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Contribution of trees to the control of heat stress in dairy cows and the financial viability of livestock farms in humid tropics

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TROPICAL AGRICULTURAL RESEARCH AND HIGHER EDUCATION CENTER

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Contribution of trees to the control of heat stress in dairy cows and the financial viability of livestock farms in humid tropics

by

Maria Helena Souza de Abreu

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CONTRIBUTION OF TREES TO THE CONTROL OF HEAT STRESS IN DAIRY COWS AND THE FINANCIAL VIABILITY OF LIVESTOCK FARMS IN HUMID TROPICS.

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ABSTRACT

This dissertation addresses two themes: the effect of shade trees in controlling heat stress in dairy cows and the contribution of trees dispersed in pastures to the financial viability of livestock farms in La Fortuna, San Carlos, Costa Rica. No quantitative data could be found on the effect of shade trees on milk production of cows grazing in pastures in Costa Rica and few studies have been carried out on dispersed trees in pastures according to the type of animal system and their financial contribution to cattle farms.

To analyse the effect of natural shaded pastures on performance of dairy cattle, eight Jersey cows were assigned to two shade levels each (shade vs. no shade) during two defined seasons. Data on climatic variables, rectal temperature, respiration rate, milk production and composition, progesterone levels and feed intake were recorded. The data from this study show that the Jersey cows' compensatory mechanisms in the shade treatment prevented a significant reduction in milk production, progesterone level and feed intake. Better performance and comfort of the Jersey cows in the shade treatment were observed, justifying the beneficial effect of natural shade in pastures for this region.

To understand the role of trees dispersed in pastures and their financial contribution to cattle farms, three types of animal production systems were studied: mixed (dairy and agriculture), specialized milk and dual purpose systems (milk and meat). The area of pasture with trees was higher in dual purpose systems, predominantly the tree species laurel (*Cordia alliodora*). On average the density of trees dispersed in pasture of all animal systems was low (11 trees ha^{-1}). In specialised milk systems, a significantly higher density of shade trees was found than in the other systems. The dual-purpose system presented the greatest abundance of laurel with small diameters, assuring a sustainable natural regeneration of this species, and the greatest merchantable volume of laurel (2.21 m^3 ha^{-1}). The highest net present value (US$ 256.18 ha^{-1}) was found in the dual-purpose systems. The average income from milk production in all three systems contributed the most to the total gross income (49.8%), while the average income from wood only made a small contribution (1.0%).

Trees dispersed in pastures currently play an important role in providing shade for the animals and consequently improving the animal performance, but in order to improve animal productivity even more, the density of shade trees in pastures should be increased. The contribution of timber trees dispersed in pastures to the total income is still small and this justifies encouraging large-scale natural regeneration and recommending silvicultural treatments which in the future would be beneficial to cattle farmers in the region.

Keywords: animal performance, Costa Rica, financial analysis, silvopastoral systems, shade trees, timber trees

RESUMEN

La presente disertación trata de dos temas: 1) el efecto de los árboles de sombra sobre el control del estrés calórico en el ganado de leche y 2) la contribución de los árboles dispersos en los pastizales para la viabilidad financiera de las fincas ganaderas en La Fortuna, San Carlos, Costa Rica. No se pudieron encontrar datos cuantitativos sobre el efecto de los árboles de sombra en la producción de leche de vacas en pastoreo en Costa Rica y son pocos los estudios que se han realizado sobre árboles dispersos en pastizales de acuerdo al sistema de manejo animal y su contribución financiera a las fincas ganaderas.

Con el fin de analizar el efecto de los pastizales con sombras naturales sobre el desempeño del ganadero lechero, se asignaron ocho vacas Jersey a dos niveles de sombra cada uno (sombra vs. sin sombra) durante dos períodos definidos. Se levantaron datos sobre variables climáticas, temperatura rectal, tasa respiratoria, producción y composición de la leche, niveles de progesterona y consumo de forraje. Los datos del presente estudio muestran que los mecanismos compensatorios de las vacas Jersey en el tratamiento bajo sombra previnieron una significativa reducción en la producción de leche, en los niveles de progesterona y en el consumo de forraje. Se observó un mejor desempeño y mejores niveles de bienestar en las vacas Jersey en el tratamiento con sombra, lo cual justifica el efecto benéfico de la sombra natural en los pastizales de esta región.

Con el fin de entender la función de los árboles dispersos en pastizales y su contribución financiera a las fincas ganaderas, se evaluaron tres sistemas de producción animal: mixto (ganadería y agricultura), especializado en leche y doble propósito (leche y carne). El área de pastizales con árboles fue mayor en el sistema doble propósito, predominando la especie arbórea laurel (*Cordia alliodora*). La densidad promedio de árboles dispersos en pastizales para todos los sistemas de producción animal fue baja (11 árboles ha^{-1}). En el sistema especializado en leche se encontró una densidad significativamente más alta de árboles de sombra que en los otros dos sistemas. El sistema doble propósito presentó la mayor abundancia de laurel con diámetros menores, asegurando una regeneración natural sostenible de esta especie; además este sistema mostró el mayor volumen comercial (2.21 m^3 ha^{-1}). El mayor valor actual neto (US$ 256.18 ha^{-1}) se presentó en los sistemas doble propósito. El ingreso promedio proveniente de la producción de leche contribuyó con el mayor ingreso bruto en los tres sistemas (49.8%), mientras que el ingreso promedio proveniente de la madera sólo representó una pequeña contribución (1.0%).

Actualmente los árboles dispersos en pastizales cumplen una función importante en la provisión de sombra para los animales y consecuentemente en el mejoramiento del desempeño de los animales. Sin embargo, con el fin de mejorar aún más la productividad animal, la densidad de árboles de sombra debería ser incrementada. La contribución de árboles maderables dispersos en los pastizales al ingreso total de la finca aún es baja, lo cual justifica el fomento de regeneración natural a gran escala y la recomendación de tratamientos silviculturales que en el futuro serían beneficiosos para los ganaderos de la región.

Keywords: desempeño animal, Costa Rica, análisis financiero, sistemas silvopastoriles, árboles de sombra, árboles maderables

DEDICATION

This dissertation is dedicated to my mother Terezinha Ferreira Souza and to my father Marcello Alves de Abreu (*in memoriam*), who never failed to support my education; to my husband, Patrick Spittler, who with emotional support and providing basic forestry knowledge joined with me in all my struggles and efforts; and to my son Gabriel, who during the last two years accompanied me without complaining during the conception of this thesis.

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BIOGRAPHY

Maria Helena Souza de Abreu was born in Rio de Janeiro (Brazil) on March 1st, 1966. She spent her childhood in Brasilia, where she concluded her elementary and high school. In January 1988, she obtained a Diploma in Veterinary Medicine at the Federal University of Viçosa in Minas Gerais, Brazil.

As a graduated professional she worked in the documentation center and in animal production projects at the Brazilian NGO AS-PTA (Assesoria e Serviços a Projetos em Agricultura Alternativa). In December 1994 she obtained her master degree in tropical animal production at the University of Goettingen in Germany.

Her current professional interests include silvopastoral systems, animal bioclimatology, integration of animal production in agricultural systems, veterinary ethnology, animal ethology and rural development.

This thesis consists of a summary part and two manuscripts which are referred to by roman numerals in the summary part.

Dissertation summary

Paper I: Shade trees and dairy cattle performance in humid tropics: physiological and productive responses (Prepared to be submitted for publication to Agroforestry Systems)

Paper II: Trees dispersed in pastures and their financial contribution to livestock farms in Costa Rica (Prepared to be submitted for publication to Agroforestry Systems)

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Paper II

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Paper I

Paper II

LIST OF ACRONYMS

ANOVA	Analysis of variance
AU	Animal unit
b	standard partial regression coefficient
BCR	Benefit-cost ratio
DAAD	German Academic Exchange Service
D	Dry bulb temperature
dbh	stem diameter at 1.30 m breast height
DM	Dry matter
GLM	General linear model
i	discount rate
MAG	Costa Rican Ministry of Agriculture and Livestock
m a.s.l.	metres above sea level
μ	true mean of observations
n	number of observations or sample size
NGO	Non Governmental Organization
NPV	Net present value
ns	not significant
PAR	Photosynthetic solar radiation
r	Coefficient of correlation
R^2	Coefficient of determination
RR	Respiration rate
RT	Rectal temperature
SAS	Statistical Analysis System
SD	Standard deviation
SEM	Standard error of the mean
THI	Temperature Humidity Index
THI-pd	THI the previous day
THI-sd	THI the same day
T-pd	Ambient temperature the previous day
T-sd	Ambient temperature the same day
W	Wet bulb temperature

CONTENTS

1. Introduction

This thesis is based on two papers, which will be referred to in the dissertation summary by their Roman numbers.

1.1 The role of dispersed trees in pastures

Trees dispersed or isolated in pastures are considered a type of silvopastoral system, when the grazing systems in which trees are present play an interactive role in animal production (for example, by providing shade to animals, promoting pasture growth, and providing tree fodder or other tree products). Interactions between the components (trees, pastures, and livestock) determine the functional importance of a silvopastoral system (Pezo and Ibrahim, 1996).

Isolated trees are a common feature of present agricultural landscapes throughout the tropics (Guevara et al., 1998; Harvey and Haber, 1999). In Costa Rica, more than 90% of cattle farms surveyed have dispersed trees in pastures which provide shade for animals and contribute directly to farm income, e.g. through the sale of timber, fruits, etc. (Leeuwen and Hofstede, 1995; Ibrahim et al., 1998).

Leeuwen and Hofstede (1995) in an evaluation of silvopastoral systems in the Atlantic Zone of Costa Rica reported, that trees can be considered as a rest factor in silvopastoral systems and in land use in general. The tree component can be found as dispersed trees in the pasture as well as live fence post used to demarcate the farm and plots. The average number of dispersed trees in the pasture is impossible to assess by interviews, since farmers usually mention less trees than can be observed in the field. Among the reasons for leaving or planting dispersed trees in the pasture, are the supply of shade and timber.

For many years farmers of Costa Rica have been setting up and developing agroforestry systems, following an empirical model, which seem to be in harmony with the environment. This fact shows the importance of describing and understanding such systems, so that they can be used as patterns in other areas, where similar components are found (Russo, 1994).

Most of the current work on silvopastoral systems is concerned with the use of tree foliage for feeding animals and the study of relationships between trees and pastures. However, a silvopastoral system, in which the trees can be grown in wide distribution with livestock grazing beneath their canopy, could provide shelter for the animals as well as producing high quality timber. The effect of such a system on the productive performance of animals has hardly been researched (McArthur, 1991).

1.2 Problem statement

In Central America, animal production on pastures is the main land use activity in terms of area used. Approximately 26% of the land (13 million ha) is currently under pastures and in many areas pastures are still expanding (FAOSTATS, 1997; CCAD, 1998). The 1991 cattle census of Costa Rica showed that total cattle population was 1.8 million heads of which 1.0 million were for beef production, 484.000 for dual purpose production (milk and meat) and 308.000 for intensive dairy production (Beck, 1995).

Large scale deforestation in Central America occurred between 1950 and 1986, primarily for cattle ranching which was driven mainly by inadequate land use tenure policies, cheap credit and high prices paid for beef (Kaimowitz, 1996). Cattle ranching is practiced on expansive lands with little use of inputs and inappropriate pasture management. In these systems, animal breeds (Brahman, Indubrasil, Nelore and Gir) that are adapted to harsh environmental conditions are selected.

Specialised dairying however is normally carried out in highlands areas (1300 meters above sea level), where climatic conditions are more favourable for milk production. In Costa Rica, specialised dairying systems are found in the Central Highland and the volcano areas of Poás, Irazú and Turrialba (Ibrahim et al., 1998). In these production systems, exotic breeds (i.e. Holstein and Jersey), capable of producing high milk yields (3500 to 6000 kg per lactation), were introduced (French, 1994). In the highland areas, temperatures vary between 7.5 to 20.5 °C and relative humidity between 40 and 90%. Under these climatic conditions exotic breeds generally do not suffer severe heat stress, since these are more favourable for animal comfort.

However, in many Central American countries, dairying is carried out in the low lands, which are characterized, by high rainfall (above 2000 mm year^{-1}), high relative humidities (above 70%) and high air temperatures (above 25 °C). In Costa Rica much of the dairy farms has moved to San Carlos (130 to 900 m a.s.l.) and Rio Frio (100 to 150 m a.s.l.) where mean temperature and relative humidity are higher than 25 °C and 85% respectively and the milk production fluctuates between 1900 and 2500 kg per lactation (Holmann et al., 1992; French, 1994). The reasons for this displacement are the eruption of volcanoes, increased land prices, the growth of non traditional crops like ornamental flowers and strawberries for export and for urbanisation (Beck, 1995).

In the lowlands, exotic dairy breeds (i.e., Holstein and Jersey) that are very susceptible to heat stress, are affected by parasites and diseases and have high nutrient requirements for maintenance and production are commonly used. Dual purpose systems are very common in the tropical lowlands and in these systems the main breeds are Brown Swiss and crossbred animals (European breeds with Brahman) that are more tolerant to climatic stress.

In general, low milk yields are obtained from the lowland areas, which is to due to improper feeding practices, the effect of climatic stress and problems of diseases and parasites. The exotic breeds are shown to suffer more from heat stress, which results in reduced feed intake and reduced efficiency of feed utilization. Heat stress is also known to be associated with reproductive disorders, e.g. infertility due to high body temperature (Finch, 1984). In the lowlands, even dual purpose crossbreeds (Holstein × Brahman; Brown Swiss × Brahman) and Brahman cattle are known to suffer from heat stress, especially on days with high temperatures and relative humidity

In general cattle, especially the more efficient exotic dairy breeds, require lower temperatures in the paddock area and therefore properly managed trees can play an important role in providing shade to reduce environmental stress. Shade trees can be used to improve the microclimate, reduce incidence of the solar radiation and consequently the heat stress of cattle.

Experience with different pasture systems showed that DM (dry matter) intake and the efficiency of feed utilization by cattle was increased when animals grazed silvopastoral systems where trees provided shade. Animals grazing in silvopastoral systems had lower body and rectal temperatures when compared to animals grazing in open grassland (Davison et al., 1988).

During the colonization of Latin America, most valuable timber and shade trees were cleared to establish grass monoculture. However, farmers today are more conscious of the role trees play in providing shade for animals and also of the economic value of precious timber trees (Viera and Barrios, 1997). In Costa Rica, shade trees are found dispersed in pastures in more than 90% of cattle farms. In the humid tropics the main species that are found in pastures are *Cedrela odorata* (cedro) and *Cordia alliodora* (laurel) and they provide shade and produce timber (CATIE, 1991).

Although trees are generally used to provide shade for animals there is practically no research to quantify the effects of shade trees on animal performance. A large volume of literature is devoted to studies of the effects of temperature, water, humidity, air movement and day length on animals, but the majority of these studies were conducted under artificial conditions to simulate climatic conditions (ambient temperature, relative humidity, wind, etc.). Of particular interest are studies of the direct response to climatic elements that address appetite, feed intake, grazing time, growth, and milk production in pastures and rangelands in warm climates (Heady, 1984). Results from studies conducted under artificial conditions cannot be extrapolated to field conditions such as the presence of tree in pastures, because of these heterogeneous environmental conditions including the simultaneous effect of solar radiation, ambient temperature, wind speed, within others.

This study was conducted in the lowlands of San Carlos, Costa Rica to determine the role of trees in controlling heat stress and in improving productive and reproductive parameters of dairy animals managed with semi-intensive grazing. Additionally, the contribution of trees to the financial viability of livestock farms was evaluated.

1.3 Research objectives

1. To describe and analyse the effect of the main meteorological variables (air temperature, humidity, solar radiation and THI (Temperature Humidity Index) on dairy cattle managed semi-intensively and on their thermoregulatory mechanisms, as well as to discuss the influence of shade trees on heat stress control and consequently on animal productivity and reproductive performance.
2. To evaluate the effect of shade trees on the feed intake of milk cows under a silvopastoral system.
3. To understand the role of trees in pastures and their financial contribution to the silvopastoral system, including the profitability to cattle farmers of milk and meat production, as well as wood production.

1.4 Hypotheses

The study was designed to test the following three hypotheses:

- The integration of shade trees in silvopastoral systems contributes to the improvement of productive and reproductive parameters of cattle.
- The shade trees have a positive influence on the feed intake of milk cows under a silvopastoral system.
- Trees in pastures contribute to the financial viability of livestock farms

2. Theoretical framework

2.1 Silvopastoral systems

A silvopastoral system is a type of animal production system that involves the integration of trees or shrubs with the traditional components of animal production (pasture and animals), and all components are managed as a single unit, that tends to improve the productivity and net benefits of the system on a long term basis (Somarriba, 1992; Somarriba et al., 1998). According to Leeuwen and Hofstede (1995) the silvopastoral system is a specific form of agroforestry, which encompasses the combination of pastures, with animals and trees on a certain piece of land. Its main components are trees and shrubs, herbaceous grasses and legumes, animals and man, together with the environmental factors of climate, soils and land form. The principal inputs of this system are: solar radiation, precipitation, seeds, labour and veterinary products; main outputs are animal and tree products and services (N_2 and CO_2 fixation, biodiversity, water, etc.), but the type and quantity of outputs depend on the components and the interaction between them (Russo, 1994). Interactions between the components determine the functional importance of a silvopastoral system. These can be either positive, for instance, trees provide shade and forage for cattle, while benefiting from the fertilizing effect of manure, or negative, for instance, tree crowns diminish light intensity for photosynthesis of the pasture.

Within this broad category, several types of systems and practices can be identified depending on the role or function of the woody component (Pezo and Ibrahim, 1996; Somarriba et. al., 1998). These include the following:

- Intensively managed

a) Protein or energy banks: The shrub species are grown densely in block configurations or along plot boundaries; the foliage is lopped periodically and fed to animals that are kept in stalls. Alternatively, livestock may browse these fodder banks.

b) Live fence post: Multipurpose tress are left to grow to develop sufficient wood so that they serve as fence posts around grazing units; the trees are lopped periodically for fodder and for poles or they are managed to provide shade for animals.

- Extensively managed

a) Browsing: Foliage (especially tender twigs, stems, and leaves) and sometimes fruits and pods of standing shrubs are consumed.

b) Trees dispersed in pastures: These systems generally consist of a diversity of woody species and a heterogeneous structure vertically and horizontally. Animals graze on the plants that are usually herbaceous species, but in the dry seasons wood species are important source of animal feed. Only those grazing systems in which trees are present and play an interactive role in animal production (for example, by providing shade to animals, promoting grass growth, and providing tree fodder or other tree products) are considered as silvopastoral systems.

According to Gregory (1995) there are five types of woodland shelter that are used for protecting livestock - shadebelts, woodlot blocks, forest grazing, tree-pasture, and shelterbelts. The term agroforestry usually refers to woodlot blocks, tree-pasture and forest grazing, where the trees are also being grown for timber. Sheep, cattle and deer have been farmed successfully in tree-pasture systems. Three functions of tree-pasture systems are to (1) provide shade for stock; (2) supply farm timber and fencing material at low cost; and (3) provide revenue from felled timber.

This present revision is focused on the role of dispersed trees in pastures in alleviating animal heat stress and the contribution of trees to the financial viability of livestock farms.

2.2 Heat stress in warm climates

Milk production in warm climates is a function of nutrition, health, genetic merit, management and climate Although nutrition plays an over-riding role in warm climates, heat (thermal) stress and its inter-relationships with other functions constitute major determining factors in animal performance (Beede et al., 1985; Pagot, 1993). Several environmental stress factors in warm climates cause physiological strain in animals, including air temperature, solar radiation and humidity (Hafez, 1973; Payne, 1992). Elevated ambient air temperatures contribute most to thermal stress, particularly in conjunction with high solar radiation, high humidity and low wind movement.

The thermoneutral zone for optimal animal performance and health is defined as the range of ambient temperatures over which metabolic heat production remains constant (Mount, 1979). However, when ambient temperatures exceed the upper critical temperature, the animal must employ physiological heat dissipation mechanisms such as sweating and panting (evaporative heat loss) to maintain homeothermy. According to Fuquay (1981) the upper critical ambient temperature for the lactating cow falls between 24 to 27 °C.

At and above an upper critical temperature the heat gain from environment and metabolism is greater than heat loss and heat stress results. Heat stress induces a thermoregulatory strain (e.g. displacement of body core temperature), which results in physiological adaptations. Amongst these, reduced feed intake, decreased metabolic rate, elevated sweating, increased respiration rates, changes in blood hormone concentrations and redistribution of total blood flow may affect body metabolism. These adaptations are survival strategies and are not necessarily geared for high production (Beede et al., 1985). Animals under heat stress dissipate heat by increasing their respiration rate and sweating and measurements of these parameters together with pulse rate and rectal temperature have been used to assess the tolerance of cattle to adverse climatic conditions (Hahn, 1999). Lemerle and Goddard (1986) noted that respiration rate and rectal temperatures appeared to be more sensitive indicators of heat stress than pulse rate. Studies conducted by Smith and Matthewman (1986) with four lactating Friesian cows showed that rectal temperature and respiration rate increased dramatically and the heart rate showed no change due to heat exposure. In practice, the heat stress of dairy cows can be assessed from their breathing pattern. When dairy cows suffer from heat stress, they usually increase their frequency and decrease their depth of respiration. This increases air movement over the turbinate bones in the nose, which provide a cooling surface without causing hyperventilation. Normal respiration frequency is between 30 and 60 breaths min^{-1}, and above 60 indicates that the cow is probably beginning to feel hot (Hansen, 1990; Webster, 1993).

McDowell (1972) introduced the temperature humidity index (THI) as an indicator of adverse climatic conditions. THI is produced from a combination of wet and dry bulb air temperatures for a particular day. THI values of 70 or less are considered comfortable, 75 to 78 stressful and at values greater than 78 extreme distress occurs and animals are unable to maintain thermoregulatory mechanisms or normal body temperature. Various researchers have used THI to relate climatic conditions to animal performance (Kabuga, 1992; Hall et al., 1999). THI can be calculated using the equation of McDowell (1972): $THI = 0.72 (W°C + D°C) + 40.6$, where W°C is wet bulb temperature and D°C is dry bulb temperature.

Research conducted by Lemerle and Goddard (1986) in Papua New Guinea showed that rectal temperature of dairy cattle increased when THI was greater than 80, while respiration rate started to increase with a THI value of about 73 and probably more steeply above 80. The authors suggested that homeostatic mechanisms including increased respiration rate can prevent an appreciable rise in rectal temperature until THI reaches 80. This is similar to the critical THI level of 78 quoted by McDowell (1972).

Heat stress affects both lactation and reproductive performance in dairy cattle (Ingraham et al., 1974; Hansen and Aréchiga, 1999), but evidence suggests that there are differences between cattle breeds in their degree of heat tolerance (Collier et al., 1981). In general, temperate dairy breeds (Holstein, Brown Swiss and Jersey) show a greater percentage reduction in milk yields compared to Brahman cows when they are managed under environmental conditions where ambient temperatures are greater than 27 °C (Ragsdale et al., 1950). However, Vaught et al. (1977) found that the effect of heat stress is greater in lactating cows than in dry cows; Ingraham et al. (1974; 1976) stated that the response varies according to the degree of stress and Turner (1982) stated that the response is influenced by breed and genotype within a breed.

Heat stress is also associated with reduced conception rates during the hot season in tropical and subtropical regions. Studies conducted in Hawaii and Mexico showed that there is a significant negative association between heat stress and fertility and even a relatively short period of stress at the time of mating causes a considerable decrease in the proportion of pregnancies (Ingraham et al., 1974, 1976). A reduction in the proportion of pregnancies was associated with an increase in rectal and uterine temperatures (Roman-Ponce et al., 1977). Physiological studies with cattle conducted by Rosenberg et al. (1977) showed that there was a relationship between progesterone profile in the oestrous cycle before insemination and conception rates. Those animals with higher concentrations of progesterone had a greater probability of establishing a successful pregnancy. This association may reflect an influence of progesterone before mating, or it may be that animals with high concentrations of progesterone in one cycle tend to have similar concentrations in later cycles. There are contradictory results of the effect of heat stress on progesterone levels of cows (Wilmut, 1985). Studies carried out in Arizona and Israel showed that heat stress was associated with reduced concentrations of progesterone (Stott and Wiersma, 1973; Rosenberg et al., 1977; Rosenberg et al., 1982). In contrast, a detailed hormonal study conducted in Florida with four lactating cows exposed to sun and five provided with shade showed that progesterone concentrations were higher in the heat stressed animals during the luteal phase (Gwazdauskas et al., 1981). The authors noted that the elevated levels of progesterone were within the range previously accepted as normal.

High temperatures are also known to have negative effects on feed intake and milk yield (Beede et al., 1985). A decline in feed consumption becomes evident at 25 to 27 °C with a marked decline occurring above 30 °C (National Research Council, 1981). At 40 °C intake is usually no more than 60% of that observed at an index temperature range of 18 to 20 °C (McDowell et al., 1969). According to Flamenbaum et al. (1986) when ambient temperature is greater than 23 °C and relative humidity is above 80%, cows begin to experience heat-induced depression of feed intake leading to an associated decline in productivity. According to Collier (1982a), with reduced feed intake, consumption of absolute amounts of essential nutrients and energy are decreased unless their dietary densities are increased proportionately. Several physiological reactions to heat stress are responsible for reduced intake. Foremost is a need to decrease metabolic heat production. Additionally, increased respiration rates and water intake, reduced gut motility and rate of passage of ingesta and a direct negative effect of elevated temperatures on the appetite centre of the hypothalamus are key factors. McDowell et al. (1969) reported that decreased feed consumption would result in corresponding declines in metabolisable energy (ME) intake. Although the digestibility of dietary energy and fibre are enhanced slightly in a hotter climate, the efficiency of utilization of energy for milk production is reduced by 30 to 50%. This effect is due to the higher maintenance requirements of heat-stressed cows (elevated body metabolism to support enhanced respiration rates to alleviate excess heat load) and lower production caused partly by reduced intake of energy and nutrients.

Heat stress is also associated with changes in milk composition (Beede et al., 1985; Webster, 1993). A review by Thatcher and Collier (1982) indicated that environmental temperatures ranging from -1 to 23.9 °C had little influence on milk composition. However, under hot room conditions, temperatures between 29.5 and 40.6 °C resulted in lower solid-non-fat (SNF), protein and lactose contents, but increased fat content (Cobble and Herman, 1951). However, studies by other authors reported that milk fat content declines with higher room temperatures (Hancock, 1954), although it is difficult to disentangle the direct and indirect effects of climate (Williamson and Payne, 1989). High environmental temperature seems to have a greater influence on SNF content than on milk fat (Beede et al., 1985).

2.3 Tree shade

According to Beede et al. (1985) and Shearer et al. (1999) there are three principal methods available for attenuating the effects of thermal stress on milk yield. These are modifying the environment so as to reduce heat by physical protection (McArthur, 1991; Gregory, 1995), the manipulation of the diet and related nutritional management strategies and the genetic development of less heat-sensitive animals, taking into consideration the viability of this last method. Some relief may be afforded to animals by partially controlling incoming thermal radiation using shade structures (Roman-Ponce et al., 1977). This approach does not change the air temperature or humidity of the surroundings (Buffington et al., 1983). However, shade structures can be effective in reducing radiant heat load by 30% or more by intercepting direct solar radiation (Bond et al., 1967). Results from various studies have shown that milk yields of cows increased by 5 to 13% when they were provided with shade (Roman-Ponce et al., 1977; Collier et al., 1981; Collier et al., 1982b and Buffington et al., 1983).

In extensive livestock production systems sophisticated artificial shades may not be justified, due to the costs of investments to install infrastructures. Obviously, taking advantage of natural shade (e.g. trees) could be beneficial (Beede et al., 1985), because trees are less expensive to establish and they provide additional benefits. Livestock outdoors is exposed to a wide range of weather conditions which often restrict their productive performance. However, shelter for the purpose of ameliorating the microclimate need not be in the form of a building. For example, in the tropics the provision of a simple shade can reduce the solar radiation reception and minimize the degree of heat stress the livestock experiences (McArthur, 1991). Shearer et al. (1991) stated that if cows were given a choice, they would prefer natural shade from trees rather than man-made structures. Trees combine protection from the sun with the radiation sink and the effect created by moisture evaporation from the leaves (Armstrong et al., 1993).

Silvopastoral systems incorporate dispersed trees in pastures. This dispersed trees consist of a combination of shade and non-shade trees and shade trees can contribute to heat stress alleviation by providing shade for livestock. The amount of shade depends on the crown of the tree. For example gavilán (*Pentaclethra macroloba*) has a large and dense crown which provides a dense shade,. while laurel and cedro which are also often found in pastures in humid regions of Costa Rica, have an open crown providing less dense shade (Russo, 1994).

At high ambient temperatures during the day, most animals dissipate excess heat through evaporative cooling. The simplest method of management for preventing heat stress in this case is to reduce radiant heat gain by allowing access to shade. Unfortunately this is sometimes neglected, and it is common to see cattle, sheep, or deer crowded together under a single tree or other limited sources of shade (Gregory, 1995).

According to Fuquay (1981) some of the earliest studies on the effect of shade showed no effect on milk production, and led many to conclude that shielding cows from the sun was of no benefit. However, it is now appreciated that milk yield is more closely related to the Temperature Humidity Index (THI) than to temperature alone. As THI rises, milk yield declines (Hahn and McQuigg, 1970; Johnson, 1980), but herds producing at low levels tend to be less affected by the THI than high-performing herds. In general, it appears that milk yield starts to become suppressed when rectal temperature reaches 40-41 °C (Fuquay, 1981; Elvinger et al., 1992). Keeping cows under shade instead of in the open in subtropical conditions has helped to raise milk yield, % SNF (solid-non-fat), and conception rate, and the frequency of clinical mastitis was shown to be lower as were respiration frequency and rectal temperature (Roman-Ponce et al., 1977; Davison et al., 1988).

Mallonee et al. (1984) noted that with mixed rations (70% total digestible nutrients) fed to lactating Holstein and Jersey cows housed in shade and no shade environments during summer, daily dry matter intake was 13% lower for cows with no shade than for those with shade.

Davison et al. (1988) attributed the decreased milk yield from Holstein-Friesian cows without shade mainly to a decrease in pasture intake as environmental and body temperature increased.

According to the same author the provision of shade during the summer in North Queensland, Australia is necessary to maximize milk yield and to prevent marked changes in milk composition. Paddocks that are required for day grazing should contain enough trees to provide shade for all lactating stock.

2.4 Economic contribution of trees

Many cattle farmers retain trees in pasture to generate additional income especially through the sale of timber and fuelwood (Camargo et al, 2000; Casasola et al., 2001). Studies conducted by COSEFORMA (1994), in the region Huetar Norte in San Carlos, which is a recently settled region of Costa Rica, showed that paddocks are of considerable importance in supplying extracted wood in relation to other land use such as primary, secondary and managed forests. Paddocks contain the highest proportion of useful wood per hectare considering trees with a dbh (stem diameter at 1.30 m breast height) greater than 30 cm. Similarly it has been observed in another study in the region of Esparza, Costa Rica, where a high proportion of wood trees with high commercial value were found in the pasture. For small farms this was estimated to be 85% of high commercial timber trees in pastures (Viera and Barrios, 1997).

In general dispersed trees in pastures are established by natural regeneration (Camargo et al, 2000). In the humid tropics, some of the most common species in pastures are laurel, cedro, lagarto (*Zanthoxylum belizense*), surá (*Terminalia oblonga*) and gavilán (*Pentaclethra macroloba*) that quickly reach maturity to commercialisation and reproduce through dispersed seeds which are not eaten by cows. Other tree species associated with pastures are: guayabo (*Psidium guajava*), guácimo (*Guazuma ulmifolia*), jícaro (*Crescentia alata*), poró (*Erythrina poeppigiana*), madero negro (*Gliricidia sepium*) and carao (*Cassia grandis*), etc. (Russo, 1994).

A study by Holmann et al. (1992) was conducted to evaluate costs and benefits of silvopastoral systems on small dairy farms in the humid tropical lowlands of Costa Rica. The association of improved pastures (*Brachiaria brizantha)* with laurel was the type of silvopastoral system studied. Assuming that the price of laurel remains constant in the future, this type of system would generate an annual income of US$ 238 ha^{-1}. This income would be lower than the profits from other alternatives studied, such as protein banks (US$ 1,705 ha^{-1} $year^{-1}$) and the association of improved pastures with legumes (US$ 1,111 ha^{-1} $year^{-1}$). However, if the price of laurel continues to increase at the same annual rate (3.24%) as in the past 13 years, this alternative would become the most profitable system.

Although several authors have commented on the occurrence of tree in pastures or have documented their importance for the conservation of forest species (Marmillod, 1989; Montagnini, 1992), there have been few systematic surveys of isolated trees in pastures. The lack of information on which species occur in pastures and how they are arranged within the agricultural landscape makes it difficult to evaluate their potential importance for the financial viability of livestock farms. There are also few formal studies of why pastures trees are retained by farmers. It is generally assumed that farmers leave a few trees for either shade, timber, forage, fruit or watershed protection (Budowski, 1993; Martinez, 1989), but it is not clear how important these motives are or whether farmers have additional reasons for leaving trees. Understanding why farmers leave trees in pastures and how they manage these trees is critical for assessing whether pasture trees can play a role in improving livestock productivity and in the financial viability of livestock farms.

3. Materials and methods

3.1 Study region

The experiment was conducted at La Fortuna, San Carlos, in a northern tropical humid region of Costa Rica (Lat. 10° 28´N., Long. 84° 39´W., altitude 250 m a.s.l). The area is classified as a tropical premountain very humid forest with mean annual precipitation ranging between 2000 and 4000 mm (Holdridge et al., 1971). Rainfall distribution is more or less uniform except for the months between January to April, which have lower rainfall. During the year, the month of March presents the lowest precipitation and July the highest. Precipitation exceeds evaporation in more than 9 months of the year (CCT, 1990). The mean annual temperature is 26 °C and the highest temperatures (30.4 to 31.3 °C) usually occurred in the months of March to June (Instituto

Meteorológico Nacional de Costa Rica and Instituto Costarricense de Electricidad (ICE), unpublished, 1998). The mean solar shine is of 3.5 hours daily sunlight and wind speed is lower than 15 km hour^{-1} (MAG, 1998). Soils are volcanic in origin (Andisoles and associated with Inceptisoles) with a sandy loam texture. The area has an undulating topography with slopes of 20 to 75% (MAG, 1998).The soil is moderately acid with acceptable levels of P (1.39 mg l^{-1}) and K (0.06 cmol (+) l^{-1}) for pasture growth. The physical characteristics shows soils predominantly made up of sand (Lopez Musalem, 1998).

Dairying is one of the main land use activities in the Fortuna region and it is practiced on the flatter lands, that are generally characterised with more fertile soils. Farm size varies from 10 to 400 ha and 13 to 180 dairy cows farm^{-1}. Most dairy farms are managed with semi-intensive grazing and in general concentrates are fed as supplements to meet nutrient requirements for high milk yields. The main dairy breeds are Holstein and Jersey. African star grass (*Cynodon nlemfuensis*) and *Brachiaria* spp. are the dominant pasture species and on many farms trees are found dispersed in pastures to provide shade to animals. Commercial timber trees are felled to generate additional income.

The region consists of pastures with (1) natural shade and (2) without shade. The natural shade is a result of isolated and/ or a clusters of trees consisting predominantly of timber trees including laurel and cedro. Guachipellin (*Diphysa robinoides*); higuerones (*Ficus spp.*); limon dulce (*Citrus sinencis*); poró (*Erythrina spp.*) and madero negro (*Gliricidia sepium*) are also frequently found in pastures and they provide shade to animals in addition to other benefits. Live fence posts are found on more than 75% of the farms with poró and madero negro being the main species.

Cattle are, at least from farmer's point of view, the most important component in the silvopastoral systems. Cattle deliver the products to be sold and to be used for home consumption, like milk and meat. In most cases the herd is reared for milk production and in some cases the herd is kept for dual purpose, meaning that both milk and meat are produced. The sale of timber also contributes to income generation on many farms though there are not many studies evaluating this component. Timber trees are usually harvested when farmers are in need of finance urgently.

Two studies were conducted in the area to evaluate silvopastoral systems. The first study (**a biophysical study**) was conducted to analyse how natural shade (trees) contribute to reducing heat stress in dairy cattle and improving their intake and productivity. In the second study (**an economic study**) cattle production and silvopastoral systems in the study area were characterised and financial analysis was carried out to determine how silvopastoral systems contribute to income generation of farms.

3.2 Biophysical study

3.2.1 Selection of the experimental farm

Biophysical and socio-economic data on each of the fifty dairy farms in the Fortuna region were collected from the Dos Pinos dairy cooperative and MAG (Costa Rican Ministry of Agriculture and Livestock), the government extension agency of Costa Rica. The farmers all belonged to the dairy cooperative, which had a good database on biophysical conditions (area, soils, topography, pasture, within others) and socio-economic conditions (land use and labour) of each farm.

Fifteen of these farms were randomly selected (Steel and Torrie, 1988) to carry out exploratory interviews as a pre-sampling. One of the fifteen farms was selected to carry out the biophysical experiment. This selection was based on the following criteria: the presence of shade trees in paddocks, the presence of dispersed trees in pastures, grazing being carried out for at least 8 hours in the day time; an appropriate physiological status of animals, a good health condition of the animals, the willingness of the farmer to cooperate and the presence of animal breeds: Jersey or Holstein. The main objective of the experiment was to study the effect of trees in controlling heat stress, using productive and reproductive performance of dairy cattle as parameters.

3.2.2 Treatments and experimental design

The treatments consisted of two shade levels (shade vs. no shade) and the effect of these two levels on the physiological and productive behaviour of Jersey cows during two defined seasons was analysed. The experimental design was a Completely Randomised Design with Split Plot in Time where shade levels were assigned to main plots and seasonal effects to sub-plots. The experimental treatments were set up using a rotational grazing system in 20 paddocks with 1.5 days grazing and 28.5 days resting. In each paddock, referred to as a replication in this experiment, trees were grown disperse in the pasture and each paddock was divided to obtain one plot with trees and one without in order to establish the shade level treatments. This experiment was conducted for a period of 6 months to obtain data in the dry (February, March and April) and rainy (June, July, August) seasons. Eight Jersey cows in lactation grazed in each treatment.

3.2.3 Selection and management of animals

Experimental animals (16 Jersey cows) were selected from a group of 40 Jersey cows that were between 3.5 and 5 years old and were in second and third lactation. Healthy cows, averaging 118 days *post lactation*, were selected. All cows were deparasited (externally and internally) at the beginning of the experiment and every three months during the experiment. The records on health and physiological conditions of each animal in the group were evaluated during the experiment to discard those cows with abnormal lactation, and reproductive and disease problems.

The experimental animals in both treatments were managed with 24 non-tester animals to avoid complications of daily routine management on the farm. The non-tester animals were divided equally between the two groups of experimental animals. The area of each pasture was divided equally to balance stocking rate. In the shade treatments, the area of shade was calculated for each cow (experimental and non-tester animals) in order to reduce experimental errors. The animals were placed in the shade and no shade treatments using a random numbers table.

The paddocks were 1 hectare in size each and were used as replications. Each paddock was divided in 2 plots giving a total of 40 plots. The size of each plot was 5000 m^2 and the sixteen experimental and non-tester animals grazed for a period of one and a half days in each plot. The estimated stocking rate was 2.2 AU ha^{-1} for each treatment (1 AU (animal unit) = 400 kg).

One experimental cycle was equal to 30 days i.e. the time it takes for the animals to complete their stay in each of the 20 paddocks. The experimental period was divided in two periods of three months each. The first period consisted of the driest months of the year (February, March and April) and the second period consisted of months with high precipitation (June, July and August).

The major mathematical model to describe the data for each treatment for all analyses was as follows:

$$Y_{ijlm} = \mu + A_i + S_j + E_{ij} + P_l + SP_{jl} + l_{ijl} + \beta + M_{ijlm}$$

Where:

Y_{ijlm}	=	response variable of the i^{th} paddock (pasture division), the j^{th} system (shade or no shade), the l^{th} season and of the m^{th} animal observations;
μ	=	true mean of observations;
A_i	=	effect of the i^{th} paddock;
S_j	=	effect of the j^{th} system;
E_{ij}	=	experimental error;
P_l	=	effect of the l^{th} season;
SP_{jl}	=	effect of the j^{th} system within the l^{th} season (season × system interaction);
l_{ijl}	=	split plot in time error and interaction error (experimental error);
β	=	covariate effects;
M_{ijlm}	=	sample error associated with the m^{th} animal within the i^{th} paddock, the j^{th} system and the l^{th} season.

The milk production was adjusted for covariate effects with data from the one-month pre-treatment period.

3.2.4 Experimental variables

Meteorological data

The meteorological measurements (maximum and minimum temperature, precipitation, dry and wet bulb temperature, and global radiation) in treatments with and without tree shade were recorded daily at 8:30 and 14:00 hrs. The dry and wet bulb temperatures were measured using an Aspiration-Psychrometer (Wilh. Lambrecht, Goettingen, Germany). The values indicated by the dry and wet bulb thermometers were used for determining the relative humidity in per cent using a specific Aspiration-Psychrometer table (Deutscher Wetterdienst, Germany) for lowland areas. The global radiation (Wm^{-2}) was obtained by converting the photosynthetically active radiation (PAR) (μ moles m^{-2} s^{-1}) estimated using a line radiometre with datalogger (Decagon Devices Inc® Pullman, WA, USA) into global radiation (Li-Cor, 1985).

The Temperature-Humidity Index (THI) was derived from the observed outside temperature and humidity. It is intended as a measure of the "apparent" temperature, i.e., how the temperature feels, and this depends on the amount of water vapour in the air. THI was calculated using the equation of McDowell (1972): THI = 0.72 (W°C + D°C) + 40.6, where W°C is the wet bulb and D°C is dry bulb temperatures.

Pasture

The pasture was predominantly *Cynodon nlemfluensis*. Pasture measurements were carried out during 2 months (February and July 1999) to estimate: 1) dry matter, 2) crude protein, 3) *in vitro* dry matter digestibility and 4) neutral and acid detergent fibre and during 4 months (February, June, July and August) to estimate forage production.

For analysing forage quality, hand-plucked samples (500 g) were collected for the analysis of crude protein (CP) (Bateman, 1970), *in vitro* dry matter digestibility (IVDMD) (Tilley and Terry, 1963) and neutral and acid detergent fibre (NDF and ADF) (Goering and Soest, 1972). Samples were dried at 65°C for 72 hours and ground to 1 mm. The analyses were carry out at the CATIE Animal Nutrition Laboratory in Costa Rica.

For estimation of forage production, the available and residual forage were measured before and after-each grazing using the Botanal method described by Tothill et al. (1978). This measurement was taken for each grazing cycle. Real samples were collected for estimating DM content and in each plot 60 visual observations were made to adjust DM yields using a regression analysis.

Physiological measurements

Two physiological parameters (rectal temperature and respiration rate) of the dairy cows were measured to evaluate heat stress. The rectal temperature was measured daily while the animals were in the barn at 9:00 hrs. A digital clinical thermometer was inserted about 5 cm into the rectum. Breathing rate was assessed twice a week at 14:30 hrs by counting the flank movements of each cow for one minute. It was assessed in the paddocks and was always done by the same person from a distance of 3 m.

Animal performance measurements

The animal performance was measured using the following parameters: feed intake, milk production and composition and progesterone profile.

1) Feed intake

Intake of forage was determined using Chromic Oxide as an external marker to estimate total fecal production and to calculate total DM intake (Iturbide, 1967; Crowder and Chheda, 1982; Kirchgessner, 1987). Four animals from each treatment were given 10 g dose of chromic oxide daily over 10 days and fecal samples (300g) were collected to determine Cr_2O_3 concentration. This measurement was carried out during the months of February and March (dry season) and July and August (rainy season). Data on supplemental feeds were collected for estimation of DM intake. Feed intake was calculated using the following formulas:

$$\text{Daily faecal output} = \frac{\text{grams marker Chromic Oxide fed/ day}}{\text{grams marker/ g faeces}}$$

$$\text{Feed intake} = \frac{\text{Daily faecal output} \times 100}{100 - \text{Digestibility}}$$

The presence of Chromic Oxide in faeces for estimating feed intake was analysed at the CATIE Animal Nutrition Laboratory in Costa Rica

2) Milk production and composition

Milk yield from each cow was recorded for morning and evening milkings once a week using a milk-metre (Bou Matic, USA). Individual milk samples were collected once every two weeks before morning and evening milkings to determine the milk composition. Composite milk samples from each cow (400 ml) containing a preservative potassium dichromate were stored under refrigerated conditions for two weeks and were analysed for fat (Babcock method), protein (Formol titration) and total solids (Direct Forced Air Oven Drying) at the CATIE Animal Nutrition Laboratory in Costa Rica. These techniques have been described by AOAC (1990) and Revilla (1996).

3) Progesterone profile

The reproductive state of the cows was evaluated by measuring the progesterone concentration in milk. Milk samples (5ml) from each cow were stripped from a teat after milking twice a week and were stored at –20 °C. The samples were analysed for progesterone levels at the hormone laboratory of the Animal Husbandry and Genetics Institute of the University of Goettingen, using the ELISA procedure of Van de Wiel and Koops (1986), modified by Moeller (1991).

3.2.5 Statistical analysis

The statistical analysis of the data from biophysical study consisted of an analysis of variance (ANOVA) carried out for shade and no shade treatment comparisons. Correlation analyses and Stepwise Multiple Regressions were used to evaluate relationships between the factors studied. Significance was set at the 5% level. The data were analysed using the general linear model procedures (GLM) of SAS System (SAS Institute Inc., 1985).

3.3 Economic study

3.3.1 Data source

Thirty-five livestock farms were chosen randomly from nine zones of La Fortuna, San Carlos, Costa Rica, to obtain information through exploratory interviews on the production of the area, types of animal production systems present, pastures, dispersed trees, live fences, cattle breeds, and milk yields.

3.3.2 Methodology for selecting farms

The selection of the thirty-five livestock farms was made from a composite list of 71 cattle farmers obtained through the Dos Pinos dairy producers cooperative and the MAG extension agency, organisations that work in this region. Using the information obtained through interviews, a canonical discriminant analysis by SAS (SAS Institute Inc., 1985) was carried out, where three different types of livestock systems were identified: 1) mixed (milk and crop production); 2) specialised milk production; and 3) dual purpose (milk and meat production). From the 35 farms selected, 5 farms were discarded, because their characteristics were different from those of the groups.

Based on the three different types of cattle systems found in the first phase of the socio-economic study, 10 farms were selected: 4 of mixed, 3 of specialised milk and 3 of dual purpose systems.

Farm selection was biased to include the best examples of each type of cattle production system. Two objectives justified this bias: (a) the presence or absence of trees in pastures and (b) the willingness of the farmers to collaborate. In spite of the limited number of farms, an effort was made to include representative examples of farms according to each type of animal husbandry system encountered in the region.

3.3.3 Data collection method

In order to determine the potential importance of isolated trees in pastures for the financial viability of livestock farms, the density and species composition, abundance, origin and distribution of isolated trees on these 10 farms were surveyed. For farms with less than 100 ha, the sample size was 10% of the surface area and for farms with more than 100 ha, the sample size was 5% of the surface area. The total sample included 42.5 ha of paddocks (9.6 ha in mixed systems; 4.2 ha in specialised milk systems; and 28.7 ha in dual purpose systems). Paddocks were randomly selected on each farm surveyed. On each selected pasture all species of dispersed trees were counted and identified. Trees that occurred in forest patches near rivers were not included.

In order to understand the regeneration dynamics and consequently ascertain the sustainability of the valuable tree species in the pasture systems of the region, abundance (n ha^{-1}) of laurel and cedro was estimated according to diametric classes in each of the three different animal production systems.

In addition, dbh, total height (ht) and the commercial height (hc) of the timber tree species laurel and cedro were measured. Dbh was measured with a linen diameter tape and height (h) with a Suunto clinometer. These measurements were taken in order to determine the wood volume of the different cattle farm systems.

3.3.4 Farmer interviews

Interviews using questionnaire surveys were applied on the 10 farms and were focused mainly on the costs and benefits (financial analysis) of the different animal production systems, including the profitability of milk and/or meat combined with wood production. Farm level input-output data were collected. The results of the present study are therefore based upon interviews and it is not known how accurately these could be extrapolated.

3.3.5 Data analysis

Tree volume

To calculate the total volume of laurel with a dbh of less than 35 cm the equation of Somarriba and Beer (1986) was used. The estimation of the merchantable volume of laurel with a dbh equal to or greater than 35 cm was based on the table of McCaffrey (1972). For cedro the equation deduced by Ford (1979) was used (See Paper II).

Financial analysis

All costs for animal production, agriculture and tree harvest were calculated. Labour used (both family and hired) was valued at the current agricultural wage for day-labourers in the region. Current market prices were used for variable inputs and outputs and were estimated for non-marketed items on the basis of interviews. The prices of agricultural and animal products were based on the table provided by Consejo Nacional de Producción (1999) and personal communications with experts from MAG and the Dos Pinos dairy producers cooperative.

The following indicators were used for the financial evaluation of the systems: net present value (NPV) with a interest rate (i) of 5.36%; benefit-cost ratio (BCR); return on annual investment and return on labour. Different sensitivity analyses on milk, meat, wood, labour and dry food prices were carried out (see Paper II).

4. Results

4.1 Biophysical study

Metereological data

The differences in mean daily temperature and relative humidity of shade and no shade treatments in both seasons and at both times were not significant ($P>0.05$). The intense afternoon global radiation was a common feature and was significantly higher in the no shade treatment than in the shade treatment ($P<0.01$) during the dry season (20 vs. 357 W m^{-2}) and the rainy season (15 vs. 292 W m^{-2}) (See Table 2 in Paper I). The greatest ambient temperature differences between no shade and shade treatments were measured in February at 14:00 during the dry season (1.4 °C) and in August at 8:30 and 14:00 during the rainy season, 1.3 °C and 1.2 °C respectively. The greatest relative humidity differences between shade and no shade treatments were recorded at 14:00 in February (4.3%) and at 8:30 in April (4.1%) during the dry season and at 8:30 in August (5.1%) during the rainy season. The greatest global radiation differences between no shade and shade treatments were recorded at 8:30 (749.6 W m^{-2}) and 14:00 (482.1 W m^{-2}) in August during the rainy season (see Figure 1 in Paper I).

The Temperature-Humidity Index (THI) values ranged between 73.9 and 78.6 for both treatments. The cows in the shade and no shade treatment were in a THI category of 72.0-78.0 during the whole dry season and in the morning of the rainy season. According to the classification of Du Preez et al. (1990), the cows were in alert (warning) and above critical index for milk production. At 14:00 in the rainy season the THI value exceeded 78.0 in both treatments, a value considered dangerous for lactating cows according to Du Preez et al. (1990) (see Table 3 in Paper I).

Pasture

Forage quality (crude protein (CP), *in vitro* dry matter digestibility (IVDMD), neutral detergent fibre (NDF) and acid detergent fibre (ADF)) before and after intake for two months is shown in Table 1.

Table 1. Forage quality before and after intake of real sample (rs) and selected sample (ss) during two months. La Fortuna, San Carlos, Costa Rica, 1999

Value	February[1]				July			
	Before intake		After intake		Before intake		After intake	
	rs	ss	rs	ss	rs	ss	rs	ss
IVDMD %	61 a	61 a	65 a	63 a	47 b	54 c	42 d	49 e
CP %	15 a	17 a	17 a	17 a	11 a	13 a	12 a	15 a
NDF %	68 a	68 a	67 a	64 a	77 b	76 b	77 b	77 b
ADF %	41 a	42 a	36 a	38 a	44 a	40 a	44 a	42 a

Values in the same row with a common letter are not significantly different (P<0.05), but do differ from those not having the same letter

[1] Forage quality from February was estimated in a previous study by De Sales (1999).

No significant differences in CP and ADF % were observed between before and after intake in February (dry season) and in July (rainy season). But IVDMD% was significantly lower in the rainy season than in the dry season ($P<0.05$) and NDF% was significantly higher in the rainy season (July) than in the dry season (January and February) for both samples (rs and ss) ($P<0.05$). The selected samples were similar in values to the real samples in January before and after intake, but in July there were significant differences between IVDMD% of real sample and of selected sample before and after intake ($P<0.05$) (Table 1).

Forage production (kg DM (dry matter) ha^{-1}) was estimated using the Botanal method and is presented in Table 2.

Table 2. Forage production (kg DM ha^{-1}) according to the Botanal method. La Fortuna, San Carlos, Costa Rica, 1999

Month	Forage production (kg DM ha^{-1})
February[1]	1,563.75 a
June	4,396.77 b
July	4,732.67 b
August	4,767.96 b

Averages with the same letter within each column are not significantly different (P<0.05)

[1] Forage production from February was estimated in a previous study by De Sales (1999).

Forage production was significantly higher in the rainy season (June, July and August) than in the dry season (February) (P<0.05). No significant differences were found between the rainy season months (Table 2).

Physiological data

Rectal temperature (RT) means did not differ significantly between treatments during the dry season, although the RT of the cows in the no shade treatment was slightly higher in this season. In the rainy season RT was significantly higher (P<0.01) in cows that had no access to shade compared with cows that did have access to shade. There was a seasonal trend in daily average RT, which was most evident in cows in the no shade treatment. The RT of the animals from both treatments was higher in the rainy season than in the dry season (see Table 4 in Paper I).

Respiration rates (RR) were significantly higher in the cows in the no shade treatment than in the cows of the shade treatment group (P<0.01) in both seasons (see Table 4 in Paper I).

Productive and reproductive data

The feed intake estimation using Chromic oxide as an indicator is shown in Table 3. The average forage intake (kg DM 100 kg^{-1} LW (Live weight)) for the shade and no shade treatments were significantly different in February (dry season) and in August (rainy season) (P<0.05) (Table 3).

Table 3. Mean feed intake (kg DM 100 kg^{-1} LW) for the shade and no shade treatments using Chromic oxide as an indicator. La Fortuna, San Carlos, 1999 (n= 8)

Month	Forage intake		Total intake	
	Shade	No shade	Shade	No shade
February[1]	2.44 a	2.03 b	3.53 *	3.34 *
March[1]	2.51 a	2.42 a	3.93 *	3.74 *
July	1.81 a	1.85 a	3.13 *	3.27 *
August	2.70 a	2.31 b	4.01 *	3.74 *

Values in the same row with a common letter or asterisk are not significantly different (P<0.05), but do differ from those not having the same letter or asterisk

[1] Feed intake from February and March were estimated in aprevious study by De Sales (1999).

The average total milk yields for the shade and no shade treatments were significantly different (P<0.001) in the dry season, but similar in the rainy season. Milk yields for the two treatments in the rainy season were significantly lower than in the dry season (P<0.05). Higher concentrations of fat, protein and total solids were observed in the no shade group, with the exception of fat in the rainy season, but only total solids presented a significant difference between treatments (P<0.05) (see Table 5 in Paper I).

The average progesterone levels from pregnant cows (9^{th} to 23^{rd} week of pregnancy) for shaded and no shaded cows were not significantly different in the dry season, although a higher level was observed in the no shade treatment. A significant difference between treatments was observed in the rainy season (P<0.05), when the shade treatment presented a higher level (see Table 5 in Paper I).

THI-pd (Temperature Humidity Index the previous day) in the dry season and T-sd (ambient temperature the same day) in the wet season had the greatest effect on rectal temperature accounting for 51.6 and 58.2% of the variation respectively. In the wet season THI-pd and THI-sd (THI the same day) had significant effects on rectal temperature though they accounted for only 6 to 10% of variation. Respiration rate (y) was affected by THI-sd (x) in the dry season ($y = -508.98 + 7.53x$) and by T-sd (x) in the wet season ($-453.45 + 19.93x$) (see Table 6 in Paper I). Combining data from both seasons, there was a significant relationship between THI-pd (x) and progesterone levels (y) of animals ($y = -27.693 - 2.972x$; $R^2 = 0.35$). Correlation coefficients (r) between milk yields and THI showed that there was a significant correlation between milk yields and THI-sd ($r = -0.423$, $p<0.03$), such that higher THI-sd values depressed milk yields.

4.2 Economic study

Characteristics of animal production systems

Based on the biophysical analysis, three cattle systems were identified: 1) mixed (milk and crop production); 2) specialised milk production; and 3) dual purpose (milk and meat production). The average percentage area of pasture with isolated trees was significantly greater ($P<0.001$) on dual purpose farms (74%) than on mixed (16%) and specialised milk production farms (27%). The average milk production per area (kg $ha^{-1}day^{-1}$) was greater on specialised milk (14.2) and mixed farms (12.6) than on dual purpose farms (4.3) ($P<0.05$) (Souza de Abreu et al., 2000b) (see Table 1 in Paper II).

Tree surveys

The most common species of timber trees found dispersed in pastures in the region were laurel and cedro, but laurel was the predominant species in all cattle farm systems of the region (see Figure 1 in Paper II). The laurel and cedro found in these silvopastoral systems originated from natural regeneration and were randomly distributed in the pastures. No silvicultural techniques were used to improve tree form and vigour. Farmers maintained laurel in paddocks because it produces construction and furniture timber and provides shade for cattle. Other tree species such as higuerón (*Ficus spp.*), limón dulce (*Citrus limetta*), naranjo dulce (*Citrus sinensis*), guava (*Inga sp.*), guayaba (*Psidium guajava*), poró (*Erythrina spp.*) and other timber trees such as lagarto (*Zanthoxylum belizense*), gavilán (*Pentaclethra macroloba*) and surá (*Terminalia oblonga*) were also found frequently dispersed in the pastures. Timber extracted by all farmers in the three cattle systems was first of all used for their own consumption and then for sale. Like laurel and cedro, other timber trees were used to generate additional income for the livestock farms. The average harvesting frequency was around once every three years.

The specialised milk production system presented a higher abundance of non-timber trees than the dual purpose and mixed systems. These provide more shade than laurel. A higher density of laurel was found in the dual purpose system (see Figure 1 in Paper II).

Tree regeneration dynamics

Excluding the diameter class 10-14.9 cm, where all systems showed a relatively low abundance of laurel, the dual purpose system was the only one that had enough trees with small diameters for a sustainable natural regeneration. The other two animal husbandry systems showed an irregular distribution of trees according to the diameter classes (see Figure 2 in Paper II).

In relation to cedro trees, no animal production system had a diametric distribution required to ensure the sustainability of this species in the system. All the cedro trees on the farms in the specialised milk system presented diameters that ranged between 15 to 29.9 cm, while the dual purpose and mixed showed a larger, but also irregular, diametric distribution (see Figure 2 in Paper II).

Tree volumes

The dual purpose system presented a significantly ($P<0.05$) greater merchantable volume of laurel than the mixed and specialised milk systems (see Table 2 in Paper II). With regards to non-merchantable volume of laurel, the specialised milk system showed a greater non-merchantable volume of laurel than the other systems (see Table 2 in Paper II). This is due to the fact that the specialised milk system contained a greater abundance of trees in the diametric classes close to 35 cm (see Figure 2 in Paper II).

Although the number of cedro trees was small, trees encountered in the mixed systems showed a higher merchantable volume for this species than laurel (see Figure 2 and Table 3 in Paper II). The number of trees with non-merchantable volume (dbh<35 cm) was small in the three systems, indicating future conservation difficulties for this species in the animal production systems of the region.

Financial analysis

Financial analyses were made for a period of one year (October 1998 to September 1999) for the three animal systems (see Table 4 in Paper II). Considering the total variable and fixed costs of the three systems, the specialised milk system showed greater costs than the mixed and dual purpose systems, mainly due to the variable costs associated with animal nutrition, maintenance costs of the animals and general costs. The mixed system had no costs for wood extraction due to the use of family labour and the farmer's own saw. The average annual income of the specialised milk system was greater than the income of the other systems, mainly because of the income from milk production. The contribution of income from wood to the total income was 1.18% for mixed systems, 1.0% for specialised milk systems and 0.89% for dual purpose systems, showing that the exploitation of wood is still a secondary activity for the farmers.

The NPV varied greatly among the three cattle systems and within the mixed and specialised milk systems. The dual purpose farms had a more homogenous NPV. The highest NPV value with a 5.36% discount rate was obtained in the dual purpose cattle system, followed by the mixed system. The NPV in the specialised milk system was negative. The mixed and dual purpose systems showed BCRs greater than 1, while the specialised milk system had a BCR lower than 1. Regarding the return on labour, the dual purpose system showed a return on labour US$ 19.90 higher than the market price for a day's wage. The return on labour shown by the mixed system was US$ 1.45 lower than the market price for a day's wage and for the specialised milk system it was US$ 7.20 lower than the market price for a day's wage. The return on annual investments is the return on capital invested in farm activities. The mixed and dual purpose systems showed a positive return, whereas the specialised milk system had a negative return (see Table 5 in Paper II).

The sensitivity analysis shows that the NPV of the mixed system responded more markedly to all price changes. With a decrease of 6.9% in milk prices, the mixed system presented a NPV reduction of 80%, whereas for the specialised milk and dual purpose systems the reductions were 32.40% and 9.95% respectively. When the price of meat fell 6.0% the mixed system showed a greater reduction in the NPV (8.52%) compared to the dual purpose (↓ 5.60%) and specialised milk systems (↓ 2.90%). An increase in prices of wood of 16.8% was beneficial with an increase in NPV of 4.73%, 1.22% and 0.60% in mixed, specialised milk and dual purpose farms respectively. Decreasing labour costs by 3% resulted in an increase of 32.54% in NPV in the mixed system, followed by specialised milk (↑ 13.21%) and dual purpose systems (↑ 3.12%). The mixed system responded to the 5.0% increase in dry food prices with the greatest reduction in NPV (32.54%), followed by the specialised milk system (↓ 13.21%) and lastly the dual purpose system (↓ 3.12%) (see Table 6 in Paper II). Another sensitivity analysis applied to milk prices simulating an increase of 5, 10, 15 and 20%, showed a marked improvement in the NPV of specialised milk systems, followed by almost the same behaviour in the NPV of mixed systems. The NPV of dual purpose systems did not change very much with an increase in milk prices. Meanwhile no significant changes in NPV of the three systems were observed when increases of 5, 10, 15 and 20% in wood prices were applied (see Figures 3 and 4 in Paper II).

Milk production is the most important activity in relation to total income of the four main activities of the region (milk, meat, crop and wood) and for the economy of all three farming systems. Its importance ranges from 88.64% for specialised milk to 54.89% in dual purpose systems. On the other hand, income from the meat production activity is more important for dual purpose farms (43.21% of total income for the four activities), followed by mixed (10.48%) and specialised milk farms (8.63%). The comparison of average annual income per ha per farm for the three systems revealed almost the same importance of income from wood production in relation to the total income of the four activities, corresponding to 1.46% in the mixed system, 2.73% in the specialised milk system and 1.41% in the dual purpose systems. Crop production in the mixed system had a greater importance as a percentage of total income for the four activities (6.24%) than in the dual purpose system (0.50%). There was no crop production in the specialised milk system.

5. Discussion

5.1 Biophysical study

Heat Stress and the effect of meteorological factors, season and THI on physiological responses, milk production and feed intake

The present study was conducted under field conditions, in which global solar radiation represented the major environmental difference between treatments. The global radiation reached values above 500 W m^{-2} in the no shade treatment during both the dry and the rainy season, indicating a discomfort for the animals. According to McArthur (1991) for animals outdoors, values of mean irradiance above about 500 W m^{-2} are unlikely. The significant difference in the average daily incidence of solar radiation between shade and no shade treatments (14.3 vs. 306.5 W m^{-2}) observed in the present study, indicates the beneficial effect of shade in intercepting the direct incidence of solar radiation.

In the present study the cows of both the shade and no shade treatment groups during the whole of the dry season and in the morning of the rainy season were in the alert (warning) and above critical index for milk production (THI values of 72.0-78.0) according to the classification of Du Preez et al. (1990). Analysing the values of THI in both treatments in the present study, the cows in both shade and no shade treatments were all suffering from heat stress. In the afternoon during the rainy season the cows in both treatments had a THI greater than 78.0 and according to the classification of Du Preez et al. (1990), this is the danger category for lactating cows. This implies that although an animal under shade is protected from the direct rays of the sun, it is still exposed to large amounts of diffuse solar energy (Blackshaw and Blackshaw, 1994). An animal in the shade of trees, such as laurel or cedro, receives more diffuse solar energy from the upper atmosphere than an animal under a low tree such as higuerones (*Ficus spp.*) and limón dulce (*Citrus sinensis*).

In a study conducted in the seasonal equatorial climate of southern Nigeria by Adeyemo et al. (1979), the milk cows were generally most comfortable during the wettest period of the year because of southwesterly winds. In contrast with the above result, in the present study the milk cows were more comfortable during the driest season according to THI values. Despite the influence of the cloud cover typical of rainy seasons, which limits the direct solar beams reaching the animals, the wettest season was more stressful. The THI value was greater in the rainy season than in the dry season, probably due to the combined effect of high temperature and the higher humidity during this season which affected the evaporative cooling mechanisms of the cows of breathing and sweating. In the present study, although the THI of the rainy season was the highest, the difference between THI of the shade and the no shade treatment was higher in the dry season than in the rainy season. This could be explained by the moisture effect created under shade, which is higher in the rainy season.

In the present study the climatic conditions represented by the THI showed that there was a significant correlation between milk production and weather on the same day during both the dry and the rainy season for no shade treatment and shade treatment. The same result was observed by Ikiror (2001), where afternoon milk yield was more sensitive to climatic factors of the same day than to climatic factors of the previous day, which suggests that reductions in the afternoon milk yield were probably caused by short-term heat stress. In the present study, THI one day previously (THI-pd) in the dry season was found to be as important as THI and ambient temperature on the same day (THI-sd; T-sd) in the rainy season in influencing rectal temperature, but respiration rate was affected more by THI-sd (dry season) and T-sd (rainy season). As in the present study, Ikiror (2001) in a coastal study in Kenya, found that THI on the day of measurement of the physiological responses was found to be as important as THI one day previously in influencing rectal temperature, but respiration rate was influenced more by THI on the same day.

Physiological responses to climatic conditions

Normal respiration frequency is between 30 and 60 breaths min^{-1}. Rates beyond 60 breaths min^{-1} indicate that a cow is beginning to feel hot. Normally a rate of 180 breaths min^{-1} is not exceeded (Hansen, 1990). In the present study, RR of cows in both shade and no shade treatments in both seasons exceeded the normal frequency, indicating that the cows were using this mechanism to attenuate the heat stress. RR of the cows in the no shade treatment was on average 15.4 (dry season) and 18.2 (rainy season) breaths min^{-1} higher than those of the cows in the shade treatment, showing a seasonal variation. As in the present study, RR of the cows showed a highly significant ($P<0.01$) seasonal variation in an experiment conducted by Adeyemo et al. (1979) in Nigeria. According to Thompson (1985), RR increases much more in the humid season than in the dry season, due to the lower evaporation and cooling power of humid air. The results observed in the present study agree with the statement cited above.

In the present study the mean RT of cows in shade and no shade treatments in both seasons remained within the normal range (38.6 to 38.9 °C). Although the difference between the RT of the cows in the shade and no shade treatments never reached a difference of 1 °C, a significant difference between treatments was observed in the rainy season. In the present study, the ambient temperature reached a maximum of 35.5 °C in the dry season and the Jersey cows in shade and no shade treatments maintained a normal mean RT. This result agrees with the results of Collier et al. (1981) when average afternoon black globe temperature was below 35.0 °C and Jersey cows were able to maintain normal RT. The differences between the RT of the animals in the shade and no shade treatments in the dry and the rainy season, suggest a seasonal trend, the RT of the cows being higher in the rainy season than in the dry season. This difference could be due to the effect of high temperature in combination with the high humidity common in rainy seasons.

In the present study, THI reached a maximal value of 78.6 in no shade treatment during rainy season and only RR showed a significant increase. THI never reached a value greater than 80.0 and RT did not increase as expected. Meanwhile RR reached values above normal (> 60 breaths min^{-1}), indicating heat stress, and was significantly higher ($P<0.01$) in the animals of the no shade treatment, yet thermal balance appeared unaltered as indicated by normal RT. This shows, that the rise in RR was effective in increasing heat loss, thereby preventing a rise in RT. These results agree with a study conducted by Lemerle and Goddard (1986) in Papua New Guinea, which showed that RT of dairy cattle increased when THI was greater than 80, while RR increased with a THI value of about 73 and probably more steeply above 80. These authors suggest that homeostatic mechanisms including increased RR can prevent an appreciable rise in RT until THI reaches 80. This is similar to the critical THI level of 78 quoted by McDowell (1972). RR is therefore a more reliable physiological measure of response to climatic stress (Buvanendran et al., 1992).

There was a limitation in the present experiment because the physiological observations were all point measurements, restricted to one time in the morning for RT and one time in the afternoon for RR. This method probably did not allow the measurement of the animals' responses when they were highest or lowest within the 24 hour cycle. According to Collier et al. (1982b), cattle are exposed to a daily cycle of environmental temperatures under natural conditions, and they should therefore be studied throughout this cycle to define more clearly the responses to natural conditions.

Productive and reproductive responses to climatic conditions

Significant differences in forage intake were observed between the shade and no shade treatments in February and August. In February and in August the forage intake was respectively 16.8% and 14.4% lower for cows in the no shade treatment than for those in the shade treatment. Mallonee et al. (1984) found similar results with Jersey cows housed in shade or no shade environments during summer, when the daily dry matter intake declined 13% in cows with no shade compared with those in the shade. The results of the present study could be explained by the fact that February and August showed the greatest differences between shade and no shade treatments for ambient temperature (February and August), relative humidity (February and August) and solar radiation (August). According to Flamenbaum et al. (1986) and National Research Council (1981) when ambient temperature is greater than about 23°C and relative humidity is above 80%, cows begin to experience heat-induced depression of feed intake leading to an associated decline in productivity.

A significant difference in the milk yields between cows in the shade and no shade treatments was found only in the dry season ($P< 0.05$). The cows in the shade treatment had greater milk yields than cows without shade in the rainy season, but this difference was not statistically significant. A similar finding was reported in an experiment conducted by Roman-Ponce et al. (1977). In contrast to this, Guthrie et al. (1967) found no improvement in milk production of cows with access to shade, although the respiration rate was, as in the present study, lower in shade treatment than in no shade treatment. In the present study, the average daily milk yield was 13.3% higher for cows in the shade treatment than for cows in the no shade treatment during the dry season in contrast to a difference of only 1.5% in the rainy season. The results for the dry season agree with the results of various studies, which showed that milk yields of cows increased by 5 to 13% when they were provided with shade (Roman-Ponce et al., 1977; Collier et al., 1981; Collier et al., 1982a; Buffington et al., 1983 and Roman-Ponce et al., 1981).

In the present experiment, the mean rectal temperature (RT) rose but remained within normal values and seems not to have had a large influence on milk yield during the rainy season. According to Fuquay (1981) and Elvinger et al. (1992), it appears that milk yield starts to become depressed when RT reaches 40-41 °C.

As in the study of Roman-Ponce et al. (1981), in the present study no significant difference between shade and no shade treatments was detected for fat (3.53 vs. 3.59%) and protein content (3.12 vs. 3.14%), but in the result for total solids (12.50 vs. 13.41%), a significant difference was found ($P<0.05$). As in the study of Collier et al. (1981) on shade management for milk yield and composition in Holstein and Jersey cows, the present experiment failed to detect a significant effect of shade on protein and fat content of the milk. The slight difference between treatments indicates that fat percentage and protein were not greatly affected by direct incidence of solar radiation. It is probable that the short duration of heat stress each day did not have the cumulative effect that is usually required for marked changes in milk composition (McDowell et al., 1969). This would seem to explain the small change observed in the milk constituents in the present study.

The average milk concentrations of progesterone in milk were significantly lower in the no shade treatment than in the shade treatment during the rainy season ($P<0.05$), although the decreased levels were considered to be within normal concentrations documented in the literature (Schiavo et al., 1975). In the dry season the milk progesterone was not influenced by treatments. There are contradictory results for the effect of heat stress on progesterone levels of cows (Wilmut, 1985). In a study by Collier et al. (1982a), plasma concentrations of progesterone were elevated for no shade compared with shade cows *prepartum* during the last trimester of pregnancy. Progesterone secretion has been shown to increase (Roman-Ponce et al., 1981; Abilay et al., 1974; Roussel et al., 1977) as well as decrease (Stott and Wiersma, 1973; Rosenberg et al., 1977) during heat stress. The effects of different climatic conditions on milk progesterone concentrations in pregnant cows seem complex and are difficult to explain. The physiological state of the cow as well as the severity of the heat stress seem to affect progesterone levels. It is possible that the response to constantly hot or acutely elevated temperatures is different from that of moderately or intermittently high temperatures (Rosenberg et al., 1982).

5.2 Economic study

Tree surveys

Although the tree component of La Fortuna, San Carlos pastures varied in species, there was a predominance of timber species, mainly laurel. The different animal production systems differed greatly both in tree abundance and species richness. The total density of trees isolated in pastures ranged from 12.96 to 22.11 No ha^{-1}, and was greater in dual purpose systems. The density encountered in La Fortuna, San Carlos is similar to that found in Monteverde, Costa Rica, but the species richness reported by cattle farmers of about 20 species is much lower than the 190 species reported in a study by Harvey and Haber (1999). This difference could be attributed to the land use histories, where a greater extension of area was cleared in La Fortuna, San Carlos than in Monteverde. The presence of a higher density of laurel in the dual purpose system could be interpreted as a strategy of the farmers to reduce the effects of meat and milk price fluctuations through diversification with high value timber trees (Pezo et al., 1999).

Compared to the dual purpose and mixed systems, the specialised milk production system presented a greater abundance of non-timber trees that provide more shade than laurel. This could be explained by the fact that such farms have pure exotic milk breeds which need more shade to minimise heat stress (Gregory, 1995; McArthur, 1991; Souza de Abreu et al., 1999).

Tree regeneration dynamics

According to Lamprecht (1990), to assure sustainable natural regeneration of a tree species, the system is expected to have many trees with small diameters to replace the trees of greater diameters that are going to be extracted. The number of trees with small diameters is higher for laurel than for cedro, especially in the dual purpose system, and this might permit a natural regeneration of this species in silvopastoral systems of the region in the future. Cedro trees in the three cattle systems will tend to disappear in the future, because the number of small trees in pastures is insufficient to ensure their natural capacity for a sustainable regeneration.

The maintenance of high quality pastures was very important for the mixed and specialised milk systems, and this did not permit a normal natural regeneration of laurel and cedro. Farmers eliminated trees from the pastures, fearing that the grass would be shaded and consequently pasture growth would be compromised. Harvey and Haber (1999) similarly found that shade management appeared to be a key factor influencing farmers' decisions to eliminate trees from pastures. Farmers in the three systems also removed trees for timber for personal use and for sale, although this use was sporadic and unplanned and may not endanger natural regeneration of laurel and cedro in the same way that elimination due to shade management would.

Cedro trees present in specialised milk systems with a dbh from 15.0 cm to 29.9 cm were used as shade trees. The reason for this is that such farms have pure exotic milk breeds, which need more shade to minimise heat stress (Gregory, 1995; McArthur, 1991; Souza de Abreu et al., 1999).

Volumes

An assessment of timber production in traditional agroforestry systems in the Atlantic Region of Costa Rica showed a good performance of naturally regenerated *C. alliodora* growing in combination with pastures (Rosero and Gewald, 1979). Their findings were: laurel with ages of 25-30 years, 200 trees per ha, a mean dbh of 37 cm, and standing volume of 380 m^3 ha^{-1}. Somarriba and Beer (1987) found dbh of 24, 26 and 36 cm for laurel associated with pastures in permanent sample plots in two humid regions of Costa Rica. The present study found: laurel of different ages, mean abundance of 11.25 trees per ha corresponding to mixed (7.33 trees per ha), specialised milk (10.34 trees per ha) and dual purpose systems (16.8 trees per ha) (Souza de Abreu et al., 2000a, 2000b); mean dbh 19.9 cm (range from 14.3 to 23.1 cm); and mean merchantable volume of 1.05 m^3 ha^{-1}. The lower results of the present study might be due to the low abundance of laurel in the pasture, site characteristics and lack of silvicultural techniques.

Financial analysis

With regards to the resulting NPV (i= 5.36%), only the mixed and dual purpose systems were able to cover the total costs and had a positive NPV, although the NPV of the mixed system was low. The negative NPV of the specialised milk system shows that the higher milk production was not able to cover the high animal costs. Although the specialised pure milk breeds should produce more milk when they receive appropriated feeding, the animals did not reach 100% of their potential production. This could be explained by the negative effect of the climatic conditions of the region on the specialised milk breeds, causing heat stress which prevents an optimal milk production (Souza de Abreu et al., unpublished, 2002).

The income from other important activities of the mixed and dual purpose systems, such as crop and meat production also improved the total income of these two systems. This shows that the diversification of production systems helps to improve NPV. On the other hand, the income from wood-production was low in all three animal production systems in comparison with the other activities and only made a small contribution (1.02%) to the total income of the three systems. The results of Marlats et al (1995) using a discount rate of 8%, showed that an increased diversification of a silvopastoral system using timber trees leads to an improved NPV. The site characteristics of the region which are suitable for the natural regeneration of laurel in pastures could be better used by increasing the use of this timber resource in the three systems. In the present study the dual purpose system presents the best opportunity to exploit the potential of a more regular use of timber for sale in the future due to a greater abundance of laurel with small diameters. Therefore the benefits derived from this type of silvopastoral system could be increased.

The financial results of the present study shows that the importance of the use of timber from the natural regeneration of trees in the region to improve farm income is still small and the farmers' adoption and exploitation of trees depends on their level of preference for animal production activities.

6. Conclusions

These studies are the first of their kind to take a holistic approach to analysing the effect of shade trees in preventing environmental stress in dairy cows and the contribution of trees to the financial viability of cattle farms in Costa Rica.

Data from the biophysical study show that cows' compensatory mechanisms prevented a significant reduction in their performance. A better performance and a greater comfort of the Jersey cows with access to shade from trees were observed, confirming the benefit of natural shade in pastures. An alternative to matching the animal to the environment is to match the environment to the animal, but the provision of an ideal microclimate in a thermally stressful macroclimate is seldom a financially viable alternative. Partial amelioration of the macroclimate by the provision of natural shade from trees could be a financially viable proposition, especially when trees can also be used for timber, but may be inadequate for the husbanding of highly productive European cattle in very thermally stressful climates. This situation may also afford some improvement in the performance of breeds of cattle more suited to these climates.

Data from the economic study showed that timber trees present in the pastures of the region, e.g. laurel and cedro, are also used as shade for the animals and spite of still having only a small contribution to the total income of the cattle farmers, these trees represent a considerable timber reserve.

The true value of shade trees in reducing heat stress and improving productivity has generally been overlooked and large areas of valuable shade have been destroyed. The most common shade tree found in the region is the timber tree laurel, however the tree density in the pastures of La Fortuna is still low. Efforts should be made to support natural tree regeneration or tree planting programmes in areas with few or no shade, so that shade is provided for the most stressed breeds which are most sensitive to heat stress. Also the recommendation of silvicultural treatments to minimise current commercial wood losses and encouraging large-scale natural regeneration would be beneficial to farmers in the region.

It is clear that trees dispersed in pastures of La Fortuna, San Carlos could contribute to the sustainability of the silvopastoral system as a whole, producing additional income, providing shade to limit heat stress in cattle, and also helping to conserve biodiversity. It is important to show these associated benefits to cattle farmers and how they could maximise them.

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Paper I

Shade trees and dairy cattle performance in humid tropics: physiological and productive responses

(Prepared to be submitted for publication to Agroforestry Systems)

Paper I

Title: Shade trees and dairy cattle performance in humid tropics: physiological and productive responses

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Abstract

Sixteen Jersey cows in their second or third lactation, averaging 118 days *post lactation*, were assigned to an experiment to study the effect of natural shade (trees) on physiological and productive behaviour of the animals during the dry and rainy seasons. Weather variables were recorded and the Temperature-Humidity Index (THI) was calculated. Milk production was recorded every week and milk samples collected twice a month to analyse composition. Rectal temperature (RT) and respiration rate (RR) were determined. Milk samples were collected to analyse progesterone levels using the ELISA procedure. The solar radiation was significantly higher in no shade treatment ($p < 0.01$). The THI values of both treatments ranged above the critical index for milk production (THI > 72). A difference of 1.7 l of milk cow^{-1}day^{-1} ($p < 0.05$) in the dry season in favour of the animals in the shade was found. Average RT ranged within normal values. RR was on average 17 counts min^{-1} higher in the no shade treatment ($p < 0.01$). A difference of 1.27% in total solids for unshaded cows was detected ($p < 0.01$) and the milk progesterone level was higher in the shade treatment during the rainy season ($p < 0.05$). THI showed a significant correlation with milk production ($p < 0.03$). RT was influenced to a great extent by THI on the previous day and ambient temperature on the same day. RR was affected by THI and ambient temperature on the same day ($p < 0.001$). Considering that climatic conditions during the experiment were above the normal values for this type of cattle, the results suggest the possibility of increasing Jersey cows' performance by improving their comfort with shade trees during grazing.

Key words: Jersey cows, milk yield, natural shade, physiological responses, progesterone, THI

1. Introduction

Milk production in warm climates is a function of genetic merit, environmental effects such as climate, nutrition, health and management (Collier et al., 1982a; Beede et al., 1985). Although nutrition plays an over-riding role in warm climates, heat (thermal) stress constitutes a major determining factor in animal performance (Beede and Collier, 1986). In the tropics exotic dairy breeds (e.g., Holstein-Friesian and Jersey), that are more susceptible to heat stress and have higher nutritive requirements than the zebuine cattle, are commonly used. For example, in humid regions of Costa Rica, such as in the lowlands of San Carlos and in Rio Frio, exotic dairy breeds are managed on farms, where mean temperature and relative humidity are higher than 25 °C and 80%, respectively (French, 1994; Souza de Abreu et al., 2000). Elevated ambient temperature contributes most to thermal stress, particularly when it occurs in conjunction with high solar radiation, high relative humidity and low air movement. If heat gain from the environment and metabolism is greater than heat loss at and above an upper critical temperature, heat stress results. Heat stress induces a thermoregulatory strain, which results in physiological adaptations. Amongst these, reduced feed intake, decreased metabolic rate, elevated sweating, increased respiration rate, changes in blood hormone concentration, and redistribution of total blood flow are the most prominent (Beede et al., 1985; Blackshaw and Blackshaw, 1994; Hahn, 1999). These adaptations are survival strategies and are not necessarily geared for high production (Beede et al., 1985). Heat stress is also known to be associated with reproductive disorders, depressed growth (Bird et al., 1992) and impaired milk production efficiency (Finch, 1984; Hahn, 1985).

McDowell (1972) introduced the temperature-humidity index (THI) as an indicator of adverse climatic conditions. The THI is composed of a combination of wet and dry bulb air temperatures. Various workers have used THI to relate climatic conditions to animal performance (Maust et al., 1972; Ingraham et al., 1974).

There are three principle methods for attenuating the effects of thermal stress on milk yield. These are: 1) modifying the environment so as to alleviate heat by physical protection; 2) manipulation of the diet and related nutritional management strategies; and 3) the genetic development of less heat-sensitive animals. The simplest method of management for preventing heat stress during daytime is to reduce radiant heat gain by providing access to shade. This is sometimes neglected, and it is common to see cattle crowding under a single tree or other limited sources of shade (Gregory, 1995). Under more extensive livestock production systems, sophisticated artificial shades may not be justified because of high cost for installation of infrastructures. In the tropics the provision of a simple natural shade (e.g. trees) can reduce the solar radiation interception for livestock and minimize the degree of heat stress they experience (Beede et al., 1985; McArthur, 1991). Shearer et al. (1991) stated that, if cows were given the choice, they would prefer natural shade from trees to shade from man-made structures. Trees combine protection from the sun with the radiation sink effect created by moisture evaporation from the leaves (Armstrong et al., 1993).

Highly productive exotic dairy breeds require lower temperatures on pastures. Therefore, properly managed trees may play an important role in providing shade to reduce environmental stress. According to Davison et al. (1988) the provision of shade is necessary to maximize milk yield and to prevent changes in milk composition.

Most studies on silvopastoral systems evaluated the relationships between trees and pasture and soil and the use of woody perennials for feeding ruminants (Nygren and Cruz, 1998; Vidhana Arachichi and Liyanage, 1998). However, an agroforestry system in which trees are grown with a wide spacing with livestock grazing beneath the canopy could provide shelter for the animals as well as producing high quality timber. According to Sanchez and Febles (1999) there is no justification for an investment in the establishment of natural shade trees in grassland if this does not have a positive response in animal productivity. In Central America, a large percentage (> 60%) of cattle farmers are known to manage trees in pasture to provide shade to the animals (Pezo and Ibrahim, 1998).

Information on the physiological responses and productive performance of dairy animals kept in the hot and humid tropical climates, and the potential contribution that shade trees in pastures may play in improving milk production, is lacking. Most studies used artificial shade to simulate heat stress in animals, but the applicability of the results in traditional silvopastoral systems is limited because of the heterogeneous composition and structure of these systems. The present study was conducted in the lowlands of San Carlos, a tropical humid region of northern Costa Rica, to assess the role of natural shade in attenuating the adverse effect of climate on dairy cattle performance during two different seasons.

2. Materials and Methods

The study was conducted on a representative dairy farm in La Fortuna, San Carlos, in the northern tropical humid region of Costa Rica (Lat. 10° 28′N., Long. 84° 39′W., altitude 250 m a.s.l.). This farm was selected from a group of fifty farms. The mean annual precipitation of the study area ranges between 3000-3500 mm and the rainfall distribution is more or less uniform, except for the months between January to April, which have lower rainfall (CCT, 1990). The mean annual temperature is 26 °C and the average relative humidity is 80%. Soils are derived from volcanic – Andisols associated with Inceptisols (MAG, 1998). Dairying is one of the main land use activities in the Fortuna region and it is practiced on the flatter lands that are generally characterised with more fertile soils. Most dairy farms are managed with semi-intensive grazing and in general concentrates are fed as supplements to meet nutrient requirements for high milk yields. The most important dairy breeds are Holstein and Jersey. African star grass (*Cynodon nlemfuensis*) and *Brachiaria spp.* are the dominant pasture species and on many farms trees are found dispersed in pastures to provide shade for animals and to generate additional income.

Sixteen Jersey cows between 3.5 and 5 years old and in their second or third lactation were selected from a herd of 40 cows to evaluate the effects of two shade levels (shade vs. no shade) on physiological and productive performance of the animals. The animals had an average of 118 days *post lactation* and a mean initial liveweight of 346.5 ± 30.8 kg (mean ± SD). Mean milk production before the trial period was 12.75 ± 2.8 kg $cow^{-1}day^{-1}$. A semi-intensive grazing system was used to manage the animals which involves grazing on pastures plus the use of concentrates to supplement the animals. The animals were allowed to graze on pasture consisting of 1 ha pastures divisions of *Cynodon nlemfluensis* Vanderyst and *Brachiaria radicans* Napper grasslands from 13:30 hrs in the afternoon to 2:30 hrs in the morning and from 4:00 to 8:30 hrs in the morning. From 9:00 to 12:00 hrs they were kept in a 40–cow tie-barn with open sides, 2.5 m^2 stall space, a high galvanised roof and concrete floors and were supplemented with 2.9 kg of citrus pellet (sub-product from the orange industry), 1.7 kg molasses and 840 g of a commercial feed composed of maize, sorghum, soya bean meal and cottonseeds. Salt and minerals (110 g $cow^{-1}day^{-1}$) and water *ad libitum* were also available in concrete troughs for each cow. The cows were machine milked twice a day at 3:00 hrs and 12:30 hrs in a modern box-stall milking parlour separated from the barn. During each milking the cows received an additional 840 g of concentrate per cow. This adds up to 2.5 kg of concentrate cow^{-1} day^{-1} distributed between the two milkings and the stay in the barn. The experiment was conducted over a period of 6 months to obtain data for the dry (February, March and April) and the rainy (June, July, August) seasons. Eight lactating Jersey cows were randomly assigned to each treatment. Cows were given a 10-day adaptation period to adjust to their environment.

The experimental design was a completely randomised design with split plot in time where shade levels were assigned to main plots and seasonal effects to sub-plots. To establish experimental treatments, a rotational grazing system was used with pasture rested for 28.5 days and grazed for 1.5 days. This required 20 pasture divisions. In each pasture division, referred to as a replication in this experiment, trees grew scattered throughout the pasture and each paddock was divided by electric fencing to obtain one plot with trees (treatment 1) and one without trees (treatment 2) to establish the shade and no shade treatments respectively. The size of each experimental plot was of 5000 m^2. The natural shade in the pastures was a result of clusters of trees consisting predominantly of timber trees such as laurel (*Cordia alliodora*) and cedro (*Cedrela odorata*); shade trees including higuerones (*Ficus spp.*) and limón dulce (*Citrus sinensis*) and live fences including poró (*Erythrina spp.*). The average density of trees in the shade treatment was 8.9 trees $plot^{-1}$.

The meteorological measurements (maximum and minimum temperature, precipitation, dry and wet bulb temperature, and global radiation) in treatments with and without tree shade were recorded daily at 8:30 and 14:00 hrs. The dry and wet bulb temperatures were measured using an Aspiration-Psychrometer (Wilh. Lambrecht, Goettingen, Germany). The values indicated by the dry and wet bulb thermometers were used for determining the relative humidity in per cent using a specific Aspiration-Psychrometer table (German Weather Service) for lowland. The global radiation (W m^{-2}) was obtained by converting the photosynthetically active radiation (PAR) (μ moles m^{-2} s^{-1}) estimated by a line radiometer with datalogger (Decagon Devices Inc® Pullman, WA, USA) into global radiation (Li-Cor, 1985).

The Temperature-Humidity Index (THI) is derived from the observed outside temperature and humidity. It is intended as a measure of the "apparent" temperature, i.e., how the temperature feels, depending on the amount of water vapour in the air. THI was calculated using the equation of McDowell (1972): THI = 0.72 (W°C + D°C) + 40.6, where W°C is the wet bulb and D°C is dry bulb temperatures.

Two physiological parameters of the dairy cows were measured to evaluate heat stress: rectal temperature and respiration rate. The rectal temperature was measured daily at 9:00 hrs while the animals were in the barn. A digital clinical thermometer was inserted about 5 cm into the rectum. The cows were approached carefully to avoid excitement. Respiration rate was assessed twice a week (Tuesday and Friday) at 14:30 hrs by counting the flank movements of each cow for one minute. It was assessed in the paddocks and was always done by the same person from a distance of about 3 m. Rectal temperature and respiration rates were measured contiguously for a period of three months in the dry season and three months in the rainy season.

Milk yield from each cow was recorded for morning and evening milkings on Friday of each week during the experimental period using a milk-metre (Bou Matic, USA). Milk samples were collected for individual cows once every two weeks before morning and evening milkings to determine the milk composition. Potassium dichromate, a preservative, was added to composite milk samples (400 ml each) of each cow and were stored under refrigerated conditions. The milk samples were analysed for fat (Babcock method), protein (Formol titration) and total solids (Direct Forced Air Oven Drying) at the CATIE Animal Nutrition Laboratory in Costa Rica. These techniques have been described by AOAC (1990) and Revilla (1996).

The reproductive state of the cows was evaluated by measuring the progesterone concentration in the milk during a period of six months. Milk samples (5 ml) from individual cows were stripped from a teat after milking twice a week (on Monday and Thursday) and were stored at minus 20 °C. The samples were analysed for progesterone levels at the hormone laboratory of the Animal Husbandry and Genetics Institute of the University of Goettingen, using the ELISA procedure of Van de Wiel and Koops (1986), modified by Moeller (1991).

Statistical analysis

An analysis of variance (ANOVA) was carried out to determine the effect of shade and seasons on the variables evaluated. Correlation and a multiple regression analysis were used to evaluate relationships between the climatic, physiological and production variables studied. The data were analysed by the general linear model procedures (GLM) of SAS

System (SAS Institute Inc., 1985). The milk production was adjusted for covariate effects with data from the one-month pre-treatment period.

3. Results

Meteorological data

Average values and ranges of daily weather variables were established for the period of the study. Although the mean minimum and maximum temperatures were higher during June to August (rainy season) than in the February to April period (dry season), no significant difference was observed (Table 1). The mean precipitation from June to August was almost double the precipitation from February to April ($p < 0.05$).

Table 1. Mean daily macroclimatic data on the experimental farm, La Fortuna, San Carlos, Costa Rica from February to August 1999

Season	Temperature			Humidity	Precipitation
	Minimum (°C)	Maximum (°C)	Mean (°C)	(%)	(mm day^{-1})
Dry (February to April)	19.6 (11.0-23.0)*	30.8 (23.5-35.5)	25.3 (21.0-27.5)	74.7 (66.5-83.3)	5.2 (0.0-69.7)
Rainy (June to August)	21.1 (18.5-23.0)	31.1 (29.0-33.0)	26.0 (24.0-27.4)	77.8 (72.7-83.9)	10 (0.0-38.3)

* Data range

The mean daily ambient temperatures were higher for the afternoon reading than for the morning reading in the no shade treatment during both the dry and rainy seasons (Table 2). The mean ambient temperature differences between treatments in the afternoon were about 1 °C in both seasons. The ambient temperature reached the maximum value of 32 °C in the no shade treatment during the rainy season. The mean daily relative humidity in the morning was higher than in the afternoon in both treatments and was highest in the shade treatment during the rainy season (84.5%). The differences in mean daily temperature and relative humidity of shade and no shade treatments in both seasons and at both hours were not significant ($p > 0.05$). The intense afternoon global radiation was a common feature and was significantly higher in the no shade treatment than in the shade treatment ($p < 0.01$) during the dry season (20 vs. 357 W m^{-2}) and the rainy season (15 vs. 292 W m^{-2}). In spite of the fact that the highest value for global radiation (1037 W m^{-2}) was measured at 14:00 hrs in the no shade treatment during the rainy season, the highest mean global radiation (380 W m^{-2}) occurred at 8:30 hrs in the no shade treatment during the rainy season.

Table 2. Means and standards errors (SEM) of observations on daily microclimatic data in shade and no shade treatments measured at two different hours in the day in two seasons. La Fortuna, San Carlos, Costa Rica from February to August 1999

Treatment	Season	Time (hours)	Ambient temperature (°C)		Relative humidity (%)		Global radiation (W m^{-2})	
			Mean	SEM	Mean	SEM	Mean	SEM
Shade	Dry	8:30	24.7	0.22	84.3	1.43	14.0	1.07
		14:00	27.2	0.24	70.9	1.20	20.0	1.18
No shade	Dry	8:30	25.4	0.25	81.5	1.14	197.0	25.5
		14:00	28.2	0.27	67.9	1.23	357.0	28.01
Shade	Rainy	8:30	26.1	0.25	84.5	1.43	8.0	1.57
		14:00	27.1	0.28	76.1	1.54	15.0	1.72
No shade	Rainy	8:30	27.1	0.24	81.5	1.47	380.0	40.93
		14:00	28.1	0.32	73.9	1.58	292.0	37.37

The greatest ambient temperature differences between no shade and shade treatments were measured in February at 14:00 hrs during the dry season (1.4 °C) and in August at 8:30 hrs and 14:00 hrs during the rainy season, 1.3 °C and 1.2 °C respectively (Figure 1). The greatest relative humidity differences between shade and no shade treatments were recorded at 14:00 hrs in February (4.3%) and at 8:30 hrs in April (4.1%) during the dry season and at 8:30 hrs in August (5.1%) during the rainy season. The greatest global radiation differences between no shade and shade treatments were recorded at 8:30 hrs (749.6 W m^{-2}) and 14:00 hrs (482.1 W m^{-2}) in August during the rainy season (Figure 1).

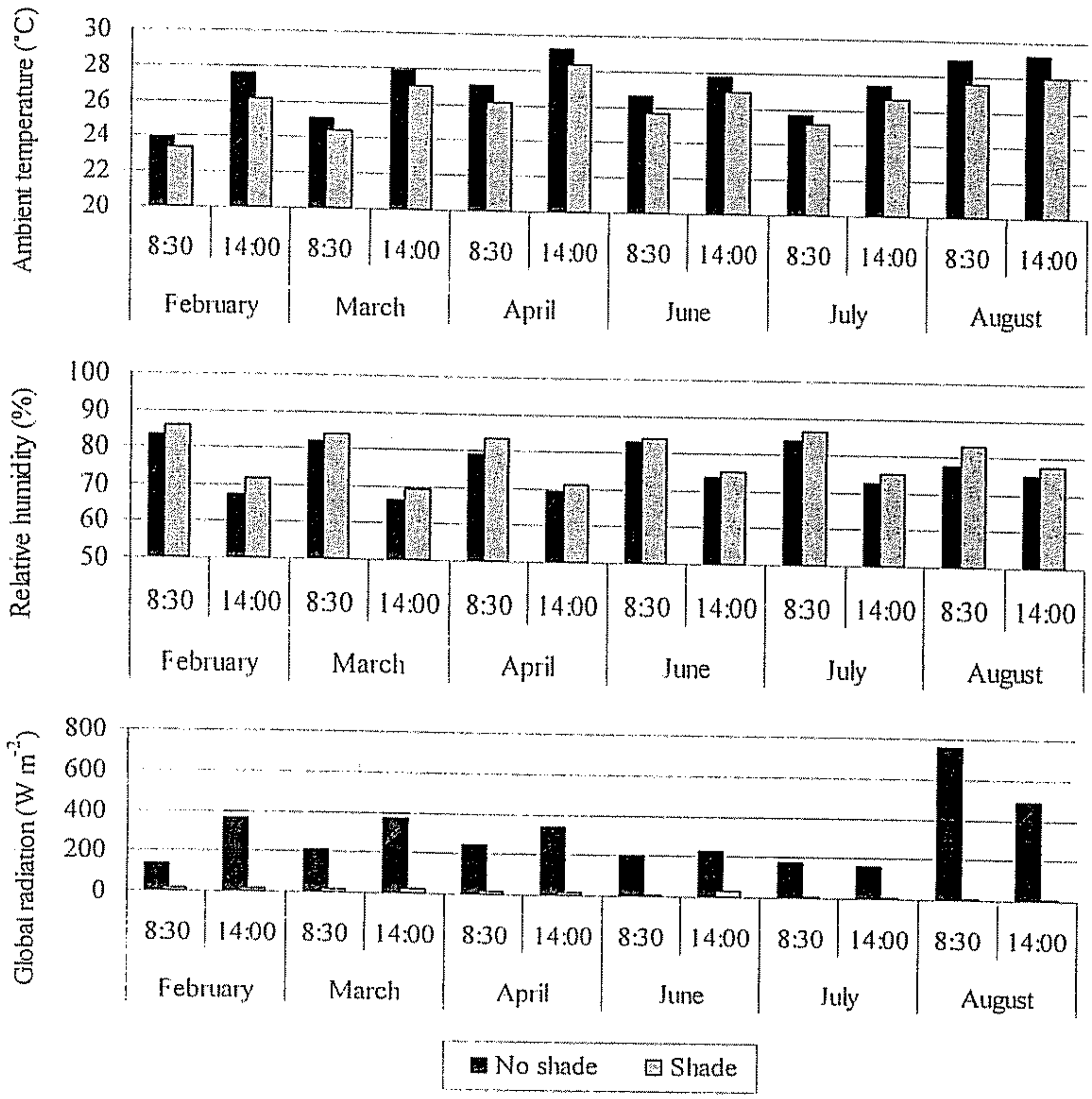

Figure 1: Differences of microclimatic data in shade and no shade treatments. La Fortuna, San Carlos, Costa Rica from February to August 1999

THI

The THI value differences between the shade and no shade treatments were of 0.8 units in the morning and in the afternoon in the dry season (Table 3). In the rainy season these differences were lower, corresponding to 0.3 and 0.1 units at 8:30 and 14:00 hrs respectively. In the dry season the THI values for shade and no shade treatments were lower than in the rainy season ($p < 0.01$).

Table 3. Means and standard errors (SEM) of dry and wet bulb temperature and THI (Temperature Humidity Index) during the dry and the rainy seasons. La Fortuna, San Carlos, Costa Rica from February to August 1999

Season	Time (hours)	Dry bulb (°C)		Wet bulb (°C)		THI* shade		THI no shade	
		shade	no shade	shade	no shade	Mean	SEM	Mean	SEM
Dry	8:30	24.2	24.9	22.1	22.5	73.9	0.18	74.7	0.21
	14:00	26.8	27.6	22.7	22.9	76.2	0.20	77.0	0.23
Rainy	8:30	25.7	26.2	23.7	23.7	76.2	0.24	76.5	0.27
	14:00	28.0	28.3	24.6	24.5	78.5	0.26	78.6	0.29

* THI = 0.72 (W°C + D°C) + 40.6, where W°C and D°C are wet and dry temperature respectively

In the present study the THI values ranged between 73.9 and 78.6 for both treatments. The THI value was categorized for lactating dairy cows by Du Preez et al. (1990) as follows: 70.0 or lower (normal), 70.0-72.0 (alert, approaching critical index for milk production), 72.0-78.0 (alert and above critical index for milk production), 78.0-82.0 (danger) and 82.0 or above (emergency).

Physiological data

Rectal temperature and respiration rate

Mean rectal temperature (RT) did not differ significantly between treatments during the dry season, although the RT of the cows in the no shade treatment was slightly higher in this season (Table 4). In the rainy season RT was significantly higher ($p < 0.01$) in cows that had no access to shade compared with cows that did have access to shade. The mean dry and rainy season RT values for the cows in shade treatment were 38.6 °C and 38.7 °C, respectively; in no shade treatment, the corresponding values were 38.6 °C and 38.9 °C.

In the dry season only during two days at the end of April did the RT of the animals show significant differences ($p<0.01$); with a mean of 38.9 vs. 39.5 °C for shade and no-shade treatments respectively. These higher RTs coincided with a high ambient temperature during these days of 30.8 and 29.7 °C. April was also, on average, the warmest month of the dry period. The highest mean maximum RT of 39.9 °C was recorded in the dry season in the no shade group.

Table 4. Means and standard errors (SEM) of observations on rectal temperature (RT) and respiration rate (RR) of 16 Jersey cows in the shade and no shade treatments for the two periods (dry and rainy seasons). La Fortuna, San Carlos, Costa Rica from February to August 1999

Within treatment

Parameter	Dry				Rainy			
	Shade (n = 8)		No shade (n = 8)		Shade (n = 8)		No shade (n = 8)	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
RT (°C)	38.57 a	0.06	38.59 a	0.06	38.72 a	0.07	39.02 b	0.07
RR (No. min^{-1})	64.72 a	1.11	80.65 b	1.11	70.39 a	1.20	88.90 b	1.16

Within season

Parameter	Shade (n = 8)				No shade (n = 8)			
	Dry		Rainy		Dry		Rainy	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
RT (°C)	38.57 a	0.06	38.72 b	0.07	38.59 a	0.06	39.02 b	0.07
RR (No. min^{-1})	64.72 a	1.11	70.39 b	1.20	80.65 a	1.11	88.90 b	1.16

Values in the same row with a common letter are not significantly different from each other (P<0.05), but do differ significantly from those not having the same letter

For seven days in the rainy season, the RT was significantly higher ($p < 0.05$) in the no shade treatment than in the shade treatment, these days being distributed during the whole period. The differences ranged from 0.4 to 0.6 °C. The highest mean maximum RT in the rainy season was 39.4 °C in the no shade group.

There was a seasonal trend in daily average RT, which was most evident in cows in the no shade treatment. The RT of the animals from both treatments was higher in the rainy season than in the dry season ($p < 0.05$) (Table 4). The mean RT difference of shaded animals in the dry and the rainy season was 0.15 and 0.43 °C for animals in the no shade treatment. The difference between the two treatments was also greater in the rainy season than in the dry season (0.30 vs. 0.02 °C).

Mean respiration rates (RR) were significantly higher in the cows in the no shade treatment than in the cows of the shade treatment group ($p < 0.01$) in both seasons (Table 4). The highest mean maximum RR was of 115 breaths min^{-1} in the no shade group in the dry season, while in the rainy season the RR was 118 breaths min^{-1} in the same group. According to field observations, the cows in the no shade treatment panted "like a dog" when the ambient temperature was above the critical limit, a sign of suffering severe heat stress.

Milk yield and composition

Average daily milk yields for cows in the shade treatment and cows in the no shade treatment at the beginning of this experiment were 13.19 and 12.31 kg cow^{-1} day^{-1}, respectively. Milk yield per cow in the shade treatment was 13.26% higher than in the no shade treatment in the dry season but differences in the rainy season were insignificant (Table 5). There was a significant interaction between shade level and season on milk yield per cow. Milk yields for the two treatments in the rainy season were significantly lower than in the day season. Higher concentrations of fat, protein and total solids were observed in the no shade group, with the exception of fat in the rainy season, but only total solids presented a significant difference between shade treatments ($p < 0.05$) such that total solids were higher for the no-shade treatment (Table 5).

Table 5. Means and standard errors (SEM) of observations on milk yield (kg day^{-1}), milk composition (fat, protein and total solids (%)) and progesterone profile (ng ml^{-1}) of 16 Jersey cows in the shade and no shade treatments for two periods (dry and rainy seasons). La Fortuna, San Carlos, Costa Rica from February to August 1999

Within treatment

Parameter	Dry				Rainy			
	Shade (n = 8)		No shade (n = 8)		Shade (n = 8)		No shade (n = 8)	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Milk yield	12.75 a	0.11	11.06 b	0.11	8.96 a	0.17	9.18 a	0.12
Fat	3.47 a	0.29	3.85 a	0.18	4.32 a	0.38	4.29 a	0.19
Protein	3.13 a	0.09	3.40 a	0.09	3.19 a	0.06	3.35 a	0.06
Total solids	12.00 a	0.36	13.34 a	0.36	12.78 a	0.25	13.55 b	0.26
Milk progesterone	41.60 a	1.24	42.42 a	1.04	35.16 a	0.81	32.66 b	0.87

Within season

Parameter	Shade (n = 8)				No shade (n = 8)			
	Dry		Rainy		Dry		Rainy	
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM
Milk yield	12.75 a	0.11	8.96 b	0.17	11.06 a	0.11	9.18 b	0.12
Fat	3.47 a	0.29	4.32 b	0.38	3.85 a	0.18	4.29 b	0.19
Protein	3.13 a	0.09	3.19 a	0.06	3.40 a	0.09	3.35 a	0.06
Total solids	12.00 a	0.36	12.78 b	0.25	13.34 a	0.36	13.55 a	0.26
Milk progesterone	41.60 a	1.24	35.16 b	0.81	42.42 a	1.04	32.66 b	0.87

Values in the same row with a common letter are not significantly different from each other ($P<0.05$), but do differ significantly from those not having the same letter

Progesterone

The average progesterone levels from pregnant cows (9^{th} to 23^{rd} week of pregnancy) for shaded and no shaded cows were not significantly different in the dry season, although a higher level was observed in the no shade treatment (Table 5). A significant difference between treatments was observed in the rainy season ($p < 0.05$), when the shade treatment presented a higher level of progesterone in cows.

Relationships between climatic factors and physiological, productive and reproductive responses

A multiple regression was carried out to analyse the relationship between climatic variables and rectal temperature (RT), respiration rate (RR), milk production and milk progesterone levels during the dry and rainy seasons. The climatic variables were ambient temperature the previous day (T-pd), ambient temperature the same day (T-sd), Temperature Humidity Index the previous day (THI-pd) and THI the same day (THI-sd).

THI-pd in the dry season and T-sd in the wet season had the greatest effect on rectal temperature accounting for 51.6% and 58.2% of the variation respectively. In the wet season THI-pd and THI-sd had significant effects on rectal temperature though they accounted for only 6 to 10% of variation. Respiration rate (y) was affected by THI-sd (x) in the dry season (y = -508.98 + 7.53x) and by T-sd (x) in the wet season (-453.45 + 19.93x) (Table 6).

Table 6. Standard partial regression coefficients (*b*), R^2 and level of significance for relationships between climatic variables [temperature the previous day (T-pd), temperature the same day (T-sd), THI the previous day (THI-pd), THI the same day (THI-sd)] and 1) rectal temperature and 2) respiration rate during the dry and the rainy seasons. La Fortuna, San Carlos, Costa Rica from February to August 1999

Season/ Climate variable	Rectal temperature			Respiration rate		
	b	Partial R^2	Significance	*b*	Partial R^2	Significance
Dry season						
T-pd	-	-	ns	-	-	ns
T-sd	-	-	ns	-	-	ns
THI-pd	0.592	0.52	$p < 0.001$	-	-	ns
THI-sd	-	-	ns	7.526	0.50	$p < 0.001$
Rainy season						
T-pd	-	-	ns	-	-	ns
T-sd	1.575	0.58	$p < 0.001$	19.930	0.73	$p < 0.001$
THI-pd	-7.267	0.09	$p < 0.02$	-	-	ns
THI-sd	-1.497	0.07	$p < 0.02$	-	-	ns

ns = not significant at the 0.05 significance level

Combining data from both seasons, there was a significant relationship between THI-pd (x) and progesterone levels (y) of animals ($y = -27.693 - 2.972x$; $R^2 = 0.35$). No significant relationship was found between climatic variables and milk production during either season. However, correlation coefficients (r) between milk yields and THI showed that there was a significant correlation ($r = -0.423$, $p < 0.03$) between milk yields and THI-sd, such that higher THI-sd values depressed milk yields.

A linear regression of respiration rate (RR) on THI was carried out. The linear regression (Figure 2) showed that there was a significant relationship between respiration rate (RR) and THI ($p < 0.01$).

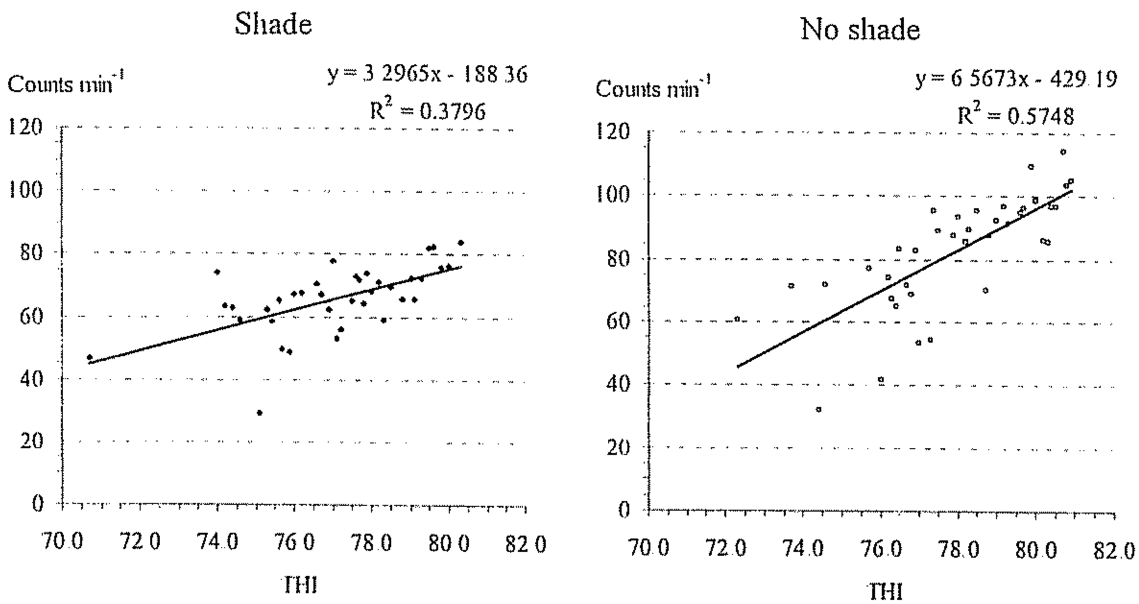

Figure 2. Respiration rate differences between shade and no shade treatments. La Fortuna, San Carlos, Costa Rica from February to August 1999.

A steeper slope (*b*) was observed for animals in the no shade compared to the shade treatment. In the shade treatment, R^2 was relatively low because of large variations between animals as seen in Figure 2.

4. Discussion

Heat Stress and the effect of meteorological factors, season and THI on thermoregulation mechanisms and milk production

The upper critical ambient temperature for the lactating cow falls between 24 to 27 °C (Fuquay, 1981). The typical climate of the study region was hot and humid (about 28 °C ambient temperature and 70% relative humidity at 14:00 hrs in the no shade treatment), which when combined make a very uncomfortable environment for lactating dairy cows. The month of August during rainy season was the month that showed simultaneously the greatest differences between the two treatments of ambient temperature, relative humidity and solar radiation, and animals in the no shade treatment suffered a greater climate discomfort than those in the shade treatment. The present study was conducted under field conditions, in which global solar radiation represented the major environmental difference between treatments. Animals gain heat by absorption of solar radiation. For animals outdoors, values of mean irradiance above about 500 W m^{-2} are uncomfortable (McArthur, 1991). In the present study, the global radiation reached values above 500 W m^{-2} in the no shade treatment during both the dry and the rainy season, indicating a discomfort for the animals. The significant difference in the average daily incidence of solar radiation between shade and no shade treatments (14.3 vs. 306.5 W m^{-2}) observed in the present study, indicates the beneficial effect of shade in intercepting the direct incidence of solar radiation. Davison et al. (1988) indicated in a study on the effect of shade in milk production of Holstein-Friesian cows that even when shade is provided, milk yield will be depressed during periods of high temperature and low wind movement. This statement agrees with results from the present experiment, where the cows under shade and no shade conditions suffered from the effects of high temperature, and a decline in milk production in both treatments was observed.

In the present study the cows of both the shade and no shade treatment groups during the whole of the dry season and in the morning of the rainy season were in the alert (warning) and above critical index for milk production (THI values of 72.0-78.0) according to the classification of Du Preez et al. (1990). At 14:00 hrs in the rainy season the THI value exceeded 78.0 in both treatments, a value considered dangerous for lactating cows according to Du Preez et al. (1990). Analysing the values of THI in both treatments in the present study, the cows in both shade and no shade treatments were all suffering from heat stress. According to Hahn (1976), when the cows experience a fair amount of heat stress, their performance is inhibited, handling becomes detrimental to their performance, the milk production can be seriously affected and cooling of the animals become desirable. In the afternoon, during the rainy season, the cows in both treatments had a THI greater than 78.0

and according to the classification of Du Preez et al. (1990), this is the danger category for lactating cows. According to Hahn (1976, when animals experienced severe heat stress, they are unable to maintain thermoregulatory mechanisms or normal body temperature, their performance could be severely affected and handling should take place only in the morning, and cooling of the animals and diet adaptations become essential. This implies that although an animal under shade is protected from the direct rays of the sun, it is still exposed to large amounts of diffuse solar energy (Blackshaw and Blackshaw, 1994). In this experiment the silvopastoral systems were characterised with tree species such as laurel (*Cordia alliodora*) or cedro (*Cedrela odorata*) that have an open canopy and higuerones (*Ficus spp.*) and limón dulce (*Citrus sinensis*) that have a closed canopy. The animals were observed to cluster under trees that are of denser canopy presumably because of a more comfortable micro-environment under the canopy of these species. According to Wilson and Ludlow (1991) the ambient temperature observed under tree shade is on average 2 to 3 °C lower than the temperature measured in open areas. In the present study the mean difference between ambient temperatures of both treatments was of only 1 °C. This difference was due to the presence in pastures of tree species with a more open canopy, such as laurel and cedro, that did not completely prevent the incidence of solar radiation. This has a lot of implications for the selection of shade trees for pastures. Farmers generally select tree species that have a more open canopy because of the possible effect of the shade on the pasture productivity and trees species that are of high timber value for silvopastoral system (Camargo et al., 2000). In intensive dairy production systems in the low lands some shade trees with denser canopy should be also selected because they provide a greater comfort to exotic dairy breeds and the advantages in milk production should be evaluated against other benefits (Souza de Abreu et al., 1999).

In a study conducted in the seasonal equatorial climate of southern Nigeria by Adeyemo et al. (1979), the milk cows were generally most comfortable during the wettest period of the year because of southwesterly winds. In contrast with the above result, in the present study the milk cows were more comfortable during the driest season according to THI values. Despite the influence of the cloud cover typical of rainy seasons, which limits the direct solar beams reaching the animals, the wettest season was more stressful. The THI value was greater in the rainy season than in the dry season, probably due to the combined effect of high temperature and the higher humidity during this season which affected the evaporative cooling mechanisms of the cows of breathing and sweating. McLean (1963) stated that an increase in the humidity of the air could restrict the evaporation from panting and sweating and, hence, have a marked effect on thermal status. For example, panting animals will increase their respiratory rate in response to rising humidity. In the present study, although the THI of the rainy season was the highest, the difference between THI of the shade and the no shade treatment was higher in the dry season than in the rainy season. This could be explained by the moisture effect created under shade, which is higher in the rainy season.

In the present study the climatic conditions represented by the THI showed that there was a significant correlation between milk production and weather on the same day during both the dry and the rainy season for no shade treatment and shade treatment. The same result was observed by Ikiror (2001), where afternoon milk yield was more sensitive to climatic factors of the same day than to climatic factors of the previous day, which suggests that reductions in the afternoon milk yield were probably caused by short-term heat stress. Unlike these studies, Maust et al. (1972) showed little relation between milk yield and weather on the same day, but climatic conditions on the previous 2, 3 and 4 days were significantly correlated with milk yield. In the present study, THI on the previous day (THI-pd) in the dry season was found to be as important as THI and ambient temperature on the same day (THI-sd; T-sd) in the rainy season in influencing rectal temperature, but respiration rate was affected more by THI-sd (dry season) and T-sd (rainy season). As in the present study, Ikiror (2001) in a coastal study in Kenya, found that THI on the day of measurement of the physiological responses was found to be as important as THI one day previously in influencing rectal temperature, but respiration rate was influenced more by THI on the same day.

Physiological responses to climatic conditions

Respiration rate (RR) has long been used as a gross indicator of heat load in animals during hot weather, increasing when animals need to maintain homeothermy by dissipating excess heat (Hahn, 1999). According to Bianca (1959), the poor sweating capacity of cattle elevates the RR, which is indicative of thermal stress. Normal respiration frequency is between 30 and 60 breaths min^{-1}. Rates beyond 60 breaths min^{-1} indicate that a cow is beginning to feel hot. Normally a rate of 180 breaths min^{-1} is not exceeded (Hansen, 1990). In the present study, RR of cows in both shade and no shade treatments in both seasons exceeded the normal frequency, indicating that the cows were using this mechanism to attenuate the heat stress. The highest frequency was found in the no shade group both in the dry and the rainy season, reaching the maximal value of 118 breaths min^{-1} in the rainy season.

RR of the cows in the no shade treatment was on average 15.4 (dry season) and 18.2 (rainy season) breaths min^{-1} higher than those of the cows in the shade treatment, showing a seasonal variation. As in the present study, RR of the cows showed a highly significant ($p < 0.01$) seasonal variation in an experiment conducted by Adeyemo et al. (1979) in Nigeria. According to Thompson (1985), RR increases much more in the humid season than in the dry season, due to the lower evaporation and cooling power of humid air. The results observed in the present study agree with the statement cited above.

Normal values of rectal temperature (RT) of cows are between 38.3 and 39.1°C (Hafez, 1973; Bianca, 1965). A state of hyperthermia occurred when the body temperature reaches 39.5 °C (Radostitis et al., 1994). In the present study the mean RT of cows in shade and no shade treatments in both seasons remained within the normal range (38.6 to 38.9 °C). Although the difference between the RT of the cows in the shade and no shade treatments never reached a difference of 1 °C, a significant difference between treatments was observed in the rainy season. In a study carried out by Collier et al. (1981) on the effect of shade on heat stress indices of Jersey cows, a greater thermal stress was observed in animals in no shade than in shade treatments ($p < 0.001$), the RT being 39.2 and 38.5 °C respectively. Ingraham et al. (1979) also showed that unshaded cows in a mildly stressing climate (daily air temperature 22-29 °C and 20-25 °C in two different study periods) had higher RT. In contrast to this, Buffington et al. (1983) stated that milk production and physiological responses achieved by providing shade for dairy cows have been inconsistent. In the results observed by Johnston et al. (1966), no significant differences in body temperature were observed between shade and no shade treatments. In the present study, the ambient temperature reached a maximum of 35.5 °C in the dry season and the Jersey cows in shade and no shade treatments maintained a normal mean RT. This result agrees with the results of Collier et al. (1981) when average afternoon black globe temperature was below 35 °C and Jersey cows were able to maintain normal RT.

The differences between the RT of the animals in the shade and no shade treatments in the dry and the rainy season, suggest a seasonal trend, the RT of the cows being higher in the rainy season than in the dry season. This difference could be due to the effect of high temperature in combination with the high humidity common in rainy seasons.

In the present study, THI reached a maximal value of 78.6 in no shade treatment during rainy season and only RR showed a significant increase. THI never reached a value greater than 80.0 and RT did not increase as expected. Meanwhile RR reached values above normal (> 60 breaths min^{-1}), indicating heat stress, and was significantly higher ($p < 0.01$)

in the animals of the no shade treatment, yet thermal balance appeared unaltered as indicated by normal RT. This shows that the rise in RR was effective in increasing heat loss, thereby preventing a rise in RT. These results agree with a study conducted by Lemerle and Goddard (1986) in Papua New Guinea, which showed that RT of dairy cattle increased when THI was greater than 80, while RR increased with a THI value of about 73 and probably more steeply above 80. These authors suggest that homeostatic mechanisms including increased RR can prevent an appreciable rise in RT until THI reaches 80. This is similar to the critical THI level of 78 quoted by McDowell (1972). RR is therefore a more reliable physiological measure of response to climatic stress (Buvanendran et al., 1992).

Solar radiation reception and RR were significantly higher ($p < 0.01$) in the no shade treatment and the RT showed no significant difference between treatments in the dry season and ranged within normal values. A study conducted by Thompson et al. (1964) comparing the reception of solar radiation and physiological responses of dairy animals in the sun and natural shade showed similar results.

There was a limitation in the present experiment because the physiological observations were all point measurements, restricted to one time in the morning for RT and one time in the afternoon for RR. This method probably did not allow the measurement of the animals' responses when they were highest or lowest within the 24 hour cycle. According to Collier et al. (1982a), cattle are exposed to a daily cycle of environmental temperatures under natural conditions, and they should therefore be studied throughout this cycle to define more clearly the responses to natural conditions.

Productive and reproductive responses to climatic conditions

For Jersey cows the reduction in milk yield takes effect above temperatures of 24 °C (Hafez, 1973). Although the mean ambient temperature in the present study was greater than 24 °C, a significant difference in the milk yields between cows in the shade and no shade treatments was found only in the dry season ($p < 0.05$). The cows in the shade treatment had greater milk yields than cows without shade in the rainy season, but this difference was not statistically significant. A similar finding was reported in an experiment conducted by Roman-Ponce et al. (1977), who found a 10.7% of increase for daily milk yield of cows in the shade treatment compared to cows in the no shade treatment. In contrast to this study, Guthrie et al. (1967) found no improvement in milk production of cows with access to shade, although the respiration rate was, as in the present study, lower in shade treatment than in no shade treatment.

In the present experiment, temperatures above 29 °C with high relative humidity were observed in both seasons, but these weather conditions usually did not last long and were generally preceded and followed by cooler days. Some authors have suggested that short bursts of heat stress will not affect productivity, as long as the heat load received by the animal can be subsequently dissipated (McDowell, 1972).

In the present study, the average daily milk yield was 13.3% higher for cows in the shade treatment than for cows in the no shade treatment during the dry season in contrast to a difference of only 1.5% in the rainy season. The differences in milk yield may be associated to greater intake of animals in the shade (2.44 kg DM/ 100 kg LW) vs in the no shade (2.03 kg DM/ 100 kg LW) treatments ($p < 0.05$) (De Sales, 1999; Souza de Abreu et al., 1999). The results for the dry season agree with the results of various studies, which showed that milk yields of cows increased by 5 to 13% when they were provided with shade (Roman-Ponce et al., 1977; Collier et al., 1981; Roman-Ponce et al., 1981; Collier et al., 1982b; Buffington et al., 1983).

The mean rectal temperature (RT) of cows in the no shade treatment rose but remained within normal values (38.87 °C) and seems not to have had a large influence on milk yield during the rainy season. According to Fuquay (1981) and Elvinger et al. (1992), it appears that milk yield starts to become depressed when RT reaches 40-41 °C.

The average percentages of some milk components for Jersey cows are as follows: fat: 4.64%, total protein: 3.73% and total solids: 14.04% (Stokes et al., 2000). As in the study of Roman-Ponce et al. (1981), in the present study no significant difference between shade and no shade treatments was detected for fat (3.53 vs. 3.59%) and protein content (3.12 vs. 3.14%), but in the result for total solids (12.50 vs. 13.41%), a significant difference was found ($p < 0.05$). As in the study of Collier et al. (1981) on shade management for milk yield and composition in Holstein and Jersey cows, the present experiment failed to detect a significant effect of shade on protein and fat content of the milk. The slight difference between treatments indicates that fat percentage and protein were not greatly affected by direct incidence of solar radiation. It is probable that the short duration of heat stress each day did not have the cumulative effect that is usually required for marked changes in milk composition (McDowell et al., 1969). This would seem to explain the small change observed in the milk constituents in the present study.

In the present experiment, the average milk concentrations of progesterone in milk were significantly lower in the no shade treatment than in the shade treatment during the rainy season ($p < 0.05$), although the decreased levels were considered to be within normal concentrations documented in the literature (Schiavo et al., 1975). In the dry season the milk progesterone was not influenced by treatments. There are contradictory results for the effect of heat stress on progesterone levels of cows (Wilmut, 1985). In a study by Wise et al. (1988), the plasma progesterone concentrations were not influenced by treatment (air-conditioned stall vs. outdoor corral with access to shade only). In contrast, a detailed hormonal study conducted in Florida with four lactating cows exposed to sun and five provided with shade, showed that progesterone concentrations were higher in the heat stressed animals during the luteal phase (Gwazdauskas et al., 1981). The authors noted that the elevated levels were within the range previously accepted as normal. In a study by Collier et al. (1982b), plasma concentrations of progesterone were elevated for no shade compared with shade cows prepartum during the last trimester of pregnancy (6.0 vs. 5.1 ng ml^{-1}). Thus, hormone of maternal origin was altered by environment and heat stress altered endocrine dynamics during pregnancy. Progesterone secretion has been shown to increase (Abilay et al., 1974; Roussel et al., 1977; Roman-Ponce et al., 1981) as well as decrease (Stott and Wiersma, 1973; Rosenberg et al., 1977) during heat stress.

The effects of different climatic conditions on milk progesterone concentrations in pregnant cows seem complex and are difficult to explain. The physiological state of the cow as well as the severity of the heat stress seem to affect progesterone levels. It is possible that the response to constantly hot or acutely elevated temperatures is different from that of moderately or intermittently high temperatures (Rosenberg et al., 1982).

There was a limitation in the present experiment because the grazing management was established such that the animals were kept indoors from 8:30 in the morning to 13:30 in the afternoon during which ambient temperature and solar radiation are supposed to be greater. This may have masked some of the effects of heat stress observed on animals in this experiment. In many areas of the tropics dairy production systems are practiced in hot weather conditions where cattle is allowed to graze the entire day and the effect of tree shade in alleviating heat stress may be even greater than in the present study.

5. Conclusions

Data from the present study showed that the cows' compensatory mechanisms prevented a significant reduction in milk production. The compensatory mechanism used by the cows in the present study was a significant increase in the respiratory rate during heat stress, which is an effective cooling evaporative mechanism to dissipate excess of body heat load.

Dairy cows in the natural shade treatment had higher milk yields in the dry season and a greater comfort (lower respiration rate) which confirms the benefits of natural shade in pastures which plays an important role in intercepting direct solar radiation. Shade trees found in the pastures of the region showed to be effective in reducing the negative effects of climate on animal performance, but the use of tree species with denser canopy could be more effective in controlling heat stress of dairy cows which could result in greater improvements in cattle productivity. However benefits with the incorporation of trees with denser canopy to control heat stress should be evaluated against the impacts on pasture productivity by incorporating farmer's local knowledge with field research.

Minimising heat loads of dairy cattle in hot humid climates is important from the point of view of both production and animal welfare. An alternative to matching the animal to the environment is to match the environment to the animal, but the provision of an ideal microclimate in a thermally stressful macroclimate is seldom a financially viable alternative. Partial amelioration of the macroclimate by the provision of natural shade from trees could be a financially viable proposition, especially when trees can also be used for timber, but may be inadequate for the husbanding of highly productive European cattle in very thermally stressful climates. This situation may afford some improvement in the performance of breeds of cattle more suited to these climates. The true value of shade trees in reducing heat stress and improving productivity has generally been overlooked and large areas of valuable shade have been destroyed. Natural tree regeneration or tree planting programmes should be supported and developed in areas with no shade, so that shade is provided for the most stressed breeds which are most sensitive to heat stress. Shade should also be available at cattle yards.

With regard to the effect of natural shade on animal performance in the region, further long term studies should be carried out to confirm these results.

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Paper II

Trees dispersed in pastures and their financial contribution to livestock farms in Costa Rica

(Prepared to be submitted for publication to Agroforestry Systems)

Paper II

Trees dispersed in pastures and their financial contribution to livestock farms in Costa Rica

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Abstract

Livestock production systems and the tree component within them were characterised in La Fortuna, San Carlos, Costa Rica. Three types of production systems were observed: mixed (dairy and agriculture), dairy, and dual purpose (milk and meat). Milk productivity (kg ha^{-1}) was highest for dairy farms. The area of pasture with trees was greater in dual purpose systems (74% of total area), predominantly timber trees. The timber tree species laurel (*Cordia alliodora*) was predominant in the pastures, although its density was low (11 trees ha^{-1}). In specialised milk systems, a significantly high density of shade trees was found compared to the other systems, protecting exotic animal breeds from direct sun. No significant differences were observed between the systems in live fence tree species and the fence lengths covered per ha of pasture. The dual purpose system presented the greatest abundance of laurel with small diameters, assuring a sustainable natural regeneration of this species, and the greatest merchantable volume of laurel (2.21 m^3 ha^{-1}). The greater abundance of laurel in the dual purpose system may be related to the fact that these livestock farmers try to reduce risk by diversifying farm production. The highest net present value (US$ 256.18 ha^{-1}) was found in the dual purpose systems. The average income from milk production in all three systems contributed the most to the total gross income (49.8%), while the average income from wood only made a small contribution (1.02%). In the future the tree component could play a more important role in the cattle production systems of the region.

Key words: *Cordia alliodora*, cattle farms, financial viability, La Fortuna, San Carlos, shade trees, timber trees

1. Introduction

Trees dispersed or isolated in pastures are considered a type of silvopastoral system, when the grazing systems in which trees are present play an interactive role in animal production (for example, by providing shade to animals, promoting pasture growth, and providing tree fodder or other tree products). Interactions between the components (trees, pastures, and animals) determine the functional importance of a silvopastoral system (Pezo and Ibrahim, 1996; Pezo et al., 1999).

Isolated trees are a common feature of agricultural landscapes throughout the tropics (Guevara et al., 1998) and they may be arranged as single trees that are generally widely spaced and/ or as group of clustered trees referred to as tree units. In Costa Rica, dispersed trees are found in more than 90% of cattle farms in order to provide shade for cattle and generate additional farm income, e.g through the sale of timber (Leeuwen and Hofstede, 1995; Ibrahim et al., 1998).

In Central America, the combination of the timber tree laurel (*Cordia alliodora* (R & P) Oken) with pastures is amongst the best examples of traditional agroforestry (Somarriba and Beer, 1987). Farmers mention several reasons for keeping trees in pastures. According to interviews carried out in Monteverde, Costa Rica, among the most commonly mentioned reasons were shade for cattle and timber (Harvey and Haber, 1999).

In northern Costa Rica cattle farming (milk and meat) is one of the main activities. The traditional cattle systems in Costa Rica are confronted with the serious problems of reduction in the price for their products and also with the degradation of the environment (Pomareda et al., 1997). Fluctuations of the market prices of farm products (milk and meat) may lead to socio-economic instability in many rural regions, especially on small and medium farms. On the other hand, forest products have shown less price variability in recent years. According to Marlats et al. (1995), silvopastoral systems can be set up as an alternative for incorporating forest exploitation using the economic benefits of each component of the system separately: the short-term financial return of farming and the favourable characteristics of the international forestry market. In this context, timber trees could be an important alternative for restoring degraded areas and for diversifying cattle farms in regions where wood production has great importance due to its commercial value (Howard, 1995).

Several studies have commented on the occurrence of trees in pastures or have documented their importance for maintaining forest species (Marmillod, 1989; Montagnini, 1992), and some studies have reported the beneficial effects of isolated trees in pastures for the conservation of biodiversity (Guevara et al., 1998; Harvey and Haber, 1999). Yet, there have been few systematic surveys on isolated trees in pastures, to study such matters as density and arrangement of these trees in paddock landscapes, the variation of the tree component according to different animal production systems and financial analysis of silvopastoral systems. This information is important in understanding the role these trees play in the financial viability of cattle farms and would enable the possibility of recommendations for reliable alternatives for improving the use of pasture trees according to their role in the different cattle farming systems.

In the present study the role of dispersed pasture trees in enhancing the income of cattle farming systems was examined. In addition, the volume and growth dynamics of the two main tree species dispersed in pastures of the region were analysed to understand their future financial contribution to the different cattle systems. This information provides a basis for assessing the importance of trees for the sustainability of cattle farming systems and their potential for producing future profits for the farmers.

2. Materials and methods

Study method and selection of cattle farms

The study was conducted in La Fortuna, San Carlos, in the northern humid tropical region of Costa Rica. La Fortuna is located 10° 28'N Lat. and 84° 39'W Long., and lies at an elevation of 250 m a.s.l. The original vegetation of the area is classified as Tropical Pre-montane Wet Forest life zone (Holdridge et al., 1971) with mean annual precipitation of 3000-3500 mm. The mean annual temperature is 26° C and the average relative humidity is 80%. Soils are derived from volcanic soils – Andisols associated with Inceptisols (MAG, 1998).

In May 1999, a study was conducted in La Fortuna to characterise the cattle production systems in the area. The location of cattle farmers (n= 71) in the pilot area was mapped out using the data base of the "Dos Pinos" dairy producers cooperative and the extension agency of the Costa Rican Ministry of Agriculture and Livestock (MAG), and consultations with local experts and farm leaders. A structured-interview was elaborated to collect data on farms and pre-tested with five dairy farmers. This survey was applied to thirty-five livestock farms that were chosen randomly from nine zones of the study area, to obtain information on the land use types, animal production systems, pastures and silvopastoral systems, cattle breeds, management, milk yields and socio-economic data. A canonical discriminant analysis (SAS Institute Inc., 1985) was performed on the data base of cattle surveys to identify farm typologies. Three different types of livestock systems were identified according to the main activity: 1) mixed (milk and crop production); 2) specialised milk production; and 3) dual purpose (milk and meat production). From the first original 35 farms, 5 farms were discarded, because their characteristics were different from those of the groups.

In September 1999 a case study was conducted to make an evaluation of the silvopastoral systems and a financial analysis of farms selected from the three farm typology identified in the area. For this case study four farms for the mixed system and three farms each for the specialised dairy and dual purpose systems were selected from the 30 farms surveyed based on the following criterias: 1) type of farming system (mixed, specialised dairy, and dual purpose; 2) farms that are representative of cattle production system in the area; 3) the presence of trees in pastures and 4) the willingness of the farmers to collaborate providing data and permitting field data collection. The case study consisted of: a detailed inventory of trees in pastures and collection of production and socio-economic data.

Tree surveys

In order to determine the potential importance of trees for the financial viability of livestock farms, a detailed inventory of the dispersed trees in pastures was carried out on the 10 farms selected (4 - mixed; 3 - specialised dairying and 3 - dual purpose), to identify the species that were present, their abundance, origin, and distribution. For farms with less than 100 ha, the sample size was 10% of the surface area and for farms with more than 100 ha, the sample size was 5% of the surface area. The total sample included 42.5 ha of paddocks

(9.6 ha in mixed systems; 4.2 ha in specialised milk systems; and 28.7 ha in dual purpose systems).

A farm plan was developed for each farm selected and a data base of paddocks was created and used for random selection of paddocks in which tree inventorying was carried out. On each selected paddock all species of dispersed trees were counted and identified. Trees that occurred in forest patches near rivers (riparian forest) were not included.

Laurel (*Cordia alliodora*) and cedro (*Cedrela odorata*) were the most common species in the paddocks. In order to understand the growth dynamics (regeneration dynamics) and consequently ascertain the sustainability of the valuable tree species in the pasture systems of the region, abundance (n ha^{-1}) of laurel and cedro was estimated according to diametric classes in each of the three different animal production systems.

In addition, dbh (stem diameter at 1.30 m breast height), total height (ht) and the commercial height (hc) of the timber tree species laurel and cedro were measured. Dbh was measured with a linen diameter tape and h (height) with a Suunto clinometer. These measurements were taken in order to determine the wood volume of the different cattle farm systems.

Farmer interviews

Interviews using questionnaire surveys were applied on the 10 farms and were focused mainly on the costs and benefits (financial analysis) of the different animal production systems, including the profitability of milk, meat and crop combined with wood production. Farm level input-output data were collected. The results of the present study are therefore based upon interviews and it is not known how accurately these could be extrapolated.

Data analysis

A. Tree volume

To calculate the total volume of laurel with a dbh of less than 35 cm the equation of Somarriba and Beer (1986) was used:

$$V_t = 0.017615 + 0.000034\,(dbh^2 ht) - 0.000086\,(dbh^2) + 0.003358\,(ht)$$

Where: V_t = Total volume (m^3)

dbh = Stem diameter at 1.30 m breast height (cm)

ht = Total height (m)

The estimation of the merchantable volume of laurel with a dbh equal to or greater than 35 cm was based on the table of McCaffrey (1972).

For cedro (*Cedrela odorata*) the equation deduced by Ford (1979) was used:

Volume (inches of Costa Rica)* = 0.21245 (dbh^2) – 77.002212

* Inches of Costa Rica (pulgadas ticas) = 0.0022 m^3

B. Financial analysis

All costs for animal production, agriculture and tree harvest were calculated. Labour used (both family and hired) was valued at the current agricultural wage for day-labourers in the region.

Current market prices were used for variable inputs and outputs and were estimated for non-marketed items on the basis of interviews. The prices of agricultural and animal products were based on the table provided by the Consejo Nacional de Producción (1999) and personal communications with experts from MAG and the Dos Pinos dairy producers cooperative.

The following indicators were used for the financial evaluation of the systems:

1. Net present value (NPV)

The net present value (NPV) is the current value of all net benefits during the period of the study. Net benefits are simply the sum of benefits minus costs. The resulting amount is discounted at the discount rate. Using this method, if NPV is greater than zero then it appears to be a good candidate for implementation. The formula used to calculate NPV (Gittinger, 1982) was:

$$NPV = \sum_{t=0}^{7} (b_t - c_t) \cdot i^{-t}$$

where:

b_t: benefits in time t

c_t: costs in time t

i^{-t}: discount rate in time t

The discount rate used to determine the present worth of a future value by discounting was calculated using the following formula:

$$\text{Discount rate (i)} = \left(\frac{(1 + \text{nominal rate})}{(1 + \text{inflation rate})} - 1 \right) \cdot 100$$

According to reports of the Central bank of Costa Rica, in recent years the nominal rate has been about 18% and inflation about 12% (Manuel Gomez, pers. comm., 2000), resulting in a discount rate of 5.36%. Considering that the investments of the animal production systems are generally uniformly distributed during the whole year, half of the discount rate was used (i= 2.68%) for the financial analysis.

2. Benefit-cost ratio (BCR)

The benefit-cost ratio (BCR) was calculated by dividing NPV of benefits by the NPV of costs (Gittinger, 1982) and might be greater than 1.

$$BCR = \frac{\sum_{t=0}^{T} b_t \cdot i^{-t}}{\sum_{t=0}^{T} c_t \cdot i^{-t}}$$

where: b_t: benefits in time t

c_t: costs in time t

i^{-t}: discount rate in time t

3. Return on annual investment

$$\text{Return on annual investment} = \frac{\text{NPV}}{\text{Total annual investment}}$$

Total annual investment includes all costs excluding depreciation costs, land rent, and purchasing of new animals

4. Return on labour

$$\text{Return on labour} = \frac{\text{NPV}}{\text{Number of days' wages}}$$

5. Sensitivity analysis

The sensitivity analysis using real prices (not considering inflation) assumed an increase in price of 16.8% for wood, which corresponds to the accumulated average variation of the real prices of standing wood in the northern zone of Costa Rica for the period from January 1996 to May 1999 (Berti, 1999). In the case of meat, a 6% reduction in the price was assumed, corresponding to the behaviour projected between 1993 and 2002 by Rosegrant and Sombilla (1997), and by Delgado et al. (1997). Considering the price of fluid milk paid to producers from January 1998 to July 1999 in Costa Rica according to the Regional Central American Agricultural Council (CORECA) (Umaña and Pomareda, 1999), a US$ 0.02 litre^{-1} reduction was observed for this period. Based on this, in the present study a reduction of 6.9% in the milk price was assumed. Changes in prices of labour and concentrates were used based on the actual trend of these in Costa Rica. These correspond to a 3.0% reduction in the real price of labour and an increase of 5 0% in the real price of external inputs such as concentrates (Manuel Gomez, pers. comm., 2000).

Considering the nominal prices (taking into account the inflation rate during the year), an increase of 5.1% in the milk price was observed in the period of analysis (Manuel Gomez, pers. comm., 2000). A sensitivity analysis was carried out taking into consideration increases of 5, 10, 15, and 20% in milk and wood prices to observe the influence of these changes on the NPV of the three different animal husbandry systems.

3. Results

Characteristics of animal production systems

Three main cattle production systems were identified in La Fortuna: mixed (milk and crop production); specialised milk production; and dual purpose (milk and meat production) (Table 1). Mean farm size and area covered by pastures of dual purpose farms were around seven times (6.95 and 6.70 respectively) greater than those of the other systems, with these differences being significant ($p < 0.001$). Dual purpose farms had a significantly ($p < 0.001$) greater percentage of pastures characterised with trees (74%) compared with mixed (16%) and specialised dairy farms (27%). Mean daily milk production per ha was greater on specialised milk (14.2 kg) and mixed farms (12.6 kg) than on dual purpose farms (4.3 kg)

Table 1. Characteristics of the cattle production systems. La Fortuna, San Carlos, 1999 (n = 30 farms)

System	Farm size (ha)	Pasture area (ha)	Area of pasture with trees (%)	Stocking rate (AU ha^{-1})	Milk yield / area (kg $ha^{-1}day^{-1}$)
Mixed (n=13)	44.0 b* (± 33.5)	35.0 b (± 26.6)	16.0 b	1.8 a (± 0.7)	12.6 a (± 8.3)
Specialised milk production (n= 9)	50.0 b (± 38.4)	46.0 b (± 37.3)	27.0 b	2.2 a (± 1.1)	14.2 a (± 11.2)
Dual purpose (n=8)	327.0 a (± 133.8)	273.0 a (± 123.1)	74.0 a	0.6 b (± 0.3)	4.3 b (± 2.4)

* Means with the same letter within each column are not significantly different ($p < 0.05$)
± Standard deviation
AU = Animal Unit (400 kg live weight)

Tree surveys

The most common timber species found in pastures in the study area were laurel and cedro which originated from natural regeneration and were randomly distributed in the pastures. The density of trees (n ha^{-1}) was greater in specialised milk production and dual purpose systems. A higher density of laurel was found in the dual purpose system ($p < 0.05$) (Table 2). Dual purpose and mixed farms had a significantly ($p < 0.001$) higher percentage of timber trees compared to specialised dairy farms which was characterised with a higher percentage of shade trees compared to other systems (Figure 1). No silvicultural techniques were used to improve tree form and vigour.

Other tree species such as higuerón (*Ficus spp.*), limón dulce (*Citrus limetta*), naranjo dulce (*Citrus sinensis*), guava (Inga *sp.*), guayaba (*Psidium guajava*), poró (*Erythrina spp.*) and other timber trees such as lagarto (*Zanthoxylum belizense*), gavilán (*Pentaclethra macroloba*) and surá (*Terminalia oblonga*) were also frequently found dispersed in the pastures.

Table 2. Abundance of trees (average number of trees ha^{-1}) according to type of cattle production system. La Fortuna, San Carlos, 1999

Trees	Mixed (n =4)	Specialised in milk production (n =3)	Dual purpose (n=3)
Laurel	7.33 b[1]	10.34 b	16.08 a
Cedro	0.63 a	1.44 a	0.62 a
Other timber trees[2]	2.51 a	4.33 a	1.26 a
Non-timber trees[3]	1.99 b	6.00 a	2.51 b
Total	12.46 a	22.11 b	20.47 b

[1] Values with the same letter in the same row are not significantly different ($p < 0.05$)
[2] Lagarto, surá, gavilán and poró
[3] Limón dulce, naranja, guayaba, guava and higuerón (fruit and shade trees)

Timber extracted by all farmers in the three cattle systems was mainly used for their own consumption and then for sale. Like laurel and cedro, other timber trees were used to generate additional income for the livestock farms (Figure 1). The average harvesting frequency was around once every three years

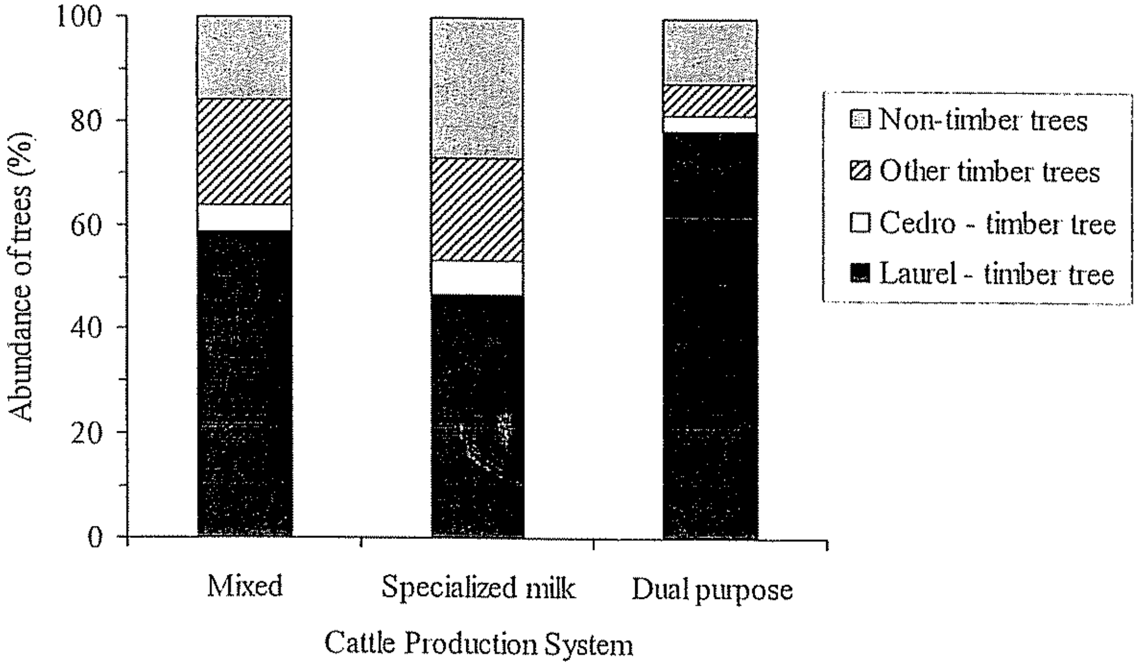

Figure 1. Abundance (%) of different types of trees in the three cattle production systems. La Fortuna, San Carlos, 1999. Other timber trees: lagarto (*Zanthoxylum belizense*), surá (*Terminalia oblonga*), gavilán (*Pentaclethra macroloba*), and poró (*Erythrina spp.*). Non-timber trees (fruit and shade trees): naranjo dulce (*Citrus sinensis*), limón dulce (*Citrus limetta*), guayaba (*Psidium guajava*), guava (*Inga sp.*), and higuerón (*Ficus spp.*)

The isolated tree species found in the different animal husbandry systems, their abundance, distribution and origin were described in detail in earlier articles of the author (Souza de Abreu at al., 2000a; Souza de Abreu et al., 2000b).

Tree regeneration dynamics

The distribution of diametric classes of all laurel and cedro trees inventoried in the pastures of the three different animal husbandry systems are given in Figure 2. In general a healthy tree species population should contain a diametric distribution in form of a reversed "J" that represents a greater abundance of trees with small diameters and a gradual reduction in the number of trees with greater diameters. According to Lamprecht (1990), to assure the sustainable natural regeneration of a tree species, the system is expected to have many trees with small diameters to replace the trees of greater diameters that are going to be extracted. Excluding the diameter class 10.0-14.9 cm, where all systems showed a relatively low abundance of laurel, the dual purpose system was the only one that follows the diametric distribution in form of a reversed "J". The other two animal husbandry systems showed an irregular distribution of trees according to the diameter classes (Figure 2).

In relation to cedro trees, no animal production system had a diametric distribution (reversed "J" form) required to ensure the sustainability of this species in the system. All the cedro trees on the farms in the specialised milk system presented diameters that ranged between 15.0 to 29.9 cm, while the dual purpose and mixed showed a larger, but also irregular, diametric distribution (Figure 2).

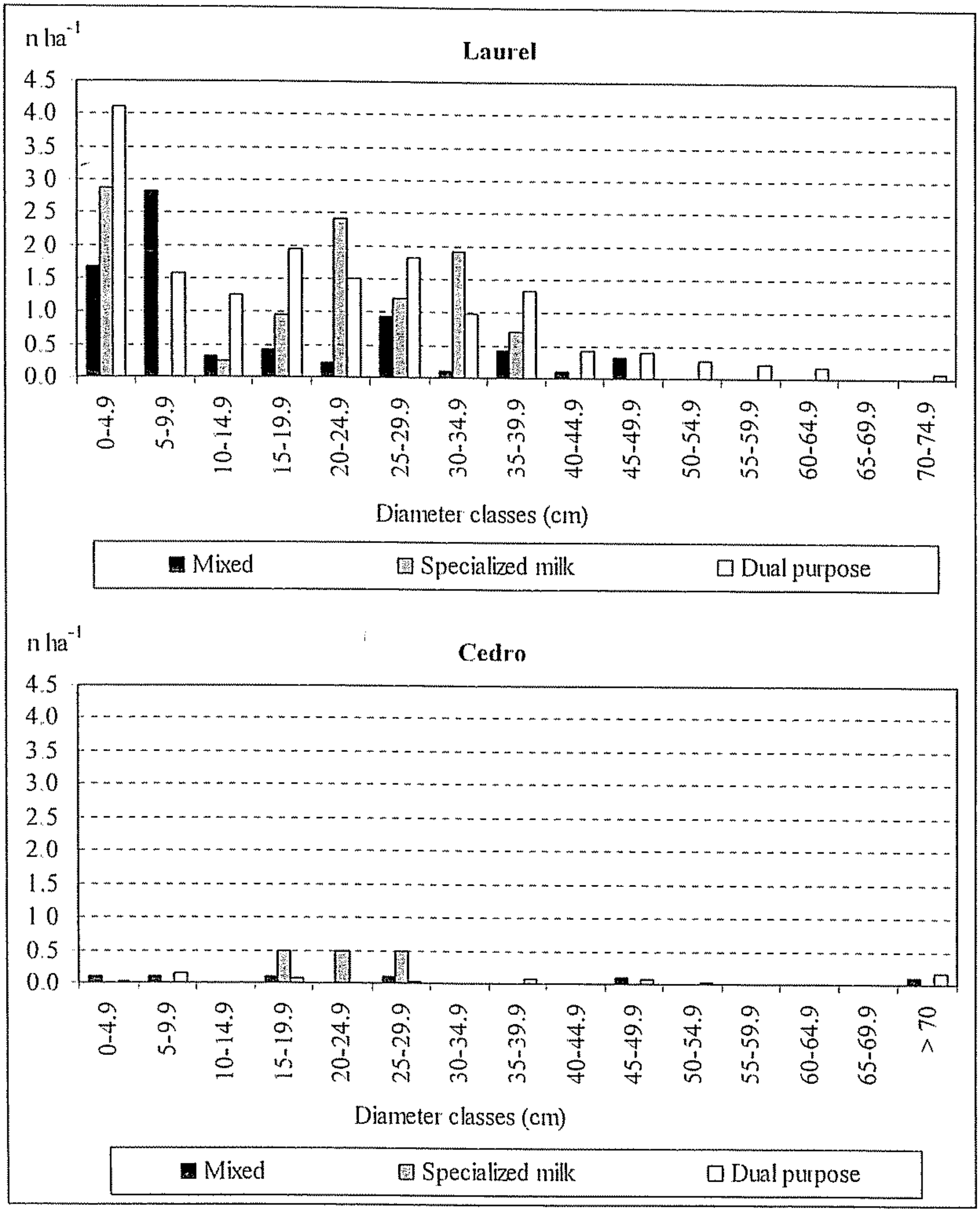

Figure 2. Abundance of laurel and cedro (n ha^{-1}), according to diametric classes, in the three cattle production systems. La Fortuna, San Carlos, 1999

B. Tree volumes

The dual purpose system presented a significantly ($p < 0.05$) greater merchantable volume of laurel than the mixed and specialised milk systems (Table 3). Mixed system had a 62% and 75% lower non-merchantable volume of laurel when compared to dual purpose and specialised diary systems respectively, and differences were significant ($p < 0.0001$).

Table 3. Average merchantable and non-merchantable volume of laurel and cedro ($m^3\ ha^{-1}$), according to type of production system. La Fortuna, San Carlos, 1999

Tree species / Type of system	Total sample size (ha)	Merchantable volume (dbh ≥35 cm) [$m^3\ ha^{-1}$]	Non-merchantable volume (dbh <35 cm) [$m^3\ ha^{-1}$]
Laurel			
Mixed (n= 4)	9.55	0.54 ± 0.12 b	0.87 ± 0.13 b
Specialised milk (n= 3)	4.16	0.41 ± 0.08 b	3.47 ± 0.71 a
Dual purpose (n= 3)	28.67	2.21 ± 0.45 a	2.28 ± 0.37 a
Cedro			
Mixed (n= 4)	9.55	1.56 ± 0.45 a	0.03 ± 0.01 a
Specialised milk (n= 3)	4.16	0.00 ± 0.00 a	0.18 ± 0.04 a
Dual purpose (n= 3)	28.67	1.18 ± 0.24 a	0.01 ± 0.00 a

Within each tree specie, means with the same letter within each column are not significantly different ($p < 0.05$)
± = standard deviation

Although the number of cedro trees was small, trees encountered in the mixed systems showed a higher merchantable volume for this species than laurel (Figure 2 and Table 3). The number of trees with non-merchantable volume (dbh<35 cm) was small in the three systems, indicating future conservation difficulties for this species in the animal production systems of the region.

Financial analysis

Financial analyses were made for a period of one year (October 1998 to September 1999) for the three animal systems (Table 4). A short description of these three animal systems is presented as follows:

1. Mixed (milk and crop production) - 3 farms *

Mixed farms used, on average, 79.5% of the total area for pasture production with the rest being used for the production of crops such as cassava (*Manihot esculenta*) and plantain (*Musa AAB*). In this system, 95.0% of the cattle were crosses of European breeds (Holstein × Jersey).

* One farm of the mixed system was excluded from participating in the financial analysis due to not having a crop harvest in the analysed period (1998-1999).

2. Specialised milk production – 3 farms

Specialised milk farms used, on average, 92.0% of the total area for pasture production. This system presented the highest milk production per unit area due to the presence of pure specialised milk breeds and also due to better management on the farms (Table 1). On specialised milk farms, 95.0% of the cattle were European breeds (Holstein and Jersey). There was a greater area under improved pastures (i.e. *Cynodon nlemfuensis, Brachiaria brizantha* and *Panicum maximum* cv. Tanzania), pasture fertilisation and greater use of supplements (3 kg cow^{-1} day^{-1}) on specialised milk than on dual purpose systems (Souza de Abreu et al., 2000b).

3. Dual purpose (milk and meat production) – 3 farms

Dual purpose farms used, on average, 83.5% of the total area for pasture production. In this system, more than 70.0% of the herd were Holstein Zebu crosses of. There was a greater area of pasture with trees in this system (about 73.0%) than in the other systems.

Table 4. Financial analysis of three different animal production systems. La Fortuna, San Carlos, 1999 (n= 9 farms)

AVERAGE ANNUAL COSTS (US$ ha^{-1})	Animal production system		
	Mixed	Spec. milk	Dual purpose
Variable costs			
Concentrates and supplemental feeds	669.06	885.22	181.51
Maintenance costs *	132.71	332.73	86.97
Labour (casual)	61.04	43.66	10.66
Transport	21.48	9.01	4.60
Veterinary services, artificial insemination	10.48	8.80	1.61
General costs (fuel, repairs, rent, water, etc.)	113.29	211.94	63.82
Wood extraction	0.00	2.86	0.81
Total variable costs	**1,008.06**	**1,494.22**	**349.98**
Fixed costs			
Land rent (rent value x total ha)	214.56	183.02	208.34
Labour (permanent)	481.60	323.27	97.91
General costs (insurance and salaries)	441.82	364.58	76.59
Depreciation (buildings and equipment)	68.52	131.87	30.98
Depreciation (animals)	121.29	198.98	45.49
Total fixed costs	**1,327.79**	**1,201.72**	**459.31**
Total variable and fixed costs	**2,355.85**	**2,695.94**	**809.29**
AVERAGE ANNUAL GROSS INCOME (US$ ha^{-1})			
Milk production	1,197.15	1,531.79	389.17
Crop production	93.34	0.00	3.83
Meat production**	146.07	156.93	251.50
Citrus production	4.43	0.00	0.00
Sundry jobs	159.47	5.24	6.49
Posts	3.59	0.00	0.00
Wood utilisation	28.97	23.70	9.57
Animal stock	483.87	504.20	364.91
Self-consumption products	341.76	147.75	53.73
Total gross income	**2,458.64**	**2,369.61**	**1,079.20**

1 US$= 279.64 colones (average from Oct. 1998 to Sept. 1999 according to Central Bank of CR)

* The costs for crop production (seeds and fertilisers) were included in services within maintenance costs. Other maintenance costs were veterinary products, hardware, animal purchase and services

** Sale of dry cows was included in the income from meat production

Considering the total variable and fixed costs of the three systems, the specialised milk system showed greater costs than the mixed and dual purpose systems, mainly due to the variable costs associated with animal nutrition, maintenance costs of the animals and general costs. The mixed system had no costs for wood extraction due to the use of family labour and the farmer's own saw, but the costs of the use of family labour was included as opportunity costs within permanent labour in fixed costs The average annual gross income (US\$ ha^{-1}) of the milk production for the specialised milk system and for the mixed system was respectively 74.6% and 67.5% greater than the income for the dual purpose system. The contribution of income from wood to the total income was 1.2% for mixed systems, 1.0% for specialised milk systems and 0.9% for dual purpose systems, showing that the exploitation of wood is still a secondary activity for the farmers.

The NPV varied greatly among the three cattle systems and within the mixed and specialised milk systems (Table 5). The dual purpose farms had a more homogenous NPV. The highest NPV value with a 2.68% discount rate was obtained in the dual purpose cattle system, followed by the mixed system. The NPV in the specialised milk system was negative. The mixed and dual purpose systems showed BCRs greater than 1, while the specialised milk system had a BCR lower than 1.

Table 5. Financial indicators of the three different animal production systems. La Fortuna, San Carlos, 1999 (n= 9 farms)

Financial indicator	Animal production system		
	Mixed	Specialised milk	Dual purpose
NPV (i = 2.68%) US$**$ha^{-1}$	97.57 (-701.76 – 567.48)*	-309.73 (-509.41 – - 108.69)	256.18 (203.28 – 294.23)
Benefit cost ratio (BCR)	1.09 (0.75 – 1.33)	0.88 (0.84 – 0.92)	1.36 (1.21 – 1.51)
Return on labour***	5.55 (-14.70 – 8.14)	-0.20 (-11.02 – -4.02)	26.90 (13.99 – 25.36)
Return on annual investments	0.11 (-0.28 – 0.40)	-0.15 (-0.19 – -0.10)	0.59 (0.31 – 0.85)

* Data range

** 1 US$= 279.64 colones (average from Oct. 1998 to Sept. 1999 according to Banco Central de Costa Rica)

*** The market price of the labour was aggregated (US$ 7.00 day's $wage^{-1}$)

Regarding the return on labour, the dual purpose system showed a return on labour US$ 19.90 higher than the market price for a day's wage. The return on labour shown by the mixed system was US$ 1.45 lower than the market price for a day's wage and for the specialised milk system it was US$ 7.20 lower than the market price for a day's wage. The return on annual investments is the return on capital invested in farm activities. The mixed and dual purpose systems showed a positive return, whereas the specialised milk system had a negative return.

Table 6. Sensitivity analysis for the three different animal production systems. La Fortuna, San Carlos, 1999 (n= 9 farms)

Item⁻	Financial indicator	Animal production system		
		Mixed	Specialised milk	Dual purpose
Milk price (↓ 6.9%)	NPV ha^{-1}	19.17 (-801.40 – 512.95)*	-410.05 (-623.19 – -146.27)	230.69 (159.93 – 272.39)
	BCR	1.06 (0.71 – 1.30)	0.84 (0.80 – 0.87)	1.33 (1.16 – 1.49)
Meat price (↓ 6.0%)	NPV ha^{-1}	89.26 (-707.44 – 551.41)	-318.67 (-540.67 – -110.93)	241.86 (192.85 – 275.24)
	BCR	1.09 (0.75 – 1.32)	0.88 (0.83 – 0.91)	1.34 (1.20 – 1.48)
Wood price (↑ 16.8%)	NPV ha^{-1}	102.19 (-709.76 – 568.51)	-305.95 (-508.15 – -104.26)	257.70 (205.84 – 295.55)
	BCR	1.09 (0.75 – 1.33)	0.88 (0.84 – 0.92)	1.37 (1.21 – 1.38)
Labour costs (↓ 3.0%)	NPV ha^{-1}	113.02 (-689.23 – 577.78)	-299.28 (-509.15 – - 105.41)	259.27 (206.79 – 297.39)
	BCR	1.10 (0.75 – 1.34)	0.88 (0.84 – 0.92)	1.37 (1.21 – 1.52)
Concentrates price (↑ 5.0%)	NPV ha^{-1}	65.82 (-760.97 – 551.08)	-350.64 (-595.43 – -120.15)	248.19 (187.40 – 290.90)
	BCR	1.08 (0.73 – 1.32)	0.87 (0.82 – 0.91)	1.35 (1.19 – 1.50)

* Data range

The sensitivity analysis shows that the NPV of the mixed system responded more markedly to all price changes when applied to the items presented in Table 6. With a decrease of 6.9% in milk prices, the mixed system presented a NPV reduction of 80%, whereas for the specialised milk and dual purpose systems the reductions were 32.40% and 9.95% respectively. When the price of meat fell 6.0% the mixed system showed a greater reduction in the NPV (8.52%) compared to the dual purpose (↓ 5.60%) and specialised milk systems (↓ 2.90%). An increase in prices of wood of 16.8% was beneficial with an increase in NPV of 4.73%, 1.22% and 0.60% in mixed, specialised milk and dual purpose farms respectively. Decreasing labour costs by 3% resulted in an increase of 32.54% in NPV in the mixed system, compared to an increase of 13.21% in specialised milk system and 3.12% in dual purpose system. A 5.0% increase in the price of concentrates resulted in a reduction in NPV of 32.54% in mixed, 13.21% in specialised and only 3.12% in dual purpose systems.

The sensitivity analysis showed that an increase in milk price by 5 to 20% , resulted in the largest change of NPV per ha. (NPV with an increase of 20% in milk price minus the present NPV) for specialised dairy, with a difference of US$ 290.77 compared to mixed (US$ 227.25) and dual purpose systems (US$ 73.87) which was less sensitive to changes in milk price (Figure 3).

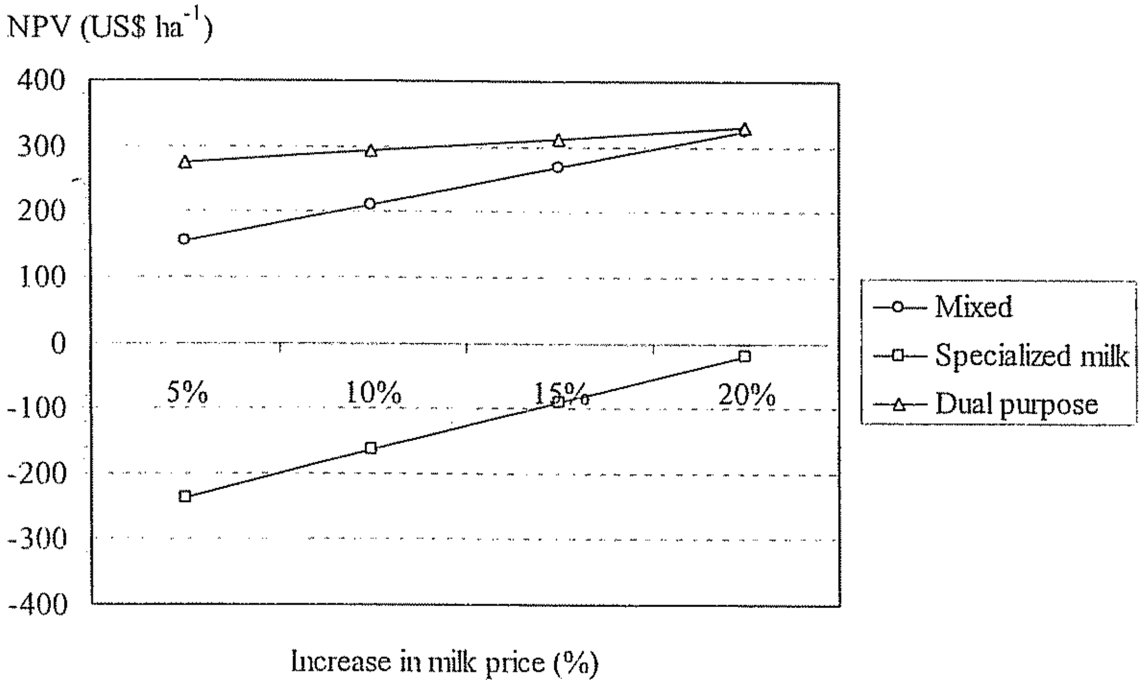

Figure 3. The effect of percentage changes (5 to 20%) in milk prices on net present value (NPV) per ha for the three animal production systems. La Fortuna, San Carlos, 1999 (n= 9 farms)

Meanwhile no significant changes in NPV of the three systems were observed when wood prices increased by 5 to 20% (Figure 4).

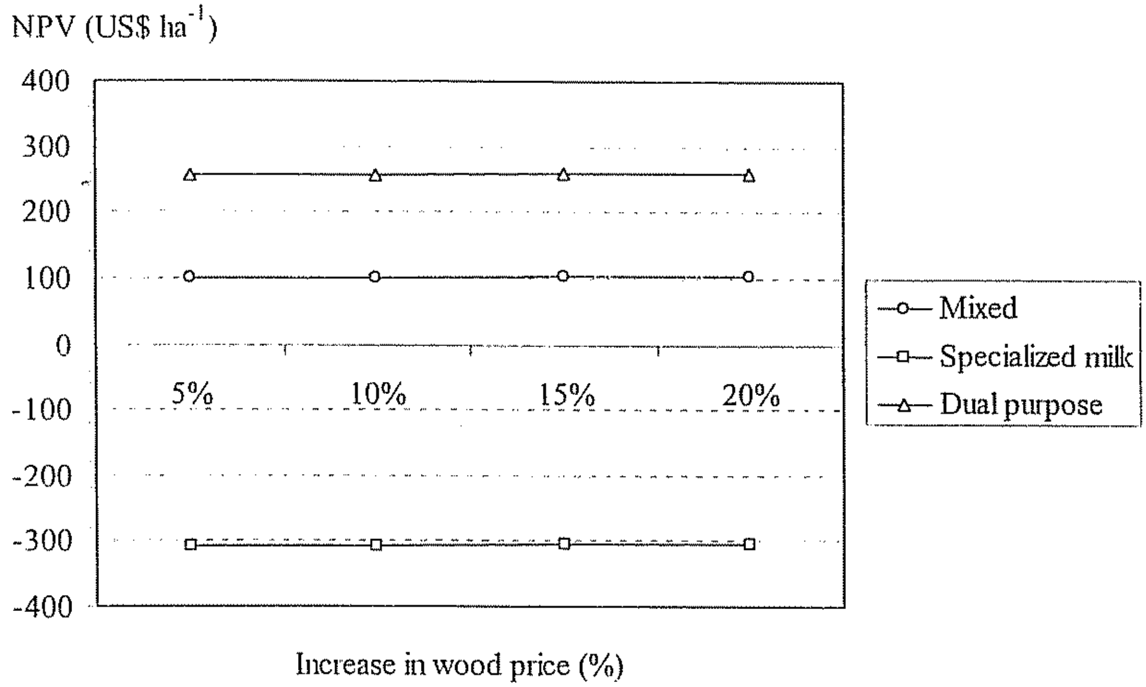

Figure 4. The effect of percent increase (5 to 20%) in wood prices on net present value (NPV) per ha for the three different animal production systems. La Fortuna, San Carlos 1999 (n= 9 farms)

The amount of labour (permanent and causal) used on farms was highest for the mixed systems which had an average of 82.79 days ha^{-1} while those of specialised milk and dual purpose systems were 46.70 and 14.38 days ha^{-1} respectively (Figure 5).

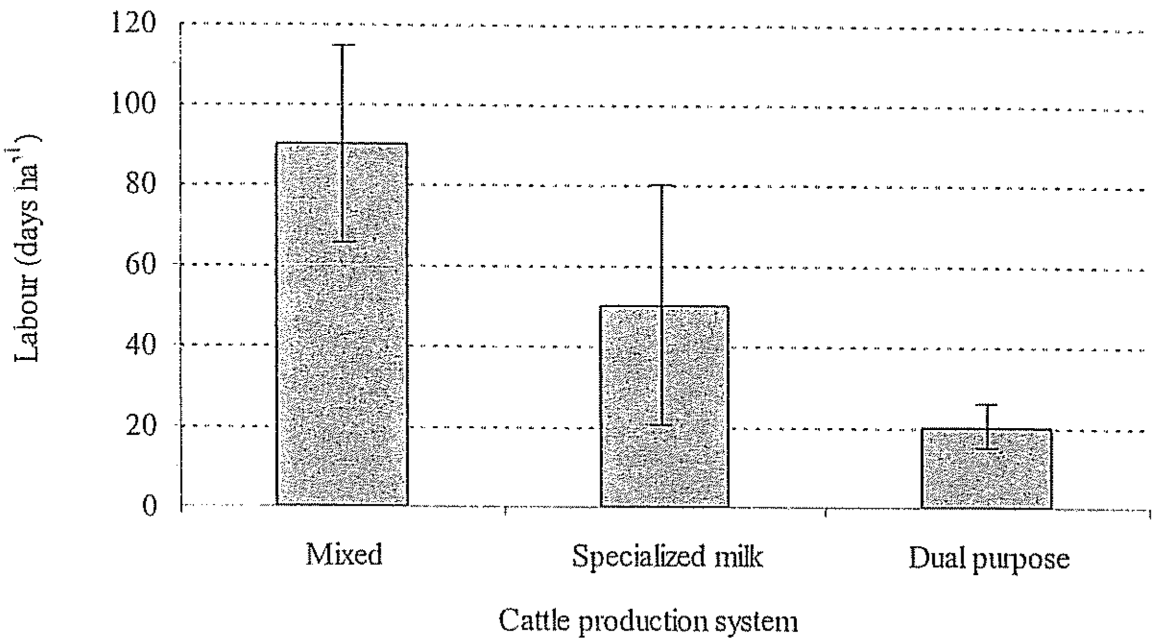

Figure 5. Mean number of labour (permanent and causal) days used per hectare for the three different animal production systems. La Fortuna, San Carlos, 1999 (n= 9 farms)

The relationship between stocking rate (AU ha^{-1} pasture) and abundance of trees (No. ha^{-1}) of the three different animal production systems is shown in Figure 6. The relationship between stocking rate (AU ha^{-1} pasture) and abundance of trees (No. ha^{-1}) did not show a clear trend with production systems (Figure 6). In dual purpose systems a low stocking rate was correlated with relatively high tree abundance whereas in specialised dairying a high stocking rate was associated with high tree abundance.

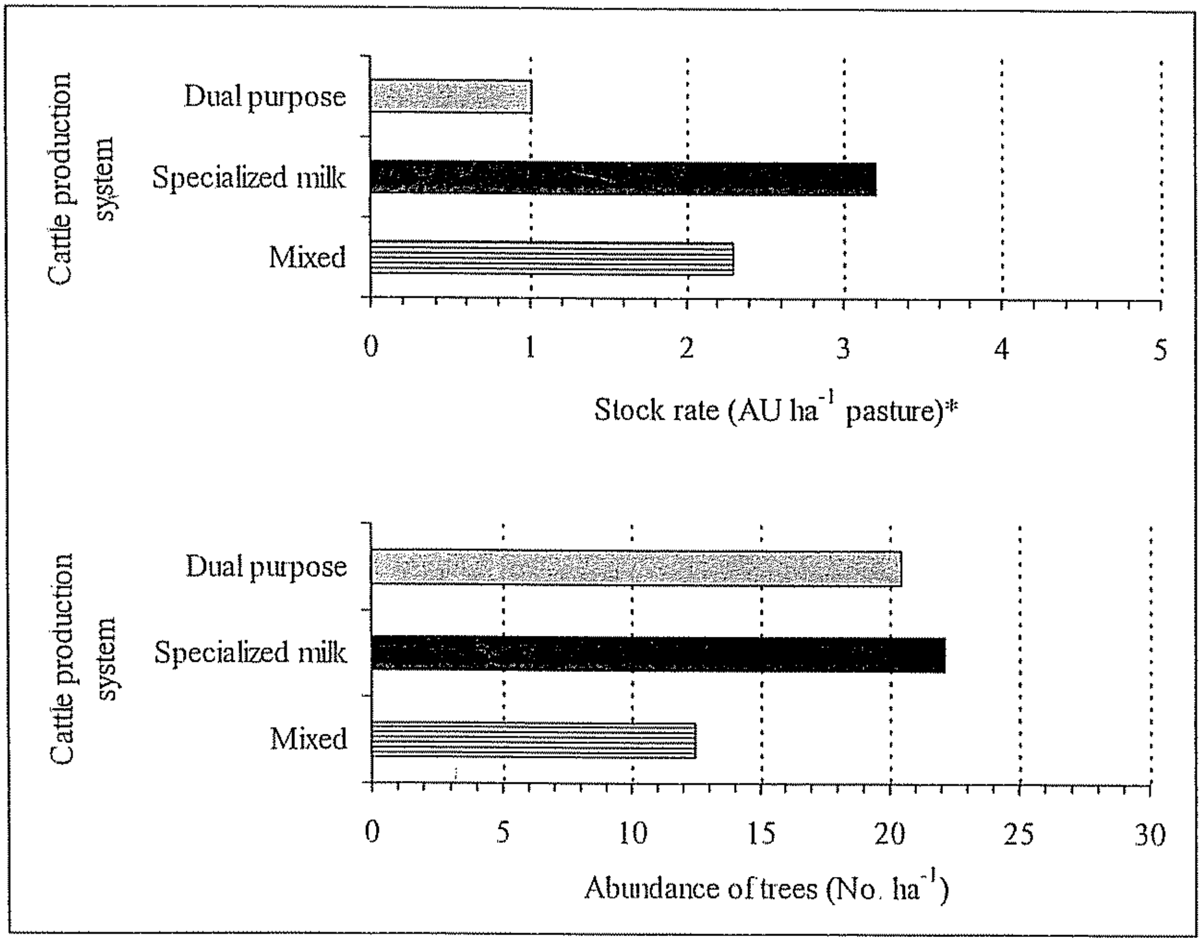

Figure 6. Stocking rate (AU ha^{-1} pasture) and abundance of trees (No. ha^{-1}) of the three different animal production systems. La Fortuna, San Carlos, 1999 (n= 9 farms) * AU (Animal Unit) = 400 kg live weight

There was also not a clear trend of how the amount of supplements fed to animals affected the abundance of trees in pastures (Figure 7).

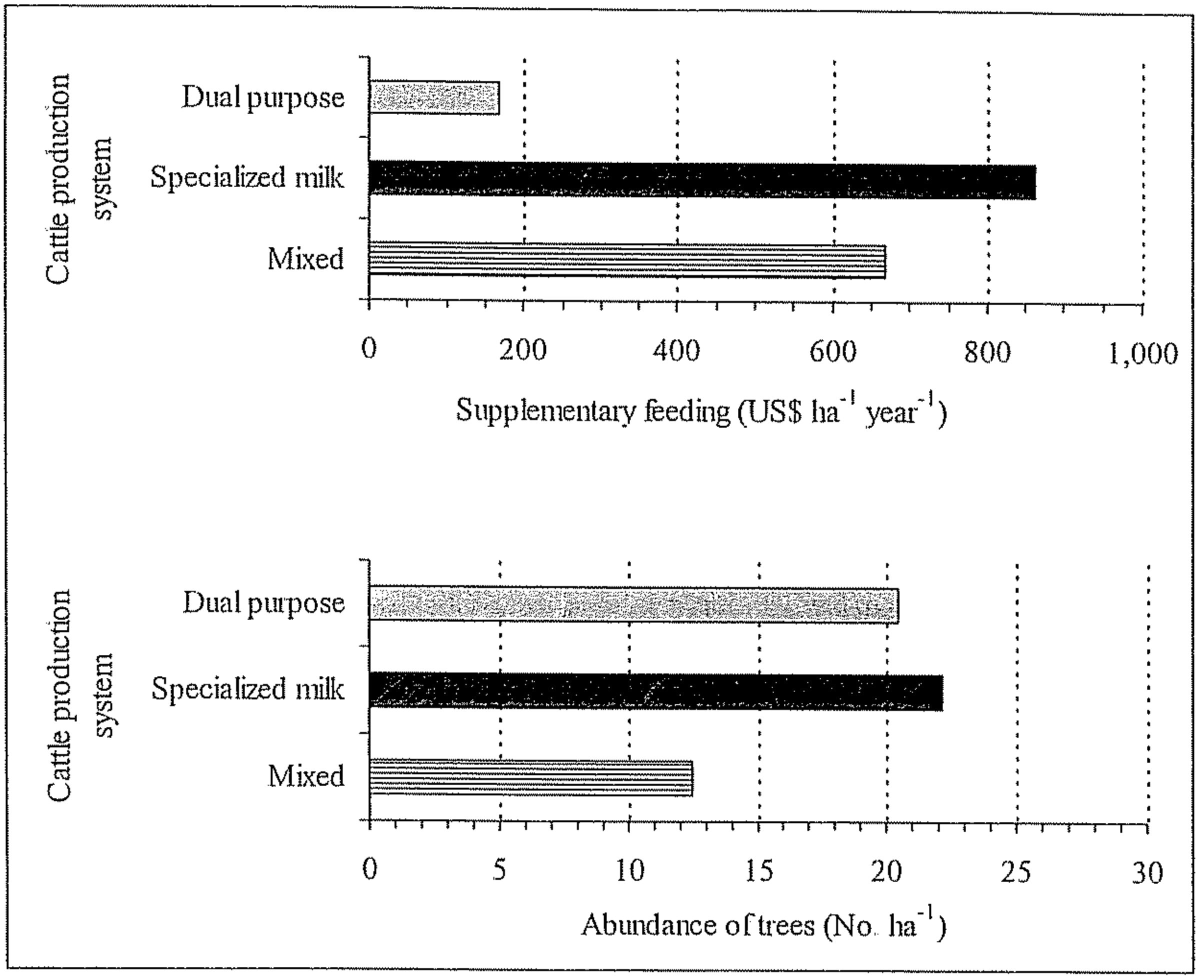

Figure 7. Relationship between supplementary feeding (US$ ha^{-1} $year^{-1}$) and abundance of trees (No. ha^{-1}) of the three different animal production systems. La Fortuna, San Carlos, 1999 (n= 9 farms)

Milk production is the most important activity in relation to total income of the four main activities of the region (milk, meat, crop and wood) and for the economy of the three farming systems. Its importance ranges from 88.64% for specialised milk to 54.89% in dual purpose systems (Figure 8). On the other hand, income from the meat production activity is more important for dual purpose farms (43.21% of total income for the four activities), followed by mixed (10.48%) and specialised milk farms (8.63%).

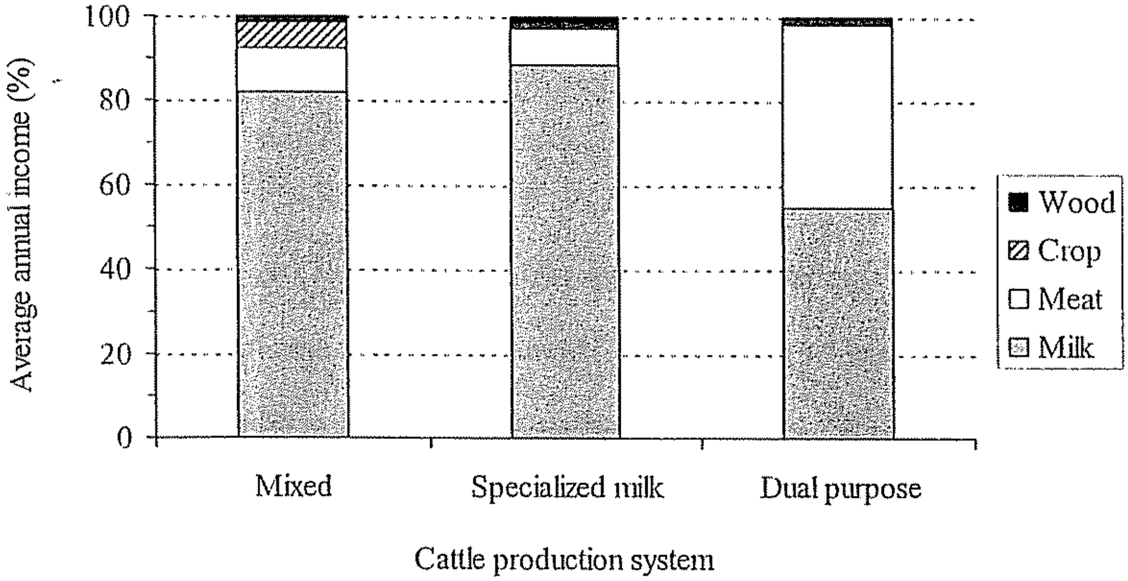

Figure 8. Average annual income (%) from productive activities in the three cattle production systems. La Fortuna, San Carlos, 1999 (n= 9 farms)

The comparison of average annual income per ha per farm for the three systems revealed almost the same importance of income from wood production in relation to the total income of the four activities, corresponding to 1.46% in the mixed system, 2.73% in the specialised milk system and 1.41% in the dual purpose systems (Figure 8).

Crop production in the mixed system had a greater importance as a percentage of total income for the four activities (6.24%) than in the dual purpose system (0.50%). There was no crop production in the specialised milk system (Figure 8).

4. Discussion

Tree surveys

Although the pastures in La Fortuna had many tree species, there was a predominance of timber species, mainly laurel and to some extent cedro in all the cattle production systems. However dual purpose farms had pastures that were characterised with a higher timber tree density (n ha^{-1}) (17.96 vs. 16.11 vs. 10.47) and a higher proportion of timber trees species in pastures (87.73 vs. 84.03 vs 72.83) compared to mixed and specialised dairy farms respectively, indicating that dual purpose farmers had a greater interest to diversify production by increasing timber production. This will help to buffer negative changes in price of milk and meat which affects profitability of livestock farming (Holmann et al., 1992).

In general trees were an important component in the cattle production systems, especially in dual purpose farms which had the greatest percentage (> 70%) of pastures with isolated or dispersed trees. Studies conducted in the sub-humid, humid and pre-montane ecosystems of Costa Rica also showed that a high percentage of pastures are characterised with trees (Harvey and Haber, 1999; Camargo et al., 2000). A lower percentage of pastures characterised with trees in mixed and specialised dairy farms may be associated to the fact that these farmers have a keen interest in intensive management of grass pastures to ensure a good supply of forage (Casasola et al., 2001).

Farmers maintained laurel in paddocks because it produces construction and furniture timber and provides shade for cattle. It also showed fast growth, abundant natural regeneration and self-pruning in open-growth situations (Somarriba and Beer, 1987). In addition, the merchantable trees represented a financial reserve that could be used in times of crop failure, and of unfavourable prices for milk, meat and crops.

Both laurel and cedro are high valued timber species and they are characterised with a small crown which permits a relatively high light penetration to the herbaceous vegetation and offers good shade for the animals, while causing little damage to the pasture (Souza de Abreu et al., 1999). These are some of the reasons why farmers prefer these species for the pasture (Camargo et al., 2000).

The density encountered in this study is similar to that found in Monteverde, Costa Rica, but the species richness reported by cattle farmers of about 20 species is much lower than the 190 species reported in a study by Harvey and Haber (1999). This difference could be attributed to the land use histories, where a greater extension of area was cleared in La Fortuna, San Carlos than in Monteverde.

Compared to the dual purpose and mixed systems, the specialised milk production system presented a greater abundance of non-timber tree species (e.g., *Ficus* spp., *Citrus limetta*, *Citrus sinensis*, *Inga* sp. and *Psidium guajava*) that are characterised with a larger crown cover than laurel and cedro. This could be explained by the fact that such farms have pure exotic milk breeds (e.g., Holstein and Jersey) that have high shade requirements to minimise heat stress (Gregory, 1995; McArthur, 1991; Souza de Abreu et al., 1999). Recent studies conducted in this study area showed that dairy cows which had access to shade trees had an average of 13.3% higher milk yields in the dry season compared to cows which did not had access to shade but differences in the rainy season was not significant (Souza de Abreu et al., unpublished, 2002).

Tree regeneration dynamics

Natural regeneration of laurel in paddocks or pastures is common in humid and sub-humid regions of Costa Rica, especially in sites that have deep and fertile soils with little compactation (Kampen, 1996; Viera and Barrios, 1997; Camargo et al., 2000). High seed production and easy seed dispersion facilitate this regeneration.

Laurel is a pioneer species quite tolerant to most soil conditions and prefers growing in low-elevation sites such as the lowland region of La Fortuna, San Carlos. It regenerates plentifully and grows rapidly in the pastures. Because of its value, farmers promoted laurel growth in their paddocks and it was common to see pastures with trees in the region. Cedro is a deciduous pioneer tree and was often present in the pastures of the region, but the number of trees was much smaller than that of laurel. Its natural regeneration in the region seemed to be more difficult than for laurel, probably due to its strict requirements of site characteristics and damage caused by insects such as *Hypsipyla grandella*.

Laurel trees are also less demanding than cedro trees. The edaphic and climatic conditions of the region seem to be more appropriate to the requirements of laurel than cedro. The three fundamental requirements of cedro are complete absence of water logging of the root system, a plentiful supply of nutrients (Lamb, 1968) and sufficient soil aeration (Lamprecht, 1990). Probably soil compaction by cattle trampling makes the natural regeneration of cedro trees difficult. Also laurel is relatively tolerant to many types of soils and therefore this species is very well suited to pasture zones, such as one in this study. One contribution of cattle to the natural regeneration of the two main species of the region is the dissemination of viable seeds in the faeces.

The maintenance of high quality pastures was very important for the mixed and specialised milk systems, and this did not permit a normal natural regeneration of laurel and cedro. Farmers eliminated trees from the pastures, fearing that the grass would be shaded and consequently pasture growth would be compromised. Harvey and Haber (1999) similarly found that shade management appeared to be a key factor influencing farmers' decisions to eliminate trees from pastures. Farmers in the three systems also removed trees for timber for personal use and for sale, although this use was sporadic and unplanned and may not endanger natural regeneration of laurel and cedro in the same way that elimination due to shade management would.

Cedro trees present in specialised milk systems with a dbh from 15.0 cm to 29.9 cm were used as shade trees. The reason for this is that such farms have pure exotic milk breeds, which need more shade to minimise heat stress (McArthur, 1991; Gregory, 1995; Souza de

Abreu et al., 1999). Cedro trees in the three cattle systems will tend to disappear in the future, because the number of small trees in pastures is insufficient to ensure their natural capacity for a sustainable regeneration.

Volumes

According to experiments carried out in Ecuador, laurel does not show good performance when associated with pasture. This is especially in the case, when trees are accompanied by overgrazing, soil compaction and consequent inhibition of the root development. Under such conditions trees often grow well in height, but not in diameter, and this leads to reduced volume increase (CATIE, 1994). This statement contrasts with the results of an assessment of timber production in traditional agroforestry systems in the Atlantic Region of Costa Rica that showed a good performance of naturally regenerated *C. alliodora* growing in combination with pastures (Rosero and Gewald, 1979). Their findings were: laurel with ages of 25-30 years, 200 trees per ha, a mean dbh of 37 cm, and standing volume of 380 m^3 ha^{-1}. Somarriba and Beer (1987) found dbh of 24, 26 and 36 cm for laurel associated with pastures in permanent sample plots in two humid regions of Costa Rica. The present study found: laurel of different ages, mean abundance of 11.25 trees per ha corresponding to mixed (7.33 trees per ha), specialised milk (10.34 trees per ha) and dual purpose systems (16.80 trees per ha) (Souza de Abreu et al., 2000a,b); mean dbh of 19.9 cm (range from 14.3 to 23.1 cm); and mean merchantable volume of 1.05 m^3 ha^{-1}. The lower results of the present study might be due to the low abundance of laurel in the pasture, site characteristics and lack of silvicultural techniques.

Financial analysis

The high costs for animal nutrition and maintenance (veterinary products, services, etc.) observed in the specialised milk system were due to the rearing of pure milk breeds such as Holstein and Jersey, which require better nutrition for maintaining high production. The milk production was higher in the specialised milk system than in the mixed and dual purpose systems, but was not high enough to cover these high total costs. The gross income from specialised milk systems could cover the total variable costs and part of the fixed costs. This is considered within agricultural enterprise as a rational (operable) financial behaviour and is considered a frequently and cyclic situation related to the behaviour of market prices of inputs and outputs (Manuel Gomez, pers. comm., 2002). The dual purpose system had the lowest costs for supplementary feeding due to the rearing of cross breeds for dual purpose (milk and meat). The mixed system showed higher costs in permanent labour than the other two systems due to the need for employment of external labour during harvest time.

With regards to the resulting NPV (i= 2.68%), only the mixed and dual purpose systems were able to cover the total costs and had a positive NPV, although the NPV of the mixed system was low. The negative NPV of the specialised milk system shows that the higher milk production was not able to cover the high animal costs. Although the specialised pure milk breeds should produce more milk when they receive appropriated feeding, the animals did not reach 100% of their potential production. This could be explained by the negative effect of the climatic conditions of the region on the specialised milk breeds, causing heat stress which prevents an optimal milk production (Souza de Abreu et al., unpublished, 2002).

The income from other important activities of the mixed and dual purpose systems, such as crop and meat production also improved the total income of these two systems. This shows that the diversification of production systems helps to improve NPV. On the other hand, the income from wood production was low in all three animal production systems in comparison with the other activities and only made a small contribution (1.02%) to the total income of the three systems.

The results of Marlats et al (1995) using a discount rate of 8%, showed that an increased diversification of a silvopastoral system using timber trees leads to an improved NPV. The site characteristics of the region which are suitable for the natural regeneration of laurel in pastures could be better used by increasing the use of this timber resource in the three systems. In the present study the dual purpose system presents the best opportunity to exploit the potential of a more regular use of timber for sale in the future due to a greater abundance of laurel with small diameters. Therefore the benefits derived from this type of silvopastoral system could be increased.

In the present study, most farmers seemed to be well aware of the economic benefits of pasture trees, and were interested in the possibility of increasing tree cover within their pastures. A similar situation was found on dairy farms in Monteverde, Costa Rica, where interviews were conducted (Harvey and Haber, 1999).

The financial results of the present study shows that the importance of the use of timber from the natural regeneration of trees in the region to improve farm income is still small and the farmers' adoption and exploitation of trees depends on their level of preference for animal production activities.

5. Conclusions

Laurel associated with pasture represents a considerable timber reserve. This justifies recommending silvicultural techniques in order to minimise current commercial wood losses and encouraging large-scale natural regeneration which would be beneficial to farmers in the region. Meanwhile, familiarity with forestry activities should increase due to the reduction of risk through diversification, recognition of the ecological benefits to conservation and the improved income possibilities from the favourable market value of timber trees such as laurel and cedro.

It is clear that trees dispersed in pastures of La Fortuna, San Carlos could contribute to the sustainability of the silvopastoral system as a whole, producing additional income, providing shade to limit heat stress in cattle, and also helping to conserve biodiversity.

At the farm level, efforts should be made to encourage cattle farmers to preserve pasture trees in the region and to use silvicultural techniques, showing them the associated benefits to the sustainability of the farm as a whole.

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