers to use 90 kg of N per hectare of maize instead of the 180 kg of nitrogen normally applied by them. However, these predictions have to be taken cautiously, for two main reasons. First as it was widely discussed in Chapter 4, the maize model may be underpredicting the nitrogen fertilizer needs of local maize due to the low stover yields predicted by it. Therefore, a lower use of nitrogen may affect stover yield; however, these assumptions need to be validated in the field.

Secondly, although all the simulated varieties reached their asymptotic grain yield values at a dose of 90 kg of nitrogen (and no significant difference was observed between 90 and 180 kg of nitrogen, see Chapter 4), it is probable that weeds are using some of the extra nitrogen applied by farmers (Okumura *et al.*, 1986). Now, because the CERES Maize model does not predict the effects of weeds on nitrogen utilisation by maize it is difficult to evaluate this assumption. Weeds utilisation of nitrogen may be occurring even for the cases where herbicide is applied because it is well known that herbicide application or the mechanical removal of weeds does not exert a complete control of weeds (Singh *et al.,* 1985).

On the other hand, it is hypothesised that the amount of nitrogen used by weeds may not be very important since the most negative effects of weeds on maize yield occur during the first 60-70 days after maize emergence (Singh *et al.*, 1985; Marais, 1985). Farmers in the Toluca Valley put particular effort on weed control (mainly by mechanical methods) during this critical period of maize growth (Figure 4-5). Fischer *et al.*, (1981) have also reported this practice in other maize producing communities of Central Mexico.

Finally, notice that the IFSM allocated a minimal amount of land for the cultivation of *CN* maize, which is determined by the monthly consumption of maize by the household (Table 8-2). The average daily consumption reported by Reyes (1990) was used to calculate the monthly consumption for the entire household, and again this varies depending upon the composition of it.

8.5. Simulating farm resources production and utilisation

Campesino farmers normally make decisions on their farming activities at more than one point in time, therefore it is quite likely that the decisions made during the current period influence decision made during future periods. Although the IFSM does not attempt to actually simulate the decision making process carried out by farmers, it can actually simulate the decisions taken over the land use and predict the effects on production and utilisation of farm products resulting from such decisions. In other words, since the IFSM is based on the expert knowledge of the local farmers, it will be fair to assume that the model predictions on the driving variables of the system (like land use) are similar to those taken by the farmers. Therefore, in theory the model's predictions on the actual production and utilisation of the farm generated resources should also be consistent with the practices observed in the field. It is believed that this goal was achieved by making the model dynamic in order to simulate the monthly periods of the production cycle at the Toluca Valley. This is a feature not seen in similar models where a single time period (usually a year or a production season) is normally simulated.

Tables 8-3 and 8-4 summarise the production and utilisation of the simulated farm products including, maize (grain), stover, milk and beef. Table 8-3 shows the main products generated from the maize production activities, and the time when they were carried out. For example, maize and stover can be harvested (*CBHV, STOHV*), sold (*CBS, STOSEL*), purchased (*STOBUY*) or fed to cattle (*CBF, STOFED*), depending on the farm needs and the optimal solution for that farm. A similar approach was used for the cattle products (see Table 8-4), milk is produced and sold (*MLK*), culled cows are sold (*NCULL*) and the same occurs with steers whether they are fatted or not (*NSTEE*). Hired labour requirements are presented in Table 8-3 too. Although hired labour is not a product generated within the production unit, its requirements depend upon the level of the crop and cattle activities; this is described in this section too.

Table 8-3. Model predictions for maize, stover and hired labour dynamics

			Case study			
	Luis González		**Lidia Estrada**		**Juan Valdez**	
Variable name and dimension	**Value**	**Input Cost**	**Value**	**Input Cost**	**Value**	**Input cost**
Crop products						
CBHV 11 (kg/farm)	18 830.5	0	3 837.5	0	38 652.2	0
CBHV 12 "	3 765.6	0	-	-	7 286.2	0
CBS 06 *(kg/month)*	261.8	1.68	138.5	1.68	-	-
CBS 11 "	18 232.7	1.68	0	1.68	37 493.6	1.68
STOHV01 (kg/month)	3321.8	0			6 182.6	
STOHV12 "	11 148.4	0	1 664.8		24 689.2	
STOSEL04 "	-	.08	-	-	-	0.08
STOBUY01 "		-0.21	2 121.5	-0.21		
STOBUY02 "	13 488	-0.21	17 115	-0.21	18 674.5	-0.21
Hired Labour						
HL 01 *(MD/month)*	0	-25	0	-25	48.43	-25
HL 02 "	0	-25	0	-25	28.0	-25
HL 03 "	0	-25	0.7	-25	56.7	-25
HL 04 "	0	-25	0	-25	36.5	-25
HL 05 "	0	-25	0	-25	42.4	-25
HL 06 "	0	-25	0	-25	49.2	-25
HL 07 "	0	-25	0	-25	67.0	-25
HL 08 "	0	-25	0	-25	40.5	-25
HL 09 "	0	-25	0.25	-25	37.8	-25
HL 10 "	0	-25	0	-25	36.2	-25
HL 11 "	33.4	-25	29.3	-25	180.0	-25
HL 12 "	36.5	-25	33.6	-25	183.3	-25

Key:***CBHV***=CB harvested, ***CBS***=CB grain sold, ***STOHV***=stover harvested, ***STOSEL***=stover sold, ***STOBUY***=stover bought, ***HL***=hired labour.

8.5.1. Model predictions for maize production and utilisation

Table 8-3, shows the amount of *CB* maize which is harvested from each case study (*CBHV*), it also shows the month in which it was harvested. Notice that Mrs Estrada harvested maize in November ($CBHV_{11}$) because she only plants irrigated maize (only harvested in this month), while the other two farmers harvested both in November and December ($CBHV_{11\ \&\ 12}$) because they planted both irrigated and non-irrigated maize.

Table 8-3 also shows that the amount of maize harvested from irrigated maize is larger than for rainfed maize. For example, if the average yield per ha of irrigated maize is calculated for Mr González fields from the values in Table 8-3, it can be observed that grain yield was 5.2 t/ha while for rainfed was 3.8 t/ha. Similar figures were observed for the other two case studies. In general, it possible to say that average yield levels selected by the model are similar to those observed in the field (see Chapter 4). As expected Mr Juan Valdez harvested the largest amount of *CB* maize, followed by Mr González and Mrs Estrada.

Model predictions for sales of *CB* maize (*CBS*) are presented in Table 8-3. Mr Valdez is the farmer who sells the largest amount of maize, 37.4 t in November, while Mrs Estrada can only afford to sell a minimal quantity in June (CBS_{06}). Mr González also sells a significant amount of maize, 18 t in the month November too. Predicted maize sales for all the farmers are higher than observed in the field, since they normally sell less maize. The amount of sold by every farmer is quite variable and will depend on the yield and the farm needs, however, it was observed that Mr Valdez sells approximately 50-60% of his annual production, while Mr González sells only 30-40%. Due to the small size of his holding, Mrs Lidia Estrada does not sell any maize at all.

Predicted maize sales shown in Table 8-3, for Mr González and Mr Valdez are higher (80% and 84% of total harvest, respectively) than the values reported by farmers. These findings can be easily explained by the fact that the model decided that it is more profitable for these farmers to feed commercial concentrate to cattle during the rainy season instead of using maize as concentrate for cattle (see section 8.6.3). The model also reduced the amount of maize allocated to feed young stock, as it will be described later. Moreover, in the case of Mr González, the model did not simulate the amount of maize fed to his sheep and pigs, which will further reduce the predicted sales of maize. Simulation of feeding systems for other livestock within the farming system may be required in order to account for the contribution and resources demand of these animals too. However, this subject goes beyond the scope of this work, since other simulation models are required such as monogastric models that simulate for example pigs and chicken consumption of maize and forages.

8.5.2. Model predictions for stover production and utilisation

Because maize stover plays an important role in the farming system, it was considered essential to emulate its utilisation over the time. Table 8-3 shows the months predicted by the model when stover is harvested, sold and purchased. The stover fed to cattle is not included in this section since it will be described in the following section with the rest of the description of the model predictions for cattle feeding systems. Data in Table 8-3 clearly illustrates that the model was able to reproduce accurately the months when these activities actually take place in the field. Farmers who planted irrigated maize harvested stover in December ($STOHV_{12}$), and farmers who planted non-irrigated maize harvested it in January ($STOHV_{01}$).

Model predictions for stover sales and purchases in Table 8-3 (*STOSELL* and *STOBUY*) are also consistent to what the farmer do, since none of them sells stover but all of them buy extra stover every year. For example, it was observed that Mr González has to buy in average between 8 to 10 tons per year (depending on herd size and composition), model prediction for stover purchased is 13.4 t per year, which is slightly more than what the farmer buys. The difference may be explained by the low stover yields predicted by the CERES-Maize model. Mrs Lidia Estrada also buys large amounts of stover (approximately 16 t /year), model predictions for this farmer are also in close agreement with the farmer's practice for this variable.

The IFSM can also simulate the amount of stover (initial inventory) that is available to the farmer at the start of each month after it was harvested, fed, sold or purchased in the previous month. The results shown in Table 8-4 represent the amount of stover in kg of dry matter, which is available ($STOV_{1:12}$) to every farmer at the start of each month. Because the model runs for one year, the amount of stover, that is available at the start of the year is equal to what is available in January next year (13th month). In this way it is possible to simulate the use of stover and grain, which is harvested from November, (January last year) throughout the simulated year (closed loop).

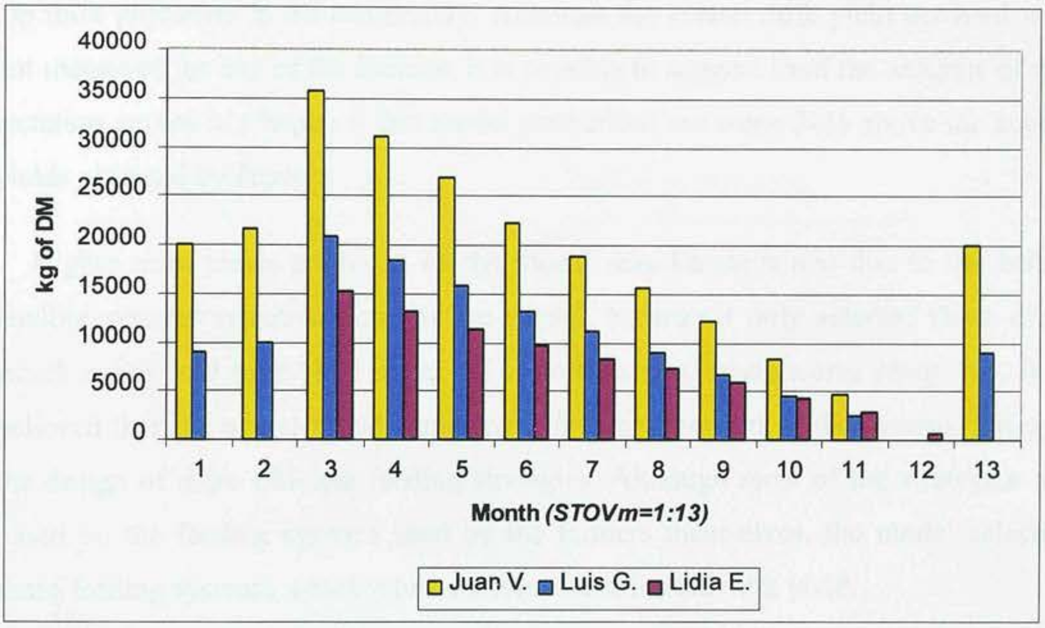
Table 8-4 shows that in the case of Mrs Estrada, the stover harvested in December, is not enough to feed her cattle, from January onwards (notice the zeros in *STOV*=1 and 2). Therefore she has to buy stover in January and February (Table 8-3). The pattern simulated by the model is consistent to the pattern observed for Mrs Estrada, since she has to buy stover as early as December or January.

The monthly stover inventories for each farm are clearly appreciated in Figure 8-1. From March to December stover inventories at the start of each month are smaller than the inventories in the previous month; this is due to the utilisation of the stover in the farm. However, it does not occur from January next year to March (loop), where higher stover inventories observed in these months indicate that some stover was purchased. Figure 8-1 indicate the periods when stover purchase takes place, for example the stover inventory at the start of month 3 for all the case studies is higher than the previous month indicating that some stover was purchased in month 2. This is particularly clear for Mrs Estrada, where no stover stock is registered during month 1 and 2 because all what is harvested and purchased was utilised.

Stover purchases indicate that for all case studies farm's production of stover is not enough to cover the internal demands. Therefore farmers have to buy stover in months 1 and 2, when it is cheaper to do so. Figure 8-1 also illustrates how the stover inventory is reduced every month (except in months 1 to 3) as it is used to feed cattle. Stover inventories are high again in month 13, because stover is harvested in December and January. This pattern is observed for all the case studies.

It is believed that the approach use here to account for the use of stover and maize is consistent with that observed in the field. Moreover, these findings could be used to advise farmers on alternative use of resources and the repercussions on the availability of the scarce farm resources. A similar approach was used to simulate maize utilisation over time (see Appendix 5 for model predictions for maize).

Figure 8-1. Stover inventory at the start of each simulated month (in kg of DM).



8.5.3. Hired labour

The data shown in Table 8-3 for hired labour are also entirely consistent to the hired labour requirements for all the case studies. It was observed that Mrs Estrada and Mrs González normally manage to supply most of the labour required to cultivate their land and look after they cattle for most of the year. However, they do require to hire extra labour during the harvest season, which occurs as mentioned in November and December. In both cases the model predicted accurately the hire labour requirements for these farmer. The model also provided consistent predictions for Mr Valdez whom due to the size of his farm and the large number of cows, has to hire one or two permanent workers and also needs to hire temporary labour to cultivate his land. Notice the large number of hired labour requirements predicted by the model for this farmer during the harvest season.

8.5.4. Model predictions for cattle products

Table 8-4 shows model predictions for milk yield in kg per month per herd. Results indicate that Mr Juan Valdez has again higher yield levels than the other two case studies. It was observed in the field that indeed Mr Valdez's herd is among the top milk producers in his community. Although the annual milk yield per herd was not measured for any of the farmers, it is possible to suggest from the analysis of the lactation curves in Chapter 6 that model predictions are some 20% above the actual yields obtained by farmers.

Higher milk yields predicted by the model may be explained due to the better feeding systems selection done by the model, because it only selected those diets which maximised milk yield but at the same time maximise income return too. It is believed that the model found some space for improvement of the system, through the design of more efficient feeding strategies. Although most of the strategies are based on the feeding systems used by the farmers themselves, the model selected those feeding systems, which when combined maximised milk yield.

Figure 8-2 shows that there is a higher monthly milk yield during the wet season than during the dry season. Two factors explain higher milk yields during the rainy season, the first factor is the seasonal characteristics of the system since as explained in Chapter 5 and Chapter 6 section 6.4.2. rainy season forages are better quality which when fed to cows resulted in more milk produced. The second factor is the result of the normal progression of the cows in the herd because for the three simulated herds there are more cows calving and lactating during some months of the rainy season than during the dry season. This is a function of the individual herd management practised by farmers but in general, it was observed that more cows calved and came into milk during the rainy season than during the dry season.

Clearly, the model prediction for milk yield shown in Table 8-4 and Figure 8-2 indicates that the model was able to capture the seasonal variation in milk production observed in most herds at the Toluca Valley. Such variation was reported in the survey work and has been reported in other works (Arriaga *et al.*, 1997a, Castelán *et al.*, 1997; Zorrila *et al.*, 1997). Figure 8-2 shows the amount of milk produced per month per herd predicted by the model in the three case studies. Notice that in all cases milk production is higher during the wet season than in the dry season, moreover 52% of all the milk produced in the year is produced during the wet season despite it only lasting 5 months.

Table 8-4. Predicted cattle outputs and stover utilisation dynamics

	Luis González	***Case Study*** **Lidia Estrada**	**Juan Valdez**	
Variable name and dimension	**Value**	**Value**	**Value**	**Input cost in Mx $**
Cattle outputs				
MLK01(kg/month)	777.75	1583.6	2361.6	2.5
MLK02 "	1037.8	1583.6	2621.5	2.5
MLK03 "	1037.8	1821.5	2859.3	2.5
MLK04 "	1336.6	1509	2847	2.5
MLK05 "	1511	1416.2	2929.4	2.5
MLK06 "	2056.6	1660.1	3716.7	2.5
MLK07 "	2056.6	1175.1	3231.8	2.5
MLK08 "	1789.7	2552	4352	2.5
MLK09 "	1670.8	3109.3	4849.8	2.5
MLK10 "	2758.4	2891.7	5759.9	2.5
MLK11 "	1679.8	1669.3	3350.4	2.5
MLK12 "	1433	1772.7	3207	2.5
Annual milk yield/herd	19 146	22 744	42 086	-
NCULL (heads)	1	1	2	2118
NSTEE "	4	3*	7	4500
Stover use				
STOV 01 (kg/month)	8870.5	0	20082.0	-
STOV 02 "	9860	0	21619.6	-
STOV 03 "	20873	15216.2	35763.0	-
STOV 04 "	18398.4	13220.4	31135.0	-
STOV 05 "	15807.3	11402.8	26869.7	-
STOV 06 "	13160.3	9597.6	22257.8	-
STOV 07 "	11041.9	8350.3	18734.5	-
STOV 08 "	8874.9	7214.7	15576.0	-
STOV 09 "	6660	5923.7	12070.4	-
STOV 10 "	4447.3	4337.7	8272.2	-
STOV 11 "	2431.8	2755.3	0	-
STOV 12 "	0	511.5	4673.8	-
STOV 13 "	8870.5	0	20082.0	-

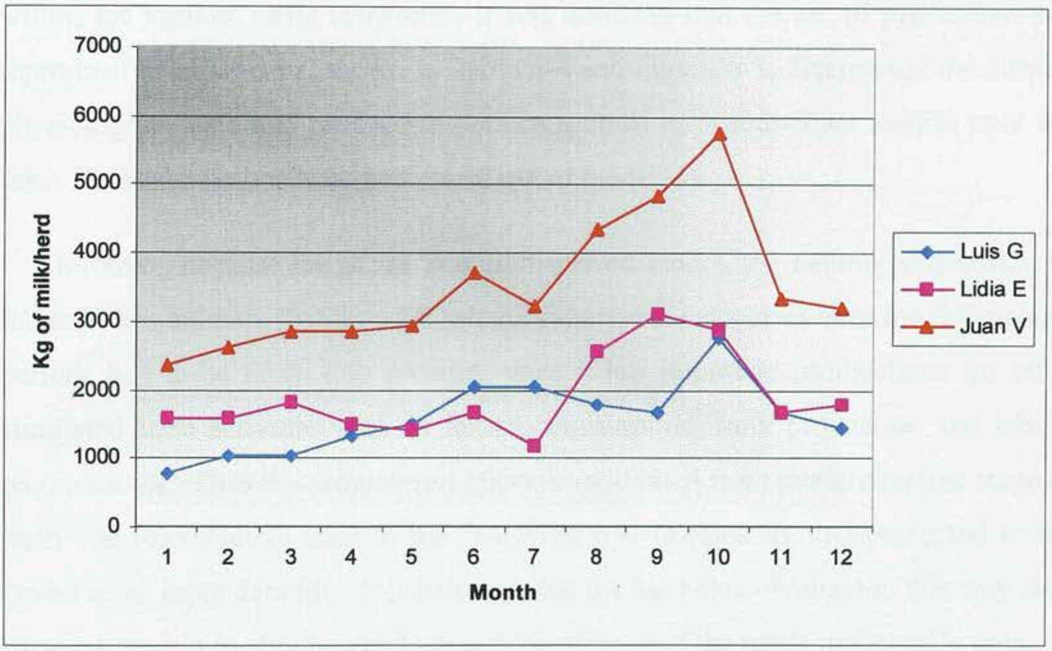
The input cost of the steers for Lidia Estrada is MX$ 1500 since they are not fatten in the farm MLK=monthly milk production/herd,** ***NCULL=number of culled cows/year, ***NSTEE***=number of fat steers sold, ***STOV=stover opening balance***

Higher milk yields in the wet season are partially explained by the allocation of better quality diets than the dry season diets to lactating cows. For example lactating cows in the wet season are fed mainly with forages W3, W2 and W4 which are the best quality fodder as described in Chapter 6 page 134. Moreover, all lactating cows were supplemented with concentrate CONC-6 which is the concentrate that produced the highest response in milk yield (see Chapter 6, section 6.4.). Maximum simulated milk yield for cows in the dry season was 17 kg/cow/d when fed forage D4 and concentrate 6, while 20.2 kg/cow/d were obtained when cows were fed forage W3 of the wet season and concentrate CONC-6. Because the IFSM selected the last feeding strategy to fed all lactating cows during the wet season higher milk yields were obtained during this season than in the dry season.

The second aspect which explained higher milk yields is the number of lactating cows in the herds during the wet and the dry season. For example, the number of lactating cow for Mr Gonzalez's herd during the dry season ranged from 2 to 4 whilst the number of lactating cows for the wet season ranged 4-6 (see Table 7-2 and Table 8-5). Larger number of lactating cows during the rainy season meant more milk produced especially in October where there are six cows, which is the highest number of cows observed in the year for Mr González's herd (see Table 7-2), the peak in milk yield observed in Figure 8-2 illustrates this.

However, the number of lactating cows depends on the management practices of individual farmers and the composition of their herds. For example, in the case of Mrs Lidia Estrada there is a drop in the monthly milk yield in July, a wet season month (Figure 8-2), this drop is explained by the reduced number of milking cows in this month, only three cows are lactating and three more are dry. Appendix 5.2 shows that the number of lactating cows passed from four in June to three in July. On the other hand, Figure 8-2 and Table 8-4, indicate that Mrs Lidia Estrada's herd achieved higher yields than the herd of Mr González. These results can be explained because the proportion of third calver cows (higher producers) is higher in the former case than in Mr González herd (see Appendix 5). These findings clearly indicate that the model is not only able to predict milk yield response for the different case studies, but also to consider the individual animals' characteristics, like age and milk yield potential of the different animals on the milk yield predictions.

Figure 8-2. Predicted milk yield per herd (in kg/month)



The same principles applies for Mr Valdez' herd, higher milk yield predicted by the model are due better quality diets and a higher number of lactating cows (see Appendix 5.3.).

Table 8-4 shows the number of steers sold and the number of cows culled and sold for every case study. Notice that the selling price of steers for Mrs Estrada is lower than for the other two case studies because she sells them before they are one year old. It is important to mention that the model does not predict the number of cows and steer sold, because these are fixed depending on the case study. However, the model does consider the feeding and labour requirements of these animals until the moment they are sold, as will be demonstrated later.

As mentioned in Chapter 7 section 7.2.4.1. the model does not optimise calving in the herd, rather it works with the initial inventory of every case study herd and a set of productive and reproductive parameters obtained during the survey work were applied to them in order to reproduce the herd dynamics over the simulated year. Recall that the contribution of every animal to the farmers' livelihoods is so important that the disappearance of only one could have important implications to the whole system. For purposes of simulating the dynamics of every individual within the various cattle categories, it was assumed that the set of productive and reproductive parameters, shown in Table 6-4 and Figure 6-1, determined the current physiological state and productive performance of each individual animal over the time. This calculations were performed out of the IFSM.

Moreover, because the IFSM is a multi-period model, the natural progression of the different animals (within each category) between categories over the different ***m*** periods had to be taken into account, since it has important implications for other simulated farm activities such as forage consumption, milk production and labour requirements. Thus the progression of every individual from one productive stage or from one reproductive state to the following was mapped in, and presented to the model as an input data file. It is believed that the herd data obtained in this way is in close agreement to structure and normal functioning of the herds in the study area.

8.6. Simulating cattle feeding systems

The results obtained in this work for cattle feeding systems suggests that the IFSM was successful in emulating the systems used by farmers at the Toluca Valley. The model realistically described the seasonal variation in the composition and availability of the forages used to feed cattle. The influence of the agricultural practices and the maize growing cycle on the forage types availability was successfully emulated too, as will be described in this section. Because stover is the main forage fed throughout the year, its utilisation dynamics are described first followed by forage utilisation strategies predicted for the dry and wet seasons.

Stover is used all year round but a seasonal variation in its utilisation was observed too. The model was able to describe this variation. For example, maize stover is the main forage fed in the dry season when few other forages are available, therefore large quantities of it are required for over a period of 7 months. The opposite is observed during the wet season, when a greater variety of forages are available and the need for stover is substantially reduced (Chapter 5).

Results shown in Figure 8-3 indicate that the model was able to emulate this pattern. The amount of stover which is fed to the herd during the wet season months (*STOFEDm=6:10*) is lower than what is fed during the dry season months (STOFED*m=1:5* and *m=11:12*), in all the simulated cases.

Figure 8-3. Model predictions for stover fed monthly to cattle (in kg of DM)

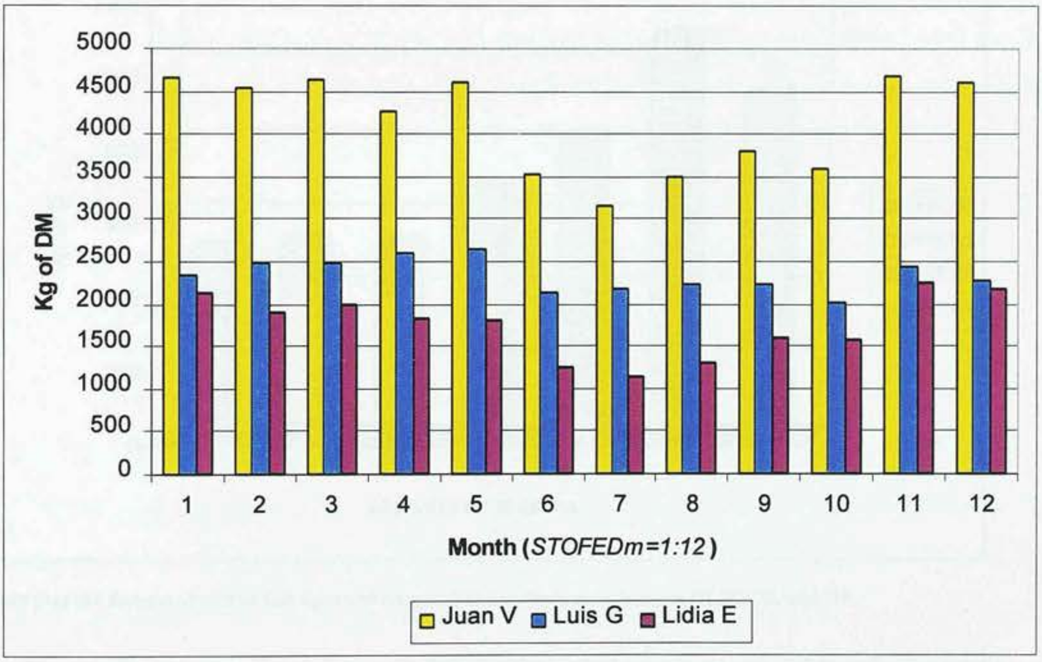
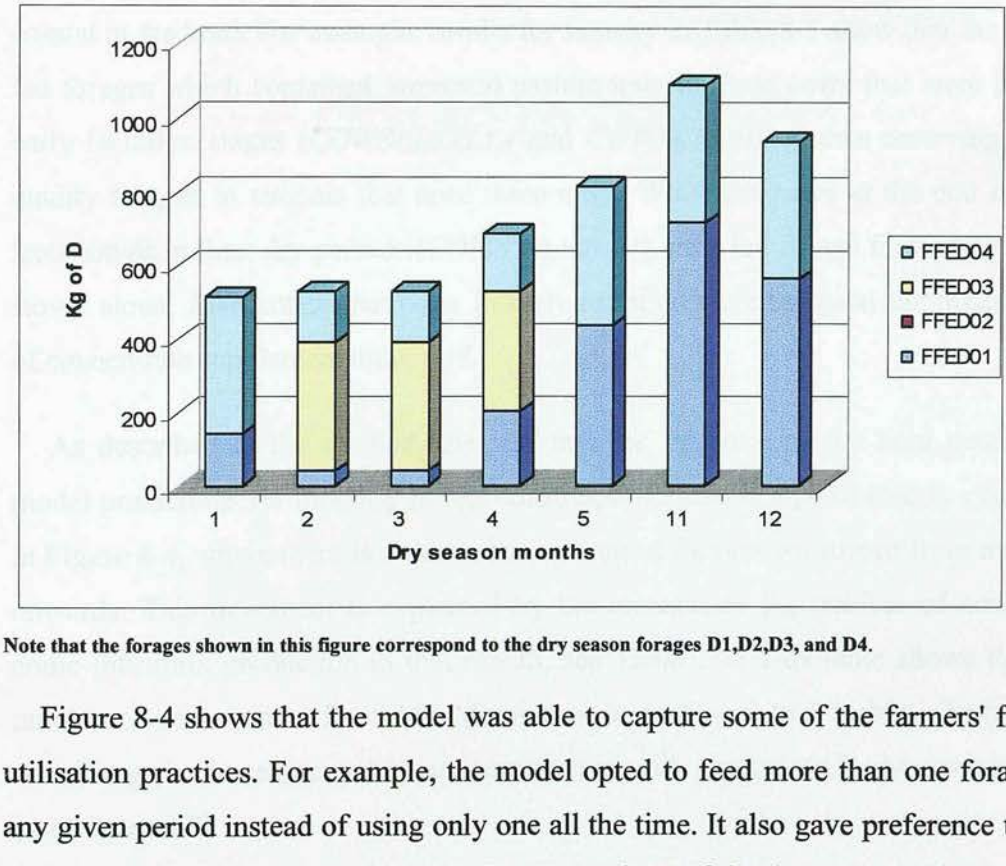


Figure 8-3 clearly indicates that the same pattern of stover utilisation was predicted for the three case studies. What is more important is that the reduction in the consumption of stover during the wet season is compensated by the utilisation of better quality forages produced during this season as show later in this section. Stover consumption data presented in Figure 8-3 represent the amount of stover consumed by all the animals in the herd and no distinction is made for category or class of cattle. Notice the difference in consumption among the different case study herds. Mr Valdez's herd has the higher consumption followed by Mr González's and Mrs Estrada's herds.

8.6.1. Dry season feeding systems

The IFSM can select the optimal feeding strategies for all classes of cattle represented in the herd, however due to size of the output, model predictions for cows are only presented here. Appendix 5 contains the predictions for heifers and other cattle. Figure 8-4 shows model predictions for the type and amount of forage fed to Mr Luis González's herd during the dry season.

Figure 8-4. Forages fed in the dry season to cows in Mr Luis González's herd



Note that the forages shown in this figure correspond to the dry season forages D1,D2,D3, and D4.

Figure 8-4 shows that the model was able to capture some of the farmers' forage utilisation practices. For example, the model opted to feed more than one forage in any given period instead of using only one all the time. It also gave preference to the forages produced in the farm (forages D1, D3 and D4 of the dry season), above those that are purchased. It is probable that the model did not select forage D2 because it contains maize silage that has to be purchased, corroborating the previous assumption (see Table 6-2 for forage composition) . The quality of the forages and their effects on milk yield are important criteria considered by the model when selecting forages. Apart from maize stover (forage D1) the model also selected forages D3 and D4, which contain 20 and 30 percent of improved pasture respectively. Inclusion of improved pasture is a common practice in the study area and is why most farmers have at least a small plot of this pasture (Castelán *et al.*, 1997). Indeed there exists the knowledge among farmers that the inclusion of small amounts of improved pasture improves the overall nutritional quality of the basal forage. However the area planted with this forage is constrained by the small size of the holding and the lack of water for irrigation (Arriaga *et al.*, 1997a).

Results shown in Figure 8-4 and Table 8-5 suggests that the IFSM could be applied in the design of nutritional management strategies for every individual animal in the herd. For example, results for January in Table 8-5 show that the model fed forages which contained improved pasture only to those cows that were in their early lactation stages ($COWS_{4,1,2,01,1,4}$ and $COWS_{4,1,3,01,1,4}$) thus reserving better quality forages to animals that need them most. While the cows at the end of their lactation or in their dry periods ($COWS_{1,5,1,01,4,1}$) were fed forage formed by maize stover alone. Also notice that cows in early lactation were assigned the highest rate of concentrate supplementation, $r=4$.

As described in the method, the size and the structure of the herd determines model predictions for monthly forage consumption. This is a point clearly explained in Figure 8-4, where there is a rise in the amount of forages consumed from month 4 onwards. This increment is explained by the increase in the number of cows that come into milk production in that month, see Table 7-2. This table shows that the number of cows passes from 3 in March to 4 in April and to 5 in May. Notice that this change is also expressed by an increment in milk production in the same months (see Figure 8-2).

Moreover, the highest forage consumption is observed in month 11, which coincides with the higher number of cows in the herd during the simulated year, seven in total (Table 7-2). In contrast milk production declined in the same month (Figure 8-2), this is explained by the fact that two cows are at the end of their lactation and one is in its dry period (see Tables 7-2 and 8-5). Figure 8-4, also shows that the consumption of forage D1 increased in this month. The model followed the same principle as farmers, it allocated lower quality forage to the cows that are producing less milk and used the higher quality one for cows that are at the start of their lactation (Table 8-5).

This explains the increment in consumption of forage one, observed in month 11. Similar predictions were obtained for the other two case studies, since the same principles apply to them. Figure 8-5 shows that the amount and the types of forages consumed by Mr Valdez's herd during the dry season are consistent to the pattern observed for Mr González's herd. Because the area planted with improved pasture is larger in this case study, the model feeds bigger amounts of forages D3 and D4 over longer periods of time.

Figure 8-5. Forages fed in the dry season to cows in Mr Juan Valdez's herd

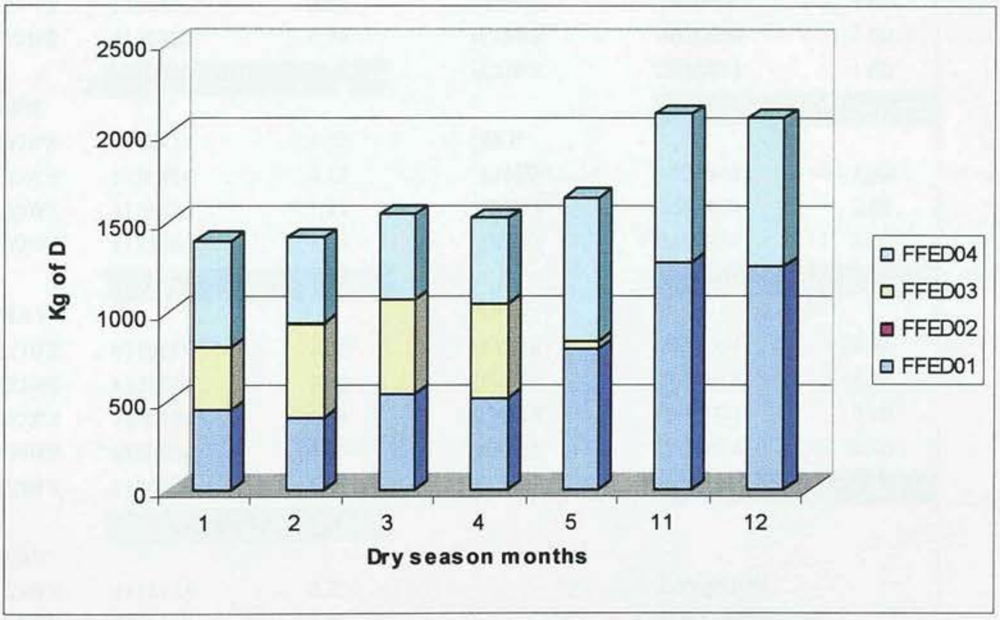


Table 8-5. Predicted feeding strategies for cows in the dry and wet seasons for Mr Luis González herd

DRY SEASON			WET SEASON		
Variable	**Strategy**	**Value**	**Variable**	**Strategy**	**Value**
JAN	*j,l,i,m,q,r**		**JUN**	*j,l,i,m,q,r**	
COWS	1510141	0.99	*COWS*	4610614	2.00
COWS	4510141	0.01	*COWS*	4620624	2.00
COWS	4120114	1.00	*COWS*	4630634	1.00
COWS	4130114	1.00		Cows/month	5.00
	Cows/month	3.00	**JUL**		
FEB			*COWS*	4610714	2.00
COWS	3120214	2.00	*COWS*	4620724	2.00
COWS	1130224	0.24	*COWS*	4630734	1.00
COWS	4130224	0.76		Cows/month	5.00
	Cows/month	3.00	**AUG**		
MAR			*COWS*	4530841	1.00
COWS	3120314	2.00	*COWS*	3610814	1.00
COWS	1130324	0.24	*COWS*	3610824	1.00
COWS	4130324	0.76	*COWS*	3620824	1.00
	Cows/month	3.00	*COWS*	3620834	1.00
APR				Cows/month	5.00
COWS	4110414	1.00	**SEP**		
COWS	1120414	0.17	*COWS*	4530941	1.00
COWS	3120414	1.83	*COWS*	3610924	2.00
COWS	1130424	1.00	*COWS*	3620934	2.00
	Cows/month	4.00		Cows/month	5.00
MAY			**OCT**		
COWS	4110514	2.00	*COWS*	2631014	1.00
COWS	1120514	1.00	*COWS*	3611014	1.00
COWS	1120524	0.64	*COWS*	2611024	2.00
COWS	4120524	0.36	*COWS*	3621034	2.00
COWS	1130534	1.00		Cows/month	6.00
	Cows/month	5.00			
NOV			**Key**		
COWS	1111114	0.87	**j*	Forage type	
COWS	4111114	1.13	*l*	Concentrate type	
COWS	1111124	1.00	*i*	Cow category	
COWS	1111134	1.00	*m*	Month	
COWS	1121134	1.00	*q*	Subcategory	
COWS	1521141	1.00	*r*	Concentrate level	
COWS	4131114	1.00			
	Cows/month	7.00			
DEC					
COWS	1521241	1.00			
COWS	1111214	0.87			
COWS	4111214	1.13			
COWS	4131214	1.00			
COWS	1111234	2.00	**Note that the number of cows in each month is**		
	Cows/month	6.00	**The same as in Table 7-2.**		

8.6.2. Wet season feeding systems

Figure 8-6 and Table 8-5 display the type and amount of forages fed to Mr González's cows during the wet season. Predictions in Figure 8-6 clearly indicate that the model was also able to capture the farmers feeding practices observed during the wet season. Moreover it was able to simulate the seasonal variation observed in both forage quality and availability associated with the land use and the maize growing cycle.

Recall that for all farmers, the model cultivated some maize with no herbicide application, the resulting effect of this maize management practice in terms of forage supply are evidenced here. In other words, because no herbicide was applied to some of the maize crop fields, weeds, and green maize fodder are available and were used to feed cattle during this season.

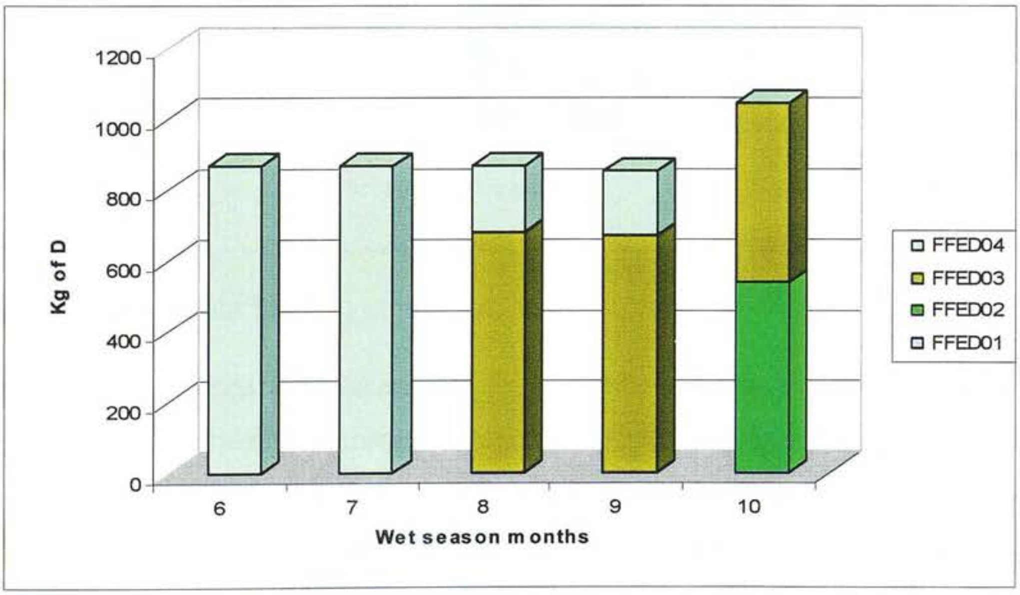
This is clearly illustrated in Figure 8-6, where the model fed the cows forage W4 of the wet season (20% maize stover, 60% improved pasture and 20% weeds), in months 6 and 7 when all the forage's components become available. Notice that the model could had fed forage 1 (which is also available in these months) instead of forage W4. However, it suggested that it selected forage W4 because it is better quality forage and promotes higher milk yields, as demonstrated in Chapter 6. Figure 8-6, shows that the model switched to forage W3 (and kept forage W4) in months 8 and 9 and to forages 2 and 3 in month 10.

Recall that forages W2 and W3 contain 30% and 40% of green maize fodder respectively (Table 6-2), and as discussed in Chapters 5 and 6, this is the best quality forage. In fact, forage W3 produced the highest milk yields simulated by the cow model. Notice that the model only fed forage W2 and W3 from month 8 onwards, this is explained because green maize fodder is only available from this month (see Figure 4-5 and Figure 5-4).

The results above described clearly suggest that the model is able to select forages which maximise milk yield. Because the quality of the forages is determined by the season and by the agricultural practices these are not available all the time. However, the model was able to select the best forage available in any given month and then switched to better quality forage when it became available. Moreover, it is able to allocate the best forages to the cows, which are producing more milk; this pattern can be better appreciated in model prediction shown in Table 8-5 for July and August. The model switched from forage 4 to forage 3 in all the cows that were producing milk in these months.

These results are entirely consistent with the farmer's practices observed in the field, both from the standpoint of the cattle nutritional management and from the maize management practices. Remember that maize thinning starts in August when farmers can identify barren plants or plants with small cobs, which are then removed from the crop fields. Farmers also fed the best quality forage to the cows which are producing milk, while cows that are at the end of their lactation or in their dry period are fed lower quality forages.

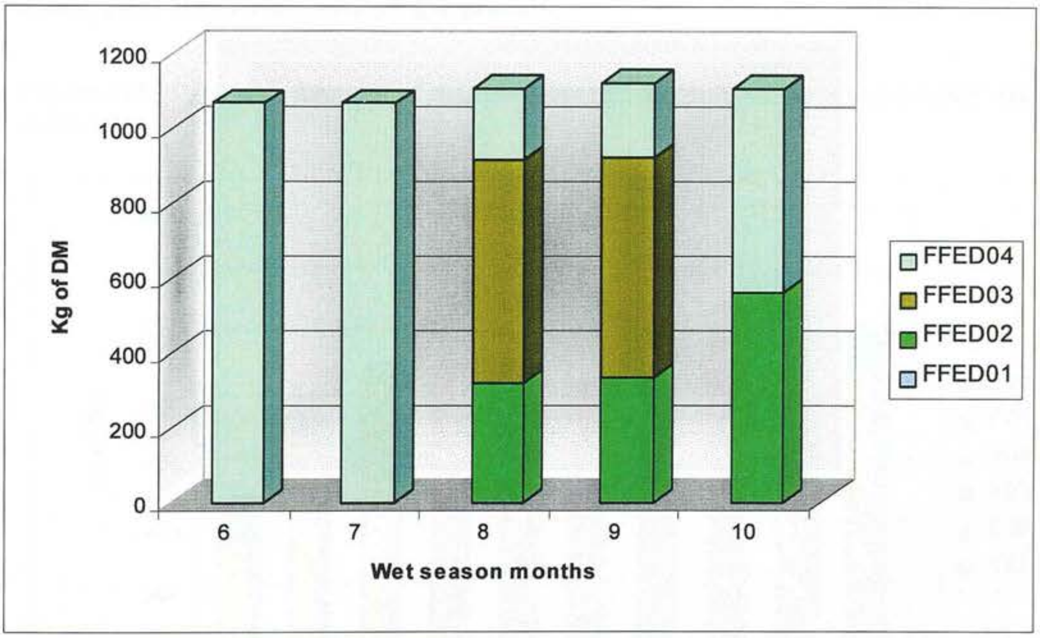
Figure 8-6. Forages fed in the wet season to cows in Mr Luis González's herd.



Notice that the forages in this figure corresponds to the wet season forages

Similar results were obtained for the other two case studies. For Mrs Estrada the model predicted that is also worthwhile for her to feed cows with forages W2 and W3, even though she only plants less than one ha of maize. The availability of green maize fodder for this farmer is lower than in the other two cases. The model compensated by feeding more forage W4, which has no any green maize fodder in it, and forage W2 that has a lower content of green maize fodder, in period 10 (Figure 8-7). Model predictions for Mrs Lidia Estrada are also consistent with the way this farmers feeds her cattle during the rainy season.

Figure 8- 7. Forages fed in the wet season to cows in Mrs Lidia Estrada's herd

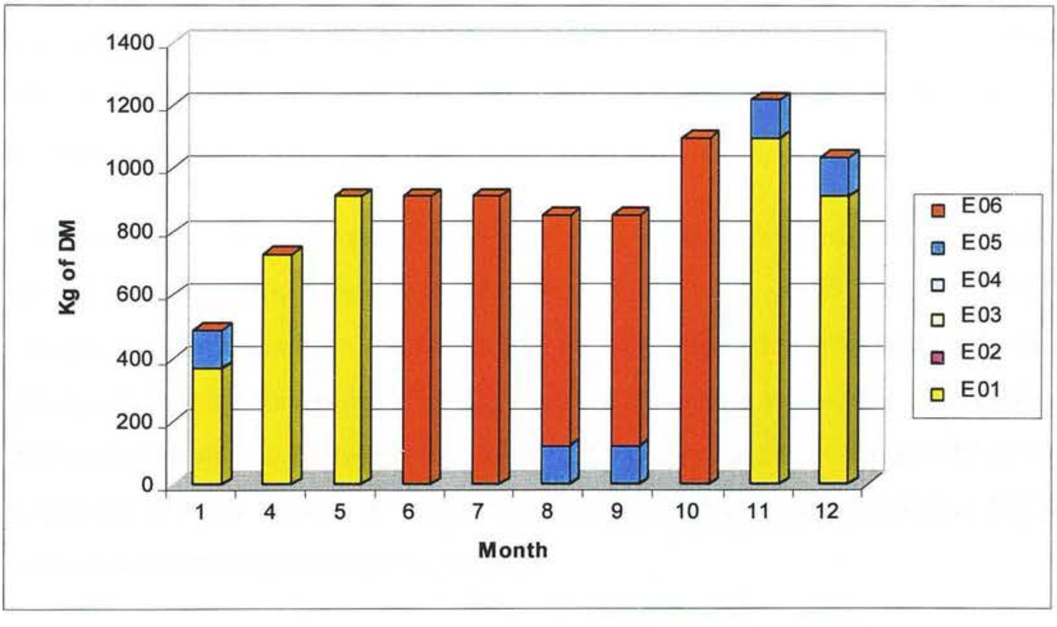


8.6.3. Concentrate feeding strategies

Model predictions for concentrates feeding followed the same principles as for forages. The best quality concentrates together with the higher supplementation rates were fed to the cows producing the higher milk yields (Table 8-5). This pattern was predicted for both the rainy and the wet seasons. Model predictions for the amount and type of concentrates fed by Mr Luis González are shown in Figure 8-8. This figure shows that during the dry season it may be more profitable to feed cows a concentrate made from ingredients produced in the farm (maize and chopped maize stover) and from low cost ingredients like chicken manure. During the wet season, it is more profitable to feed cows with a commercial concentrate since the extra milk yielded easily pays-off the cost of the commercial concentrate.

Recall that the same concentrates were used during the dry and wet seasons, and that concentrate Conc-6 (commercial concentrate) provided the higher predictions for milk yield, followed by Conc-1 (Chapter 6). From the model prediction for concentrate utilisation, it can be suggested that the IFSM provided a nutritional strategy that could be used in the improvement of the system in terms of increased milk yields. This solution is valid if the price of the commercial concentrate does not increase beyond Mx$ 2.7 pesos, while the profit will increase as the price of the concentrate gets closer to Mx$ 2.2 pesos.

Figure 8-8. Type and amount of concentrates fed to Mr González's cows (wet and dry seasons)



Model predictions for the dry season consumption of concentrates are in substantial agreement with those observed in the field for most farmers, not only the case studies. Moreover, these results suggest that it may be worth while for farmers to use a concentrate that has a higher content of maize, and some 30% of chicken manure, which may offer a better balance of nitrogen-energy (ERDP/FME ratio), such as concentrate Conc-1 (see Figure 6-5). These results are consistent with the nutritional quality of concentrates determined in Chapter 5 and simulated in Chapter 6. Farmers like Mrs Estrada, may need to reduce the amount of chicken manure in her concentrate, and increase the amount of energy in order to obtain a better response in terms of milk yield.

8.7. Conclusions and future research

From the results obtained in this work it can be concluded that the Integrated Farming systems model was able to emulate the main components of the Campesino Farming system of the northern part of the Toluca Valley. Model predictions for land use were consistent to the land use pattern observed in each one of the case studies used in this work, this may suggest that the IFSM model was able to both identify and capture the functioning of driving variables of the target farming system. Moreover, it is believed that the model was able to emulate the main relationships between these variables, particularly the complex interactions between the farmers, the crops and the livestock.

The strong seasonal variation observed in the farming system was also captured in the model. The seasonal effects on labour demand and forage availability and quality were properly reproduced in the model too. A robust system was developed to deal with the nutritional management of the cattle during the wet and the dry seasons. This system is able to reproduce the effects of minor changes in the quality of the forages fed to cattle in term of milk production and design feeding strategies for all the classes of cattle represented in the model.

On the other hand, it is believed that the model must be improved in order to reproduce other components of the system, such as other livestock like pigs, sheep and poultry that also play an important role it. It is acknowledged that the role of livestock in nutrient recycling observed has to be simulated too, if a proper picture of the systems is desired. As mentioned in Chapters 4 and 5, livestock plays a fundamental role in nutrient recycling in the system; therefore it is believed that this role must be emulated too. Although the model can be tested for different scenarios, such as different inputs and outputs prices and changes in the household and cattle herd size and compositions, more time is required to carry out this activity.

Finally, it is important to mention that the maize and cattle production technologies simulated by all the models used here were based on the expert knowledge of the farmers of the Toluca Valley. Few new technologies were tested, since it was recognised from the beginning that it is farmers who have developed and tested through years of experience the best possible ways of production within their environment and socio-economic conditions. It is also acknowledged the fact that despite the enormous size and complexity of the model, it only was able to emulate the functioning of the main components of the farming system.

Chapter 9. General conclusions and future areas of research

The main objective of this work was to develop a "Decision-Support System" based on the integration of three simulation models, with a detailed set of survey data on *campesino* maize-cattle production systems. Three main aspects were covered in this work. First a methodology to calibrate and develop simulation models using survey data was demonstrated. Second, a methodological approach used to integrate biological models to socio-economic models in order to develop a more holistic DSS was illustrated. Finally the DSS developed was used in identifying and testing different technologies and management strategies to maximise farmers' income. The results obtained suggest that calibration of biological models and construction of socio-economic models using input data collected from farmers and their cropping fields instead of using experimental data, is possible and may be crucial in developing systems models. Furthermore, it is suggested that the successful application of simulation models in development situations or in decision support to farmers must necessarily consider farmers' knowledge and experience. Data collection does not represent a problem so long as adequate survey techniques are used and a good level of continuous interaction with farmers can be achieved.

Farmers' participation in developing and validating of decision support systems should be standard practice because more useful system would be developed and predictions will be more relevant to the problems that the model is intended to tackle. Farmers are experts in their farming systems, so it is quite likely that they are already using the optimal solutions or technologies for some of their problems or systems' limitations. Emulating current systems first and then finding spaces for improvement could be a better approach instead of trying to develop new farming systems or to introduce big changes from the beginning. If the DSS is able to reproduce the main components and functioning of the target system, it should also be able to reproduce some of its failures and problems too. Thus it will be easier to find solutions to these problems through the simulation process.

Modellers should be able to identify the main components of the target farming system in order to simulate them. Thus decision support systems should capture and simulate these components and the interactions among them. Simulation of interactions between components is essential in mixed crop-livestock systems because cattle rely on crops for feeding and crops rely on cattle for organic fertilizer and capital needs (Chapter 3). Simulation models particularly biological models, need to be able to simulate interactions between farmers and their crops and livestock. Traditionally simulation models only reproduce very few production technologies, such as irrigation or fertilisation. However, as demonstrated in Chapter 4, there is continuous interaction between the farmers and crops, which resulted in a more efficient use of farm resources. Biological models of crops need to be flexible enough to simulate farmer's cultivation technologies such as weeding and thinning or some other traditional cultivation practices used by farmers in tropical countries. These models should consider that farmers normally obtain more than one product from cropping fields (*milpa* in Mexico) and that stover or other by-products are as important as grain production. Crop models such as the CERES-Maize model should give equal importance to both products when simulating organic matter partition.

As demonstrated in this work model integration provides a flexible approach to simulate the system as a whole and the system's main components. It would have been impossible to simulate the *campesino* system by using only one model, particularly a biological one. Biological models only reproduce at most one biological component (plant or animal) of the farming system (Chapters 4 and 6) but do not consider the socio-economic aspects of the system. Socio-economic models (mathematical programming) are more concerned with the economic aspects of the model and with the decision making process but often neglect the biological components, especially the response of these to different technological packages. Chapters 4 and 6 illustrate how maize and cattle responded to different technologies and levels of input use. Socio-economic models do not allow this flexibility, thus integration offered the opportunity to integrate both social-economic aspects to biological aspects of the farming system.

Model integration is clearly demonstrated in this work. It is suggested that a more holistic representation of the farming system was achieved through this method. The survey provided the data to parameterise the maize model and the cow model. These models were used to generated information on the crop and cattle productive responses to different management systems and different levels of inputs use. All the technologies were based on the expert knowledge of campesino farmers who know the "productive boundaries" of the system. Thus if the maize model predictions suggest that high yields can be achieved by increasing the planting density to more than 80 000 plants /ha, we can be sure that this is not feasible since farmers' experience suggests that the optimal production is reached at lower densities.

Most of the technologies tested in the biological model attempted to reproduce the cultivation and cattle husbandry practices of campesino farmers, thus when integrated into the Farm Model its was not surprising to observe that the model was able to simulate the system. The flexibility of the IFSM was demonstrated by simulating three case studies, which were different in the amount of resources such as land and cattle. The model was able to reproduce the land use and productive practices of the case studies. It is suggested that the model integration approach used here contributed to improve the current knowledge on the use of models and how these can be more efficient in supporting development and farmers' decision making.

The IFSM is flexible enough to permit simulating the main components of the farming system in an individual fashion and then evaluating their effects on the farming system as a whole. Thus a crop or livestock production technology which may appear as a good option when simulated individually (one model) may not perform similarly when reproduced for a farming system as a whole. For example supplementation to cows with commercial concentrate (Conc-6) during the dry season appeared to be an adequate option (Chapter 6), but when this technology was evaluated in relation to the rest of the system activities, it proved not to be adequate. Model integration also permitted to explain the scientific basis of some of the farmers' practices. This is the case of stover chopping and the use of green maize fodder to feed cattle. These are only a few examples of farmers' practices, which are not evident to researchers that are foreigners to the system and find difficult to understand why farmers do things the way they do.

There are still some problems which may limit the practical application of the DSS for development situations or for improvement of the farming systems. Of particular relevance for this work is the partial failure of the CERES-Maize model to simulate maize growth and development within the temperature range of the Toluca Valley and the incapacity to simulate stover yield of local maize cultivars. In both cases the DCMM did not produce satisfactory results. The Cow Model offered the possibility to test thousands of feeding strategies, and it is believed that a better understanding of the effects of protein-energy interactions, the response to concentrate supplementation and forage-concentrate substitution rates and their effects on milk yield, was achieved. However, it is suggested that the model needs to be extensively validated against field data particularly for feed intake from feeding systems with diverse forage and mainly low quality concentrate sources. The model also needs to be improved to incorporate protein requirements in the calculation of milk yield in order to provide better estimates of animal performance when the protein content of the diet varies widely or when it is limiting.

The IFSM needs to be improved in order to reproduce other components of the system, such as other livestock like pigs, sheep and poultry that also play an important role. The role of livestock in nutrient recycling has to be simulated too, which is very important not only for *campesino* farmers but for most smallholder or subsistence farmers in tropical countries. More optimisation objectives also have to be included in order to simulate different farmer's priorities, such as labour minimisation. Finally, it is suggested that the approach used in this work may offer to CICA researchers and other members of the SDSN a simple but robust method for the simulating the *campesino* farming systems of Central Mexico, since the IFSM is flexible enough to incorporate other farming activities.

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Appendices

Appendix 1. Calibrated output of the DSSATv3 CERES-Maize model for maize cultivars *Criollo Blanco* and *Criollo Amarillo*

1.1. Cultivar *Criollo Blanco*

```
*SIMULATION OVERVIEW FILE

*RUN   1        : WHITE MAIZE + 183 KG N
 MODEL          : GECER940 - MAIZE
 EXPERIMENT     : UMTA9602 MZ    NITROGEN VERSION CALIBRATED
 TREATMENT  1   : WHITE MAIZE + 183 KG N

 CROP           : MAIZE          CULTIVAR : VICENTWTA (CB)         -
 STARTING DATE  : JAN  1 1996
 PLANTING DATE  : APR 12 1996    PLANTS/m2 :   4.8     ROW SPACING :  80.cm
 WEATHER        : UMTL   1996
 SOIL           : CCQU000033     TEXTURE : CLLO  - Clay
 SOIL INITIAL C : DEPTH:196cm EXTR. H2O:221.9mm  NO3: 18.3kg/ha  NH4: 19.1kg/ha
 WATER BALANCE  : RAINFED
 IRRIGATION     : NOT IRRIGATED
 NITROGEN BAL.  : SOIL-N & N-UPTAKE SIMULATION; NO N-FIXATION
 N-FERTILIZER   :      183 kg/ha IN     2 APPLICATIONS
 RESIDUE/MANURE :        0 kg/ha IN     1 APPLICATIONS
 ENVIRONM. OPT. : DAYL= A     .0 SRAD= A     .0 TMAX= A     .0 TMIN= A    1.0
                  RAIN= A     .0 CO2 =       .0 DEW =       .0 WIND=       .0
 SIMULATION OPT : WATER   :Y  NITROGEN:Y  N-FIX:N  PESTS  :N  PHOTO  :C  ET :R
 MANAGEMENT OPT : PLANTING:R  IRRIG   :N  FERT :R  RESIDUE:R  HARVEST:A  WTH:M

*SUMMARY OF SOIL AND GENETIC INPUT PARAMETERS

    SOIL LOWER UPPER   SAT  EXTR  INIT   ROOT   BULK     pH    NO3    NH4    ORG
   DEPTH LIMIT LIMIT    SW    SW    SW   DIST   DENS                          C
    cm   cm3/cm3    cm3/cm3    cm3/cm3         g/cm3          ugN/g ugN/g     %
--------------------------------------------------------------------------------
   0-  5  .351  .470  .485  .119  .410   1.00    .90   6.40   3.80   1.00   1.50
   5- 15  .354  .473  .488  .119  .414    .88    .90   6.40   3.70   1.00   1.50
  15- 30  .377  .494  .509  .117  .436    .71    .90   6.40   3.04    .93    .70
  30- 45  .396  .511  .526  .115  .453    .41    .91   6.46   1.94    .53    .67
  45- 60  .415  .527  .542  .112  .471    .22   1.10   7.30   1.10   1.00    .20
  60- 90  .425  .535  .550  .109  .479    .14   1.10   7.63    .60   1.00    .12
  90-120  .435  .546  .561  .111  .491    .07   1.02   7.70    .42   1.00    .20
 120-150  .441  .553  .568  .112  .497    .00   1.00   7.70    .21   1.00    .16
 150-180  .424  .537  .552  .113  .480    .00   1.01   7.70    .19   1.00    .14
 180-196  .371  .488  .503  .117  .430    .00   1.10   7.70    .10   1.00    .08

 TOT-196  80.8 103.0 105.9  22.2  91.9  <--cm   -  kg/ha-->   18.3   19.1  62401
 SOIL ALBEDO    :  .09         EVAPORATION LIMIT : 6.75        MIN. FACTOR  : 1.00
 RUNOFF CURVE # :76.00         DRAINAGE RATE     :  .60        FERT. FACTOR : 1.00

 MAIZE      CULTIVAR :UM0002-VICENTWTA          ECOTYPE :      -
 P1     : 151.00 P2       :  .6000  P5      : 510.00
 G2     : 460.00 G3       : 13.000  PHINT   : 75.000
```

```
*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

 RUN NO.  1    WHITE MAIZE + 183 KG N

   DATE CROP GROWTH    BIOMASS  LAI  LEAF   ET  RAIN IRRIG SWATER CROP  N  STRESS
        AGE  STAGE     kg/ha         NUM.  mm   mm    mm      mm  kg/ha %  H2O   N
--------------------------------------------------------------------------------
  1 JAN    0 Start Sim       0   .00   .0    1     0     0   110     0  .0 .00 .00
 12 APR    0 Sowing          0   .00   .0   25    12     0    98     0  .0 .00 .00
 13 APR    1 Germinate       0   .00   .0   25    12     0    98     0  .0 .00 .00
 26 APR   14 Emergence      19   .00  1.7   31    22     0   102     1 4.4 .00 .00
 17 MAY   35 End Juveni     42   .09  6.2   40    37     0   107     2 3.9 .06 .02
 22 MAY   40 Floral Ini     80   .17  7.3   47    77     0   141     3 4.1 .00 .00
 20 JUL   99 75% Silkin   4114  1.95 17.6  246   424     0   208    92 2.2 .00 .02
 16 AUG  126 Beg Gr Fil   5903  1.80 17.6  354   497     0   172    65 1.1 .00 .02
 11 OCT  182 Maturity    11804   .80 17.6  537   700     0   192   139 1.2 .00 .00
  5 NOV  207 Harvest     11804   .80 17.6  552   724     0   202   139 1.2 .00 .00

*MAIN GROWTH AND DEVELOPMENT VARIABLES

@     VARIABLE                        PREDICTED     MEASURED
      --------                        ---------     --------
      FLOWERING DATE (dap)                   99          103
      PHYSIOL. MATURITY (dap)               182          175
      GRAIN YIELD (kg/ha)                  6108         6493
      WT. PER GRAIN (g)                   .3900         0.42
      GRAIN NUMBER (GRAIN/m2)              1566         1632
      GRAINS/EAR                         326.26          340
      MAXIMUM LAI (m2/m2)                  2.05          -99
      BIOMASS (kg/ha) AT ANTHESIS          4114          -99
      BIOMASS N (kg N/ha) AT ANTHESIS        92          -99
      BIOMASS (kg/ha) AT HARVEST MAT.     11804        14480
      STALK (kg/ha) AT HARVEST MAT.        5696       7987
      HARVEST INDEX (kg/kg)                .517       .45
      FINAL LEAF NUMBER                   17.62       18
      GRAIN N (kg N/ha)                     104       108.1
      BIOMASS N (kg N/ha)                   139       184.3
      STALK N (kg N/ha)                      35       76.2
      SEED N (%)                           1.70       1.66

*ENVIRONMENTAL AND STRESS FACTORS

------------------------------------ENVIRONMENT-----------------STRESS----------
 |--DEVELOPMENT PHASE--|-TIME-|-------WEATHER--------| |---WATER--| |-NITROGEN-|
                        DURA TEMP  TEMP  SOLAR PHOTOP PHOTO  LEAF  PHOTO  LEAF
                        TION  MAX   MIN    RAD  [day] SYNTH EXPAN. SYNTH  EXPAN.
                        days   oC    oC  MJ/m2    hr
--------------------------------------------------------------------------------
 Emergence-End Juvenile  21 22.95   6.57 23.01  12.79  .030  .065  .022  .055
 End Juvenil-Floral Init  5 24.40   7.20 19.90  12.96  .000  .000  .000  .001
 Floral Init-End Lf Grow 59 21.80   7.47 21.78  13.10  .000  .000  .022  .054
 End Lf Grth-Beg Grn Fil 27 20.96   7.07 20.93  12.83  .000  .000  .022  .054
 Grain Filling Phase     51 20.33   7.14 19.50  12.18  .000  .000  .000  .000

                                                       (0.0 = Minimum Stress
                                                        1.0 = Maximum Stress)

      MAIZE     YIELD  :    6108 kg/ha [   97.3 bu/acre ]
```

1.2. Cultivar *Criollo Amarillo*

```
*RUN   1        : YELLW MAIZE + 160 KG N
 MODEL          : GECER940 - MAIZE
 EXPERIMENT     : UMTA9602 MZ    NITROGEN VERSION CALIBRATED
 TREATMENT  6   : YELLW MAIZE + 160 KG N

 CROP           : MAIZE          CULTIVAR : JUANYLWIR (CA)       -
 STARTING DATE  : JAN  1 1996
 PLANTING DATE  : APR 12 1996    PLANTS/m2 :  4.6     ROW SPACING :  80.cm
 WEATHER        : UMTL   1996
 SOIL           : CCQU000033     TEXTURE : CLLO  - Clay
 SOIL INITIAL C : DEPTH:196cm EXTR. H2O:221.9mm  NO3: 18.3kg/ha  NH4: 19.1kg/ha
 WATER BALANCE  : RAINFED
 IRRIGATION     : NOT IRRIGATED
 NITROGEN BAL.  : SOIL-N & N-UPTAKE SIMULATION; NO N-FIXATION
 N-FERTILIZER   :      183 kg/ha IN     2 APPLICATIONS
 RESIDUE/MANURE :        0 kg/ha IN     1 APPLICATIONS
 ENVIRONM. OPT. : DAYL= A     .0  SRAD= A     .0  TMAX= A     .0  TMIN= A   1.0
                  RAIN= A     .0  CO2 =       .0  DEW =       .0  WIND=       .0
 SIMULATION OPT : WATER    :Y  NITROGEN:Y  N-FIX:N  PESTS  :N  PHOTO  :C  ET :R
 MANAGEMENT OPT : PLANTING:R  IRRIG   :N  FERT :R  RESIDUE:R  HARVEST:A  WTH:M

*SUMMARY OF SOIL AND GENETIC INPUT PARAMETERS

    SOIL LOWER UPPER   SAT  EXTR  INIT   ROOT   BULK     pH    NO3    NH4    ORG
   DEPTH LIMIT LIMIT    SW    SW    SW   DIST   DENS                          C
    cm   cm3/cm3    cm3/cm3   cm3/cm3          g/cm3         ugN/g  ugN/g    %
--------------------------------------------------------------------------------
    0-  5  .351  .470  .485  .119  .410   1.00    .90   6.40   3.80   1.00   1.50
    5- 15  .354  .473  .488  .119  .414    .88    .90   6.40   3.70   1.00   1.50
   15- 30  .377  .494  .509  .117  .436    .71    .90   6.40   3.04    .93    .75
   30- 45  .396  .511  .526  .115  .453    .41    .91   6.46   1.94    .53    .71
   45- 60  .415  .527  .542  .112  .471    .22   1.10   7.30   1.10   1.00    .20
   60- 90  .425  .535  .550  .109  .479    .14   1.10   7.63    .60   1.00    .12
   90-120  .435  .546  .561  .111  .491    .07   1.02   7.70    .42   1.00    .18
  120-150  .441  .553  .568  .112  .497    .00   1.00   7.70    .21   1.00    .11
  150-180  .424  .537  .552  .113  .480    .00   1.01   7.70    .19   1.00    .13
  180-196  .371  .488  .503  .117  .430    .00   1.10   7.70    .10   1.00    .08

 TOT-196  80.8 103.0 105.9  22.2  91.9  <--cm   -  kg/ha-->  18.3   19.1  61360
 SOIL ALBEDO     :  .09       EVAPORATION LIMIT : 6.75        MIN. FACTOR  : 1.00
 RUNOFF CURVE # :76.00        DRAINAGE RATE     :  .60        FERT. FACTOR : 1.00

 MAIZE       CULTIVAR :UM0003-JUANYLWIR          ECOTYPE :
 P1      : 151.00  P2      :  .5000  P5      : 488.00
 G2      : 490.00  G3      : 12.500  PHINT   : 75.000
```

```
*SIMULATED CROP AND SOIL STATUS AT MAIN DEVELOPMENT STAGES

 RUN NO.  1    YELLW MAIZE + 160 KG N

   DATE CROP GROWTH   BIOMASS  LAI  LEAF   ET  RAIN IRRIG SWATER CROP  N  STRESS
        AGE  STAGE     kg/ha         NUM.  mm   mm    mm    mm kg/ha %  H2O  N
--------------------------------------------------------------------------------
  1 JAN    0 Start Sim      0   .00   .0    1     0     0   110    0  .0 .00 .00
 12 APR    0 Sowing         0   .00   .0   25    12     0    98    0  .0 .00 .00
 13 APR    1 Germinate      0   .00   .0   25    12     0    98    0  .0 .00 .00
 26 APR   14 Emergence     18   .00  1.7   31    22     0   102    1 4.4 .00 .00
 17 MAY   35 End Juveni    40   .09  6.2   40    37     0   107    2 3.9 .06 .02
 22 MAY   40 Floral Ini    77   .16  7.3   46    77     0   141    3 4.1 .00 .00
 20 JUL   99 75% Silkin  3944  1.87 17.6  243   424     0   208   89 2.2 .00 .02
 16 AUG  126 Beg Gr Fil  5663  1.72 17.6  352   497     0   173   62 1.1 .00 .02
  6 OCT  177 Maturity   11097   .77 17.6  522   683     0   188  130 1.2 .00 .00
 31 OCT  202 Harvest    11097   .77 17.6  536   723     0   213  130 1.2 .00 .00

*MAIN GROWTH AND DEVELOPMENT VARIABLES

@     VARIABLE                        PREDICTED     MEASURED
      --------                        ---------     --------
      FLOWERING DATE (dap)                 99          100
      PHYSIOL. MATURITY (dap)             177          171
      GRAIN YIELD (kg/ha)                5604        5745
      WT. PER GRAIN (g)                 .3475        0.37
      GRAIN NUMBER (GRAIN/m2)            1613        1720
      GRAINS/EAR                       350.56        374
      MAXIMUM LAI (m2/m2)                1.96        -99
      BIOMASS (kg/ha) AT ANTHESIS        3944          -99
      BIOMASS N (kg N/ha) AT ANTHESIS      89          -99
      BIOMASS (kg/ha) AT HARVEST MAT.   11097        12546
      STALK (kg/ha) AT HARVEST MAT.      5494        6801
      HARVEST INDEX (kg/kg)              .505       .46
      FINAL LEAF NUMBER                 17.62        18
      GRAIN N (kg N/ha)                    95         90.7
      BIOMASS N (kg N/ha)                 130        141.0
      STALK N (kg N/ha)                    35        51.0
      SEED N (%)                         1.70        1.58

*ENVIRONMENTAL AND STRESS FACTORS

-----------------------------------ENVIRONMENT-----------------STRESS-----------
 |--DEVELOPMENT PHASE--|-TIME-|-------WEATHER--------| |---WATER--| |-NITROGEN-|
                         DURA TEMP  TEMP  SOLAR PHOTOP PHOTO  LEAF  PHOTO  LEAF
                         TION  MAX   MIN    RAD  [day] SYNTH EXPAN. SYNTH  EXPAN.
                         days   oC    oC   MJ/m2    hr
--------------------------------------------------------------------------------
 Emergence-End Juvenile   21  22.95   6.57 23.01  12.79  .030  .064  .022  .055
 End Juvenil-Floral Init   5  24.40   7.20 19.90  12.96  .000  .000  .000  .001
 Floral Init-End Lf Grow  59  21.80   7.47 21.78  13.10  .000  .000  .022  .054
 End Lf Grth-Beg Grn Fil  27  20.96   7.07 20.93  12.83  .000  .000  .022  .054
 Grain Filling Phase      47  20.45   7.15 19.99  12.21  .000  .000  .000  .000

                                                       (0.0 = Minimum Stress
                                                        1.0 = Maximum Stress)

      MAIZE     YIELD :    5604 kg/ha [    89.2 bu/acre ]
```

nd degradation rates for forages and concentrates

NTRATES FEEDS

concentrate	undegCPconcent	k9concentrate	k10concentrate	k14concentrate	Starch(%)*
0.563	0.086	0.139	0.070	0.030	0.432
0.669	0.042	0.207	0.103	0.030	0.867
0.398	0.088	0.115	0.057	0.030	0.225
0.680	0.038	0.209	0.105	0.030	0.855
0.393	0.084	0.118	0.059	0.030	0.210
0.57	0.1	0.15	-	-	0.7

FORAGES

CPforage	undegCPforage	k9forage	k10forage	k14forage
0.570	0.136	0.080	0.040	0.030
0.507	0.122	0.116	0.058	0.030
0.585	0.125	0.112	0.056	0.030
0.582	0.119	0.128	0.064	0.030
0.571	0.145	0.096	0.048	0.030
0.618	0.131	0.107	0.054	0.030
0.629	0.131	0.111	0.056	0.030
0.622	0.101	0.180	0.090	0.030

resentsthe percentage of starch of the soluble carbohydrate fraction "a"

gi *et al*., (1988); NRC, (1996); AFRC, (1993); Negi *et al*., (1988); Matthewman (1993); Unal *et*

Appendix 3. Summary of the output of the Cow Model

Dry Season simulated feeding strategies for forages D1
and concentrates Conc-1 to 6.

Figures in this table correspond to the Input data table ***tab1*** (see Table 7-7)

Milk yield is in kg/cow/day
Forage and concentrate intakes are in kg of DM/cow/day
Table dimension

j	*l*	*I*	*q*	*r*	*u1*	*u2*	*u3*
Forg-type	**Conc-type**	**Lact No**	**Lact-stage**	**Conc-level**	**Conc-Intake**	**forg-Intake**	**Milk yield**
1	1	1	1	1	0	7.37	3.12
1	1	1	1	2	2	6.59	3.42
1	1	1	1	3	4	5.78	5.48
1	1	1	1	4	6	4.97	9.74
1	1	1	2	1	0	7.03	0.72
1	1	1	2	2	2	6.32	1.1
1	1	1	2	3	4	5.51	3.11
1	1	1	2	4	6	4.71	7.27
1	1	1	3	1	0	6.86	0.32
1	1	1	3	2	2	6.14	0.66
1	1	1	3	3	4	5.35	2.69
1	1	1	3	4	6	4.51	6.85
1	1	1	4	3	4	5.35	0
1	1	1	4	3	4	5.35	0
1	1	1	4	3	4	5.35	0
1	1	1	4	3	4	5.35	0
1	1	2	1	1	0	8.15	6.02
1	1	2	1	2	2	7.46	6.29
1	1	2	1	3	4	6.58	8.04
1	1	2	1	4	6	5.66	11.76
1	1	2	2	1	0	7.66	2.64
1	1	2	2	2	2	6.87	2.91
1	1	2	2	3	4	6.06	4.75
1	1	2	2	4	6	5.21	8.68
1	1	2	3	1	0	7.17	1.31
1	1	2	3	2	2	6.44	1.57
1	1	2	3	3	4	5.68	3.59
1	1	2	3	4	6	4.85	7.67
1	1	2	4	3	4	5.68	0
1	1	2	4	3	4	5.68	0
1	1	2	4	3	4	5.68	0
1	1	2	4	3	4	5.68	0
1	1	3	1	1	0	8.98	8.9
1	1	3	1	2	2	8.02	8.42
1	1	3	1	3	4	7.29	10.27
1	1	3	1	4	6	6.24	13.31
1	1	3	2	1	0	8.35	4.94

1	1	3	2	2	2	7.56	5.02
1	1	3	2	3	4	6.76	6.78
1	1	3	2	4	6	5.83	10.2
1	1	3	3	1	0	7.84	3.27
1	1	3	3	2	2	7.08	3.48
1	1	3	3	3	4	6.28	5.34
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1	2	1	3	1	0	6.89	0.248
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