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Evaluation and Utilization of Forages in Dairy Cattle Rations in Northeastern Mexico

by

Ramon Armando Martinez Parra

A THESIS

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IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE
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Abstract

Forages produced in the Comarca Lagunera desert region of Mexico were examined with respect to current utilization patterns in commercial dairy rations and their nutritive value as measured by apparent digestibility, voluntary intake, and influence on milk production and mineral status in Holstein cows. Alfalfa greenchop was the most common forage utilized in the rations of nine farms surveyed; 100% of the farmers used the forage at a mean level of 68% of the forage in the diet. Corn silage and annual ryegrass were used by 53 and 50% of the farmers at a mean level of 16.5 and 10% of the forage, respectively. Sudangrass, forage oats and sorghum silage were also used to a limited extent. Milk production on dairy farms was higher ($P<0.05$) during the winter than in the summer (18.2 vs 17.5 kg/cow/day). Dry matter (DM) intake and milk production were significantly related ($r^2=0.90$). In trials conducted at the research station in which six cows were fed 4 kg concentrate along with different individual forages, cows fed alfalfa produced more ($P<0.05$) milk than those fed annual ryegrass, sudangrass, and corn and sorghum silages (21.8, 18.9, 15.1, 13.2 and 11.8 kg/cow/day, respectively). Cows fed forage oats produced 20.7 kg milk/day. Milk production was closely related to DM intake ($r^2=0.84$). Forage crude protein (%) was correlated with DM intake ($r^2=0.78$), and protein intake and milk production were highly related ($r^2=0.99$) when the protein content of forages was below 15%. Mean plasma

concentrations of copper, iron and zinc were 111, 255 and 161 ug/dL respectively, which indicated normal nutritional status of the cows for these elements. Although the mean plasma magnesium level (2.03 mg/dL) across all forages was within the normal range, mild hypomagnesaemia occurred in cows consuming alfalfa greenchop (mean 1.3 mg magnesium/dL; range 1.1–1.7 mg/dL). Least cost rations and least water rations (based on the amount of irrigation water required to produce 1 kg of forage DM) indicated that all–roughage diets based on sudangrass(least cost) or corn silage (minimization of water) for the summer, and annual ryegrass for the winter, were the best at a level of milk production of 10 kg/cow/day. Above 10 kg of milk least cost and least water rations were identical during the winter and were based on concentrate, corn silage, annual ryegrass and alfalfa hay. Summer diets for milk production levels over 10 kg/cow/day contained alfalfa greenchop rather than alfalfa hay; more corn silage and less alfalfa greenchop were used in least water rations than in the least cost rations. The close agreement between least cost and least water rations ocurred even though forage prices and economy of water use by plants were not closely related (r^2=0.06). High marginal values for DM intake in least cost and least water rations and the low DM intakes achieved in trials, especially with corn and sorghum silages, indicated that more emphasis on factors influencing the voluntary intake of forages is necessary in forage research programs.

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I. Introduction

More digestible energy and protein can be produced for ruminants per unit area of land from forages than from cereal crops (Hodgson 1979). This suggests that the amount of forage used in dairy cattle diets should be maximized if the philosophy is to produce the most milk per unit area of land rather than to maximize production per animal. Some countries of the world are, in fact, using mainly forage diets and avoiding concentrate feeding as much as possible with the goals of producing milk at low cost and directing the use of grain towards human consumption (McMeekan 1966). Currently the principal challenges associated with increasing the amount of roughages utilized in milk production include the need to increase efficiency of production of forages, the need to develop procedures for quickly determining the quality of forages and the need to determine how cows respond to forages of differing quality. A greater knowledge of regional forages is also imperative for some areas (Hodgson 1979).

The Comarca Lagunera area of northeastern Mexico is the country's most important milk production center. Climatic conditions are typical of a desert area and the majority of the forage production is dependent upon irrigation from underground water reservoirs. Water is a yield limiting resource and the water table is currently decreasing at a rate of 1.75 meters per year. The restriction imposed upon plant production by the need for water and a declining supply of water make it imperative that this resource be used efficiently in forage production. Most forages in the area have been evaluated in terms of potential dry matter (DM) production but it is necessary to evaluate them in terms of water usage; field observations have indicated that there is a difference in the amount of water required by each forage grown in the area. It is known that water use efficiency is influenced by type of plant and management practices as well as by environmental and soil factors (Clanton 1973; Sammis 1981).

Information on forage quality is scarce in Northeastern Mexico; in particular, values for the trace element composition of forages do not exist. Since it is known that forage quality is greatly influenced by environmental factors (Raymond 1969; Londsdale and Tayler 1971; Reed 1978; Marsh 1975; Underwood 1981; Van Soest 1982), it is of extreme importance that information on the nutritive value of forages grown in the Comarca Lagunera region be obtained so that potential changes in the forage production and utilization ystems can be completely evaluated.

The objectives of this study can thus be stated as follows: 1) to identify and quantify the types and amounts of forages currently being used in diets for dairy cows in the Comarca Lagunera region of Mexico, 2) to obtain a nutritional evaluation of the most important forages in the area, and 3) to evaluate and propose alternate systems of forage production and utilization for the region.

II. Literature Review

A. Forages in Diets for Dairy Cattle

Role of Forages in Diets

Forages are a primary constituent of most dairy cattle rations and often make up to 60 to 70 percent of the total DM intake for dairy cattle in North America (Foley et al. 1972; Miller 1979). Dairy cattle must consume adequate amounts of fiber, usually supplied by forages, to ensure rumen function and to maintain milk fat percentages (Miller 1979; Waldo and Jorgensen 1981). Also the cost per unit of nutrient from forages is usually lower than the cost per unit of nutrient from concentrate feeds (Schmidt and Van Vleck 1974; Etgen and Reaves (1978) which is a major reason for their importance in dairy cattle rations.

It has been reported that more digestible energy and protein can generally be produced per hectare from forages than from cereals (Hodgson 1979). This is also true in the Comarca Lagunera region of Mexico where yields of grain are 4 to 5 tonnes of DM/ha in comparison with 12 to 18 tonnes DM/ha for some of the regional forages (SARH 1980). These production levels suggest that the amount of forage used in dairy cattle rations should be maximized even to the extent of obtaining less milk yield per cow. Indeed, under certain conditions it may not be profitable to feed any grain to lactating cows (Henderson 1938; Foley et al. 1972; Schmidt and Van Vleck 1974), even though under most circumstances the ration that results in near-maximum energy intake and near-maximum milk production will be the most economical (Ward and Kelley 1969; Coppock et al. 1981).

Scott (1981) claims that four different systems of feeding and management of dairy cattle are seen in major milk producing countries. These are 1) feeding purchased roughages and concentrate to zero grazed, penned cows (Southern California); 2) home growing of roughages and most concentrates for zero grazed animals (Wisconsin); 3) feeding concentrates with conserved forage and other roughages in winter and a reduced amount of concentrate to grazed cattle in spring and summer (England); and 4) feeding cattle on pasture and conserved forage throughout the year (New Zealand). The average amount of fat corrected milk(FCM) produced per cow in these systems was 7140, 5300, 4670 and 3475 kg respectively, but milk output per hectare was estimated to be 4700 to 10,000, 4400 to 5300, 5200 to 5800 and 7000 kg of FCM, for the four systems respectively. In terms of energy output/input the high roughage New Zealand system was estimated to be three to four times as efficient as any others, and the milk production cost was only about 40% of that in the United States and England.

Milk Production With All-Roughage Diets

There is a limit to the amount of forage that cows will voluntarily consume. The maximum daily intake of forages by lactating dairy cows ranges between 1.5 and 3.5 kg of DM per 100 kg of body weight; the better the forage quality the more a cow will consume (Foley et al. 1972). Several researchers have reported silage DM intakes in the range of 1.3 to 2.3 kg of DM per 100 kg of body weight (Huber and Thomas 1971; Baxter et al. 1980; Grieve et al. 1980a). Foley et al. (1972) and Flynn (1981) claim that maximum silage intake is only about 2.2 kg DM per 100 kg of body weight which is less than that achieved with hay diets. When corn silage is the only source of forage the addition of hay has improved total DM intake (Thomas et al. 1970; Grieve et al. 1980a).

The limit to voluntary intake of cows imposes a limit on their nutrient intake when they are fed all-roughage diets. Potential milk production on such diets is thus usually restricted to a maximum of 14 to 20 kg/cow/day (Putnam and Loosli 1959; Ronning and Laben 1966). If lactating dairy cows are fed some grain in addition to roughage, nutrient intake and potential milk production can be increased (Journet and Remond 1976).

Roughage Concentrate Ratios

Numerous experiments have been conducted in which the response of lactating cows to supplemental concentrate has been examined. No statistical differences in milk production were observed in cows consuming diets of roughage to concentrate ratios of 80:20, 60:40 and 40:60 when these diets were fed ad libitum and included mixed hay or legume—grass and corn silage in a 1:3 proportion (Putman and Loosli 1959). The actual milk productions obtained were 22.9, 24.5 and 25.5 kg/day for the three diets, respectively, suggesting that statistical inadequacies may have prevented differences from being detected. Dry matter intake increased as the proportion of concentrate in the diet increased. Similar trends were observed for the digestibility of DM, crude protein and ether extract but the digestibility of crude fiber decreased as concentrate increased.

Conrad et al. (1966) using a forage consisting of coarsely chopped, high DM legume—grass silage, found that digestible DM intake decreased as the percent grain in the ration increased above 50% and that cellulose digestiblity decreased as the percentage of grain in the ration was increased from 34 to 72%.

A 60:40 ratio of forage to concentrate resulted in the best performance in an experiment in which tested forage to concentrate ratios were 90:10, 60:40, 30:70 and 0:100 (Ronning and Laben 1966). The actual milk productions obtained from first lactation cows were 14.3, 18.4, 16.1 and 17.6 kg/cow/day, respectively, with corresponding DM intakes of 19.6, 18.8, 17.1 and 14.6 kg/cow/day. It was suggested that the high concentrate rations caused an overconditioning of the cows, probably because the energy intake exceeded milk production potential.

Nelson et al. (1968) working with pelleted Coastal Bermuda grass and using Holstein cows and roughages to concentrate ratios of 100:0; 75:25; 50:50, 25:75; 0:100 found a small significant increase in DM intake as the concentrate content of the diet was increased. Milk productions of the cows for the different diets were 12.32, 15.86, 18.49, 19.74 and 19.08 kg/cow/day respectively, with statistical differences only occurring between the two highest and three lowest roughage diets.

Murdock and Hodgson (1969) fed alfalfa hay with two levels of concentrate to lactating cows; milk production was slightly, but not statistically higher for the high level of concentrate (17.2 and 16.2 kg fat corrected milk (FCM)/day).

Based on results such as these, several authors have concluded that a ratio of roughage to concentrate of 60:40 results in the best performance of animals as measured by milk production, and that increased levels of concentrate also cause a drop in milk fat percentage (Ronning and Laben 1966; Nelson et al. 1968; Ward and Kelley 1969; Tyrrel 1980). Of course the extent of the response which will be obtained with grain supplementation depends upon the level of milk production and the age of the cows (Journet and Remond 1976) as well as upon the quality of the forage.

Corn Silage Rations

In the Comarca Lagunera region of Mexico there is concern with dairymen that some alfalfa is essential in diets for dairy cows. Indeed, since corn silage is low in calcium, phosphorus, and protein it is convenient to feed this forage in combination with a legume crop, such as alfalfa, to increase the concentration of these nutrients (Hemken and Vandersall 1967; Sauer et al. 1980). Some problems encountered with corn silage as the only forage include a greater incidence of ketosis, displaced abomasum, parturient paresis, and lower DM intakes (Hemken and Vandersall 1967).

Several researchers, however, have found that feeding programs based upon corn silage as the sole roughage source are feasible (Thomas et al. 1970; Coppock et al. 1974; Belyea 1975; Grieve et al. 1976; Grieve et al. 1980a; Gordon 1980a,b). Advantages given for an all corn silage forage program included a high energy content, ease of mechanization in a feeding system and high yield per ha. However, for a corn silage forage system to gain widespread acceptance with dairymen it must prove suitable for raising young stock as well as for resulting in maximum milk productivity or longevity (Sauer et al. 1980; Steen and Gordon 1980). Several multilactation experiments have been conducted comparing corn silage as the only forage with hay or with combinations of corn silage and hay. In each case, milk production per cow was similar with corn silage diets to that obtained with legume-grass forage when fed either as hay or silage (Thomas 1970; Belyea et al. 1975).

In general, then, it has been concluded that corn silage is satisfactory as the sole source of roughage for performance of lactating cows. Moreover, corn silage can be fed satisfactorily to dairy cattle, including heifers, for prolonged periods as the sole forage without adversely affecting health and reproduction (Grieve et al. 1980b).

B. Effect of Environment on Forage Quality

Forage, at the time of harvest, is a product of the distribution of photosynthetically converted energy and absorbed nutrients and is thus influenced by the environment in which the plants were grown. Environmental temperature has a dominant effect on plant composition, while the effects of season and light are secondary. Other environmental parameters of importance include water supply and soil fertility. The combination of these environmental factors contributes to the unique nutritive qualities of forages from different geographical locations and between first cuttings in spring and aftermath cuttings (McCloud and Bula 1974; Van Soest et al. 1978; Van Soest 1982).

Temperature

Higher environmental temperatures decrease water soluble carbohydrate content and increase fiber content of plants causing decreased digestibility of forages (Deinum et al. 1968). A decrease from 84.6 to 74.2% of DM digestibility of forage in late spring (18°C,mean) in comparison with early spring (13.7°C,mean) was reported by Deinum et al. (1968). This difference was caused by both increased temperatures and stem formation. With no stem formation the vegetative grass in summer (21.9°C,mean) would drop from 84.6 to 78.4% DM digestibility due to the higher temperature. Minson and McLeod (1970) reported a significant correlation between DM digestibility and the mean daily temperature for the month prior to cutting (r=-0.97) and also with total evaporation (r=-0.91). This high correlation appears to indicate that high temperatures are associated with low digestibility in tropical grasses.

Alfalfa leaves show little change in digestibility with changes in environmental temperature in tropical climate but lignification of stems and their consequent lower digestibility occurs in a hotter environment (Van Soest 1982). This results in a widening of the range in quality between the more and the less digestible parts of the alfalfa plant.

Season

Spring cut perennial ryegrass has been reported as having more digestible organic matter than autumn cut ryegrass (Reed 1978; Ribeiro et al. 1979). Beever et al. (1978) also reported a 6% higher organic matter digestibility in spring than in autumn cut ryegrass. Hidiriglou et al. (1966) suggested that seasonal variation can occur in forage quality. The digestibility of alfalfa DM was 70.3% in October and 62.8% in June, however the spring alfalfa was harvested at a later stage of maturity. It is well known that digestibility decreases as stage of maturity increases (Van Soest 1982).

There appears to be no consistent variation or regular season variation in the content of nitrogen, phosphorus and potassium in forages whereas calcium tends to reach a peak value in late summer (Whitehead 1966; Karlen et al. 1980). Magnesium shows a seasonal variation with higher concentrations occurring late in the year. Copper and molybdenum concentrations in forage have a tendency to increase from early summer to autumn (Whitehead 1966; Karlen et al. 1980). There are differences in intake of forages harvested at different seasons of the year even though the digestibility of the forage is similar; higher intakes occur with spring growth (Londsdale and Tayler 1971; Marsh 1975; Reed 1978).

Light

Light intensity has been reported as having little effect on digestibility. Deinum et al. (1968) reported a drop from 78.6 to 76.4% DM digestibility due to low light intensity (cal/cm²/day). Raymond (1969) reported no significant effect of light intensity on DM digestibility.

Soil Fertility

Fertilization of the forage with nitrogen increases crude protein content but has a minor effect on digestibility according to Reid et al. (1959) who worked with tall fescue. Deinum (1968) and Raymond (1969) also reported little effect of nitrogen fertilization on digestibility of ryegrass and cocksfoot using widely differing levels of application.

Plant deficiences of calcium, magnesium and potassium can occur, and do so, most commonly on acid soils with low cation exchange capacities. Despite this, the content of magnesium and potassium in forages are often higher on acid than on calcareous soils, presumably due to less competition for uptake from calcium. Trace element deficiences and excesses are especially related to acid or calcareous soil type (Mortvedt et al. 1972; Aubert and Pinta 1977; Bruce 1978; Schute 1964). It has been reported that liming caused a decrease of copper, manganese, iron and zinc and an increase in the molybdenum content of plants (Sauchelli 1969; Nicholas and Egan 1975; Benson and Matrone 1976). In most soils the total content of all trace elements is sufficient for the production of any crop. In soils where available supplies are low, trace elements deficiencies will be accentuated when high yields of herbage are cut and removed (Whitehead 1966; Underwood [illegible]; Underwood 1981).

C. Evaluation of Forage Quality

When forages are utilized for feeding livestock both the amount of DM produced and the quality of the DM are important, particularly in diets for dairy cattle. There are several definitions of forage quality but according to Barnes and Marten (1979) quality may be defined as the type and amount of digestible nutrients available from the forage to the animal per unit time. Forage quality is thus a function of the rate and level of intake, the rate and extent of digestion and the efficiency of utilization of specific nutrients in or derived from the forage. Any or all of these functions may be inhibited by the presence of anti-quality substances in specific forages. Hence, forage quality is related to the potential of livestock to produce meat, milk and other products from forage through the utilization of its available nutrients. The factors of primary economic importance in conversion of forage to animal product are generally considered to be voluntary intake of gross energy, digestibility of energy, and efficiency of converting digested energy to animal products (Waldo and Jorgensen 1981).

Prediction of Digestibility

It is widely accepted that the in vitro procedure of estimating forage quality can provide the most accurate predictions of the digestibility of the forage DM (McQueen and Van Soest 1975; Morrison 1976; Birrel 1980; Burns and

Smith 1980). The in vitro laboratory techniques used for forage quality prediction do not apply equally to all the forages though, and the accuracy of the several variations in methods used is questionable since there is considerable variability within and between the techniques employed at different laboratories (Johnson 1966). Due to this variation, if each of the laboratories calculated relationships between their in vitro and in vivo data different regression lines would be obtained. Other authors have reported that the in vitro procedure per se is probably not a significant contributor to differences among observed in vivo and in vitro relationships; inherent differences in the characteristicas of subtropical grasses, temperate grasses and legumes are suggested as the primary cause (Minson and McLeod 1970; Lipke 1980). This suggests that for the most exact interpretation of in vitro data, in vitro vs. in vivo relationships should be available for each species of forage tested, or at least for each group of similar species, e.g. temperate grasses, temperate legumes, tropical grasses, tropical legumes (Johnson 1966; McLeod and Minson 1969; Minson and McLeod 1970). Consequently, because of this problem and the need to standardize other factors such as inoculum source, sample preparation, etc., caution must be used in the interpretation and use of unadjusted in vitro DM digestibility values. When corrected values are desired, enough forage samples of appropriate type and known digestibility must be included in each in vitro run to provide an adjustment factor. On the other hand, there is evidence that once a technique has been standardized and regression equations have been determined, the in vitro rumen fermentation technique may prove highly valuable in studying forage quality (Reid et al. 1959; Reid 1961; Reid et al. 1964; Gordon and Murdock 1978).

Most of the techniques for prediction of forage quality have been developed with hays and little information is available on the accuracy of various methods for estimating the nutritive value of corn silage (Sudweeks et al. 1979; Boila et al. 1980; Jones et al. 1980). It has been reported that the two stage in vitro technique is well correlated with corn silage in vivo DM digestibility but that the correlation obtained is lower than that for other forages (Alderman et al. 1971).

Although the in vitro rumen fermentation method is a good way of predicting the in vivo digestibility of several species and mixed forages it does have disadvantages. Morrison (1976) pointed out that the in vitro procedure takes a long time (6 days per determination) and it involves the necessity of having an available source of rumen inoculum. Other methods of digestibility estimation which are simple, quick, reliable and inexpensive must be seriously considered as there are more and more situations in which the in vitro method cannot be used (Hartley et al. 1974; Towerth et al. 1975; Morrison 1976; Goto and Minson 1977). Chemical, physical, in vivo, small animal bioassay and enzymatic methods are thus often used for forage quality evaluation. Recently infrared reflectance spectroscopy has been proposed as a rapid assay for chemical constituents in food and feed (Norris et al. 1976). Waldo and Jorgensen (1981) believes that the speed of this technique will cause its increasing application to analysis of dry forages. Van Soest (1982) states that the infrared reflectance spectrophotometry technique is not adapted to basic work on the composition of forages but it can be very useful in programs for evaluating large number of similar samples.

Prediction of Intake

A very important factor in forage utilization studies is DM intake (Barnes and Marten 1979). The prediction of intake must therefore be a goal of forage quality studies. Voluntary intake has been correlated with animal production and several authors are in agreement that the intake of digestible energy has the most influence on animal production; body weight gain appears to be solely a function of digestible energy intake (Swan and Broster 1976), and milk production is a function of energy intake (Blaxter and Wilson 1962; Blaxter 1964; Kleiber 1975; Fadel 1978; Lippke 1980) with diets containing adequate protein, minerals and vitamins.

There are several animal factors that can affect the voluntary consumption of feed. The effective size of the rumen and the amount of ingesta in the rumen at feeding time and at the end of the feeding period are important (Campling and Balch 1961; Buchman and Hemken 1964). Numerous other factors such as physiological status of the animal, sensory cues, osmolarity of the rumen contents and blood, disease and nutrient deficiencies, eating rate, gastrointestinal fill, rate of fermentation, and rate of passage can affect intake (Baile 1979; Van Soest 1982). The number of these factors makes it very difficult to accurately predict the intake of individual animals.

Plant factors reported to be associated with the voluntary intake of animals include stage of maturity, percent moisture in the forage, DM digestibility, physical form, nutrient balance and cell wall constituents. Increased maturity causes a decrease in forage intake, and this is inversely related to the moisture percent in the forage (Smith et al. 1958; Reid et al. 1959; Conrad et al. 1962; Ademosum et al. 1965). If the protein content of the forage is below 10% this may reduce voluntary intake (Raymond 1969; Swan and Broster 1976). Higher digestibilities in forages are associated with greater intakes (Minson 1963; Church and Pond 1974; Church 1979). In this regard, Conrad et al. (1964) reported that with low digestibility forages (52.1 to 66.7%) the factors regulating feed intake are body weight (reflecting roughage capacity), amount of undigested residue consumed per unit of body weight per day (reflecting rate of passsage) and DM digestibility. With high digestibility forages (66.7 to 80.0%) the intake appeared to be dependent on metabolic size, production level of the animal and DM digestibility. A similar relationship for silages is not defined clearly; for example when ryegrass silage was fed to Holstein cows they consumed less DM when the digestibility was higher (Tayler and Aston 1976). The authors suggested that differences in concentrations of fermentation acids between the silages could have obscured the potential effect of digestibility on voluntary intake.

Although in vivo and in vitro digestibility are both correlated with voluntary intake, hemicellulose and neutral detergent fiber are more consistently associated with intake (Van Soest et al. 1978). Rottweder et al. (1978) stated that neutral detergent fiber was the chemical method of choice for estimating voluntary intake; the correlations between neutral detergent fiber and intake ranged from - 0.32 to -0.94 in their experiments depending upon forage species and location.

There are external factors, not attributable to the animal or the forage, which can affect voluntary intake. Rainfall and temperatures above 20°C may cause decreases in voluntary intake (Duble et al. 1971; Reed 1978). On the other hand, in one report (Dragovich 1978) no difference was found between intake on days having varying heat intensities above the 27°C threshold, and neither prolonged periods of high temperatures nor the rapid onset of hot weather resulted in consistent declines in milk production. Acclimatization of the cows to high temperatures probably contributed to the lack of a significant decline in production in this experiment.

Other Quality Factors

Intensification of production or confinement of cattle often imposes restriction on movements, and animals become dependent upon forages produced on a single soil type, or a narrow range of soil types. Forages grown on such soils may be incapable, without appropriate treatments, of sustaining health, fertility and productivity of stock. This is particularly true for mineral elements where nutritional abnormalities may arise as simple deficiencies or excesses of single elements. More commonly abnormalities in mineral nutrition occur as deficiencies or excesses conditioned, to some extent, by other mineral elements, nutrients, or organic factors which are present in the environment and are capable of modifying the ability of the animal to utilize the deficient or toxic element. Therefore, it is recommended that mineral deficiency or toxicity studies include animal trials as well as forage measurements (Church and Pond 1974, Underwood 1977).

D. Water Use by Forages

Plant growth in semiarid regions is limited more by water than by any other factor (Fairbourn 1982). Water—plant relationships as they affect plant growth then, have been the subject of considerable study. Fairbourn (1982) claims that more research on water use by different forage species could improve the economics of forage production.

Factors that Influence Plant Response to Water

The soil, the plant, and the atmosphere form the complete system of water exchange. Usually more attention has been given to the individual elements of this system than to the system as a whole; it is the interaction of the three components of the system, not their absolute values, which influences the growth and behaviour of plants (Lemon et al. 1957).

Some of the main soil factors reported as having an effect on plant response to water are: texture, structure, hydraulic conductivity, organic matter content, salt concentration, temperature, aeration, moisture content, and capacity of the soil to store water (Stanhill and Vaadia 1967; Dolgov et al. 1979; Vaughn et al. 1980). The main environmental factors influencing plant response to water are: temperature, solar radiation, humidity, wind, vapor pressure, and length of growing season (Stanhill and Vaadia 1967; Vaughn et al. 1980; Fairbourn 1982; Yanuka et al.1982). An important factor, but one not normally considered in relation to the plant response to water, is the size of the irrigated area. In arid and semiarid zones there is usually a very significant contrast between the microclimate of irrigated fields and surrounding dry areas; plant response to water may well be quite different in small plot experiments than in large- scale field practice (Stanhill and Vaadia 1967). Among the plant factors influencing response to water are root system of the plant, type of foliage, nature of leaves, stage of growth, depth of root zone, and photosynthetic activity of the plant (Gates and Hangs 1967; Vaughn et al. 1980).

The amount of DM produced per unit of water used can be greatly increased if fertilizers are used to increase DM yield. Thus fertilization, if fertilizers are needed, can play a major role in increasing the efficiency of use of water by all forages (Viets 1962). Fertilizers may also increase root development within the soil so that water is used at higher soil water tensions and at greater depths (Viets 1962; Tisdale and Nelson 1966). Wilkinson and Londgale (1974) reported that in coastal bermudagrass, clipped at 4-week intervals, water-use efficiency was improved by 76% by increasing nitrogen fertilization from 200 to 600 kg/ha/year. Phosphorus fertilization in alfalfa increased DM yield and water-use efficiency by up to 100% at different levels of soil moisture (Stanberry et al. 1955). Recent evidence (Carter and Sheaffer 1983) seems to indicate that water-use efficiency of alfalfa could be improved by 34% through better irrigation scheduling methods, while maintaining forage DM yields.

Because the water-plant relationship is controlled by a number of soil, climatic, and plant factors the concept of evapotranspiration has been used to integrate these factors.

Evapotranspiration is defined as the sum of two terms: (1) transpiration, which is the water entering plant roots and which may be used to build plant tissue or which may pass through the leaves of the plant into the atmosphere, and (2) evaporation, which is the amount of water which will evaporate from the soil, water surfaces, and from the surfaces of leaves of the plant. Since evaporation integrates many weather factors, the influence of climate could be assumed to be represented in the evapotranspiration concept (Gates and Hangs 1967; Vaughn et al.1980). It is reported that during the growing season crop yield varies directly with evapotranspiration (Farnworth 1976; Feddes and Vanwijk 1976). Under field conditions evapotranspiration can be calculated by a water balance method which takes into account irrigation, rainfall, drainage, and change in the soil moisture (Bauder et al. 1978; Sammis 1981).

Using indexes of evapotranspiration several researchers have calculated values for the water use efficiency of plants, which is defined as the relation between DM yield and evapotranspiration, and which can be expressed as m^3 of water required to produce 1 kg of DM (Sammis 1981; Metochis and Orphanos 1981; Fairbourn 1982; Yanuka et al. 1982).

Water Use Efficiency of Alfalfa

At high environmental temperatures growth of alfalfa is limited and at the same time water use is higher; as a result water use efficiency is reduced (Metochis and

Orphanos 1981). Metochis and Orphanos (1981) conducted an experiment in the Eastern Mediterranean to determine how DM yield and water use efficiency were affected by discontinuing irrigation for one, two or three growth periods in July and August (a hot period). Alfalfa not irrigated for one or two growth periods produced similar DM yields to the control which was irrigated the whole year, however alfalfa not irrigated for three growth periods produced 20% less forage than the control. Water use efficiency was improved to 0.63 m^3/kg DM by withholding irrigation for three growth periods in comparison with 0.72 m^3/kg DM when irrigation was applied throughout the growing season.

Sammis (1981), working with irrigated alfalfa in southern New Mexico (USA) with a range of water levels and using a sprinkle line source to determine DM yield and evapotranspiration under deficient irrigation, reported that there was a linear response of alfalfa DM yield to evapotranspiration. The response was different for each cutting with the water use efficiency being better towards the end of the season than during the hot months. The actual values for water use efficiency reported for alfalfa ranged from 0.83 to 1.11 m^3 of water to produce 1 kg of alfalfa DM.

In Cyprus under hot and dry conditions (40 °C) alfalfa DM yield normally declines markedly in July through August. Water use efficiency under these conditions was 1.54 m^3/kg DM whereas it improved to 0.54 m^3/kg DM in March through May

(Metochis and Orphanos 1981).

Daigger et al. (1970) and Bauder et al. (1978) while studying the relationship between DM yield of alfalfa and evapotranspiration, reported almost identical water use efficiencies of 0.83 m^3 of water/kg DM.

Fairbourn (1982) reported that under greenhouse conditions the water use efficiency (as measured by evapotranspiration) for alfalfa was 0.87 m^3/kg DM, but under field conditions the water use efficiency was 1.75 m^3/kg DM. This 201% increase under field conditions was because of the greater air velocity, increased radiation, lower temperatures, and lower humidity than in the greenhouse.

Water Use Efficiency of Crops Other Than Alfalfa

Farnworth (1976) working under irrigated conditions in Saudi Arabia reported DM yields of 30.7 tonnes per hectare with a cropping pattern of barley and sorghum, when 564 cm of water was applied from January 1973 to February 1974. These values are equivalent to 1.83 m^3 water/kg DM. Under desert conditions in Israel water use efficiency for oats has been reported to be 0.37 m^3/kg DM when the plant was receiving water only from rainfall (Tadmor et al. 1966); under these conditions the water use efficiency of alfalfa was 0.66 m^3/kg DM.

Yanuka et al. (1982) applied water to corn by trickle irrigation; the maximum DM yield obtained was 32,440 kg DM /ha of forage corn, with a total evapotranspiration of 730 mm. This is equivalent to a water use eficiency of 0.23 m^3 /kg DM. This value is low in comparison with that obtained by other researchers (Sammis 1981; Metochis and Orphanos 1981; Fairbourn 1982) but water application by trickle irrigation may be more efficient than with other irrigation systems.

III. Utilization of Forages on Dairy Farms in the Comarca Lagunera Region of Northeastern Mexico

A. Introduction

The research described in this thesis was conducted in the Comarca Lagunera, which is an area of northeastern Mexico located at 26 ° N and 103 ° W, at an altitude of 1100 m. The area has a desert climate with a mean annual rainfall of 210 mm and evaporation rate of 2553 mm per year. The mean annual temperature is (20.5 °C); in the hottest month, July, the mean temperature is (29 °C) with daytime temperatures reaching (34° C), whereas the coldest monthly mean temperatures reached during the winter is (14.2 °C). The mean relative humidity is 45% and 54% for the hottest and coldest month respectively (Soto and Jauregui 1979).

The main forages which are grown in the region include alfalfa (Medicago sativa), corn silage (Zea mays), sorghum silage (Sorghum vulgaris), sudangrass (Sorghum sudanensis) forage oats (Avena sativa), and annual ryegrass (Lolium multiflorum). Annual ryegrass and forage oats grow during the fall and winter and corn silage, sorghum silage, and sudangrass grow during the spring and summer; alfalfa is the only crop that grows throughout the year. Quiroga et al. (1981) reported that the most common crop on local farms is alfalfa. The annual crop which is most prevalent during the summer is corn silage which is grown either as one or two crops in the spring-summer seasons. Sorghum is [illegible] common and normally is clipped for silage two times during the season. Sudangrass is not commonly used in the area.

The dairy industry in the area started to develop in 1966. Since then a seven fold increase has occurred in number of animals while the production area of forages has only doubled (Martinez et al. 1981). This small increase in forage area is probably due to the limitations of available underground water. Currently forage production is clearly insufficient to meet the needs of the dairy cattle in the area and most milk producers are dependent upon forage produced in regions up to 500 km distant in order to complete their needs. As a result forage utilization systems on dairy farms are unstable and dependent upon the quantity and quality of forage on offer.

Very little information exists on the form and efficiency of regional feeding systems for dairy cattle in the Comarca Lagunera. Two reports mentioned that the majority of the dairy farms in the area feed mainly greenchop forage along with some silage and hay (Martinez 1971; Martinez 1972). Another study reported that alfalfa is the main source of forage in this area, and that feeding cost comprised up to 80% of the total cost of milk production (Avila 1976). It was suggested that any reduction in cost through increased efficiency in forage utilization would result in significant savings for dairy farmers.

It is very difficult to evaluate systems of forage utilization in diets for lactating cows and to recommend and implement changes in such systems unless there is a clear understanding of the systems currently in use. The objective of the research reported in this section was thus to determine how dairy farmers are currently utilizing the forage available in the Comarca Lagunera region in diets for dairy cows.

B. Materials and Methods

Official records used to establish background information concerning the number of dairy farmers, size of the farms and number of cows were obtained from Secretaria de Agricultura y Recursos Hidraulicos (1978). Normally cows on small farms are fed a variety of diets because the farmers depend on purchased feed. For this reason, and since it would be impossible to obtain reliable data from all dairy farms in the area, a preliminary visit was made to 35 farms with different populations of cows with the objective of determining which farms would be suitable for further study. Many of these farms lacked accurate records of milk production, amount of roughage and concentrate fed, and fertility of cows. Only 19 of the 35 farms initially visited had reliable records suitable for in-depth study. Nine farms were selected from these based on the amount of forage fed and the possibilities of obtaining reliable data for a further one year study. The nine farms were selected to fall into two groups; one with low forage intake (three farms) and the other with higher forage intakes. In the latter category a further division was made according to whether concentrate intake was low (four farms) or high (two farms).

The nine farms were visited once every month for a one year period between July 1979 and June 1980. Every farmer measured the milk produced per cow twice daily and these values were checked once monthly on the day of the farm visit. Also on the day of the visit a check was made to determine the amount of forage offered; normally this was done by supervising the weighing of the amount given to one group of cows in a corral. If comparisons between reported and actual results were acceptable the rest of the values for the month were taken from the records and reported as an average. The same procedure was used to determine the amount of concentrate offered. The farms visited had only Holstein cows which is the predominant breed in the area. The stage of lactation, lactation number, and month of calving were not recorded because of lack of reliable records but all operations produced milk throughout the entire year.

Just before leaving the farm, samples were collected directly from the forage offered, packed in plastic bags and taken to the laboratory for forage quality analysis. Acid detergent fiber and neutral detergent fiber were determined by the analytical procedures described by Van Soest (1966) and Van Soest and Wine (1967); crude protein was obtained by the Kjeldahl procedure; in vitro dry matter disappearance was obtained using the Van Soest method (1966); gross energy was determined in a Parr Bomb Calorimeter; the minerals potassium, calcium, magnesium, iron, manganese, zinc and copper were determined using a flame atomic absorption spectrophotometer (Perkin Elmer, Model no 403) and phosphorus was analyzed by the colorimetric procedure. All the minerals were determined using the techniques described by Fick et al. (1974).

Results were analyzed statistically using analysis of variance, linear and multiple regression procedures (Steel and Torrie 1980). During statistical analyses one farm from the high-forage, low-concentrate group was eliminated because of lack of reliable data throughout the different seasons.

C. Results and Discussion

Preliminary Survey

The number of dairy farms, classified by herd size, in the region is shown in Table III.1. The data provided by the Secretaria de Agricultura y Recursos Hidraulicos, is not complete with respect to number of cows and farmers, since it was mainly obtained from farms surrounding the city. Also there are farms with less than 25 cows per farm which are not officially registered. In spite of these limitations the data was considered to be useful in selecting herds for further study.

Data obtained from the 19 farms in which more or less complete information could be obtained are given in Table

Table III. 1. Dairy farms officially registered in the Comarca Lagunera and number of cows per farm

Number of cows	Number of Dairy farms
25-99	174
100-199	76
200-299	37
300-399	13
400-499	18
500-599	8
>600	13

III.2. This data, because it was obtained from unsubstantiated farmers claims, and only on the basis of the results reported to have occurred on the day of the farm visit, is considered only to give an approximation of the actual feeding and milk production levels in the area. The nine farms selected for further study are also noted in the table.

Forage Quality

Information on the quality of forages used on the nine farms for the period from July 1979 to June 1980 is presented in Table III.3. The crude protein contents of the forages sampled on dairy farms were within normal ranges reported in the United States (National Academy of Science 1971). This was also true for acid detergent fiber, with the exception that corn silage contained more fiber than average values. Neutral detergent fiber was found to be slightly higher than listed values in most of the forages which suggests that the forages of the region contain more hemicellulose than normal. The gross energy concentration was lower than listed values (National Academy of Science 1971) especially for sudan grass (15.88 MJ/kg DM) and sorghum silage (15.88 MJ/kg DM). One explanation for these low values could be the high concentration of minerals in the forages. In vitro dry matter disappearance values (69–84%) are considered normal in comparison with values reported for similar forages in a vegetative state (Van

Table III. 2. Forage utilization systems and milk production in a preliminary survey of 19 farms

Farm Number	Daily intake (kg/animal)		Cow herd size	Hectares of Forage		Milk production (kg/cow/day)
	Green Forage	Concentrate		Total	Alfalfa (%)	
8+	32	5	216	44	32	16
23+	50	5	100	65	46	18
15+	40	6	300	120	50	16
6	50	5	103	64	52	16
16	40	8	97	26	62	16
17	50	13	154	24	50	16
18	60	—	150	103	15	20
19	40	—	120	54	4	16
23	50	5	100	65	46	18
5+	60	6	361	120	33	19
10+	63	6	243	189	47	20
13+	61	7	430	104	42	19
21+	63	6	800	189	47	20
3	65	8	447	164	27	18
20	65	7	640	170	53	20
24	46	6	620	185	54	20
4+	60	10	1400	112	26	20
7+	55	13	1400	120	0	19
2	65	9	645	207	53	20
12	64	9	960	318	38	23

+Farms selected for further study.

Table III. 3. Crude protein, fibre, in vitro dry matter digestibility and gross energy content of forages.

Parameter	Sudan[1] Grass (Greenchop)	Forage[1] Oats (Greenchop)	Annual[1] Ryegrass (Greenchop)	Corn[1] (Silage)	Sorghum[1] (Silage)	Alfalfa[1] (Greenchop)	Alfalfa[1] (Hay)
Crude Protein (% of DM)							
Mean	10.6	11.1	20.6	11.0	9.6	21.2	17.4
SD†	2.19	2.95	5.34	2.52	2.56	4.68	4.26
NDF (% of DM)‡							
Mean	67.6	53.3	51.3	58.8	63.9	45.5	49.9
SD	3.04	9.25	6.69	3.53	7.66	9.59	6.51
ADF (% of DM)§							
Mean	42.7	32.2	28.7	39.9	44.1	30.8	36.6
SD	1.91	7.09	3.97	3.53	3.60	4.30	5.89
IVDMD (%)′							
Mean	71.1	79.6	84.5	73.1	69.3	78.6	72.7
SD	10.18	2.65	5.80	4.25	2.59	5.05	4.00
Gross energy (MJ/kg DM)							
Mean	15.88	16.74	16.74	16.32	15.88	16.74	17.15
SD	0.59	0.88	0.96	0.59	1.30	1.17	0.63

†Standard deviations based on 6, 6, 12, 22, 6, 42 and 32 observations for sudan grass, forage oats, annual ryegrass, corn silage, sorghum silage, alfalfa greenchop, and alfalfa hay respectively.

‡Neutral detergent fibre.

§Acid detergent fibre.

′ In vitro dry matter digestibility

Soest 1966; Wilson et al. 1978; Burns and Smith 1980; Jones et al. 1980) except for annual ryegrass which had an extremely high digestibility. Probably this high digestibility was due to the stage of maturity at harvest since younger material is more digestible than more mature forage (Raymond 1969; Barnes and Marten 1979).

Mineral concentrations (Table III.4) obtained from the sampled forages were compared with average values for forages in the United States (National Academy of Sciences 1971). The comparison established that potassium concentrations were higher in all the forages (2.14–3.69% of DM) in this region of Mexico than in USA listed values (1.05 –2.08%). The soils of the study area are rich in potassium; no fertilization with this element is required for any crop and the potassium content of forages increases with high soil potassium levels (Whitehead 1966). The amount of phosphorus in forage DM (0.20–0.24%) was within ranges (0.2–0.5%) reported for these forages with the exception of corn silage (0.09%) and forage oats. Calcium contents were normal in sudan grass, corn silage, forage oats and slightly higher in annual ryegrass than listed values, whereas magnesium contents were within normal ranges(0.08–0.30% of DM). Manganese was within the range of listed values (25–200 mg/kg DM) in forage samples. Iron content in alfalfa greenchop (467 mg/kg DM) and annual ryegrass (547 mg/kg DM) was high relative to National Academy of Science (1971) values (200–300 mg/kg), whereas it was in lower

Table III. 4. Average mineral content of forage dry matter obtained from nine farms in the Comarca Lagunera region of Mexico.

Mineral	Sudan Grass (Greenchop)	Oats (Greenchop)	Ryegrass (Greenchop)	Corn (Silage)	Sorghum (silage)	Alfalfa (Greenchop)	Alfalfa (Hay)
Phosphorus (%)							
Mean	0.25	0.17	0.22	0.09	0.07	0.24	0.20
SD†	0.05	0.02	0.08	0.06	0.06	0.08	0.05
Potassium (%)							
Mean	3.04	3.00	3.69	2.14	2.22	3.53	3.65
SD	0.40	0.64	0.88	0.62	1.15	0.73	0.56
Calcium (%)							
Mean	0.59	0.56	1.01	0.66	0.55	2.31	1.85
SD	0.10	0.11	0.30	0.39	0.01	0.71	0.38
Magnesium (%)							
Mean	0.23	0.11	0.26	0.21	0.26	0.26	0.22
SD	0.12	0.02	0.08	0.05	0.07	0.07	0.07
Iron (mg/kg)							
Mean	262	66	547	286	276	467	143
SD	180	12	318	165	180	281	94
Manganese (mg/kg)							
Mean	68	43	177	79	30	92	47
SD	12	12	46	28	25	24	16
Zinc (mg/kg)							
Mean	41	71	176	42	160	58	32
SD	6	38	128	7	106	45	3
Copper (mg/kg)							
Mean	21	10	9	6	4	11	9
SD	6.1	2	2.8	4.4	2.1	3.2	1.4

†Standard deviations are based on 6, 6, 12, 12, 2, 15 and 22 observations for sudan grass, oats, annual ryegrass, corn silage, sorghum silage, alfalfa greenchop and alfalfa hay respectively.

concentrations in forage oats (66 mg/kg DM). Copper concentrations were lower than normal (10 mg/kg DM) in alfalfa hay, corn silage and annual ryegrass. Copper deficiencies in plants grown in sandy alkaline soils, in which availability of copper decreases with increasing pH, have been reported (Sauchelli 1969; Nicholas and Egan 1975; Benson and Matrone 1976; Aubert and Pinata 1977). The pH of the soils in the Comarca Lagunera is 8.5.

According to information on the nutrient requirement of dairy cattle (National Academy of Sciences 1978; Commonwealth Agricultural Bureaux 1980) the forages would fulfill the mineral requirements of lactating cows except for phosphorus with all the forages, magnesium when oats were fed, manganese when sorghum silage was fed, zinc when alfalfa hay was fed, and for copper when corn silage, annual ryegrass and alfalfa hay were fed.

Forage Utilization Patterns on Dairy Farms

Alfalfa is the only plant that can produce forage for more than 10 months per year and this is reflected in the differing patterns of forage utilization seen in Table III.5. The availability of arable land and water in each farm as well as management decisions influence the forage utilization patterns for each farm. During the summer months 100% of the farms visited utilized alfalfa greenchop with the range of use varying from 51 to 93% (mean 68%) of the forage DM (Table III.5). In the winter months there was a

Table III. 5. Forage utilization patterns on dairy farms in the Comarca Lagunera region of Mexico

	Summer†			Winter‡		
	Frequency of§ utilization (%)	Percentage of dietary Forage DM Offered mean	Range	Frequency of utilization (%)	Percentage of dietary forage DM Mean	Range
Alfalfa (greenchop)	100	68.0	51-93	66	14	0-27
Alfalfa (hay)	32	14.0	5-27	83	28	23-31
Corn (silage)	53	16.5	0-38	83	29	22-40
Sorghum (silage)	5	1.0	0-4	-	-	-
Sudan grass (greenchop)	5	0.5	0-3	-	-	-
Annual ryegrass (greenchop)	-	-	-	50	10	0-19
Forage oats (greenchop)	-	-	-	66	19	0-46

†Months of May-October

‡Months of November-April

§Percentage of farms that used the forage.

decrease in the use of greenchop alfalfa especially in terms of the amount used in the ration (mean 14%; Table III.5). The reason for this is that during the winter months there is a reduced DM production from alfalfa due to low temperatures.

When greenchop is added to a ration containing corn silage or alfalfa hay, increased milk production has been reported (Baxter et al. 1973; Montgomery et al. 1976; Baxter et al. 1978). However, since dairy cattle require a maximum of 16% crude protein in the dietary DM (National Academy of Science 1978), feeding alfalfa greenchop as the sole source of forage could cause an excess of protein in the diet. High intakes of protein can lead to the production of excessive ammonia (Annison and Lewis 1959; Lake et al. 1974a; Clanton 1977) and the excess nitrogen must be eliminated from the system. The normal function of the liver in removing ammonia from portal blood can be over-taxed and consequently the ammonia concentration in peripheral blood may be raised. Excessive dietary protein can thus cause a reduction in the efficiency of the metabolism of nutrients (Hickey 1960; Lake et al. 1974b; Acton and Tayler 1980). Greater efficiency of use of protein could thus potentially be achieved in summer months in this region if less alfalfa greenchop was fed.

Most of the farmers in the area offer corn silage along with alfalfa greenchop or hay with variations in the proportions used during summer and winter (Table III.5). The forages utilized in greater amounts in the diet during the winter months besides corn silage, were alfalfa hay, forage oats and annual ryegrass. Normally oats are utilized in early winter and ryegrass in late winter.

Milk Production on Dairy Farms

The data on milk production and forage and concentrate intakes collected from the nine farms in the survey were analyzed by the three groups formed on the basis of the initial survey but no statistical difference was encountered between groups. Thus the data was then examined by individual farms according to season (Table III.6). Milk production was affected ($P<0.05$) by season with 4.2% more milk per cow being produced during the winter months than during the summer months. Milk production and DM intake are known to be reduced when cows are exposed to high environmental temperatures (Duble et al. 1971; Dragovich 1978; Reed 1978). Since no statistical difference by season was detected in concentrate or forage DM intake, and digestibility was highly related ($r^2=0.90$) with DM intake it is possible that factors other than environmental temperatures caused the lowered summer milk production.

Mean DM intakes (forage plus concentrate) were well correlated ($r^2=0.90$) with milk production across all dairy farms visited (Figure III.1). A multiple regression analysis showed that both concentrate DM intake and forage DM intake were significantly related to milk production (F values of 39.1 and 6.9 for concentrate and forage respectively, with

Table III. 6. Concentrate and forage dry matter intake and milk production of cows on the farms surveyed

Parameter by Season	Farm Number 15	10	4	21	13	7	8	23	Mean
Forage intake (kg/DM/day)†									
Summer	16.9	14.5	14.0	14.1	13.7	12.2	11.5	10.0	13.36^{a}
Winter	15.7	14.0	14.6	13.9	16.2	12.2	11.1	12.9	13.82^{a}
Mean	16.3^{a}	14.3^{b}	14.3^{b}	14.0^{b}	15.0^{b}	12.2^{c}	11.3^{c}	11.5^{c}	
Concentrate intake (kg/DM/day)‡									
Summer	7.7	6.9	7.6	5.0	11.0	8.0	4.9	0.0	6.39^{a}
Winter	7.5	5.9	7.5	5.0	10.4	8.2	3.6	0.0	6.01^{a}
Mean	7.6^{c}	6.4^{d}	7.6^{c}	5.0^{e}	10.7^{a}	8.1^{b}	4.3^{f}	0.0^{g}	
Milk Production (kg/day)§									
Summer	19.0	17.7	19.7	19.0	19.0	19.0	14.0	12.4	17.47^{b}
Winter	21.6	18.2	20.0	19.0	19.7	19.0	14.4	13.0	18.21^{a}
Mean	20.3^{a}	18.0^{d}	19.9^{ab}	19.0^{c}	19.4^{bc}	19.0^{c}	14.2^{e}	12.7^{f}	

†Standard error of mean was 0.37 for season and 0.74 for farms with six observations per mean

‡Standard error of mean was 0.13 for season and 0.27 for farms with six observations per mean

§Standard error of mean was 0.22 for season and 0.44 for farms with six observations per mean

a–f Means with different letters are significantly different ($P<0.05$)

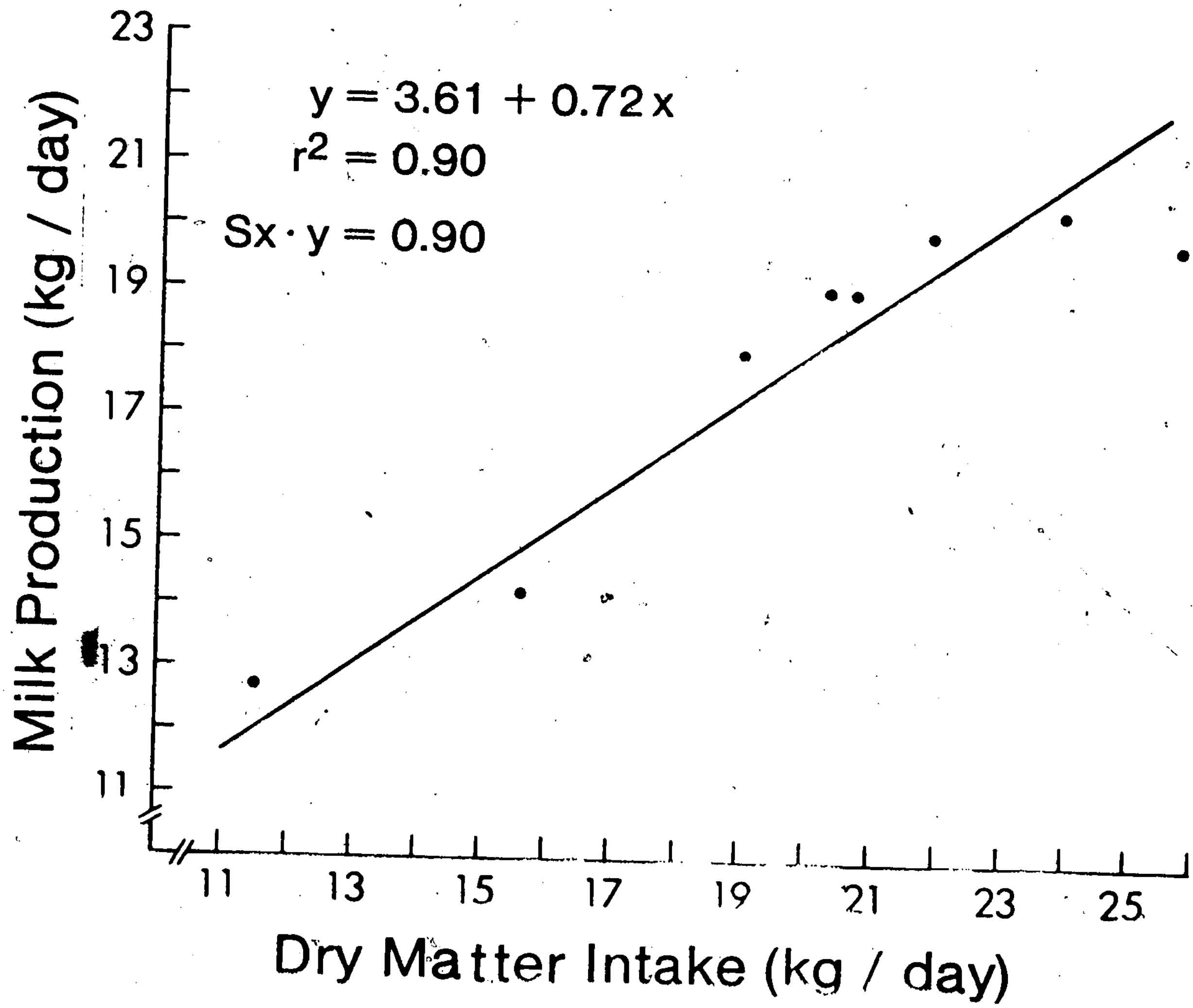

Figure III. 1 Relationship between dry matter intake and milk production on dairy farms.

1 and 6 degrees of freedom, respectively); but concentrate intake explained more (r=0.88) of the variation in milk production than did forage DM intake (r=0.51). Although feeding grain according to milk production was not practiced on these farms, some farmers fed more concentrate in early lactation than in late lactation.

It could be speculated that a better description of the effect of forage and concentrate intake on milk production could be established if digestible energy values were available for the specific forages fed since it is reported that, although DM intake is correlated with milk production at lower levels of milk production, output of milk is mainly a function of energy intake rather than DM intake (Blaxter et al. 1964; Kleiber 1975; Swan and Broster 1976; Lippke 1980).

D. Summary and Conclusions

1) Forage utilization patterns were different for spring—summer than for fall—winter months; the main reason for this is that different forages are produced in the region in different seasons of the year.

2) The most common forage used on dairy farms was alfalfa greenchop which was utilized to some extent in all rations during the summer; during the fall and winter alfalfa hay, corn silage, forage oats and annual ryegrass were used in higher proportions in the diet.

3) Forage quality was similar to average values reported elsewhere except for gross energy which was low in some forages, and for potassium which was high.

4) In several forages copper was found in low concentrations in relation to published values and animal requirements.

5) Milk production on the farms studied was higher during the fall–winter than during the spring–summer period but no statistical differences were found for forage and concentrate DM intake in the different seasons.

6) Forage DM intake, concentrate DM intake, and milk production were statistically different between the farms in the study; a high correlation (r^2=0.90) was found for total DM intake and milk production across all farms. Using multiple regression techniques it was found that concentrate DM intake (r=0.88) explained more of the relationship between DM intake and milk production than did forage DM intake (r=0.51).

IV. Nutritive Value of Forages for Dairy Cows

Limited information is available for the Comarca Lagunera region of Mexico regarding the nutritive value of the regional forages for dairy cows. In vitro digestibility and crude protein values have previously been obtained for most of the forages and acid and neutral detergent fiber values are available for some forages (Annual reports of the Pasture Management Project, Research Station of the Comarca Lagunera, CIAN—INIA). No information was available for mineral content of the regional forages and no measurements of in vivo digestibility, DM intake or influence on milk production have previously been made with forages from the region. The objective of the experiments reported in this section was to evaluate the most important forages in the Comarca Lagunera in terms of their nutritive value in dairy rations.

A. Materials and Methods

The experiments were conducted at the research station of the Comarca Lagunera, Centro de Investigaciones Agricolas del Norte, Instituto Nacional de Investigaciones Agricolas, located 17 km east of the city of Torreon, Coahuila, Mexico. The evaluation of forages was mainly carried out in experiments over a 17 month period from July 1979 to November 1980. In each experiment the relative nutritive value of one forage was evaluated by comparing it to alfalfa hay. The forages evaluated included alfalfa (hay and greenchop), sudangrass (greenchop), oats (greenchop), annual ryegrass (greenchop), corn silage and sorghum silage. The combinations of evaluated forages and the time of testing are shown in Table IV.1. Each experimental period consisted of approximately 40 days plus 15 days of pretest adaptation. In each experiment 12 different Holstein cows were used; six per forage tested. The cows were alloted to treatments so that milk production, stage of lactation (approximately 110 days postpartum), number of calvings (second or third calving), and body weights were equalized on the two treatments. Forages were offered ad libitum at a level of 10% in excess of the maximum intake obtained during the adaptation period. Alfalfa was fed in the form of long hay; corn silage was prepared the previous year and sorghum silage the year in which it was fed. Silages were stored in a bunker silo (6m x 50m x 2m deep) until the time of feeding. Forages offered as greenchop were harvested twice a day with a forage harvester and offered to each group of animals after each milking. Forage intake was determined by weighing the offered and rejected forage and taking 1 kg samples of both for DM determinations. Concentrate (12% protein) was individually fed at the level of 3.68 kg DM (1.84 kg at each milking) per cow per day. The composition of the concentrate was: sorghum grain 80.3%, wheat 5.0%, meat meal 1.1%, deflourinated rock phosphate, 1.0%, cottonseed meal 1.6%, safflower meal 4.0%, molasses 5.0%, urea 1.0% and salt 1.0%. A trace mineralized salt was

Table IV. 1. Species of forage and time of testing in forage evaluation studies

Trial No.	Species	International feed No.	Maturity	Length of test (days)†	Test period date
1	Sudangrass (greenchop) Alfalfa hay‡	2.04.492 1.00.059	Prebloom Early bloom	50	July 26 - Sept.14, 1979
2	Forage oats (greenchop) Alfalfa hay	2.03.371 1.00.059	Immature Early bloom	48	Dec.16, 1979 - Jan.23, 1980
3	Annual ryegrass (greenchop) Alfalfa hay	2.04.060 1.00.059	Immature Early bloom	43	Feb. 2 - March 17, 1980
4	Corn silage Alfalfa hay	3.02.819 1.00.059	Dough stage Early bloom	39	April 16 - May 24, 1980
5	Sorghum silage Alfalfa hay	3.04.466 1.00.059	Dough stage Early bloom	37	Sept. 26 - Nov. 2, 1980
6	Alfalfa greenchop Alfalfa hay	1.00.155 1.00.059	Early bloom Early bloom	37	Sept. 26 - Nov. 2, 1980

†Not including a 15 day adaptation period.

‡Alfalfa hay was purchased for these trials.

offered ad libitum to the cows. The cows had an average intake of 50 g/cow/day of this mixture and this supplied 5 mg manganese, 0.5 mg molybdenum, 2.5 mg cobalt, 5 mg zinc, 2.5 mg copper, and 210 mg iron per day.

The cows were milked twice daily at 0600 and [illegible]0 h and the amount of milk was recorded using a True-Test scale (Scientific Farm Appliances Ltd., Hamilton, N.Z.). Milk fat was measured once weekly from all the cows in the experiment using the Babcock test (Judkins and Keener 1960). The cows on each treatment were maintained and fed forage as a group in an open corral which was provided with a sunshade and which was close to the milking parlor. Water was offered ad libitum. Jugular blood samples were taken in an open test tube from each cow after the morning milking at the end of the experimental period. Blood samples were immediately taken to the laboratory for centrifugation for separation of plasma. This plasma was frozen for analysis.

A digestion trial was performed for each forage utilized in the study. In the first two trials chromic oxide (Cr_2O_3), wrapped in a cellulose paper container, was given twice daily by a stomach tube to the cows at a level of 10 g/day for a period of 20 days; the last 10 days of which was the sampling period. Fecal samples were collected rectally twice a day after each milking from each cow on study. Fecal samples were then taken to the laboratory, frozen and stored for future analysis.

In vivo digestibility was also measured by a total collection procedure, using mature wethers of mixed breeding (Ramboullet, Merino) and with an average weight of 55 kg. Four sheep were utilized for each forage tested. The animals were held in metabolic cages and were fed forage at a level of 10 percent in excess of the maximum intake achieved during the adaptation period. The adaptation period was 14 days and the fecal collection period 7 days. Forage was offered twice daily and samples of forage offered and refused were taken at this time as well. Feces were collected daily and frozen.

Acid detergent fiber, neutral detergent fiber, crude protein, in vitro DM disappearance, gross energy and the minerals phosphorus, calcium, potassium, magnesium, iron, manganese, zinc and copper were determined by the procedures outlined previously in section III. Chromic oxide was determined using the technique described by Bolin et al. (1952).

The results were analyzed statistically using analysis of variance and linear regression techniques (Steel and Torrie 1980).

B. Results and Discussion

Forage Quality

Information on the quality of forage utilized in the six experiments carried on at the research station is summarized in Table IV.2.

In comparing these results with those obtained in local dairy farms it is apparent that the crude protein and fiber values for alfalfa hay were similar, except that the alfalfa hay fed during the last two experimental periods contained about 3% more crude protein than that used in earlier trials or by dairy farmers. Alfalfa greenchop was similar in protein content to alfalfa greenchop commonly used in the region (Table III.3). The crude protein content of the corn (8.8%) and sorghum silages (7.4%) used in the experiments were lower than in the samples collected on local dairy farms. This was probably due to differing stages of maturity. The gross energy of sudangrass (18.7 vs 15.9 MJ/kg DM) was higher in experimental station forage than in the forages used on the dairy farms (Table IV.2) with the rest of the parameters for this forage being very similar. Annual ryegrass and forage oats fed at the research station (14.84% and 20.53% crude protein respectively) were very different in protein contents from that on the dairy farms (20.6% and 11.1% respectively). This could be attributable to the stage of maturity; normally dairy farmers harvest forage oats at a full bloom stage and annual ryegrass at an immature stage; at the research station forage oats was harvested at early leaf stage and annual ryegrass was harvested at an immature stage.

Overall the concentrations of crude protein, neutral detergent fiber, acid detergent fiber, and gross energy in

Table IV. 2. Crude protein, fibre and gross and digestible energy in experimental forage dry matter

Trial	Forage	Crude Protein DM (%)	Digestible Crude Protein (%) Obtained†	Digestible Crude Protein (%) Predicted‡	NDF§ (%)	ADF# (%)	Gross Energy (MJ/kg)	Digestible Energy† (MJ/kg)
1	Sudan grass	9.6	4.3	5.4	60.3	45.2	18.7	13.0
	Alfalfa hay	18.5	13.2	13.7	58.5	45.8	18.4	13.0
2	Forage oats	20.5	15.1	15.6	46.7	28.5	16.9	13.0
	Alfalfa hay	17.6	11.5	12.8	49.7	38.6	17.2	12.6
3	Annual Ryegrass	14.8	9.0	10.3	50.7	29.3	16.7	12.6
	Alfalfa hay	19.4	14.0	14.5	47.5	31.1	17.6	13.4
4	Corn Silage	8.8	3.5	4.7	64.1	41.4	17.1	13.0
	Alfalfa hay	18.7	12.0	13.8	48.9	28.7	17.6	13.4
5	Sorghum Silage	7.4	2.1	3.4	63.7	45.1	16.3	9.6
	Alfalfa hay	21.5	14.9	17.1	58.9	41.9	17.2	12.1
6	Alfalfa greenchop	22.1	16.9	17.0	54.5	35.9	18.0	13.4
	Alfalfa hay	21.4	15.9	16.4	58.9	41.9	17.6	13.4

†Based on results obtained with four sheep

‡Y=0.929 (% crude protein) - 3.48; National Academy of Sciences (1975)

§NDF = Neutral detergent fiber

#ADF = Acid detergent fiber

the research station forages (Table IV.2) were within normal ranges reported for these forages (National Academy of Science 1971). The values of digestible energy (12.1-12.9 MJ/kg DM) for the greenchop forages were higher than tabulated values, but were considered to be accurate because of the agreement between sheep and cattle results (Table IV.4) and because the forages were harvested at an early vegetative stage. Even higher digestible energy values (13.81 MJ/kg DM) have been reported for high protein forage oats harvested at an early stage of maturity (Singh et al. 1977; Kishan and Singh 1978; Schoedrer et al. 1978).

Digestibilty Trials

The first two experiments, in which annual ryegrass and sudangrass were compared with alfalfa hay, were used to establish a comparison between the in vivo digestibility of forage in sheep, the in vitro digestibility in the laboratory, and the apparent digestibility of the complete ration in the cows as determined by using chromic oxide to estimate fecal production.

No statistical differences ($P>0.05$) were found in the digestibility of alfalfa hay DM using the in vitro and sheep results (Table IV.3). Similar agreement between in vitro and in vivo digestibilities are reported (Tilley and Terry 1963; Van Soest 1966; Van Soest 1967) for high digestibility forages. However, the in vitro method provided a higher ($P<0.05$) digestibility for annual ryegrass and lower

Table IV.3 Dry matter digestibilities (%) as determined by total collection with sheep, with chromic oxide in cows and from in vitro estimations.

Trial	Forage	Forage: In vitro	Forage: Sheep[+]	Forage plus Concentrate: Chromic Oxide (cows)[‡]	SEM
	Annual ryegrass	84.1[b]	79.4[a]	81.3[a]	
1	Alfalfa hay	79.6[a]	77.4[a]	79.5[a]	0.72
	Mean	81.9	78.4	80.4	
2	Sudangrass	68.4[b]	73.9[a]	76.6[a]	
	Alfalfa hay	80.0[a]	80.8[a]	81.4[a]	1.32
	Mean	74.2	77.4	79.0	

[+]DM intakes were 79, 86, 77, 89 g/kg .75/day for annual ryegrass, alfalfa hay, sudangrass and alfalfa hay, respectively.

[‡]DM intakes were 128, 146, 96, 126 g/kg .75/day for annual ryegrass, alfalfa hay, sudangrass and alfalfa hay, respectively. Corresponding concentrate DM intake (g/kg 0.75/day) were 26.2, 25.8, 22.4 and 22.3.

digestibility ($P<0.05$) for sudangrass than the in vivo results. One possible reason for the higher digestibility using the in vitro technique is that forages were given to the animal ad libitum and it is reported that with increased intake there is a decrease in digestibiltiy (Church and Pond 1974; Church 1979; Miller 1979). It is also reported that, for forages of very high digestibility, the in vitro technique normally overestimates digestibility (McLeod and Minson 1969). No explanation can be given for the lower in vitro digestibility of sudangrass since the source of inoculum was obtained from a fistulated steer feeding on the same forage. There were no statistical differences between the DM digestibilities of pure forages determined with sheep and the digestibilities of the complete rations (containing 20.5%, 17.7%, 23.3%, and 17.6% concentrates on a DM basis for annual ryegrass, alfalfa hay, sudangrass, and alfalfa hay, respectively) as determined using the chromic oxide procedure in the lactating cows (Table IV.3). The lack of statistical improvement in DM digestibility with the addition of concentrate is not too surprising since the calculated digestible energy value of the concentrate (14.0 MJ/kg DM) was not substantially different from the measured digestible energy values in the forages (12.6 13.4 MJ/kg DM, Table IV.2), and since digestibility would be expected to be depressed somewhat in the cattle because of higher intakes relative to sheep.

Based on all experiments a relationship between in vivo (sheep) and in vitro DM digestibility was established, as shown in Figure IV.1a. In vitro digestibility only accounted for 74% of the variability in in vivo digestibility and could only predict digestibility with a standard error of ± 5.02%. If the values for the annual winter forages (annual ryegrass and forage oats) were eliminated the r^2 value increased to 0.82. In this case the equation changed to y=4.15 + 0.95 X (SE y.x=3.56) (Figure IV.1b). The reason for the improvement in the relationship upon elimination of the winter forages could be because both forages were harvested at a very early stage of maturity normally associated with very high digestibility (Smith et al. 1958; Reid et al. 1959; Birrel 1980; Vinet et al. 1980). As discussed above in vitro results may overestimate digestibility in such cases (McLeod and Minson 1969). Also, the in vivo method could have yielded low measurements because of the high intakes and because the forage was offered as greenchop. Forage offered as greenchop may be less digestible than hay (Reid et al. 1959; Barnes and Marten 1979).

These differences between in vitro and in vivo results means that in future studies it will be essential to include forages of known in vivo digestibilities in the in vitro analysis, as recommended by Johnson (1966) and Jones et al. (1980) especially now that forages of known in vivo digestibility from these experiments are available. With this in mind, the relationship between in vitro and in vivo

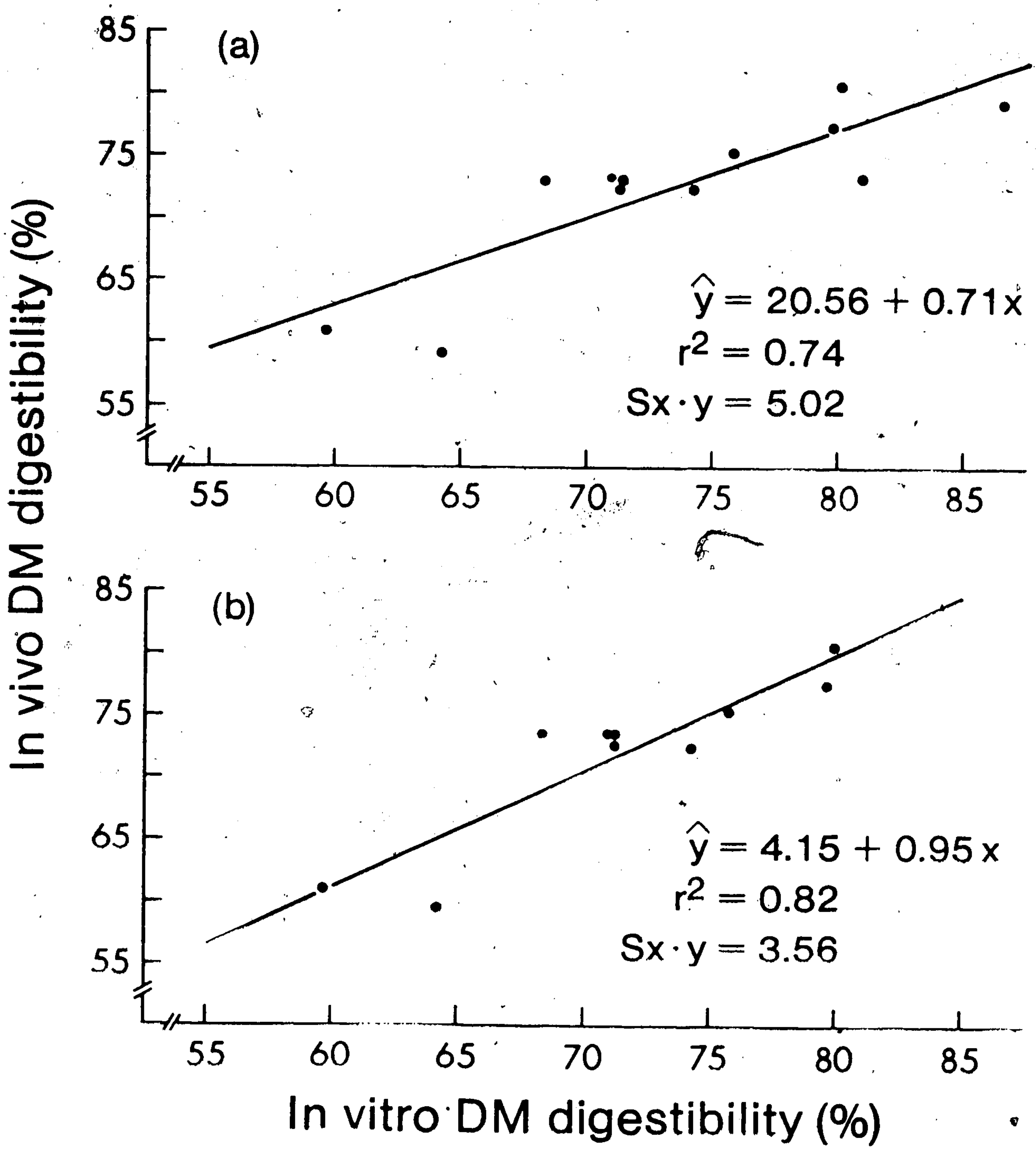

Figure IV. 1 Relationship between *in vitro* dry matter digestibility and *in vivo* dry matter digestibility as estimated with sheep.

results reported here are considered to be satisfactory for use in studies in the immediate future for assesing the relative nutritive value of forages produced under different environmental conditions (winter and summer months) in the Comarca Lagunera region of Mexico. However, it will be necessary to obtain more precise data so the in vitro, or any new superior technique, can be used to estimate the nutritive value of feed by-products and less common forages.

Voluntary Intake of Sheep and Cattle

Mean intakes of forage (kg DM/kg$^{0.75}$) were different ($P<0.05$) for sheep and cattle; cattle having higher intakes than sheep of all feeds (Table IV.4). When such an intake comparison between these two species of animals is made, however, it must be remembered that the cows were lactating whereas mature non-lactating sheep were used. DM intakes can be expected to increase during lactation (National Academy of Sciences 1978; Miller 1979). With this reservation in mind, the relative intakes are in agreement with several studies which report that when cattle are offered a roughage which is more than 50% digestible, they consume more of it per unit of metabolic weight than do sheep (Alexander et al. 1962; Buchman and Hemken 1964; Playne 1978). No difference was found in forage DM intake per 100 kg of body weight between sheep and cattle when the intake means from all the experiments were analyzed (Table IV.4), although for some forages the two species had differing intakes.

Table IV. 4. Voluntary intake of forage dry matter by sheep and cattle

Forage	Mean weight (kg)		Intake (kg/100 kg weight)		Intake (kg/kg.75)	
	Sheep	Cattle	Sheep	Cattle	Sheep	Cattle
Sudan grass	54.3	612	2.82	1.93	0.077	0.096
Alfalfa hay	58.0	627	3.21	2.53	0.089	0.126
Forage oats	55.3	522	2.50	2.66	0.068	0.126
Alfalfa hay	56.7	498	2.87	3.11	0.079	0.146
Ryegrass	55.3	513	2.91	2.69	0.079	0.128
Alfalfa hay	56.7	502	3.14	3.16	0.086	0.146
Corn silage	53.0	557	2.36	1.36	0.064	0.066
Alfalfa hay	56.7	558	3.19	3.38	0.087	0.146
Sorghum silage	54.3	530	1.75	1.26	0.048	0.056
Alfalfa hay	55.6	580	2.18	2.87	0.069	0.131
Alfalfa greenchop	52.7	558	2.60	2.97	0.070	0.144
Alfalfa hay	56.0	544	2.25	3.06	0.061	0.146
Mean[†]	55.4	550	2.65[a]	2.58[a]	0.072[b]	0.124[a]

[†]Standard error of mean was 0.30 and 0.058 for intakes when expressed on the basis of kg/100kg body and $kg/kg^{.75}$, respectively with 13 observations per mean.

[a,b]Means within the same comparison with different letters are significantly different ($P<0.05$)

Mineral Analyses of Forage and Plasma

Minerals in forage.

The concentration of minerals in the feed (Table IV.5) can be compared with figures obtained from local dairy farms (Section III). The concentration of phosphorus in the forage DM tested at the research station (0.12–0.40%) was higher than in forages collected from dairy farms (0.09-0.25%) but was still lower than the range reported (0.2-0.5%) as normal (Whitehead 1966; Sauchelli 1969). This element was present at high enough concentrations only in sudangrass and annual ryegrass to meet the dairy cows requirement of 0.26–0.40% in DM (National Academy of Sciences 1978). Iron was in higher concentrations in forage oats (304 mg/kg DM) than in forages from dairy farms (66 mg/kg DM) Manganese was present in lower amounts (34–89 mg/kg DM) in forages at the research station. Copper concentrations were similar in alfalfa at the research station (9–11 mg/kg DM) and on dairy farms but differences were noted for the other forages. The concentration of potasssium, calcium, magnesium and zinc were similar in the dairy farms and research station forages.

In general all the forage trace element concentrations were within the ranges reported for these species of forages (National Academy of Sciences 1971;

Table IV. 5. Mineral content of forage dry matter

Experiment	Forage	Phosphorus (%)	Potassium (%)	Calcium (%)	Magnesium (%)	Iron (mg/kg)	Manganese (mg/kg)	Zinc (mg/kg)	Copper (mg/kg)
1	Sudan grass	0.40	2.90	0.50	0.18	196	65	36	7.3
	Alfalfa	0.19	3.07	1.58	0.21	159	49	23	7.5
2	Forage oats	0.20	3.20	0.42	0.14	304	89	30	5
	Alfalfa hay	0.27	4.25	1.50	0.23	325	59	32	10
3	Annual ryegrass	0.29	3.00	0.82	0.27	397	35	55	13
	Alfalfa hay	0.22	3.71	1.52	0.18	201	45	25	10
4	Corn silage	0.16	2.86	1.10	0.23	202	93	45	11
	Alfalfa hay	0.19	3.22	1.65	0.29	260	72	28	9
5	Sorghum silage	0.12	2.10	0.47	0.18	275	71	43	7
	Alfalfa hay	0.21	4.02	1.60	0.26	183	34	23	10
6	Alfalfa greenchop	0.23	3.35	1.67	0.23	360	62	30	10
	Alfalfa hay	0.21	4.02	1.60	0.26	183	34	23	10

Church and Pond 1974; Underwood 1977; Miller 1981; Georgievskii et al. 1982) although zinc and iron were in the upper limits of the ranges in most of the forages. Copper concentrations were below recommended values for dairy cows (National Academy of Sciences 1978) in sudangrass (7.3 mg/kg DM), sorghum silage (7 mg/kg DM), forage oats (5 mg/kg DM) and alfalfa hay (7.5 mg/kg DM). Copper concentrations in the soils of arid lands is expected to be high (Benson and Matrone 1976) but the availability decreases with increased pH. The pH of the soil in the study area is 8.5. Copper and molybdenum as well as sulphur are nutritionally related (Nicholas and Egan 1975; Undewood 1977). According to several authors (Sauechelli 1969; Mortvedt et al. 1972; Benson and Matrone 1976) molybdenum content in the soil is high in arid areas and the availability of this mineral increases with increased pH, thus the molybdenum content of the forage could be high enough to adversely affect the copper availability. Molybdenum was not determined in this study because of lack of equipment. Although high concentrations of zinc may depress copper absorption by plants in soils (Nicholas and Egan 1975) by competing with copper for absorption, the zinc concentration of these forages was within the limits (15–60 mg/kg DM) reported as normal (Whitehead 1966; Georgievskii 1982).

Mineral Status of Cows.

The concentrations of calcium, magnesium, copper, iron, and zinc in the plasma of the cows fed the different forages plus 3.68 kg concentrate DM are presented in Table IV.6. When comparing the concentration of the elements in the plasma of cows fed the alfalfa hays it is apparent that only copper concentrations differed between experiments; plasma copper concentrations were lower ($P<0.05$) during the first trial which was the only one conducted during the summer season. Since, with this exception, experimental period did not influence ($P>0.05$) plasma mineral levels it was considered valid to directly compare the different forages in terms of their influence on plasma mineral concentrations. No statistical difference ($P>0.05$) was found between cows fed different forages for calcium, iron, and zinc; only plasma magnesium and copper concentrations reflected a significant difference ($P<0.05$) between forages. Plasma magnesium concentrations were lower in cows fed alfalfa greenchop and sorghum silage than in those fed other forages. The plasma copper concentration, although relatively low (57 ug/dL) when sudangrass was offered in the first trial was not ($P>0.05$) different from values obtained when alfalfa hay was fed during the same period, thus the apparent difference between sudangrass and the other forages was considered to be a period effect.

Table IV. 6. Mineral concentration in plasma of dairy cows in all experiments

Mineral	Trial 1		Trial 2		Trial 3		Trial 4		Trial 5		Trial 6	
	Alfalfa hay	Sudan grass	Alfalfa hay	Forage oats	Alfalfa hay	Annual ryegrass	Alfalfa hay	Corn silage	Alfalfa hay	Sorghum silage	Alfalfa hay	Alfalfa greenchop
Calcium (mg/dL)	12.2[a]	14.4[a]	13.4[a]	13.2[a]	12.9[a]	15.6[a]	13.3[a]	13.9[a]	12.0[a]	12.4[a]	12.0[a]	11.6[a]
Magnesium (mg/dL)	1.70[abc]	2.13[abc]*	2.70[a]	1.72[abc]	2.40[ab]	2.30[ab]	*2.70[ab]	1.63[abc]	2.10[abc]	1.60[bc]	*2.10[abc]	1.30[c]
Copper (ug/dL)	67[b]	57[b]	124[a]	122[a]	112[a]	122[a]	120[a]	133[a]	108[a]	100[a]	108[a]	132[a]
Iron (ug/dL)	230[a]	233[a]	262[a]	248[a]	264[a]	236[a]	283[a]	253[a]	266[a]	250[a]	266[a]	258[a]
Zinc (ug/dL)	85[a]	84[a]	150[a]	146[a]	188[a]	190[a]	133[a]	163[a]	180[a]	196[a]	180[a]	168[a]

†Standard error of the mean was 0.28, 0.08, 3.75, 5.99 and 7.67 for Ca, Ma, Cu, Fe and Zinc respectively with 6 observations based on six cows per mean

a,b Means with different letters within a row are significantly different (P<0.05)

* Means significantly different (P<0.05) within a trial

In general calcium concentrations appear to be high in comparison to mean values reported in the literature (Church and Pond 1974; Church 1979). It is known that plasma calcium levels are normally maintained between 9–12 mg/dL by the regulatory actions of parathyroid hormone, calcitonin, and the active metabolite of vitamin D (Underwood 1981). However, it is known that the overall level of calcium in blood increases during the second half of pregnancy and during lactation (Georgievskii 1982); all of these experiments were performed with lactating cows which were approximately 110 days postpartum. It is also reported that a dietary deficiency of phophorus can cause a rise in plasma calcium concentration from a normal 9–12 mg/dL to 13–14 mg/dL (Underwood 1981).

Normal plasma magnesium concentrations are reported to be 1.7 to 3.2 mg/dL (Underwood 1981; Geogievskii 1982); the plasma levels of magnesium in cows fed corn silage, sorghum silage, and alfalfa greenchop were thus below the level reported as normal. Since it is known that plasma is an adequate sampling site for detection of deficiencies of this mineral (Underwood 1981), the mean magnesium concentrations of cows fed alfalfa greenchop (1.3 mg/dL) were low enough to suspect a magnesium deficiency; in fact one cow given this forage had only 1.1 mg magnesium/dL of plasma which is in the range where an accute deficiency can occur. This is surprising since the magnesium content of alfalfa greenchop was 0.23%, which meets the suggested requirements (0.2% magnesium/kg DM) for dairy cattle (National Academy of Science 1978). One reason for these low plasma magnesium concentrations could be that the availability of this element to the animal is reduced by high levels of nitrogen and potassium, which were present in the alfalfa greenchop at this early stage of maturity (Whitehead 1966). In light of this observation consideration should be given to providing supplemental magnesium to cows fed alfalfa greenchop, particularly since alfalfa greenchop is such a common forage in dairy cattle diets in this region (Table III.5).

The level of copper in plasma of these cows (Table IV.6) was between 57 and 133 ug/dL of plasma. Since normal ranges for cattle are between 50 to 150 ug/dL (Church and Pond 1974; Underwood 1981; Georgievskii 1982) and plasma copper concentrations are useful in evaluating the copper status of cows (Underwood 1981), this suggest that the cows were not deficient in this nutrient. Further it would indicate that, although the molybdenum content of forages was not measured, molybdenum was not present in high enough levels to adversely influence the copper status of the animal (Underwood 1981). The normal copper status of the cows was somewhat surprising since the copper concentrations (5–11 mg/kg) of the experimental forages appeared to be only marginal in meeting the animal requirements (10 mg/kg DM; National Academy of Sciences 1978) and only a negligible amount of the element (2.5 mg/cow/day) was obtained from the mineral supplement.

The normal ranges reported for plasma iron and zinc concentrations in cattle are between 89–253 ug/dL and 80–200 ug/dL respectively (Church and Pond 1974; Underwood 1981; Georgievskii 1982). Since values measured in these experiments ranged from 230–283 ug/dL and 84–196 ug/dL for iron and zinc respectively, and it is known that the concentration of these elements is indicative of the animal status, it is considered that no problem existed regarding the nutritional status of the animals for these two trace minerals.

Milk Production Studies

Since differing feeding methods can influence the persistency of lactation (Miller 1979) the effect of the length of time after the 2 week adaptation period for which the forage was fed on milk production and DM intake was examined. Only for sudangrass and forage oats were significant differences ($P<0.05$) obtained for milk production by week, and when giving these forages no consistent trend was noticed with time for an increase or decrease. Also no difference ($P>0.05$) was found between weeks of the experiment for forage DM intake or percentage milk fat. With this supporting data and since the six cows given each forage test were fed as a group rather than individually, data was statistically analyzed using weekly means for each forage tested.

There was a significant ($P<0.05$) difference in milk production of the cows fed alfalfa hay between seasons, with a 3.9 kg/cow/day lower production occurring in the summer season (Table IV.7). This is similar to the results obtained from the dairy farms survey where it was reported that 4.2% more milk per cow ($P<0.05$) was produced during the winter months than during the summer months (Table III.6). Milk production is known to be reduced when cows are exposed to high environmental temperatures (Duble et al., 1971; Dragovich 1978; Reed 1978). No corresponding statistical difference ($P>0.05$) between seasons was detected in DM intake.

Effect of Forages on Milk Production.

Since no statistical difference ($P>0.05$) in DM intake was found when comparing alfalfa hay in all the experiments and in only one experiment (conducted in the summer) was there a difference in milk production, comparisons can be established for milk production, milk fat, DM intake, digestible energy intake, and crude protein intake across all forages (Table IV.8).

Milk production, milk fat and DM and digestible energy intakes of cows fed alfalfa greenchop were similar to when alfalfa hay was fed but the cows given alfalfa greenchop consumed more crude protein daily.

Table IV. 7. Milk production and forage dry matter intake when alfalfa hay was fed to lactating cows

	Observations	Milk production (kg/day)	Dry matter intake (kg/day)
Summer	1	18.0[b]	15.9[a]
Winter	5	21.9[a]	16.9[a]
SEM[†]		0.24	1.26

[†]SEM based on six observations per mean

[ab]Means within the same row with different letters are significantly different ($P<0.05$)

Table IV.8. Milk production, milk fat (%), and intake of dry matter, crude protein and digestible energy in six experiment.

Trial and season	Forage	Milk production (kg/day)	Intake/cow/day[‡]			
			Dry matter (kg)	Digestible energy (MJ)	Crude protein (kg)	Milk fat (%)
1 Summer	Alfalfa hay	$^{*}18.0^{c}$	$^{*}19.34^{ab}$	$^{*}61.11^{ab}$	$^{*}3.35^{bc}$	3.07^{bcd}
	Sudangrass	15.1^{d}	15.45^{d}	49.26^{d}	1.56^{e}	2.97^{cd}
2 Winter	Alfalfa hay	$^{*}22.6^{a}$	$^{*}19.55^{ab}$	$^{*}60.34^{ab}$	3.22^{c}	$^{*}3.08^{bcd}$
	Forage oats	20.7^{b}	17.61^{bc}	55.57^{bc}	3.30^{c}	2.78^{d}
3 Winter	Alfalfa hay	$^{*}21.8^{ab}$	$^{*}18.68^{ab}$	$^{*}60.73^{ab}$	$^{*}3.41^{bc}$	$^{*}3.02^{bcd}$
	Annual ryegrass	18.9^{c}	16.57^{c}	53.11^{c}	2.37^{d}	3.43^{a}
4 Spring	Alfalfa hay	$^{*}21.5^{ab}$	$^{*}19.07^{ab}$	$^{*}61.04^{ab}$	$^{*}3.56^{b}$	$^{*}3.08^{bcd}$
	Corn silage	13.2^{e}	11.20^{e}	36.26^{e}	1.10^{f}	3.40^{ab}
5 Fall	Alfalfa hay	$^{*}21.8^{ab}$	$^{*}19.75^{a}$	$^{*}58.88^{ab}$	$^{*}3.94^{a}$	3.04^{bcd}
	Sorghum silage	11.8^{f}	10.43^{e}	28.48^{f}	0.94^{f}	3.34^{ab}
6 Fall	Alfalfa hay	21.8^{ab}	19.76^{a}	58.91^{ab}	3.88^{a}	3.04^{bcd}
	Alfalfa greenchop	21.4^{ab}	19.32^{ab}	62.85^{a}	3.98^{a}	3.20^{abc}
	SEM[†]	0.46	0.41	1.36	0.14	0.03

[†] Standard error of mean was based upon six cows per treatment

[‡] Includes an intake of 3.6 kg DM from concentrate/day

[a-f] Means with different letters within the same column are significantly different ($P<0.05$)

*Means significantly different ($P<0.05$) within trial.

Milk production, and DM, digestible energy and crude protein intakes were higher ($P<0.05$) when cows were fed alfalfa as compared to other forages with the exception of forage oats (Table IV.8). It has been reported that more DM from alfalfa is eaten by ruminants than from grasses when forages of similar digestibily are given (Van Soest 1973).

Cows fed forage oats had lower ($P<0.05$) levels of butterfat in milk (2.8%) than those fed alfalfa greenchop (3.2%), annual ryegrass (3.4%), corn silage (3.4%), and sorghum silage (3.3%)(Table IV.8). This difference is related to the lower acid detergent fiber content(28.5%) of this forage (Table IV.2) which is known to cause milk fat depression (Foley et al. 1972). No difference ($P>0.05$) between milk butterfat levels was observed for sudangrass, corn silage, sorghum silage or alfalfa greenchop in comparison with alfalfa hay.

The particularly low intakes of DM and corresponding low milk production with sudangrass, corn silage and sorghum silage could be due to several factors. Generally, decreased digestibility results in low intake (Church and Pond 1974; Barnes and Marten 1979; Miller 1979) and these forages had lower digestibilities than the rest of the forages. Overall, however, the relationship between the digestible energy content of the forages and their intake or the milk production was not high ($r^2=0.45$ and 0.41 for DM intake and milk production, respectively). A close relationship (r^2=0.87) was established between crude protein intake and milk production (Table IV.10). Numerous researchers (Van Horn and Someta 1978; Cressman et al. 1980; Edwards et al. 1980; Claypool 1980; Journet and Remond 1981; Holter et al. 1982) agree that there is no increase in milk production with dietary protein concentrations above 15%, but it is known that in ruminants concentrations of dietary protein below 10% may substantially reduce voluntary intake (Raymond 1969; Swan and Broster 1976). Since no response in milk production has been reported with protein contents above 15% it seemed logical to make a division between forages having protein contents below or above 15 percent. Analyzing the data in this way a very low correlation (r^2=0.07) was found between forage protein intake (kg/day) and milk yield for forages above 15% crude protein whereas for forages of lower protein levels the correlation with milk production was high (r^2=0.99) (Table IV.10). Similarly there was no correlation between DM intake and percentage crude protein for forages containing above 15% protein (r^2= 0.00) whereas for low protein percentage forages the correlation was good (r^2=0.78). Based on these relationships, and the fact that the crude protein intakes of cows fed the low protein forages (Table IV.2) were substantially below National Academy of Sciences (1978) suggested

Table IV. 9. Forage dry matter intake and milk production of cows fed diets containing corn silage plus alfalfa hay or corn silage

	Corn silage	Corn silage (66%) plus alfalfa (34%)	SEM[†]
No. cows	4	4	
Crude protein in diets (%)	10.2	14.2	
Milk production (kg/day)	16.7[b]	18.6[a]	0.79
Total intake (kg DM/day)	13.1[b]	16.9[a]	0.25
Forage intake (kg DM/day)	9.4[b]	13.2[a]	0.25
Corn silage intake (kg DM/day)	9.4[a]	8.7[b]	0.13
Crude protein intake (kg/day)	0.97[b]	1.88[a]	0.04

[†]Standard error of mean is based on four animals per treatment

[a,b]Means within the same row with different letters differ significantly ($P < 0.05$)

requirements (15% crude protein for a cow producing between 17–23 kg of milk per day) it was considered that the cause for the very low intakes of corn silage, sorghum silage and sudan grass was a deficiency of crude protein in the diet. This concept is consistent with reports of Huber and Thomas (1971) where raising the crude protein levels from 8.5 to 13.6% of the entire ration resulted in significant increases in crude protein and DM intakes as well as in milk production.

Further evidence that low protein content limited the intake of cows fed corn silage and sorghum silage was that sheep ate almost as much DM /$kg^{0.75}$ as cattle for these forages, whereas other forages were eaten in considerably greater amount by cattle than sheep (Table IV.4). Since the sheep were mature and not lactating they would have a lower protein requirement than the lactating cows thus they would be less affected by a low dietary crude protein intake.

To check the extent to which the low protein level of these forages had a negative effect on voluntary intake, a mixture of corn silage (66% of forage DM) and ground alfalfa hay (34% of forage DM) with a protein content of 14% in DM was compared with corn silage containing 10% crude protein in the DM in an intake experiment of 25 days using the same procedures as outlined previously with the exception that four cows were used. The intakes obtained with corn silage alone were higher than in the previous experiment (9.4 kg. versus 7.6 kg, Tables IV.8 and IV.9); this difference may have been related to the lower crude protein concentration (8.8%) in the corn silage used in the first trial. Mixing alfalfa with the corn silage resulted in an increase ($P<0.05$)in DM intake of 3.8 kg/cow/day, an increase of 0.91 kg in crude protein intake and an increase of 1.9 kg/cow/day ($P<0.05$) in milk production (Table IV.9). The results of this trial further demostrates the importance of providing adequate protein in dairy cattle rations.

The protein content of forages can be increased through nitrogen fertilization or by manipulating the stage of maturity at harvesting; less mature forage has a higher protein content in the DM (Van Soest 1973). Since urea supplementation does not improve DM intake or milk production when added to rations for dairy cows, particularly at high levels of feeding (Hermel and Bartley 1971) and natural protein sources are very expensive or have to be imported, it may be more desirable to employ management procedures to increase the protein content of the forage or to utilize different forages rather than use natural protein supplements. There is evidence that nitrogen fertilization could improve protein content of the forages (Wilkinson and Londgale 1974; Van Soest 1982). Also through the use of fertilizers water—use efficiency

Table IV. 10. Relationship of various parameters to dry matter intake (DMI) and milk production (Milk)

Independent variable	Equation†	r^2	SE
Nutrient in feed (%)			
Crude protein	DMI = 3.73 + 0.63X	0.78	1.83
Crude protein (below 15%)	DMI = 0.492 + 0.94X	0.78	2.01
Crude protein (above 15%)	DMI = 17.38 - 0.524	0.00	1.50
Nutrient intake			
Dry matter (kg/day)	Milk (kg/day) = 2.27 + 0.95X	0.84	1.54
Digestible energy (MJ/day)	Milk (kg/day) = 6.23 + 1.34X	0.87	5.73
Crude protein (kg/day)			
All forages	Milk (kg/day) = 9.91 + 3.09X	0.87	1.38
Forages (below 15% protein)	Milk (kg/day) = 7.72 + 4.53X	0.99	0.28
Forages (above 15% protein)	Milk (kg/day) = 17.23 + 1.09X	0.07	1.45
In vitro dry matter (kg/day)	Milk (kg/day) = 7.73 + 1.076X	0.81	1.70

† Relationship based on 12 means except for feeds with less or more than 15% crude protein which had 4 and 8 means respectively.

may be improved (Viets 1962; Tisdale and Nelson 1966).

A close relationship ($r^2=0.84$) existed between DM intake and milk production (Table IV.10). This relationship has been reported previously and was also noted in results obtained in the dairy farms survey (section III), but several authors (Blaxter 1964; Fadel 1978; Kleiber 1975; Swan and Broster 1976) are in agreement that intake of digestible energy rather than DM intake has most influence on animal production. A very small improvement was, in fact, obtained in the correlation ($r^2=0.87$) when milk production was related to digestible energy intake. Digestible DM intake, as estimated from in vitro data was also significantly correlated (Table IV.10) with milk production ($r^2=0.81$). Several other relationships were explored: digestible energy content with DM intake and milk production, neutral detergent fiber and acid detergent fiber content with DM intake and milk production; and in vitro DM digestibility with DM intake and milk production. None of these relationships accounted for more than 50% of the variation in observations. Similarly acid detergent fiber was regressed against in vitro DM digestibility and again the relationship was poor ($r^2=0.28$). These results are in contrast to reports that acid detergent fiber and neutral detergent fiber are well correlated with digestibility and intake, respectively (Van Soest 1966). One possible explanation for these contradictory results is that the combination of temperature, light, plant maturity, water, fertilization and plant disease cause a difference in nutritive quality in forages between first cuttings in spring and aftermath cuttings (Van Soest et al. 1978). Also silages were included in the above relationship and the correlation between neutral and acid detergent fiber with silage DM intake and digestibility is not well defined (Tayler and Aston 1976; Thomas et al. 1981).

C. Summary and Conclusions

1) The results from this section were obtained with species of forages which are generally used by farmers of the region in dairy cow rations.

2) The correlation obtained in this study between in vivo and in vitro digestibility ($r^2=0.82$) is considered satisfactory such that differences between forages can be evaluated by the in vitro technique. However, a control of known in vivo digestibility should be included in each in vitro run to improve accuracy.

3) The high correlation found between DM intake and digestible energy intake with milk production could be used for practical ration formulation and for forage evaluation purposes. More information concerning this relationship is needed for higher milk production levels and with higher amounts of concentrate in the ration.

4) Evidence was obtained that a large part of magnesium in alfalfa greenchop might be unavailable to the cows. Magnesium supplementation of this forage should be considered.

5) Copper concentrations in plasma were lower in the summer experiment than in the autumn and winter experiments.

6) Feeding alfalfa either as hay or greenchop resulted in the highest milk production levels, although production was not significantly ($P>0.05$) reduced when annual ryegrass and forage oats were fed. The use of alfalfa greenchop should be examined in terms of labour, forage quality and economy of water usage, since it did not improve milk production above that obtained with alfalfa hay.

7) Milk production during the summer was lower ($P<0.05$) than in the other seasons in these experiments.

8) Percent crude protein in the forage was related to DM intake ($r^2=0.78$), and crude protein intake was highly related to milk production ($r^2=0.99$) for forages containing less than 15% crude protein. The low intake of the summer annuals of low protein content and the increase of DM intake obtained by increased level of protein in the ration suggested that factors influencing the protein content of the summer annual forages should be examined.

V. Optimal Forage Utilization Systems for the Comarca Lagunera Region of Mexico

A. Introduction

Patterns of forage utilization used by farmers in the region have been identified and the forages evaluated in terms of their nutritive value as reported in section III and IV. The objective of research reported in this section was to evaluate forage production and utilization systems for the region on the basis of cost of forage DM and economy of water use by the different forage species.

B: Materials and Methods

Measurements of irrigation water applied to various forage crops and DM yield were obtained from a study carried out by Quiroga et al. (1981) on the research station, located 17 km east of the city of Torreon, Coahuila (Appendix 1). This information was combined to yield an economy of water use index (m^3 of water/kg DM produced). It is important to realize that these water-use efficiency indexes are not absolute values but were obtained with fertilization and water application procedures that were similar to those used by some of the best farmers in the region and where the objective was to maximize DM yield rather than efficiency of water-use. The actual feed cost per kg milk produced in experiments was calculated from data reported in section IV (Table IV.8). Least cost rations were

Table V. 1. Crude protein, digestible energy, calcium, phosphorus and acid detergent fiber content of forage dry matter used for least cost rations for dairy cows†

Forage	Crude Protein (%)	Digestible energy (MJ/kg)	Calcium (%)	Phosphorus (%)	Acid detergent fiber (%)
Alfalfa hay	18.5	12.97	1.70	0.21	37.2
Alfalfa greenchop	21.0	12.97	1.70	0.23	33.4
Corn silage	9.9	12.97	0.[illegible]	0.13	40.4
Sorghum silage	8.5	9.67	0.47	0.12	43.1
Sudan grass	10.0	12.55	0.54	0.33	44.2
Annual ryegrass	18.0	12.55	0.91	0.26	29.0
Forage oats	13.0	12.55	0.49	0.18	29.0
Concentrate (12%)‡	12.0	14.64	0.05	0.35	9.0
Concentrate (16%)‡	16.0	14.64	0.05	0.35	9.0
Mineral mix			23.0	19.0	0

†Mean values of data in Section 3 and Section 4

‡Refers to the percentage protein in the concentrate

computed from data obtained on the nutritive value of forages reported in section III and IV and summarized in Table V.1; crude protein, acid detergent fiber, calcium and phosphorus were averages of the dairy farms surveyed and research station forages whereas digestible energy values were obtained from research station forages. The requirements for a 600 kg lactating cow were obtained from the National Academy of Sciences (1978) bulletin on dairy cattle (Table V.2). Costs assumed for forages and concentrates were based on market prices, and were obtained from the local dairymen's association in the month of September 1983.

Computation of least cost rations was based on a Fortran version of a general linear programming program which was available at the University of Alberta. Linear programming may be defined as the optimization of a linear function subject to specific linear inequalities or equalities (Singh 1977). The linear function may be written as:

Maximize $$Z=\sum_{j=1}^{n} X_j C_j \qquad (1)$$

Subject to

$$\sum_{j=1}^{n} a_{ij} X_j \le b_i \quad (i=1, 2,\ldots n) \qquad (2)$$

$$X_j \ge 0 \quad (j=1, 2,\ldots n) \qquad (3)$$

Where Z is the linear function or the objective function, X_j is the level of activity j(j=1, 2,....n), C_j is the net price or net return from one unit of the j-th activity, b_i is the quantity available of the i-th resource, and a_{ij} is the amount of the i–th resource required by the j–th activity. The goal of linear programming is to maximize the profit or minimize the cost of production by assigning values to and determining the magnitudes of X_j. However, the values assigned to X_j must be consistent with the restrictions expressed in the form of inequalities as in equation (2). In the more specific case of computation of least cost rations the program provides the cheapest nutritionally balanced ration by finding the minimum cost of a combination of ingredients for a given set of specifications. These specifications can contain both nutrient and non–nutrient requirements. The nutrient requirements set restrictions on the maximum and minimum amount of nutrients (i.e. crude protein, calcium, phosphorus). Non–nutrient requirements place restrictions on the maximum and minimum amounts of individual or group of ingredients to be used (i.e. intake, fiber content). In addition the program provides the price ranges (lower and upper limits) of an ingredient, which indicates the price at which a feed would be included in the least cost ration and the extent to which the ingredient price can change without bringing a change in the ration. Other information provided by the program is the marginal value, which represents the cost of restrictions imposed in the program, and indicates the potential change in cost if a restriction is increased by one additional unit in the ration. In the least cost rations prices were assigned to each forage using market rations prices were assigned to each forage using market prices from september 1983. In the optimum rations for the economy of water-use the indexes of economy of water-use for each forage (Appendix 1A) were used in the objective function.

C. Results and Discussion

Feed Cost and Economy of Water Use in Relation to Actual Milk Production

The actual feed cost per kg milk produced was least when diets containing forage oats (5.4 cents/kg milk)and annual ryegrass (5.5 cents/kg milk) along with 3.68 kg concentrate DM were fed (Table V.3). Low feed cost/kg milk produced was also obtained for sudangrass during the summer (6.9 cents/kg milk). Corn silage, sorghum silage and alfalfa greenchop rations were very similar in terms of cost/kg milk produced (8.5–8.8 cents/kg milk). In all the experiments feeding alfalfa hay was more expensive in terms of feed cost/kg milk than any other forage (11.3-14.3 cents/kg milk).

Milk production in the trials conducted at the research station can also be related to the amount of irrigation water required to produce the forage which was fed to the cows. The most irrigation water required to produce 1 kg of milk occurred when alfalfa was fed (0.81–1.02 m^3/kg milk). Sudangrass, annual ryegrass and forage oats were

Table V. 2. Constraints utilized for least cost rations for dairy cows[†]

Parameter		Milk Production kg/cow/day[‡]					
		10	15	20	25	30	35
Digestible energy (MJ)	≥	134.72	162.76	190.79	218.82	246.86	274.89
Crude protein (g)	≥	1309	1719	2129	2539	2949	3359
Calcium (g)	≥	47	60	73	86	99	112
Phosphorus (g)	≥	35	43	52	61	70	78
Acid detergent fiber (g)	≥	2730	3150	3360	3780	3990	4200
Intake (kg DM)	≤	11	12	14	16	18	20
Corn silage (kg DM)	≤	8.0	8.0	8.0	8.0	8.0	8.0
Sorghum silage (kg DM)	≤	7.0	7.0	7.0	7.0	7.0	7.0
Sudan grass (kg DM)	≤	12.0	12.0	12.0	12.0	12.0	12.0

[†]From National Academy of Sciences (1978) and based upon a 600 kg mature cow

[‡]Based upon total (3.2% fat) rather than fat corrected milk.

Table V. 3. Feed cost and economy of water use per kg milk produced for cows being fed winter forages, alfalfa greenchop and alfalfa hay

Parameter	Trial 2		Trial 3		Trial 6	
	Alfalfa hay	Forage oats	Alfalfa hay	Annual ryegrass	Alfalfa hay	Alfalfa greenchop
Forage crop						
DM yield (tonnes/ha)†	21.6	6.4	21.6	10.8	21.6	21.6
Irrigation water applied (M^3/ha)†	25455	5416	25455	9710	26455	25455
Economy of water use (M^3/kg DM)†	1.16	0.85	1.16	0.90	1.16	1.16
Animals						
Forage DM intake (kg)‡	15.9	14.0	15.9	14.0	16.7	16.6
Equivalence in water (M^3)	18.4	11.9	18.4	12.6	19.4	19.3
Milk production (kg)	22.6	20.7	21.8	18.9	21.8	21.4
Equivalence in water/kg milk (M^3)	0.81	0.57	0.84	0.67	0.89	0.90
Economic data§						
Forage cost (¢/kg DM)	12.75	4.07	12.75	4.07	12.75	8.13
Concentrate cost (¢/kg DM)	14.23	14.23	14.23	14.23	14.23	14.23
Fed cost (¢/kg milk)	11.43	5.43	11.32	5.50	12.25	8.83

†Values obtained from appendix 1 tables A3 and A5

‡Values obtained from section IV

§Economic data in Canadian currency, September 1983

Table V. 4. Feed cost and economy of water use per kg milk produced for cows being fed summer forages and alfalfa hay

Parameter	Trial 1		Trial 4		Trial 5	
	Alfalfa hay	Sudan grass	Alfalfa hay	Corn‡ silage	Alfalfa hay	Sorghum‡ silage
Forage crop§						
DM yield (Tonnes/ha)	21.6	16.6	21.6	24.4	21.6	23.4
Irrigation water applied (M^3/ha)	25455	13673	25455	13759	25455	12698
Economy of water-use (M^3/kg DM)	1.16	0.82	1.16	0.56	1.16	0.54
Animals						
Forage DM intake (kg)/	15.9	11.9	19.0	7.6	16.8	6.7
Equivalence in water (M^3)	18.4	9.8	22.0	4.3	19.5	3.6
Milk production (kg)/	18.0	15.1	21.5	13.2	21.8	11.8
Equivalence in water/kg milk (M^3)	1.02	0.65	1.02	0.33	0.89	0.31
Economic data^ρ						
Forage cost (¢/kg DM)	12.75	4.07	12.75	7.32	12.75	7.32
Concentrate cost (¢/kg DM)	14.23	14.23	14.23	14.23	14.23	14.23
Feed cost (¢/kg milk)	14.27	6.88	13.45	8.53	12.31	8.86

†Forage offered as greenchop

‡Two harvests per season

§Values obtained from Appendix 1 Tables A4 and A5

/Values obtained from Section IV

ρEconomic data in Canadian currency, September 1983 intermediate when the feed cost of producing milk was expressed on the basis of irrigation water requirements (Table V.3 and V.4). Corn and sorghum silages rations resulted in the least water requirements per kg milk produced (0.33 and 0.31 m³/kg milk respectively). Corn and sorghum silages cannot be fed as the sole source of roughage at high amounts because of the relatively low DM intake obtained in section IV (7.6 and 6.7 kg/cow/day respectively).

Least Cost Rations for Dairy Cattle

The least cost program provided rations (Tables V.5 and V.6) that would be the most economical for the region at the prices prevailing in September 1983. The rations were considered to be realistic since they were based on the National Academy of Sciences (1978) requirements and since, at least for cows producing 20 kg milk daily, total DM intake was within the limits reported in actual experiments at the research station (Tables V.3 and V.4).

Winter Rations.

A ration based only on annual ryegrass and mineral mix was selected as the cheapest ration for cows producing 10 kg milk daily (Table V.5). This ration gave the least feed cost per kg of milk produced. As the level of milk production increased corn silage, alfalfa hay and concentrate were included in the ration, with the proportion of alfalfa hay and concentrate in the

Table V. 5. Least cost rations for dairy cows during the winter in the Comarca Lagunera region of Mexico

Parameter	Cost ¢/kg DM	Milk produced (kg/cow/day)† 10	15	20	25	30	35
Ingredients (kg DM/day)							
Alfalfa hay	12.75		0.91	1.24	4.31	4.63	4.83
Corn silage	7.32		4.23	3.28	2.47	1.51	0.58
Sorghum silage	7.32						
Annual ryegrass	4.07	10.73	2.29	3.54	1.88	3.14	4.54
Forage oats	4.07						
Concentrate (12%)§	14.23						
Concentrate (16%)§	17.07		4.49	5.86	7.24	8.61	9.94
Mineral mix	25.00	0.03	0.07	0.08	0.09	0.10	0.10
Total in ration (kg DM)		10.76	11.99	14.00	15.99	17.99	19.99
Cost of ration (¢/cow/day)		44.62	130.47	156.25	206.72	232.50	256.77
Feed cost (¢/kg milk)		4.46	8.70	7.81	8.27	7.75	7.33
		LOWER AND UPPER LIMITS FOR PRICES (¢/kg DM)‡					
Alfalfa hay	12.75	4.00	7.6	7.6	7.6	7.6	7.6
Corn silage	7.32	4.02	-160/18.4	-160/18.4	-160/18.4	-160/18.4	-160/18.4
Sorghum silage	7.32	3.02	-43.3	-43.3	-43.3	-43.3	-43.3
Annual ryegrass	4.07	0.34/4.15	0/9.9	0/9.9	0/9.9	0/9.9	0/9.9
Forage oats	4.07	3.99	-6.63[2]	-6.63	-6.63	-6.63	-6.63
Concentrate (12%)§	14.23	4.93	9.24	9.24	9.24	9.24	9.24
Concentrate (16%)§	17.07	4.93	-19.3/22.4	-19.3/22.4	-19.3/22.4	-19.3/22.4	-19.3/22.4

†Total milk production rather than fat corrected milk

‡Prices at which the least cost rations would change

§Percent crude protein in the concentrate ration increasing with milk production.

The forage:concentrate ratio in the least cost rations varied from a 100% roughage ration at 10 kg of milk production to a 50:50 forage:concentrate ratio at 35 kg of milk production. At 20 kg of milk production a 60:40 roughage to concentrate ratio was observed. Experimental results indicate that concentrate levels above 50% in the diet may actually decrease DM intake and milk production (Conrad et al. 1966; Murdock and Hodgson 1969; Tyrrel 1980).

Feed cost per kg of milk produced was highest at the level of 15 kg of milk with a tendency to decrease as the level of milk production increased (Table V.5). The 16% protein content concentrate was selected over the 12% protein although the former was more expensive which indicates that protein was limiting in winter rations because of the inclusion of corn silage. At all levels of milk production annual ryegrass was selected; probably this was because protein content was high (18%) in this forage (Table V.1).

Summer Rations.

Alfalfa greenchop was included in the ration in all instances with corn silage being included at milk production levels above 10 kg/cow/day (Table V.6). An all-roughage ration (sudangrass and alfalfa greenchop) was selected for the production level of 10 kg of milk/cow/day; above this level the amount of alfalfa

Table V. 6. Least cost ration for dairy cows during the Summer in the Comarca Lagunera region of Mexico

Parameter	Cost ¢/kg DM	Milk produced (kg/cow/day)† 10	15	20	25	30	35
Ingredients (kg DM/day)							
Alfalfa hay	10.47	-	-	-	-	1.07	3.29
Alfalfa greenchop	8.13	2.09	3.90	5.53	7.16	8.00	8.00
Corn silage	7.32	-	4.06	3.31	2.57	1.55	0.27
Sorghum silage	7.32	-	-	-	-	-	-
Sudan grass	7.11	8.57	-	-	-	-	-
Concentrate (12%)§	14.23	-	3.95	5.05	6.15	7.24	8.29
Concentrate (16%)§	17.07	-	-	-	-	-	-
Mineral mix	25.00	0.001	0.008	0.01	0.01	0.01	0.01
Total in ration (kg DM)		10.66	11.92	13.90	15.89	17.87	19.86
Cost of ration (¢/cow/day)		77.99	117.84	141.36	164.85	191.02	219.86
Feed cost (¢/kg milk)		7.80	7.86	7.07	6.59	6.37	6.28
		Lower and upper limits for prices (¢/kg·DM)‡					
Alfalfa hay	10.47	7.91	7.97	7.97	7.97	7.96/15.47	7.96/15.47
Alfalfa greenchop	8.13	7.32/11.66	7.45/11.53	7.45/11.53	7.45/11.53	0/11.53	0/11.53
Corn silage	7.32	7.29	-13.0/7.96	-13.0/7.96	-13.0/7.96	-0.69/7.83	-0.69/7.83
Sorghum silage	7.32	5.49	-3.03	-3.03	-3.03	-2.48	-2.48
Sudan grass	7.11	3.79/7.14	6.42	6.42	6.42	6.56	6.56
Concentrate (12%)§	14.23	8.52	8.79/18.98	8.79/18.98	8.79/18.98	9.91/17.41	9.91/17.41
Concentrate (16%)§	17.07	8.60	13.22	13.22	13.22	14.50	14.50

†Total milk (3.2% fat) production rather than far corrected milk

‡Prices at which the least cost rations would change

§Protein content of the concentrate

greenchop and concentrate in the ration increased as the level of milk production increased. Corn silage was also included in rations for higher producing cows which was similar to results obtained with winter forages. The 12% protein concentrate was probably selected for the summer rations because of the inclusion of alfalfa greenchop which is high in protein (21%; Table V.1).

Roughage:concentrate ratios for the summer ranged from 100:00 for the lowest level of milk to 58:42 for the highest level of milk production. The latter ratio was close to 60:40 roughage:concentrate ratio which is reported to result in best performance in dairy cattle rations (Ward and Kelley 1969; Tyrrel 1980). There was a tendency for decreased feed cost per kg milk as level of milk production increased from 15 kg/cow/day to 35 kg/cow/day (7.9 and 6.3 cents/kg milk, respectively).

Optimum Rations for Economy of Water Use

The nutrient requirements and constraints used to compute these rations are the same as the ones used for least cost rations (Tables V.1 and V.2). It was difficult to decide on water-use values for concentrate since no data was available and the ingredients were not grown in the area. Values of 0.50 and 0.51 m^3 water/kg DM produced were selected and used for the 12 and 16% protein concentrates, respectively, on the basis that these economies of water-use were similar to the one obtained for the most water-efficient forage in the area (Appendix 1A). In fact no difference in ration composition was found by changing the water-use indexes from 0.50 to 1.50 m^3/kg DM and only very small changes in ration composition occurred when values of 0 were assumed for the water-use indexes.

Winter Rations.

During the winter, annual ryegrass and corn silage were always included in the water optimization rations. Above 10 kg of milk production/cow/day alfalfa hay was included in the ration. The 16% crude protein concentrate was selected over the 12% protein concentrate and its inclusion in the ration increased as the level of milk production increased. For 10 kg of milk production an all-roughage ration was selected and the economy of water use was greatest in terms of irrigation water applied to forage (0.42 m^3/kg milk produced). At milk production of 15 kg/cow/day the most water was required (0.52 m^3/kg milk) whereas as milk production increased above this level the amount of irrigation water required to produce forage decreased (0.43 m^3/kg milk at 35 kg milk/cow/day; Table V.7).

These optimal water rations were identical to the least cost rations (Table V.5) for the winter period for cows producing over 10 kg milk daily. This is not surprising since corn silage is the cheapest source of digestible energy on the basis of both economy of water use and actual cost.

Table V. 7. Optimum rations for dairy cattle during the winter in terms of economy of water-use in the Comarca Lagunera region of Mexico

Parameter	Water M^3/kg DM	Milk Production (k/cow/day)† 10	15	20	25	30	35
Ingredients (kg DM/day):							
Alfalfa hay	1.16	-	0.91	1.24	4.31	4.63	4.83
Corn silage	0.56	7.04	4.23	3.28	2.47	1.52	0.58
Sorghum silage	0.54	-	-	-	-	-	-
Annual ryegrass	0.90	3.46	2.29	3.54	1.88	3.14	4.54
Forage oats	0.85	-	-	-	-	-	-
Concentrate (12%)§	0.50	-	-	-	-	-	-
Concentrate (16%)§	0.51	-	4.50	5.86	7.24	8.61	9.94
Mineral mix	-	0.01	0.07	0.08	0.09	0.10	0.10
Total in the ration (kg DM)	-	10.51	11.98	14.00	15.99	18.00	19.99
Cost of ration (M^3/day)	-	4.20	7.78	9.45	11.76	13.43	15.08
Feed water cost (M^3/kg milk)	-	0.42	0.52	0.47	0.47	0.45	0.43
			Lower and Upper limits of water use (M^3/kg DM)‡				
Alfalfa hay	1.16	0.94	1.02/-	1.02/-	1.02/-	1.02/-	1.02/-
Corn silage	0.56	0.50/0.68	-3.9/0.97	-3.9/0.97	-3.9/0.97	-3.9/0.97	-3.9/0.97
Sorghum silage	0.54	0.47	0.007	0.007	0.007	0.007	0.007
Annual ryegrass	0.90	0.54/1.00	0/1.00	0/1.00	0/1.00	0/1.00	0/1.00
Forage oats	0.85	0.69	0.41	0.41	0.41	0.41	0.41
Concentrate (12%)§	0.50	0.40	0.13	0.13	0.13	0.13	0.13
Concentrate (16%)§	0.51	0.42	0.12/0.90	0.12/0.90	0.12/0.90	0.12/0.90	0.12/0.90

†Total milk production
‡Prices at which the least cost rations would change
§Protein percent of the concentrate

Summer Rations.

During the summer the only forages selected on the basis of water use were corn silage and alfalfa greenchop. Corn silage was the main ration constituent at levels of milk production of less than 20 kg daily; as milk production increased from 10 to 35 kg, alfalfa greenchop increased from 2 to 6.5 kg daily. The 16% crude protein was selected over the 12% crude protein concentrate because of the low content of protein in corn silage. The roughage:concentrate ratio was about 60:40 at the levels of 15 and 20 kg of milk production but at 35 kg of milk this ratio dropped to 49:51.

A high economy of water use (0.41 m^3/kg milk) was obtained at 10 kg of milk production. At this level of milk production an all-roughage ration based mainly on corn silage could be fed. Above 15 kg of milk production the economy of water use improved from 0.52 m^3 water/kg milk to 0.42 m^3 water/kg milk at a production level of 35 kg/cow/day (Table V.8).

At the level of 10 kg/cow/day of milk production the least cost ration was based mainly on sudangrass and alfalfa greenchop whereas corn silage with alfalfa greenchop was used in the optimal water use rations. At 15 kg of milk per day and higher the least cost and economy of water use rations were similar in that the basal feeds were alfalfa greenchop (with amounts increasing at increased levels of milk production), corn

Table V. 8. Optimum rations for dairy cattle during the summer in terms of economy of water-use in the Comarca Lagunera region of Mexico

Parameter	Water M^3/kg DM	Milk produced (kg/cow/day)†					
		10	15	20	25	30	35
Ingredients (kg DM/day)							
Alfalfa hay	1.16	-	-	-	-	-	-
Alfalfa greenchop	1.16	1.97	2.06	3.18	4.55	5.41	6.54
Corn Silage	0.56	8.93	4.98	4.49	3.88	3.51	3.06
Sorghum silage	0.54	-	-	-	-	-	-
Sudan grass	0.82	-	-	-	-	-	-
Concentrate (12%)§	0.50	-	-	-	0.54	-	-
Concentrate (16%)§	0.51	-	4.88	6.23	6.93	8.95	10.27
Mineral mix	-	0.01	0.01	0.01	0.01	0.01	0.01
Total in ration (kg DM)	-	10.40	11.93	13.91	15.91	17.88	19.88
Cost of ration (M^3/cow/day)	-	4.10	7.78	9.47	11.49	12.91	14.54
Feed water cost (M^3/kg milk)	-	0.41	0.52	0.47	0.46	0.43	0.42
		Upper and Lower limits of water use (M^3/kg DM)‡					
Alfalfa hay	1.16	1.10	1.10	1.10	1.10	1.04	1.04
Alfalfa greenchop	1.16	1.12/1.37	0.59/1.22	0.59/1.22	0.59/1.22	0.82/1.31	0.82/1.31
Corn silage	0.56	0/0.57	0/0.75	0/0.75	0/0.75	0/0.58	0/0.58
Sorghum silage	0.54	-2.30	-2.30	-2.30	-2.30	0.51	0.51
Sudan grass	0.82	0.62	0.63	0.62	0.62	0.62	0.62
Concentrate (12%)§	0.50	0.30	0.30	0.30	0.26/0.69	0.26	0.26
Concentrate (16%)§	0.51	0.34	0.34/0.72	0.34/0.72	0.34/0.72	0.07/0.73	0.07/0.72

† Total milk production

‡ Prices at which the least cost rations would change

§ Protein percent of the concentrate

silage (which decreased with milk production), and concentrate . Subtle differences between the rations were apparent, with slightly less alfalfa greenchop being included in the optimal water use rations as compared to the least cost rations. The close agreement between the rations was somewhat surprising since there was not a close relationship between the price of forage and the index of economy of water use (r^2=0.06).

Marginal Values for Nutrients in Dairy Cattle Rations

Least Cost Rations.

The figures obtained for marginal values (i.e. the change in daily ration cost if one additional unit of nutrient is required) showed that at low levels of milk production during the winter (i.e. 10 kg/cow/day) the energy and phosphorus content of forages were the limiting factors economically (Table V.9). In contrast, during the summer digestible energy was the most expensive dietary component at this level of milk production.

At higher levels of milk production the relative importance of energy, protein and phosphorus in affecting the final cost of the ration can be approximated by calculating the cost of increasing the nutrient content of the ration by 1% (i.e. 1% of nutrient required times the marginal value for the nutrient). If these calculations are done for winter

Table V. 9. Marginal values[†] for winter and summer least cost rations for dairy cows in the Comarca Lagunera region of Mexico

Parameter	Milk Production (kg/cow/day)[‡]					
	10	15	20	25	30	35
Winter:						
Crude protein (g)	0.00	0.20	0.20	0.20	0.20	0.20
Digestible energy (MJ)	0.30	15.56	15.56	15.56	15.56	15.56
Calcium (g)	0.00	0.00	0.00	0.00	0.00	0.00
Phosphorus (g)	0.13	1.52	1.52	1.52	1.52	1.52
Fibre (g)	0.00	0.11	0.12	0.12	0.12	0.12
Intake (kg)	0.00	-264	-264	-264	-264	-264
Mineral mix (kg)	0.00	0.00	0.00	0.00	0.00	0.00
Summer:						
Crude protein (g)	0.01	0.01	0.01	0.01	0.01	0.03
Digestible energy (MJ)	0.50	3.06	3.06	3.06	2.77	2.77
Calcium (g)	0.00	0.00	0.00	0.00	0.00	0.00
Phosphorus (g)	0.01	0.19	0.19	0.19	0.19	0.18
Fibre (g)	0.00	0.00	0.00	0.00	0.00	0.00
Intake (kg)	0.00	-33.3	-33.3	-33.3	-32.4	-32.4
Mineral mix (kg)	0.00	0.00	0.00	0.00	0.00	0.00

[†] Marginal values are defined as the increase in daily ration cost in cents associated with a unit increase in requirement.

[‡] Actual milk produced (3.2% fat) rather than fat corrected milk.

rations the cost of a 1% increase in daily requirements for digestible energy would be 29.3 cents/day for a milk production level of 20 kg/cow/day (i.e. the normal for the region). Comparable costs were 5.1 cents/day for protein and 0.8 cents/day for phosphorus. This indicates that at this production level energy was more economically limiting than protein and phosphorus. To determine the extent to which an increase in energy requirement could influence the type of ration used in the winter actual least cost rations were computed for a cow producing 20 kg milk daily with a 1% increase (1.88 MJ/day) in energy requirement (Table 2A1; Appendix 2). As predicted from the data on marginal values the cost of the ration increased by 29.3 cents/day. The large increase in cost was associated with an increased usage of alfalfa hay and concentrate and a decreased usage of annual ryegrass in the ration.

Marginal values (Table V.9) indicated that the greatest change in daily ration cost per 1% change in constraints could be achieved if potential DM intake was increased by 1% (36.96 cents/day). The actual computation of the winter ration with the 0.14 kg/day greater intake (Table 2A6; Appendix 2) showed a saving of 37.01 cents/day through increased use of annual ryegrass and the inclusion of the 12% protein concentrate instead of the 16% protein concentrate.

During the summer energy was also the most economically limiting factor at all levels of milk production (4.9, 5.8, 6.7, 7.6 and 8.3 cents/day increase in cost for a 1% increase in energy intake at 15, 20, 25, 30 and 35 kg of milk production, respectively, whereas an extra 1% of the requirements of protein cost 0.13, 0.17, 0.24, 0.29 and 0.34 cents/day for these milk production levels). The extent to which the ration would change if a greater intake was assumed can be ascertained from Table 2A6; Appendix 2.

Least Water Rations.

During the winter marginal values indicated that digestible energy was the most expensive factor; there was a cost of 0.30 m^3 of water for a 1% increase in energy in the ration at 20 kg of milk production. An extra 1% protein would cost 0.21 m^3 of water at this level of milk production. DM intake marginal values indicated that a reduction of 0.26 m^3 of irrigation water required to produce forage for 1 day could be obtained if DM intake increased 1% at milk production levels of 20 kg/cow/day (Table 2A7; Appenidx 2).

In the summer, marginal values for the economy of water use again indicated that energy was the most costly factor at high levels of milk production; 0.62 m^3 of water were required for a 1% increase in energy intake at a production level of 20 kg/cow/day whereas an extra 1% protein cost 0.17 m^3 of water. At this production level marginal values indicated that a saving of 0.23 m^3 of water could be achieved for a 1% increase in DM intake. The actual computation of least water ration with the DM intake increased by 1% showed that a saving of 0.22 m^3 of water was obtained by using more corn silage and alfalfa greenchop and less concentrate.

Lower and Upper Limits and Forage Composition

The figures obtained for lower and upper limits (i.e. the limits in price at which the least cost ration would change) for each individual forage are presented in Tables V.5, V.6, V.7 and V.8. Information on how these rations would change if the digestible energy content of the forage in the ration was changed by 5% is given in Table 2A2; Appendix 2 for cows at the normal production level of 20 kg/cow/day. Similar information is given for protein changes in forages in Table 2A4 where rations were calculated using a range of protein in the forage similar to that observed in forages collected in the dairy farms surveyed (Section III).

Winter Rations.

In both least cost and least water rations the feeds selected at 20 kg of milk production/cow/day were alfalfa hay, corn silage and annual ryegrass for the winter. The wide price range (-160 to 18.4 cents/kg DM) found for corn silage and its actual price (7.32 cents/kg DM) indicated that its proportion in the diet would not have changed unless there was a substantial

Table V. 10. Marginal values† for winter and summer optimum rations of economy of water-use in the Comarca Lagunera region of Mexico

Parameter	Milk Production (kg/cow/day) ‡					
	10	15	20	25	30	35
Winter:						
Crude Protein (g)	0.00	0.01	0.01	0.01	0.01	0.01
Digestible energy (MJ)	0.01	0.52	0.69	0.69	0.69	0.69
Calcium (g)	0.00	0.00	0.00	0.00	0.00	0.00
Phosphorus (g)	0.00	0.04	0.06	0.06	0.00	0.00
Fibre (g)	0.00	0.00	0.00	0.00	0.06	0.06
Intake (kg)	0.00	-8.45	-9.27	-11.7	0.00	0.00
Mineral mix (kg)	0.00	0.00	0.00	0.00	-11.7	-11.7
					0.00	0.00
Summer:						
Crude protein (g)	0.01	0.01	0.01	0.01	0.01	0.01
Digestible energy (MJ)	0.00	0.33	0.33	0.62	0.33	0.33
Calcium (g)	0.00	0.00	0.00	0.00	0.00	0.00
Phosphorus (g)	0.00	0.02	0.02	0.04	0.02	0.02
Fibre (g)	0.00	0.00	0.00	0.00	0.00	0.00
Intake (kg)	-0.03	-4.63	-4.63	-8.98	-4.63	-4.63
Mineral mix (kg)	0.00	0.00	0.00	0.00	0.00	0.00

† Increase in daily ration cost in M^3 of water associated with a unit increase in requirement.

‡ Actual milk production (3.2% fat) rather than fat corrected milk.

change in price (Table V.5). A similar conclusion can be drawn concerning the economy of water use index (Table V.7). This is not surprising since corn silage is the cheapest source of digestible energy for both least cost and least water rations and digestible energy was determined to be very expensive in winter rations based on high marginal values. In fact, if the digestible energy content of corn silage was increased by 5% a saving of 23.5 cents/day in least cost rations could be obtained (Table 2A2; Appendix 2) with an increased use of annual ryegrass occurring. If the energy content of annual ryegrass was increased by 5% the ration would be based mainly on this forage (92% of the forage diet) and the cost would decrease by 55 cents/day. In least water rations a 5% increase in the energy content of corn silage and annual ryegrass would result in savings of 0.17 and 0.27 m^3 of irrigation water respectively (Table 2A3; Appendix 2). These observations indicated that more attention should be given to factors influencing the digestible energy content of the winter annual ryegrass grown in the region.

Summer Rations.

Least cost and least water rations for the summer included corn silage and alfalfa greenchop along with concentrate at 20 kg of milk production/cow/day. The negative values of sorghum silage (Tables V.6 and V.8) indicated that dairy farmers would have to be paid to include this forage in the ration.

The wide price range (-13.0 to 7.96 cents/kg DM) found in corn silage in relation to its actual price (7.32 cents/kg DM) indicated that it would be included in the ration at the same level at lower prices but if the price was very much higher its use would decrease. The same situation arose with least water rations. The upper limit of sudangrass (6.42 cents/kg DM) in relation to its actual price (7.11 cents/kg DM) suggests that it could be considered as an alternative crop. The observations that alfalfa hay was almost selected in least water rations at 20 kg milk/cow/day, and that when the protein content of alfalfa greenchop was reduced from 21.2% to 15% it was replaced by alfalfa hay (Table 2A4; Appendix 2), suggested that crude protein content is a very important factor in summer forages. Increased levels of protein in corn silage and alfalfa greenchop (9.9 to 13.2% and 21.2 to 25%, respectively) caused a substantial saving in irrigation water (1.29 and 0.66 m^3 of water/day for corn silage and alfalfa greenchop, respectively).

Optimal Forage Systems

When suggesting an optimum feeding system it is helpful to combine the feasibility of that system, the cost of the diet and the most limiting factors of the region, which in this case is water for irrigation. The data reported in this study indicates that it is very difficult to select only one forage to provide the roughage for dairy rations because: 1) they grow in different seasons of the year, 2) they will have a different relative value depending upon the cost and composition of alternative forages, 3) they will have different relative values at different levels of milk production, and 4) different forages may be selected in least cost and least water rations.

Low Milk Production Levels.

An all-roughage ration based mainly on annuals (annual ryegrass, sudangrass or corn silage) is the most efficient in terms of cost and economy of water use in both summer and winter (Tables V.5, V.6, V.7 and V.8). Such rations can only sustain up to 10 kg of milk production/cow/day, however, and thus unless other costs of milk production are low in relation to feed costs, it is unlikely that rations based only on these forages will be feasible.

Higher Milk Production Levels.

Rations based on concentrate and corn silage, with differing amounts of alfalfa greenchop for different milk production levels in the summer, and in combination with annual ryegrass and alfalfa hay in the winter, may be the best for the area. Increased use of annual forages (annual ryegrass and corn silage) could cause a substantial saving on irrigation water and cost in comparison with the forage utilization pattern actually in use in the area (Table III.5). Despite the relatively high cost and low economy of water use, some alfalfa has to be included in the forage production and utilization patterns of the region basically as a source of protein and because it is eaten in relatively large amounts by dairy cows. Information obtained in section IV also indicates that it supported the highest level of milk production of any of the forages tested. The use of alfalfa in rations for dairy cows, however, should be restricted, at least to the amounts found as optimal. In summer this would be 68% of the forage DM at 20 kg of milk production (in comparison with 82% used by dairy farmers; Table III.5) and in the winter this would be 15% of the forage DM as alfalfa hay (in comparison with 42% of the forage in current winter diets in the area). Utilizing optimum rations could potentially represent savings in cost of 38% in the winter and 44% in the summer and savings in water of 47% in the summer and winter in comparison with rations generally in use for cows producing 20 kg of milk daily. It is expected that the efficiency of water-use could be further improved by using different management practices, although at this time it is unclear whether water-use efficiency could be improved more in some forage species than in others.

D. Summary and Conclusions

1) Based upon research station results feeding diets containing alfalfa hay was more expensive in terms of money and economy of water use than feeding rations based on annual crops.

2) The summer forages selected in least cost and optimum water rations were corn silage and sudangrass along with alfalfa greenchop. Corn silage, annual ryegrass and alfalfa hay were the forages selected for the winter rations.

3) The least cost and least water rations were very similar in composition at milk production levels of 15 kg and above. This occurred even though there was not a close relationship between the price of the forage and the economy of water use of the forages ($r^2=0.06$).

4) Utilizing optimum rations for the region, which would entail a decrease in the use of alfalfa, could represent savings of 38–44% and 47% per kg of milk produced (at 20 kg/cow/day) for cost and irrigation water, respectively, in comparison with rations generally in use.

5) In most instances the 16% crude protein concentrate was selected over the 12% protein concentrate because of the inclusion of corn silage in summer and winter rations.

6) Digestible energy was the most economically limiting factor in lactation rations, except for cows with a daily milk yield of 10 kg during the summer when protein become more important.

VI. General Discussion

Currently farmers in the Comarca Lagunera region of Mexico rely mainly on alfalfa greenchop during the spring and summer months and on annual ryegrass and forage oats along with corn silage and alfalfa hay during the autumn and winter months in rations for dairy cows. The least cost rations for a level of milk production of 10 kg/cow/day were all-roughage rations based mainly on sudangrass with alfalfa greenchop in the summer and on annual ryegrass in the winter. Rations which minimized the use of irrigation water at this level of milk production were based mainly on corn silage along with alfalfa greenchop in the summer and annual ryegrass in the winter. At milk production levels over 15 kg daily least cost and least water rations were almost identical with the use of corn silage being maximized. Least cost rations indicated that a saving of 38% in feed cost could be potentially achieved during the winter in comparison to an all-alfalfa diet at a milk production level of 20 kg/cow/day (normal for dairy cows of the area). The comparable figure for summer diets was a 44% saving. In terms of optimum use of irrigation water a 47% reduction in water requirements could be achieved during the summer if optimum rations rather than alfalfa-based rations were used. Water requirement could be reduced further in all regional forages through more extensive fertilization and improved management practices. However, according to actual experimental results milk production was higher when alfalfa was included in the ration which may tend to justify the use of this forage in dairy rations in this region

Even though sudangrass and forage oats were not included in the least cost or least water rations for milk productions higher than 10 kg/cow/day they could be considered as alternative crops. Sudangrass was included in the summer least cost rations at a production level of 10 kg milk daily, and marginal values indicated that if the price was decreased (or if the quantity of protein in the forage could be increased) it would have been included in the diet at a milk production level of 20 kg/cow/day. On the basis of water usage, however, sudangrass would be less attractive as an alternative crop in the region. Increasing the level of crude protein in forage oats to 20% (i.e. the crude protein content found in the forage at the research station, at a very early stage of maturity) resulted in the replacement of annual ryegrass in least cost rations by forage oats. However, at 18% crude protein content, forage oats would not enter the ration. This suggests that, except for any necessity of growing forage oats for agronomic reasons, it may not be a good forage alternative for the area even though relatively high milk productions were obtained with it as a single forage in the diet (section IV). In the case of sorghum silage, even if the protein or digestible energy contents of this forage were increased by 5% of the original value, it would not be included in least cost or least water rations. This would suggest that less emphasis should be placed on it as a potential forage crop for the region.

It has been shown that it is possible to obtain similar levels of milk production as obtained with alfalfa hay when other forages including corn silage are fed to lactating cows, if these forages are included at a lower proportion of the total diet than used in the present experiments (Thomas 1970; Belyea et al. 1975; Wallenious 1978). Corn silage is relatively low in crude protein, though, and alfalfa greenchop, alfafa hay and annual ryegrass (21, 18.5 and 18% crude protein respectively) were thus included in the ration primarily to balance for protein. Since the protein content of corn silage is considerably below the requirements for the dairy cow, and milk production and DM intake were increased with higher crude protein levels (up to 15%), it is apparent that considerable attention should be given to factors influencing the protein content of the corn silage.

Even though protein is very limiting in dairy cow diets based on corn silage, the marginal values obtained from the least cost and least water rations indicated that digestible energy was the most costly factor to provide in rations. Marginal values also indicated the importance of DM intake. The importance of voluntary intake in high forage diets was further emphasized in results obtained at the research station and in dairy farms where positive relationships (r^2=0.84 and r^2=0.90; respectively) were obtained between DM intake and milk production. There is thus a real need to pursue studies with forages in terms of maximizing the intake of DM and digestible energy.

Even though it was believed that mineral deficiencies might limit milk output from cows fed forage produced in desert areas (Sauchelli 1969; Benson and Matrone 1976), no evidence to support this concept was found in these trials with the exception that phosphorus has to be supplemented (as expected) and that magnesium levels in plasma were low enough to suspect a mild hypomagnesaemia in dairy cows fed alfalfa greenchop. Further studies are needed to examine the incidence of hypomagnesaemia in cows fed this forage and also to determine why the copper status of the cows was apparently influenced by season.

In addition to providing information on optimum forage utilization patterns for dairy farms in the Comarca Lagunera region, research conducted in the course of this study provided additional useful information for the area. Specifically it has been shown that the in vitro technique for estimating digestibility was suitable for grasses and alfalfa hay but further data was required for the technique to be useful with greenchop forages at an early stage of maturity or with silages. Also as a result of this study forages of known in vivo digestibility can be included in the in vitro determinations to improve accuracy of prediction.

A 4.2% greater ($P<0.05$) milk production was observed in winter months than in summer months in dairy farms and this trend was also observed at the research station. This result along with the lower plasma copper content during the summer suggest that more attention could be given to the plant–animal–environmental relationships.

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Appendix 1A

A. Water use by Forage Crops in the Comarca Lagunera Region of Northeastern Mexico

Introduction

This research was performed at the research station of the Comarca Lagunera, located 17 km east of the city of Torreon, Coahuila. Quiroga M., M. Farias, and R. faz conducted the experiments (Quiroga et al. 1981). Martinez R. was the overall leader of the Pasture Management Project.

Materials and Methods

The forage production patterns tested are shown in Table 1A1. Alfalfa was established in a plot of 6120 m^2 and the rest of the forage patterns in plots of 2040 m^2 each. The plan was to simulate as much as possible the irrigation system used by farmers. In the case of alfalfa normally farmers irrigate plots 12 m wide by 50 to 100 m long at one time, whereas for summer annuals they irrigate by 0.90 m wide rows. The amount of water applied does not differ during the summer and winter but the frequency is different; normally for alfalfa the farmers irrigate twice every 30 days in June, July and August (a hot period) and once every 30 days the rest of the year. In this research water was applied to the plots as needed using practical criterion obtained from previous experiments at the research station with the amount of water applied being kept between narrow limits (17–20 cm/irrigation). The criterion for fertilization were: alfalfa, 110 kg of phosphorus /ha/year; corn silage, sorghum silage and sudangrass 120 kg of nitrogen and 60 kg of phosphorus/ha; annual ryegrass and forage oats 80 kg of nitrogen and 60 kg of phosphorus/ha at the establishment and 50 kg of nitrogen/ha every clipping. Seeding and clipping of the forages was conducted with standard equipment available in the region. The criterion for clipping were: alfalfa, early bloom; sudangrass, prebloom; corn and sorghum silage, dough stage; annual ryegrass, immature; forage oats, prebloom.

In all the forage experiments DM production/ha was determined as well as the amount of water applied/ha to each pattern. Using these two values an economy of water-use index (m^3/kg DM produced) was computed by dividing the amount of water applied by the DM yield. The amount of water applied per hectare was measured by a water meter located in the water canal just at the entrance of the experimental plots. The experiments were conducted in a soil which had 62.4% clay, 20.5% sand and 17.1% humus at 0–30 cm depth; at 30–60 cm depth the soil composition was: 53.6% clay, 39.1% sand and 7.3% humus. The pH of the soil was 8.23 at 0–30 cm depth and 8.20 at 30–60 cm depth.

Data obtained from the annual reports 1979, 1980, 1981 (Quiroga 1981) were analyzed by year, by season and by pattern by Martinez R. at the University of Alberta using standard analyses of variance procedures (Steel and Torrie 1980).

Results

The mean temperatures and rainfall during the experimental period at Torreon are presented in Table 1A2. Data on the economy of water use and DM production for individual species are presented in Tables 1A3, and 1A4, whereas data on forage combinations during the whole year are shown in Table 1A5.

Table 1A1. Forage production patterns tested in the Comarca Lagunera region

Forage Pattern	Fall - Winter	Spring - Summer
1	Forage oats	Corn silage - Corn silage
2	Forage oats	Sorghum silage (2 clippings)
3	Forage oats	Sudangrass (4 clippings)
4	Annual ryegrass (3 clippings)	Corn silage - Corn silage
5	Annual ryegrass (3 clippings)	Sorghum silage (2 clippings)
6	Annual ryegrass (3 clippings)	Sudangrass (4 clippings)
7	Annual ryegrass (4 clippings)	Corn silage
8	Annual ryegrass (4 clippings)	Sorghum silage (1 clipping)
9	Alfalfa	Alfalfa

Table 1A2. Monthly mean temperatures and precipitation during 1979, 1980, 1981 in the Comarca Lagunera region of Mexico

	1979†		1980†		1981†		10 years mean*	
	temp. °C	rain (mm)	temp. °C	rain (mm)	temp. °C	rain (mm)	temp °C	rain (mm)
January	13.9	0	15.6	5.3	14.5	53.9	15.5	6.1
February	16.4	0	16.4	9.5	16.8	0.8	17.3	2.8
March	20.2	0	21.1	0	20.3	3.1	20.3	0.2
April	22.5	5.3	22.8	0.2	22.9	68.5	23.6	9.8
May	25.4	4.5	28.3	0	26.5	25.0	27.1	13.8
June	26.2	77.7	30.6	0	29.1	47.0	29.4	24.8
July	27.9	21.4	28.5	4.1	28.1	3.4	27.9	31.5
August	25.9	16.5	26.2	81.3	28.0	32.8	27.3	43.5
September	23.7	1.3	25.2	6.1	24.8	7.5	25.4	45.0
October	22.5	0	21.0	9.5	22.6	15.0	22.5	14.6
November	15.5	5.5	13.9	7.9	15.4	0.0	16.2	6.2
December	14.0	13.4	14.4	0.4	13.1	0.0	14.2	7.5

†Values from monthly climatic data for the world (1979, 1980. 1981)

*Values obtained from Soto and Jauregui (1979).

Table 1A3. Dry matter production, water applied and economy or water use during the fall-winter seasons†

Forage production pattern	Dry matter (tonnes/ha)	Water applied (M^3)/ha	Economy of water usage (M^3/kg DM)
Forage oats (1 clipping)	6.07[cd]	5264[a]	0.87[a]
Forage oats (1 clipping)	5.00[d]	5245[a]	1.11[b]
Forage oats (1 clipping)	6.70[bcd]	5167[a]	0.83[a]
Annual ryegrass (3 clippings)	8.10[bc]	7362[b]	0.91[a]
Annual ryegrass (3 clippings)	6.13[cd]	8061[b]	1.36[c]
Annual ryegrass (3 clippings)	8.77[b]	7652[b]	0.89[a]
Annual ryegrass (4 clippings)	11.83[a]	10820[c]	0.91[a]
Annual ryegrass (4 clippings)	11.87[a]	10657[c]	0.90[a]

† Values are means for 1979, 1980 and 1981.

a,d Means with different letters are significantly different ($P<0.05$)

Table 1A4. Dry matter production, water applied and economy of water use during the Spring-Summer season†

Forage production pattern	Dry matter (tonne/ha)	Water applied (M^3/ha	Economy of water usage (M^3/kg DM)
1. Corn silage - corn silage	24.60[a]	14218[b]	0.58[b]
2. Sorghum silage (2 clippings)	25.03[a]	13267[b]	0.53[b]
3. Sudangrass (4 clippings)	17.17[b]	14499[b]	0.84[c]
4. Corn silage - Corn silage	24.20[a]	13299[b]	0.55[b]
5. Sorghum silage (2 clippings)	21.77[a]	12128[b]	0.56[b]
6. Sudangrass (4 clippings)	15.97[b]	12847[b]	0.80[c]
7. Corn silage (1 clipping)	8.93[c]	7235[a]	0.81[c]
8. Sorghum silage (1 clipping)	15.77[b]	6163[a]	0.39[a]
9. Alfalfa†	-	-	-

†Values are the means of the years 1979, 1980, and 1981

a,c Means with different letters are significantly different

Table 1A5. Dry matter production, water applied and economy or water usage during the whole year†

Forage production pattern	Variables		Economy of water usage (M^3/kg DM)
	Dry matter (tonnes/ha)	Water applied (M^3)/ha	
1. Forage oats - corn silage - corn silage	30.67^{ab}	19482^{bc}	0.64^{ab}
2. Forage oats - Sorghum sialge	30.07^{b}	18512^{abc}	0.62^{ab}
3. Forage oats - Sudangrass	23.87^{c}	19655^{bc}	0.82^{c}
4. Annual ryegrass - corn silage - Corn silage	32.70^{a}	20661^{c}	0.63^{ab}
5. Annual ryegrass - Sorghum silage	27.90^{b}	20219^{bc}	0.73^{b}
6. Annual ryegrass - Sudangrass	24.73^{c}	20499^{c}	0.85^{c}
7. Annual ryegrass - Corn silage	20.77^{d}	18056^{ab}	0.87^{c}
8. Annual ryegrass - Sorghum silage	27.63^{b}	16820^{a}	0.61^{a}
9. Alfalfa	21.55^{d}	25455^{d}	1.16^{d}

†Values and the means of three years (1979, 1980 and 1981)

a,d Means with different letters are significantly different ($P<0.05$)

Appendix 2A

Table 2A1. Least cost winter and summer rations for 600kg dairy cows producing 20kg milk (3.2% fat) daily using different digestible energy requirements

Parameter	Cost (¢ per kg DM)	Digestible energy requirements			
		Winter		Summer	
		179.8MJ/day†	181.6 MJ/day‡	179.8 MJ/day†	181.6 MJ/day‡
Ingredients (kg DM/day)‡					
Alfalfa hay	12.75	1.24	3.48		
Alfalfa greenchop	8.13	-	-	5.53	5.37
Corn silage	7.32	3.28	3.22	3.31	2.63
Annual ryegrass	4.07	3.54	0.59	-	-
Concentrate 12%	14.23	-	-	5.05	5.90
Concentrate 16%	17.07	5.86	6.63	-	-
Total in ration (kg DM)		14.00	14.00	13.90	13.91
Cost of ration (¢/kg DM)		156.25	185.54	141.36	147.13
Feed cost (¢/kg milk)		7.81	9.28	7.07	7.36
		Lower and Upper limits for prices (¢kg DM)§			
Alfalfa hay	12.75	7.6/	7.6/	7.97	7.97
Alfalfa greenchop	8.13	-	-	7.5/11.5	7.5/11.5
Corn silage	7.32	-160/18.4	-160/18.4	-13/7.96	-13/7.96
Annual ryegrass	4.07	0/9.9	0/9.9	-	-
Concentrate (12%)	14.23	9.24	9.24	8.8/18.98	8.8/18.98
Concentrate (16%)	17.07	-19.3/22.4	-19.3/22.4	13.22	13.22

† Requirement for digestible energy for a cow producing 20kg milk (3.2% fat) daily

‡ A 1% increase over requirements

Table 2A2. Least cost winter rations for 600kg dairy cows producing 20kg milk (3.2% fat) using different levels of digestible energy content in the forage

Parameter	Cost (¢ per kg DM)	Digestible energy content of forage (MJ/kg DM)								
		Annual Ryegrass			Corn silage			Alfalfa hay		
		11.92	12.55†	13.18	12.34	12.97†	13.60	12.34	12.97†	13.60
Ingredients (kg DM/day):										
Alfalfa hay,	12.75	2.57	1.24	-	3.64	1.24	-	1.65	1.24	2.73
Corn silage	7.32	3.24	3.28	0.84	3.22	3.28	2.90	3.27	3.28	1.09
Annual ryegrass	4.07	1.79	3.54	9.17	0.38	3.54	5.84	3.00	3.54	5.06
Forage oats	4.07	-	-	-	-	-	-	-	-	-
Concentrate 12%‡	14.23	-	-	3.92	-	-	0.96	-	-	5.05
Concentrate 16%‡	17.07	6.32	5.86	-	6.68	5.86	4.23	6.00	5.86	-
Mineral mix	25.00	0.08	0.08	0.07	0.08	0.08	0.07	0.08	0.08	0.07
Total in ration (kg DM)		14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00
Cost of ration (¢/cow/day		173.69	156.25	100.99	187.65	156.25	132.72	161.62	156.25	137.06
Feed cost (¢/kg milk)		8.68	7.81	5.05	9.38	7.81	6.63	8.08	7.81	6.85
		Lower and Upper Limits for prices (¢/kg DM)‡								
Alfalfa hay	12.75	9.93	9.93	0.78	11.70	7.61	5.52	5.60	7.61	10/18
Corn silage	7.32	-52/11	-16/19	2/311	-173/9	-160/18	3/28	-287/27	-160/18.4	3/9.8
Annual ryegrass	4.07	0/5.9	0/9.9	0/7.3	0/8.2	0/9.9	0/7.9	0/10.9	0/4.9	-5/5.5
Forage oats	4.07	2.33	-6.63	-3.20	-1.20	-6.63	0.11	-12.2	-6.63	2.41
Concentrate (12%)§	14.23	12.13	9.24	-.9/17	13.6	9.24	4.8/16	5.06	9.24	-2/17
Concentrate (16%)§	17.07	-17/19	-19/22	14.23	-18/18	-19/22	14/29	-19/28	-19/22	15.25

†Mean digestible energy content of feed (MJ/kg DM)

‡Prices at which the least cost ration would change

§Protein percent of the concentrate

Table 2A3. Least water winter rations for 600kg dairy cows producing 20kg milk (3.2% fat) using different levels of digestible energy content in the forage

		Digestible energy content of forage (MJ/kg DM)								
	Cost (M^3 per kg DM)	Annual ryegrass			Corn silage			Alfalfa hay		
Parameter		11.92	12.55†	13.18	12.34	12.97†	13.60	12.34	12.97†	13.60
Ingredients (kg DM/day):										
Alfalfa hay	1.16	2.57	1.24	-	3.64	1.24	-	1.65	1.24	6.54
Corn silage	0.54	[illegible]	3.28	3.56	3.22	3.28	3.42	3.27	3.28	4.20
Annual ryegrass	0.90	1.79	3.54	6.02	0.38	3.54	5.51	3.00	3.54	-
Forage oats	0.85	-	-	-	-	-	-	-	-	-
Concentrate (12%)§	0.50	[illegible]	-	-	-	-	-	-	-	-
Concentrate (16%)§	0.51	[illegible]	5.86	4.34	6.68	5.86	4.99	6.00	5.86	3.15
Mineral mix	0.00	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.11
Total in ration (kg DM)		14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00	14.00
Cost of ration (M^3/cow/day)		9.62	9.45	9.18	9.77	9.45	9.28	9.50	9.45	9.36
Feed cost (M^3/kg milk)		0.48	0.47	0.46	0.49	0.47	0.46	0.48	0.47	0.46
		Lower and Upper limits for economy or water use (M^3/kg DM)‡								
Alfalfa hay	1.16	1.02/—	1.02	1.02	1.02	1.02	1.02	1.02	1.02	1.02
Corn silage	0.56	-2.3/0.780	0/0.97	0/0.57	0/0.88	0/0.57	0/0.57	0/1.10	0/0.57	0/0.76
Annual ryegrass	0.90	0/1.00	0/1.00	0/1.00	0/1.00	0/1.00	0/1.00	0/1.00	0/1.00	0.83
Forage oats	0.85	0.50	0.41	0.58	0.47	0.58	0.58	0.35	0.58	0.51
Concentrate (12%)§	0.50	0.16	0.13	0.26	0.17	0.26	0.26	0.08	0.26	0.70
Concentrate (16%)§	0.52	0.13/0.84	0.1/0.90	0.3/0.69	0.1/0.82	0.3/0.70	0.3/0.70	0.1/1.00	0.3/0.70	0.1/0.80

†Mean digestible energy content of the forage (MJ/kg DM)

‡Prices at which the least cost ration would change

§Protein percent of the concentrate

Table 2A4. Least cost summer rations per 600kg dairy cows producing 20kg milk (3.2% fat) using different levels of crude protein in the forage dry matter

Parameter	Crude protein content of forage (% of DM)								
	Corn silage			Alfalfa greenchop			Sudan grass		Sorghum silage
	8.0	9.9†	13.2	15.0	21.2†	25.0	13%	10%†	13%
Ingredients (kg DM/day):									
Alfalfa hay	-	-	-	5.47	-	-	-	-	-
Alfalfa greenchop	6.00	5.53	4.24	3.48	5.53	4.29	5.53	5.53	5.53
Corn silage	2.85	3.31	4.57	-	3.31	4.54	3.31	3.31	3.31
Sudangrass	-	-	-	-	-	-	-	-	-
Sorghum silage	-	-	-	-	-	-	-	-	-
Concentrate (12%)§	5.04	5.05	5.08	4.96	5.05	5.07	5.05	5.05	5.05
Concentrate (16%)§	-	-	-	-	-	-	-	-	-
Total in ration (kg DM)	13.90	13.90	13.90	13.90	13.90	13.90	13.90	13.90	13.90
Cost of ration (¢/cow/day)	141.67	141.36	140.49	146.37	141.36	140.52	141.36	141.36	141.36
Feed cost (¢/kg milk)	7.08	7.07	7.02	7.82	7.07	7.03	7.07	7.07	7.07
	Lower and Upper limits for prices (¢/kg DM)‡								
Alfalfa hay	8.31	8.34	8.42	8.6/12.17	8.34	7.86	8.34	8.34	8.34
Alfalfa greenchop	7.5/9.85	7.5/9.77	7.5/9.59	6.0/9.23	7.5/9.77	7.5/12.72	7.5/9.77	7.5/9.77	7.5/9.77
Corn silage	1.4/7.95	-1.3/7.96	-2.1/7.98	4.57	-1.3/7.96	-29.4/7.96	-1.3/7.96	-1.3/7.96	-1.3/7.96
Sudan grass	6.52	6.42	6.14	3.64	6.42	6.41	6.42	6.42	6.42
Sorghum silage	-2.82	-3.03	-3.65	-8.74	-3.03	-3.06	-3.03	-3.03	-3.03
Concentrate (12%)§	9.7/19.0	8.8/18.98	8.2/18.93	6.2/16.31	8.8/18.98	8.7/19.0	8.8/18.98	8.8/18.98	8.8/18.98
Concentrate (16%)§	13.20	13.22	13.27	15.38	13.22	13.16	13.22	13.22	13.22

†Mean crude protein content of the forage (%)

‡Price at which the least cost ration would change

§Protein percentage of concentrate

Table 2A5. Least water summer ration for 600kg dairy cows producing 20kg milk (3.2% fat) using different levels of crude protein in the forage DM

Parameter	Crude protein in forage (% of DM)								
	Corn silage			Alfalfa greenchop			Sudangrass		Sorghum silage
	8.0	9.9†	13.2	15.0	21.2†	25.0	13%	10%†	13%
Ingredients (kg DM/day):									
Alfalfa hay	-	-	-	-	-	-	-	-	-
Alfalfa greenchop	3.82	3.18	1.41	3.18	3.18	4.29	3.18	3.18	3.18
Corn silage	3.87	4.49	6.21	4.49	4.49	4.54	4.49	4.49	4.49
Sudangrass	-	-	-	-	-	-	-	-	-
Sorghum silage	-	-	-	-	-	-	-	-	-
Concentrate (12%)§	-	-	-	-	-	5.07	-	-	-
Concentrate (16%)§	6.22	6.23	6.28	6.23	6.23	-	6.23	6.23	6.23
Total in ration (kg DM)	13.91	13.90	13.90	13.90	13.90	13.90	13.90	13.90	13.90
Cost of ration (M^3/cow/day)	9.74	9.47	8.18	9.86	9.47	8.81	9.33	9.47	9.29
Feed water cost (M^3/kg milk)	0.49	0.47	0.40	0.49	0.47	0.44	0.46	0.47	0.46
	Lower and Upper limits for economy of water use (M^3/kg DM)‡								
Alfalfa hay	1.05	1.02	0.96	0.85	1.02	0.90	1.02	1.02	1.03
Alfalfa greenchop	0.1/1.30	0.6/1.20	0.7/1.40	1.1/1.50	0.6/1.20	0.9/1.60	0.8/1.20	0.6/1.20	0.6/1.30
Corn silage	0/0.66	0/0.70	0/0.70	0/0.60	0/0.70	0/0.57	0/0.57	0/0.60	0/0.75
Sudangrass	0.72	0.62	0.34	0.64	0.62	0.60	0.80	0.64	0.62
Sorghum silage	0.20	0.49	0.19	0.49	0.49	0.52	0.51	0.49	0.52
Concentrate (12%)§	0.30	0.30	0.18	0.20	0.30	0/0.70	0.26	0.20	0.29
Concentrate (16%)§	0/0.69	0.3/0.7		0/0.80	0.3/0.70	0.40	0.4/0.70	0.3/0.70	0/0.70

† Mean crude protein content (%) of forage
‡ Prices at which least cost rations would change
§ Protein percentage of concentrate

Table 2A6. Least cost winter and summer rations for 600kg dairy cows producing 20kg of milk (3.2% fat) daily assuming different dry matter consumptions†

Parameter	Dry matter intake (kg/cow/day) Winter 14.0†	Winter 14.4†	Winter 14.7†	Summer 14.0†	Summer 14.4†	Summer 14.7†
Ingredients (kg DM/day)						
Alfalfa hay	1.24	-	-	-		
Alfalfa greenchop	-	-	-	5.53	5.57	5.71
Corn silage	3.28	2.27	-	3.31	4.23	7.90
Annual ryegrass	3.54	6.90	11.84	-	-	-
Concentrate (12%)§	-	3.23	2.80	5.05	4.23	0.95
Concentrate (16%)§	5.86	1.67	-	-	-	-
Total in ration (kg DM)	14.00	14.14	14.70	13.90	14.14	14.70
Cost of ration (¢/kg DM)	156.25	119.24	89.54	141.36	136.70	118.1
Feed cost (¢/kg milk)	7.81	5.96	4.48	7.07	6.84	5.90
Lower and Upper limits for prices (¢/kg DM)‡						
Alfalfa hay	7.6	11.5	5.52	7.97	7.96	7.96
Alfalfa greenchop	-	-	-	7.5/11.5	7.5/11.5	7.5/11.5
Corn silage	-160/18.4	-0.1/9.10	5.22	-13/7.96	-13/7.96	-13/7.96
Annual ryegrass	0/9.9	0/7.99	0/4.29	-	-	-
Concentrate (12%)§	9.24	13.4/17.1	4.9/17.1	8.8/18.98	8.8/18.98	8.8/18.98
Concentrate (16%)§	-19.3/22.4	14.2/17.8	14.23	13.22	13.22	13.22

†Required, 1% increase above required, and 5% increase above required, respectively

‡Prices at which ration would change

§Percent protein in concentrate

Table 2A7. Least water winter and summer rations per 600kg dairy cows producing 20kg milk (3.2% fat) using different dry matter intakes

Parameter	Dry matter intake (kg/cow/day)					
	Winter			Summer		
	14.0†	14.14†	14.70†	14.0†	14.14†	14.70†
Ingredients (kg DM/day)						
Alfalfa hay	1.24	-	-	-	-	-
Alfalfa greenchop	-	-	-	3.18	4.32	4.42
Corn silage	3.28	3.93	5.64	4.49	5.46	9.17
Annual ryegrass	3.54	5.56	6.88	-	-	-
Concentrate (12%)§	-	-	-	-	4.24	0.96
Concentrate (16%)§	5.86	4.57	2.07	6.23	-	-
Total in ration (kg DM)	14.00	14.14	14.70	13.91	14.14	14.70
Cost of ration (M^3/kg DM)	9.45	9.19	8.65	9.47	9.25	8.71
Feed water cost (M^3/kg milk)	0.47	0.45	0.43	0.47	0.46	0.43
	Lower and Upper limits for economy of water use (M^3/kg DM)‡					
Alfalfa hay	1.02	1.02	1.02	1.02	1.02	1.02
Alfalfa greenchop	-	-	-	0.6/1.20	0.8/1.30	0.8/1.30
Corn silage	0/0.90	0/0.57	0/0.57	0/0.70	0/0.58	0/0.58
Annual ryegrass§	0/1.00	0.7/1.00	0.7/1.00	—	—	—
Concentrate (12%)§	0.13	0.26	0.26	0.30	0.27	0/0.60
Concentrate (16%)§	0.1/0.90	0.3/0.69	0.3/0.69	0.3/0.70	0/0.70	0.40

†Required, 1% increase above requirement, and 5% increase above requirement, respectively

‡Value at which ration would change

§Percent protein in the concentrate