THE EFFECT OF TREE DENSITY AND CHARACTERISTICS, WITHIN SILVOPASTORAL SYSTEMS, ON COW PRODUCTIVITY IN THE DRY TROPICS OF NICARAGUA.

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Declaration

I, Justin Ainsworth, declare that this thesis is a result of my own research investigations and findings. The data on which it is based has been collected by me and is not fabricated or part of another work. This thesis has not been copied, either in part or in full, from any other existing work. I have recognised and cited all reference sources. This work has not been previously submitted to any other university for academic qualifications.

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Contents

Abstract

Shade, provided by trees within pastures, can affect cattle productivity through mitigating heat stress and altering understorey pasture growth, soil properties and cattle behaviour. Models for daily milk yield and body condition were used to evaluate the effect of tree density and characteristics on dual purpose cow productivity within silvopastoral systems in the dry tropics. Daily milk yield and body condition were both negatively affected by pasture shade ($p<0.05$ and $p<0.001$ respectively). Stocking density ($p<0.001$) and age ($p<0.001$) also had negative effects on daily milk yield, whilst night grazing had a positive effect ($p<0.05$). In addition, body condition was negatively affected by average daily milk yield ($p<0.01$) and was positively affected by feed supplementation ($p<0.001$). There was a correlation between pasture shade and stocking density in both production models ($p<0.05$) suggesting farmers compensated for decreased cow productivity, associated with increased pasture shade, by reducing stocking density. It is proposed that the positive effect of shade mitigating heat stress was likely present but its effect did not compensate for the decreased nutrient intake by the cows caused by either negative behavioural effects or reduced pasture productivity, or both. Pasture forage analysis, soil assessments and cattle behaviour studies are required to investigate these effects further.

Introduction

Silvopastoral systems consist of pasture with varying densities of trees, fodder banks, alley crops and live fences. Silvopastoralism is the most commonly practiced type of agroforestry in the developed world and is also found throughout the tropics (Sharrow 1999). Scattered trees offer many ecosystem functions, both on a local and landscape level, and can be regarded as key stone structures (Manning *et al.* 2006). Silvopastoral landscapes have an important role in conservation and biodiversity (Harvey *et al.* 1999, Trejo *et al.* 2002, Harvey *et al.* 2004, McAdam *et al.* 2007 and Treydte *et al.* 2008). In the tropical regions of Latin American, farmers have retained trees in pastures for numerous reasons including; cattle shade, timber, support for wildlife, fence posts, maintenance of humidity in the dry seasons, wind protection, firewood and as a source of cattle forage (Harvey *et al.* 1999).

Trees can affect understorey growth through various mechanisms. Canopy shade alters light and humidity levels in the understorey which in turn affects plant growth and species composition (Menezes *et al.* 2002). Soil moisture can be increased by the hydraulic lift of water from deep horizons by the tree roots, but may be decreased if there is root competition for moisture in the upper soil horizons (Liste *et al.* 2008, Everson *et al.* 2009, Pollock *et al.* 2009). Soil nutrient levels are altered through root competition, facilitative root interactions, defoliation, fruit fall and altering animal behaviour influencing the distribution nutrients from animal waste (Powell *et al.* 1996, Arevalo *et al.* 1998, Schroth 1999, Xu *et al.* 2005, Michel *et al.* 2007). The balance of tree effects on understorey growth and providing a reduction in the negative effects of heat stress in cattle is important to developing and maintaining silvopastoral systems.

Fifty-four percent of semi-arid tropical silvopastoral systems show a similar or increased productivity compared to sole crops (Tilander *et al.* 1999, Andrade *et al.* 2008). In the African savannah, grasses under large trees have a higher forage quality than in the open (Ludwig *et al.* 2008). However, natural silvopastoral systems have been reported to have reduced forage biomass compared to grass monoculture (Trejo *et al.* 2002).

Motagnini and Ugalde (2002) compared several tree species for pasture restoration in Costa Rica and concluded that a mix of slow, e.g. *Vochysia guatemalensis,* and fast growing tree species, e.g. *Calophyllum brasiliense,* was likely best, as this allowed for quick pasture improvement and productivity but also allowed for expensive timber product growth as well. *Canavalia ensiformes* (Jack bean or feijão-de-porco) can be used as a fodder crop but also has positive effects on tree growth during the establishment of silvopastoral systems in degraded pastures when grown in the understorey (Aguirre *et al.* 2002).

Plants and trees, such as *Acacia spp* and *Leucaena spp*, are used as fodder crops within silvopastoral systems (Maasdorp *et al.* 1999). Fodder crops can be eaten by livestock in situ or used in cut and carry systems. *Acacia auriculiformis, Ailanthus triphysa, Casuarina equisetifolia* and *Leucaena leucocephala* all show a positive effect on understorey production in the first 3 years of growth but as tree crowns grow the production begins to decline (Kumar *et al.* 2001). The improved grass productivity remains increased for two seasons after tree felling (Kumar *et al.* 2001).

Soil quality and management is essential to productivity and sustainability in agricultural systems (Pimentel *et al.* 1995). Soil degradation and erosion can occur following poor agricultural practices and deforestation (Hajabaashi *et al.* 1997). Soil degradation is an increasing threat to world food security, with productivity declining on approximately 16 % of agricultural land in developing countries and 75 % of agricultural land in Central

American classified as seriously degraded (Scherr 1999). Facilitative root interactions between trees and pasture can infer benefits under intensive production (Hauggaard-Nielsen *et al.* 2005). Leguminous trees can contribute significantly to grass nutrition by elevating soil nitrogen (Daudin and Sierra 2008) and improve and maintain increased digestibility of *Brachiaria decumbens* pasture in the dry season (Margarida *et al.* 2002). Preserved tree species, following conversion of native forest into silvopastoral land, can increase soil biological activity, soil nutrient levels and organic matter content (Wick *et al.* 2000).

Heat stress occurs when any combination of environmental conditions cause the effective temperature of the environment to be higher than the animal's thermoneutral zone (Armstrong 1994). In response to heat stress cattle employ a range of physiological and behavioural adaptations to maintain their core temperature within the thermoneutral zone, including; shade seeking, increased water intake, peripheral vasodilation, increased sweating and increased respiratory rate (Blackshaw and Blackshaw 1994, Kadzere *et al*. 2002).

In addition to environmental factors, genetic factors can influence the degree of heat stress with *Bos indicus* breeds having greater resistance to heat stress than *Bos taurus* breeds (McManus *et al.* 2009). Current breeding programmes reduce heat tolerance as performance traits are selected for, as incorporating heat resistant traits into *Bos taurus* breeds may reduce inherent energy metabolism (Finch 2000). However, it is thought possible to select for both increased performance and heat resistance traits concurrently (Ravagnolo *et al.* 2000). The lack of farm production records, long generation intervals, late sexual maturation, low reproductivity and the high calf mortality of tropical cattle breeds limit the establishment of effective breeding programmes in many tropical regions (Syrstad *et al.* 1998).

Dry matter intake and food conversion efficiency are negatively affected by heat stress resulting in decreased milk productivity and milk constituent quality with increasing temperature-humidity index (Mayer *et al.* 1999, West 2003). A 79 % increase in late lactation milk production from cooled cows compared to non cooled cows has been seen in the tropics (Chaiyabutr *et al.* 2008) and 3% in Holstein Friesian cows in New Zealand when ambient temperature was above 25°C (Fisher *et al.* 2008). Milk production in *Bos taurus* cows is reduced in warm climates compared to temperate climates (Nassuna-Musoke *et al.* 2007), however, the net production potential of a heat stressed *Bos taurus* is still greater than that of a *Bos indicus* (Hansen 2004). Humidity is the limiting factor of heat stress in humid climates, where as dry bulb temperature is the limiting factor of heat stress in dry climates as measured by declining milk yield (Bohmanova *et al.* 2007).

Grazing behaviour of cattle is affected by daytime heat accumulation, by the size of the gastrointestinal tract (breed difference) and by body condition score (Sprinkle *et al.* 2000). Time spent in the shade is positively correlated to ambient temperature, solar radiation and rectal temperature (Bennett 1983). Total daily time allocation for key cattle behaviour (grazing, resting, moving and ruminating) has been shown not to differ between cattle provided shade (artificial or woodland) and those not provided shade, but cattle in wooded pastures tend to graze more in midday and have a reduced rumination in the day, presumed to be a result of mitigated heat stress under the canopy (Fisher *et al.* 2008, Hirata *et al.* 2009). A study of cattle time budgets in Nicaragua found that cattle rested closer to trees and fed further away from trees than random, with tree species and size affecting resting and feeding distances, and cattle fed closer to trees in the morning and midday than in the afternoon (Nilsen 2006).

The negative effects of heat stress on bovine reproductive physiology and behaviour include; decreased expression of overt oestrus, reduced conception rate, poor oocyte and embryo quality and a decline in the uterine environment reducing implantation (Badinga *et al.* 1985, De Rensis *et al.* 2003). Conception rates can be increased by cooling dairy heifers for short periods before and after artificial insemination during heat stress (Moghaddam *et al.* 2009). In the pre-partum period reproductive performance is not affected by cumulative pre-partum heat stress, although it is associated with very difficult calving scores (Avendaño-Reyes *et al.* 2010).

Shading has been shown to be an effective means of reducing the negative behavioural and physiological effects of heat stress on cattle productivity (Mitlöhner *et al.* 1999, Marcillac-Embertson *et al.* 2009). Tree shade can completely eliminate any occurrences of severe heat stress (Bloomberg and Bywater 2007). Cattle seek shade offering radiation protection levels up to 50%, above which no greater preference is shown (Schütz *et al.* 2009). A level of 50 % shading can be attained with most commonly used tree species within 3 years of planting (Kumar *et al.* 2001). As well as the radiative protective influence on shade usage, area is an important factor, with increased shade usage when over 9.6 m^2 shade/cow is provided (Schütz *et al.* 2010).

This thesis examines the variations in cow productivity in relation to farm structure and management. Cow productivity is assessed through measurement of milk yield and body condition. Farm structure is defined in terms of the amount and type of tree cover, tree characteristics, tree distribution, farm size and paddock sizes. Aspects of farm management examined included; herd structure, stocking rates and food supplementation.

Materials and Methods

Study location

The location for the study was the municipality of Belén, in the Rivas province of Nicaragua, 11°35'N 85°58' W. The study area covered approximately 3650 hectares (Figure 1).

The biogeography of the region is classified as tropical dry forest and savannah (Gillespie *et al.* 2001 and Weaver *et al.* 2003). Soils are derived from volcanic material and are deep, sometimes with impermeable horizons with a mainly sandy loam texture, except for some limited areas with clay soils (Suttie 2008). Paddock elevations ranged from 74 masl to 195 masl.

The regional annual average temperature is 27ºC, annual average humidity is 78% and an annual precipitation of 1400 mm. The wet season is between August and October with up to 320 mm of rainfall monthly (INETER 2000). The average daily temperature and humidity ranged from 24-30°C and 70-96%, respectively during the study period.

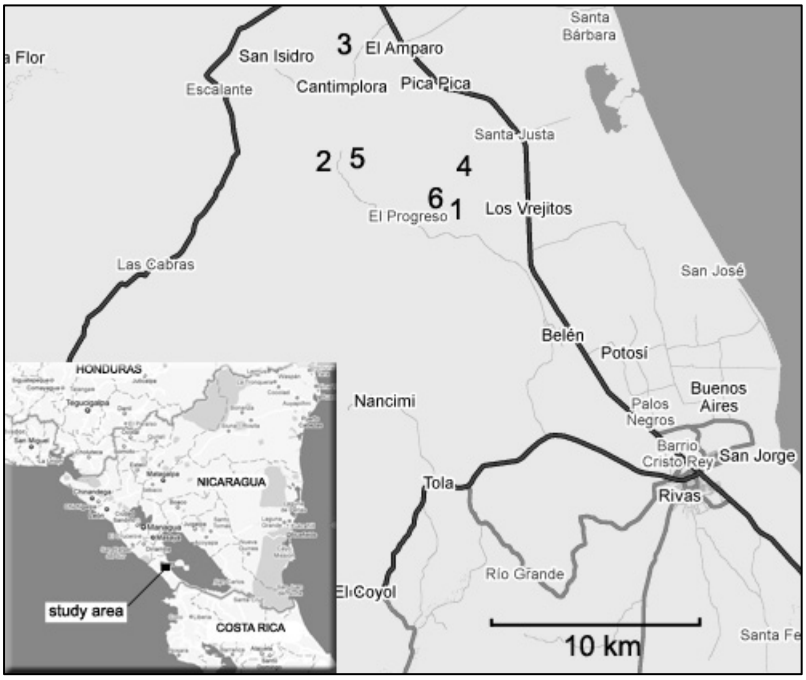

Figure 1 Map of the study area with farm locations numbered 1- 6, and inset map of Central America showing study area location (adapted from Google® maps).

Farm selection and description

The study was carried out concurrently using 6 farms between October and November 2009. Recording periods for the farms ranged from 29 to 42 days (37 days average). A total of 121 dual purpose cows, including 1st calved heifers, were used in this study. Dual purpose cattle are used for both meat and milk production. Milking herd sizes varied from 5 to 49 with a milking cow average per farm of 21. The breed composition was 55% Brahman, 31% Brahman crosses (with either, Gir, Indo-Brazil, Pardo, Simmental or Brown Swiss), 12 % other breeds (Indo-Brazil, Pardo, Brown Swiss and Gir) and 2 % Brown Swiss crosses with breeds other than Brahman. The ages of the cows ranged from 3 to 11 years with an average age of 6.5 years. The number of lactations per cow ranged from 1 to 8 with an average of 3 lactations. Time in milk at the start of the study period ranged from 1 week to 7 months with an average of 3.7 months.

The cows were milked by hand, once daily in corrals close to the farm houses. All farms practiced partial suckling systems to feed the calves and improve milk let down (Coulibaly *et al.* 1998). There appeared to be some variation in suckling length between farms, with some farmers interrupting milking to allow calves a second feed. These inter-farm differences in partial suckling systems, or handling techniques at milking, were not detailed in this study.

The farms had a total of 33 paddocks used for grazing. The paddock grasses consisted of "natural pasture" species such as Bombasa (*P. maximum var. Bombasa*), zacate rosado (*Rhynchelytrum roseum*), zacate torcido (*Heteropogon contortus*) and zacate gallina (*Cynodon dactylon*) but also invasive and improved pasture species including Jaragua (*Hyparrhenia rufa),* Gamba (*Andropogon gayanus*)*,* Gallina (*Cynodon dactylon*), Estrella (Star grass, *Cynodon nlemfluensis*) and *Brachiaria brizantha*.

The majority of all the farm incomes were derived from meat and milk products. Other agricultural activities on the farms included crops of rice, beans (*Phaseolus vulgaris*), wheat, maize (*Zea mays*), plantain and yucca.

Paddock surveys

Boundaries for the paddocks were recorded using a Global Positioning System (GPS, Garmin® *e*-trex). All trees within the paddocks of diameter at breast height (DBH) ≥5cm were recorded in the paddock survey. Trees were classified as either dispersed, clustered, live fence or riparian. A tree was classed as dispersed if its canopy edge was >1m distant from any other tree canopy edge and its trunk was >1m from the paddock boundaries. Tree clusters were defined as two or more neighbouring trees whose canopies were ≤1m from each other, or overlapping, and with trunks >1m from the paddock boundaries. Trees classified as live fence were trees either directly on the paddock boundary, in many cases serving as fence posts or physical barriers, or trees whose trunks were ≤1 m of the boundary. Riparian trees were those trees in clusters around river or stream beds, representing linear forest remnants along waterways. All tree locations, except those of the riparian areas, were recorded using GPS.

DBH, tree height, height to crown and canopy diameters were recorded for the dispersed trees, clustered trees and live fence trees. The DBHs were measured using a diameter tape to an accuracy of 1 cm. Height measurements were taken to an accuracy of 25 cm using a laser site (Laser Tech® Impulse 200LR) or clinometer from either a 10m or 15 m fixed distance from the tree bases depending on total tree height. Canopy diameters were recorded in two, perpendicular, directions using a measuring tape or laser measure (Laser Tech® Impulse 200LR) to an accuracy of 10 cm.

Individual tree measurements for the clustered trees, was the same as with the dispersed trees. In addition the total canopy width of the clusters was measured, again with two perpendicular measurements. Tree species was recorded for all dispersed, clustered and live fence trees.

Trees within riparian areas were not recorded as individuals. The borders of these regions with riparian forest were recorded by GPS to allow calculation of the area of the paddocks covered by riparian forests and the length of the riparian boundaries with the pasture. The riparian area was deducted from the field areas to give the pasture area as most riparian areas were impassable to cattle and were too dense to allow understorey growth.

Calculation of basal area

Basal are has been defined here as: the area of a given section of land that is covered by the cross sections, at breast height, of the trunks of the trees occupying the given section of land.

$$\text{Paddock basal area} = \sum \pi(DBH_{1,2,3\ldots}/2)^2/A$$

Where; $DBH_{1,2,3\ldots.}$ is the diameter at breast height of all dispersed and clustered trees in a given paddock of pasture area A.

Calculation of tree density

Paddock tree densities were calculated using the numbers of dispersed and clustered trees. Live fence trees were not included in the tree density calculations. The tree densities were calculated both on an individual paddock basis and an overall farm density level.

$$\text{Paddock Tree density} = (Tot_{disp} + Tot_{clus})/A$$

Where; Tot_{disp} is the total number of dispersed trees and Tot_{clus} is the total number of clustered trees within a paddock of area A.

$$\text{Overall farm tree density} = \left(\sum Tot_{disp\ 1,2,3\ldots} + \sum Tot_{clus\ 1,2,3\ldots} \right) / \sum A_{1,2,3\ldots}$$

Where; Tot_{disp} and Tot_{clus} are the total number of dispersed trees and clustered trees within paddocks $_{1,2,3\ldots}$. A $_{1,2,3\ldots}$ are the areas of all the paddocks within a given farm.

Calculation of canopy cover

Canopy cover was calculated as a percentage of the pasture area that was covered by the vertical projections of the tree crowns (Korhonen *et al*. 2006) of the dispersed, clustered and live fence trees. The average value of the two perpendicular canopy width measurements was used for canopy area calculations. The canopy cover was calculated on both an individual paddock level and on an overall farm level by including all pasture on a given farm. The degree of canopy cover provided by live fence trees was calculated separately from that provided by the dispersed and clustered trees which were calculated together. The individual canopy measurements for the clustered trees were not used but rather the overall canopy diameters for the separate clusters. The canopy area measurements for the live fence trees were halved as these trees lie on or ≤ 1m from the paddock boundaries.

$$\text{Canopy cover, \%} = \sum \pi \, (d_{av1,2,3....}/2)^2 / A \times 100$$

$$\text{Total canopy cover, \%} = \sum \pi \, (d_{av\ disp+clus\ 1,2,3....}/2)^2 + \sum (\pi \, (d_{av\ lf\ 1,2,3....}/2)^2/2)/A \times 100$$

Where; d_{av} is the average canopy diameter for a given tree ($_{1,2,3....}$) in area A which is either the paddock pasture area when calculating individual paddock canopy cover or the total farm pasture area when calculating the overall farm tree density. Disp= dispersed trees, clus= tree clusters, lf= live fence trees.

Calculation of riparian shade

The shade cover of the riparian areas was calculated by multiplying the length of the boundary between the riparian areas and the pastures of a given paddock by a riparian canopy width factor, C_{rip}. C_{rip} was calculated by averaging all live fence canopy diameters from all farms to give an average canopy diameter. This all farm average for canopy diameter was then used as an approximation for the riparian edge canopy width or riparian canopy width factor, C_{rip}.

Riparian canopy cover, $CC_{rip} = BL_{rip} \times C_{rip}$

Where; BL_{rip} is the total length of riparian edges bordering a given paddock's pasture areas and C_{rip} is the riparian shade cover constant. $C_{rip} = 3.49$, which is calculated from the average canopy radius of all live fence trees.

Calculation of pasture shade

The total shade cover for the paddocks, pasture shade, was calculated by combining the canopy covers of the dispersed, clustered, live fence trees and the canopy cover of the riparian edges. This total canopy cover area was then divided by the pasture area of the paddocks, as measured during paddock survey, and the pasture shade was then calculated as a percentage canopy cover of the pasture area for each farm. The orientation of the live fences and riparian edges was not included in this shade model.

$$\text{Pasture shade} = (CC_{disp + clus} + (CC_{lf}/2) + CC_{rip}) / A \times 100$$

Where; CC is the total canopy area of the dispersed (disp), clustered (clus), live fence (lf) and riparian boundaries (rip) for a given paddock or farm area, A.

Data gap filling

Farm 3 had three paddocks that were not recorded in the database. Aerial imagery was used to give an estimate of tree densities and riparian border lengths. The averages for canopy diameters and basal areas of all other paddocks surveyed were then used to estimate the canopy covers and shade factors for these paddocks.

Farm 6 had a large proportion of charral type pasture. This type of pasture consists of secondary regeneration of native shrubs and herbaceous plants and often develops following abandonment. These dense vegetation layers made field surveys of two of this farm's paddocks impractical. The boundaries of these fields were recorded to allow for area calculations. Estimates were then made for tree cover based on survey data from a neighbouring paddock belonging to the same farmer, which was at a less advanced charral stage. This was thought to be more accurate than using the all farm paddock averages as with farm 3.

Paddock survey summaries

A total of 3650 trees were surveyed in 28 paddocks. There were 64 dispersed tree species and 57 live fence tree species recorded with a total of 72 species identified (Table 1). The average diameter at breast height was 29 cm and the average canopy size was 48 m^2 (Table 1).

Table 1 Summary of tree characteristics for dispersed trees, which includes trees categorised as clusters, and live fence trees for the surveyed paddocks (n=28). DBH is the trunk diameter at breast height.

	Dispersed	Live fence	Dispersed and live fence
No. of trees surveyed	2364	1286	3650
No. of tree species	64	57	72
Average DBH (cm)	29.3	28.6	29.0
Average canopy size (m^2)	48.2	47.9	48.1

The farm pasture areas averaged 24.3 ha (11.1 to 44.5 ha, table 2), with an average paddock size of 6.23 ha (1.00 to 11.15 ha, table 3). Average tree density, dispersed and clustered, per paddock was 22 trees/ha (0 to 66 trees/ha, table 3). Farm dispersed tree density ranged from 7 to 63 trees/ha and total farm pasture shade ranged from 9.5 to 28.7 % (Table 2).

Table 2 Summary by farm of pasture area and tree characteristics. The pasture shade is the sum of the areas of the canopy cover provided by the dispersed, live fences and riparian areas expressed as a percentage of the farm pasture area. Dispersed includes trees categorised as clusters.

Farm	Pasture area, ha	Basal area, m^2/ ha	Dispersed trees/ ha	Dispersed tree canopy cover, %	Pasture shade, %
1	11.1	1.9	23	6.7	12.4
2	15.6	2.4	21	22.6	28.7
3	28.0	1.3	10	8.7	13.3
4	27.9	0.9	7	7.8	9.5
5	44.5	1.6	26	19.6	23.5
6	17.2	0.8	63	7.7	18.8

Table 3 Overview of paddock characteristics (n=33). The pasture shade is the sum of the areas of the canopy cover provided by the dispersed, live fences (LF) and riparian areas expressed as a percentage of the paddock pasture area. Dispersed includes trees categorised as clusters.

Farm	Paddock	Pasture area, ha	Basal area, m^2/ ha	Dispersed trees/ ha	Canopy cover			Pasture shade, %
					Dispersed, %	LF, %	Riparian, m^2	
1	1	5.8	2.5	27	4.6	4.8	0	9.4
1	2	4.0	1.3	21	8.2	6.4	0	14.6
1	3	1.4	1.1	9	11.4	7.3	0	18.7
2	4	1.1	1.9	31	10.9	11.3	0	22.2
2	5	3.7	3.5	14	25.1	6.0	0	31.1
2	6	1.0	0.7	8	3.2	23.5	0	26.6
2	7	3.0	2.1	35	27.2	1.0	628	30.3
2	8	1.9	4.5	35	40.4	4.5	0	44.9
2	9	2.6	2.4	20	31.9	0	942	35.5
2	10	2.2	0	0	0	4.4	0	4.4
3	11	3.4	0.7	4	3.2	3.9	0	7.0
3	12	1.7	1.5	14	24.0	1.1	471	27.9
3	13	3.1	0.8	7	5.9	2.1	0	8.0
3	14	4.5	0.3	11	4.7	1.1	0	5.8
3	15	2.9	2.6	9	19.8	2.7	1089	26.4
3	16	1.4	2.0	11	19.2	10.3	0	29.6
3	17*	3.7	2.9	11	5.2	3.1	1173	11.5
3	18*	2.0	7.4	15	7.2	5.5	628	15.8
3	19*	5.4	2.5	14	6.6	2.1	1546	11.5
4	20	9.6	1.1	8	5.5	0.5	0	6.0
4	21	7.3	1.0	11	15.3	1.5	0	16.8
4	22	11.2	0.8	4	5.0	1.7	1382	7.9
5	23	7.5	1.8	42	30.9	3.7	0	34.6
5	24	6.2	2.9	44	53.5	5.6	2003	62.4
5	25	7.7	0.2	3	2.2	1.0	1294	4.9
5	26	5.8	1.4	15	13.3	3.0	1099	18.3
5	27	7.4	0.9	12	7.8	0.5	0	8.4
5	28	9.9	2.3	38	15.8	2.5	942	19.3
6	29	3.6	0.6	3	2.7	0.3	373	4.0
6	30	1.4	0.8	53	7.1	1.5	907	14.8
6	31	1.5	0.9	66	9.3	0.5	0	9.9
6	32**	6.8	0.9	66	9.3	0.5	1120	11.0
6	33**	3.8	0.9	66	9.3	0.5	0	9.6
Average		6.2	1.7	22	13.5	3.7	472	18.4

* This tree data has been compiled using aerial imagery and data on tree sizes from all other paddocks, as no ground inventory was conducted on these fields. ** This tree data has been compiled using data from the other paddocks on farm 6.

Cow production measurements

Daily milk yield and body condition scores were used as production indicators for the cows. Body condition scores were assessed using a 1-5 grading system of the spine and hindquarters as described by Wildman *et al.* (1982) and Edmonson *et al.* (1989). Condition scores were taken for all milking individuals at the start and end of the study period.

Commercial spring balance scales (American® and Tiger Tools®) were used to measure individual cow daily milk yield. The scales were calibrated to account for the weight of the milking buckets. Milk quantities were recorded to the nearest ¼ lb. A total of 1480 individual daily milk yield measurements were recorded. Individual milk recordings from all cows on the farms were conducted a total of 89 times (10 to 21 times per farm, average 15). Paddock rotation, feed supplementation and any illness in the cows (e.g. lameness) was noted. Cows introduced late, or who were dried off early in the recording cycle were omitted from the analysis of milk yields but were included in stocking density analysis. Initially all individual milk recordings were supervised by field workers but following training, to a satisfactory level, some farmers were aiding in recording.

Farmer interviews and stock inventories

In order to understand the herd profiles and to check for differences in farm management, which may have been required for inclusion as independent variables, the farmers were interviewed. Questions were asked about aspects of routine cattle management including; worming, vaccination, replacement rates, animal sourcing, grazing rotations, crop rotations, length of dry periods and age at weaning. Time in milk was determined by the farmer interviews and checked against estimations of calf ages where present.

The total of all grazing stock, including cattle, horses and mules, was recorded for each farm. Breed, age, parity and time in milk for all milking cows were recorded. The stocking rates were calculated using the stock inventory compiled from interviews with the farmers. All grazing animals using the paddocks were then included in the stocking rate calculations even if they were not grazing alongside the lactating cows. Many of the farms practiced a follow on system with the lactating cows entering the paddocks first within a paddock rotation and the other grazing animals (e.g. bulls and horses) entering the paddock only after the lactating cows leave the paddock to graze the next paddock in the rotation. Other farms had separate holdings where all non lactating grazing stock, except for pre-weaned calves, were kept. Pre-weaned calves were not included in the LU calculations as all farmers kept their calves in corrals.

Weighing of the animals was not possible during this study. Stocking densities were calculated using livestock units (LU) with 1 LU equivalent to 400 kg live weight (Yamamoto *et al.* 2007). The following equivalencies were used: 1.0 for lactating and dry cows, 0.75 for heifers (1.5-3 years), 1.0 for steers in the fattening stage (older than 3 years), 1.25 for bulls and oxen, 0.75 for steers in the rearing stage (1.5-3 years old) and 0.5 for weaned calves (Yamamoto *et al.* 2007).

$$\text{Stocking density} = LU_{total} / A$$

Where LU_{total} includes all grazing animals for a given farm and A is the pasture area of the farm restricted to the use of these animals only.

Statistical analysis

The statistics software package R, version 2.10.1 by the R foundation for Statistical Computing (http://www.r-project.org), was used for all data analysis. The dependent and independent variables used in the data analysis are listed in table 4. Some dependent variables were also used as independent variables depending on the model in question.

Table 4 List of dependent and independent variables used in the data analysis.

Variable	Unit
Dependent variables	
Individual average daily milk yield	l/cow/day
Average body condition score	BCS 1-5
Change in body condition score over the study period	BCS 1-5
Independent variables	
Age of cow	years
Breed	
Parity	
Time in milk	months
Farm stocking rate	LU/ha
Pasture shade, proportion of pasture area under canopy cover	%
Density of dispersed trees	trees/ha
Dispersed tree canopy cover	%
Farm average basal area	m^2/ha
Feed supplementation with dried poultry waste	y/n

Where; BCS 1-5 is the scale of the body condition score system used and LU = livestock unit, which is equivalent to 400 kg liveweight.

Lactation curves for dairy cows can be described using the following gamma function (Wood 1967, Val-Arreola *et al.* 2002, Silvestre *et al.* 2006, Gradiz *et al*. 2009, Seangjun *et al.* 2009);

$$Y_t = a\, t^{b} e^{-ct},$$

Where; Y_t = daily milk yield at time t. The constant a is a scale factor associated with average daily milk yield at the start of the lactation, b is associated with the increase in milk before peak yield, and c is related to the decrease in milk after peak yield.

As the logarithmic form of the equation is log Y_t = log a + b log t – c t, the following equation was formulated to allow modelling of the average daily milk yield adjusted for the individual lactation stage (time in milk);

$$MY = \log Y_t \,(1/ (\log a + b \log t - ct))$$

Where; MY = the adjusted average daily milk yield (l/cow/day) for lactation stage (time in milk), Y_t = the average daily milk yield of a given cow during the study period and t is taken as the time in milk in the middle of the study period.

Due to time limitations, recording of complete lactation cycles was not possible in this study. Mean values for coefficients *a*, *b* and *c* were taken from previous studies including data from small scale farms, using dual purpose crossbred cows, in Honduras and Central Mexico (Gradiz *et al*. 2009 and Val-Arreola *et al.* 2002). Non parity adjusted and parity adjusted lactation curve coefficients (Table 5) were used in the production models.

Table 5 Lactation curve coefficients used to adjust average daily milk yield for lactation stage or lactation stage and parity.

Parameter	Gradiz model		Val-Arreola model					
	All parities		1st parity		2nd parity		3rd parity	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
a	4.67	3.35	9.77	2.23	22.2	4.45	16.3	2.75
b	0.43	0.21	0.18	0.06	0.0001	0.025	0.31	0.04
c	0.005	0.00	0.004	0.0007	0.0014	0.0003	0.002	0.0005

Values are taken from Gradiz *et al*. 2009 and Val-Arreola *et al.* 2002 using Wood's gamma function for lactation curves. Where *a* is a scale factor associated with average daily yield at the start of the lactation, *b* is associated with the increase in milk before peak yield, and *c* is related to the decrease in milk after peak yield. S.D. is the standard deviation. The Gradiz model coefficients are not adjusted for parity. 3rd parity also includes subsequent parities.

Multivariate linear regression analysis, with backward elimination of variables using a critical alpha value of $p>0.05$, was used in data analyis. Principal component analysis was conducted to aid in assessment of influential variables and interactions. Independent variables for interaction terms were centred, mitigating multicollinearity and aiding in interpretation of interactions (Fürst *et al.* 2009). Models were checked for outliers, constancy of variance and normality of errors with model-checking plots; residuals *vs* fitted, normal Q-Q, scale-location and residuals *vs* leverage. Linear and quadratic effects of variables were tested (Waltner *et al.* 1993). Parsimonious principles and one-way ANOVA comparisons were used in the selection of the final models (Crawley 2007).

A general model for milk production was developed including; farm management effects (housed at night in a corral, feed supplementation and stocking density), tree shade effects (dispersed tree density, dispersed tree canopy cover, average basal area and pasture shade) , cow body condition scores and cow factors (time in milk, parity, breed and age). Climatic conditions, genetic and epigenetic factors (although accounted for in part by the breed variable) were not included in the models and would therefore account for some of the model error. Tree effect variables were run in separate models as they were not independent from each other and pasture shade is a product of the other tree variables. Models using non adjusted, lactation stage adjusted and lactation stage and parity adjusted milk yields were compared. Time in milk and parity were included or excluded as independent variables depending on the milk yield adjustment used in the model.

General models for milk yield as the production parameter;

$$MY_{ijklmno} = \mu + F_i + T_j + BCS_k + \Delta BCS_l + S_m + P_n + TIM_o + E_{ijklmno}$$

Where; MY= individual average daily milk yield which is either unadjusted for lactation stage or parity, adjusted for lactation stage or adjusted for both lactation stage and parity, μ = general mean of milk production, F= farm management effects, T= tree effects, BCS= average individual body condition score, ΔBCS= change in body condition score, S = cow factors , P= parity, TIM= time in milk, E= experimental error and *i,j,k,l,m,n* and *o* are constants associated with the variables. T and P were included or excluded from the model depending on the milk yield adjustment used.

Body condition general production models were run using both the unadjusted and adjusted daily milk yields. The unadjusted daily milk yields may more accurately represent the energy demand on a given cow. Depending on the milk yield adjustment used, parity and time in milk were included or excluded from the model. The same farm management and tree effects were used in these models as in the milk production models. Change in body condition score and average body condition score were tested as separate independent variables.

General models for body condition as the production parameter;

$$BCS_{ijklmno} = \mu + F_i + T_j + \Delta BCS_k + S_l + P_m + TIM_n + MY_o\ E_{ijklmno}$$

$$\Delta BCS_{ijlmnop} = \mu + F_i + T_j + BCS_p + S_l + P_m + TIM_n + MY_o + E_{ijlmnop}$$

Where; BCS= average body condition score, ΔBCS= change in body condition score, μ = general mean of milk production, F= farm management effects, T= tree/shade effects, S = cow factors (breed and age), P= parity, TIM= time in milk, MY= individual average milk yield , E= experimental error and *i,j,k,l,m,n,o* and *p* are constants associated with the variables.

Results

The average, unadjusted, daily milk yield per farm ranged from 2.5 to 5.1 l/cow/day (Table 6). The mean milk yield for all cows was 4.0 l/cow/day, with a range of 1.6 to 8.3 l/cow/day (Table 6). Average milk yield per hectare by farm was 3.0 l/ha/day, with a range of 0.9 to 5.9 l/ha/day (Table 6). The mean body condition scores by farm ranged from 1.9 to 3.1 body condition score points with an all cow mean of 2.8 ranging from 1.3 to 4.5 (Table 6). The mean change in body condition scores by farm ranged from -0.1 to 0.6 body condition score points (Table 6). The changes in body condition ranged from -1.0 to 1.5, with a mean of 0.35 body condition score points (Table 6).

Table 6 Mean values for dependent variables by farm and means and ranges for all cows.

Farm	MY, l/cow/day (n=121)	Milk yield per hectare, l/ha/day	BCS (n=108)	ΔBCS (n=82)
1	2.5	2.0	2.9	0.2
2	3.9	2.8	2.7	0.2
3	5.1	3.4	2.7	0.4
4	3.6	5.9	2.3	0.6
5	4.1	3.2	3.1	0.4
6	2.9	0.9	1.9	-0.1
Mean	4.0	3.0	2.8	0.4
Range	1.6 to 8.3	na	1.3 to 4.5	-1.0 to 1.5

MY = Average daily milk yield per cow over the study period (unadjusted for lactation stage or parity), BCS = average body condition score, ΔBCS = change in body condition score over the study period. Body condition scores were on a 1-5 scale. Range is the minimum and maximum values for all cows in the study.

The final reduced model for milk production used the lactation stage and parity adjusted milk yields and pasture shade as the only tree variable. It did not include the variables for body condition scores, parity and time in milk. Daily milk yield (l/cow/day) was negatively affected by pasture shade ($p<0.05$), stocking density ($p<0.001$), age ($p<0.001$) and housing overnight in a corral ($p<0.05$) (Table 7). There was a positive interaction between pasture shade and farm stocking density ($p<0.05$). The regression analysis explained 36 % of the variation in the adjusted average daily milk yield (R^2 0.36, table 7).

Table 7 Summary of reduced model for daily milk yield†, without inclusion of body condition scores, parity and time in milk as predictor variables and the use of pasture shade as the only tree variable.

Coefficients:	Estimate	SE	t-value	p-value
Intercept	1.50	0.16	9.32	<0.001
Predictor variables				
Pasture shade	-0.03	0.01	-2.43	0.017
Farm stocking density	-0.60	0.18	-3.40	<0.001
Age	-0.09	0.02	-5.35	<0.001
Corral	-0.62	0.25	-2.52	0.013
Interactions				
Pasture shade : farm stocking density	0.13	0.05	2.40	0.018
R^2 : 0.36, F-statistic: 11.56 on 5 and 102 DF, p-value: < 0.001				

† The log of the parity and lactation adjusted average daily milk yield, (l/cow/day), was used in this final model.

The final reduced model for average body condition (Table 8) showed feed supplementation, with dried poultry waste, had a positive effect on body condition ($p<0.001$). Body condition was negatively affected by pasture shade ($p<0.001$) and average daily milk yield ($p<0.01$). There was a positive interaction between pasture shade and farm stocking density ($p<0.05$, table 8). The regression analysis explained 29 % of the variation in average body condition score (R^2 0.29, table 8). Regression analysis failed to show any significant predictor variables for change in body condition score.

Table 8 Summary of reduced model for average body condition, which included pasture shade as the only tree variable.

Coefficients:	Estimate	SE	t-value	p-value
Intercept	2.81	0.31	9.10	<0.001
Predictor variables				
Daily milk yield	-0.64	0.23	-2.78	0.006
Pasture shade	-0.18	0.04	-4.25	<0.001
Supplementation	2.73	0.62	4.43	<0.001
Farm stocking density	-0.43	0.33	-1.29	0.200
Interactions				
Pasture shade : farm stocking density	0.20	0.08	2.56	0.012
R^2:0.29, F-statistic: 8.329 on 5 and 102 DF, p-value: <0.001				

Where; daily milk yield is the log of the unadjusted individual average daily milk yields (l/cow/day).

Discussion

General performance

The mean daily milk yield was 4.0 l/cow/day (Table 6). This compares favourably to other estimates of milk yield in the tropics of 2.5 to 6 l/cow/day (Stobbs *et al.* 1978, Neidhardt *et al.* 1979, Suttie 2008). Mean milk yield per hectare was 3.0 l/ha/day (Table 6) which is high compared to a study conducted in central Nicaragua (Matiguas municipality) with a yield of 1.35 l/ha/day for the October/November period and 1.38 l/ha/day all year mean (Yamamoto *et al.* 2007).

Pasture shade and the pasture shade stocking density interaction on production

Pasture shade had a negative effect on milk yield ($p<0.05$, table 7) and body condition ($p<0.001$, table 8). Stocking density had a negative effect on milk yield ($p<0.001$, table7) which is in accordance with previous findings (MacDonald *et al.* 2000). There was a correlation between pasture shade and stocking density on both average daily milk yield ($p<0.05$, table 7) and body condition score ($p<0.05$, table 8). As pasture shade increased on the farms, stocking density decreased. This correlation between pasture shade and stocking density appears to show that the farmers are adjusting stocking density in order to maintain milk production and possibly body condition. These findings agree with those of Abdallah *et al.*(1999).

The cause for the negative effect of pasture shade on the cow production parameters is unclear from this study. There are two likely mechanisms for this negative effect of pasture shade on production (Figure 2). Firstly, the shade may have altered cattle behaviour, both spatially and temporally, leading to a decreased feed intake. Secondly, the shade may have had direct effects on pasture productivity, either in terms of quantity or quality of understorey

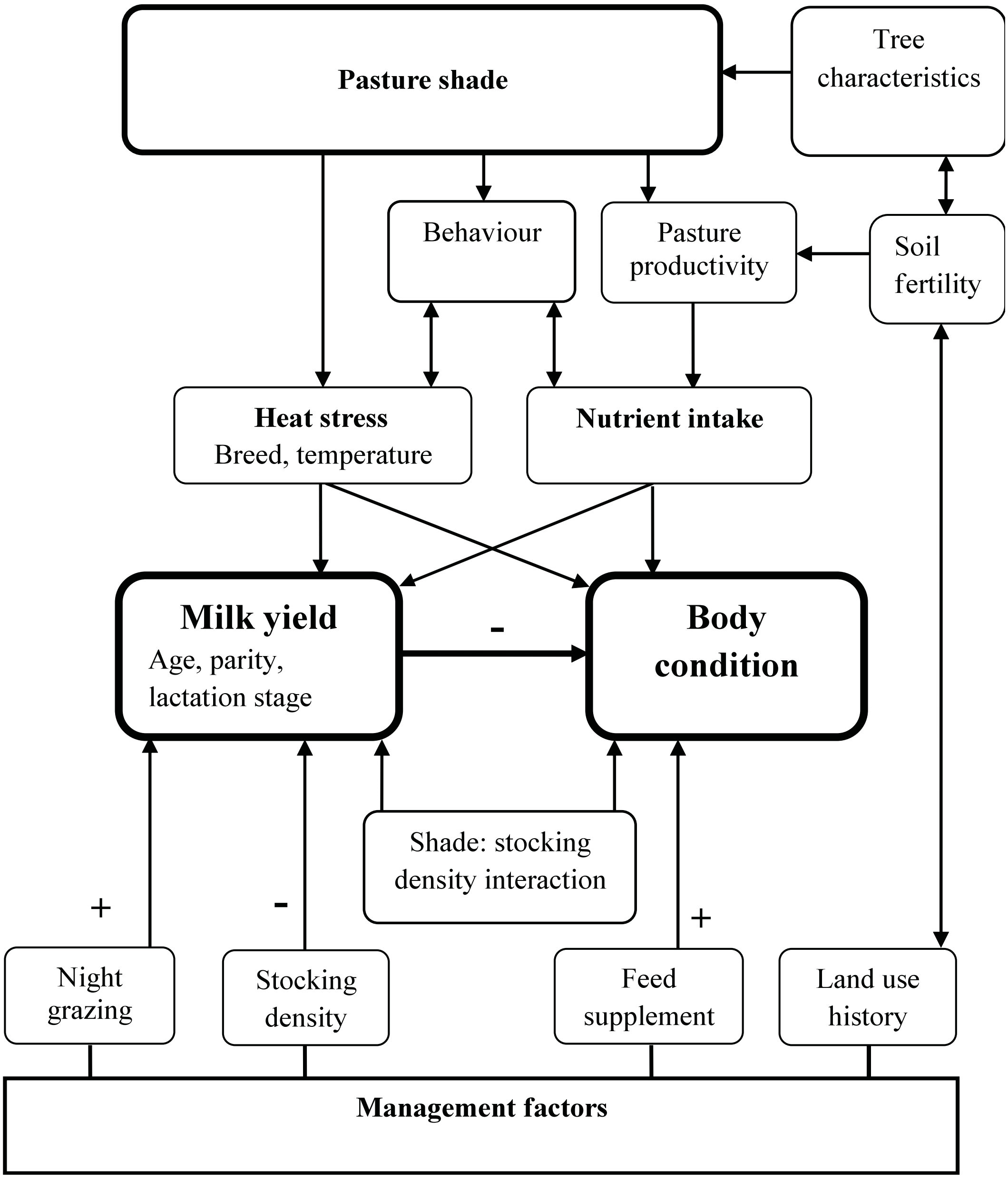

Figure 2. A conceptual framework for the effects of trees and management on the production variables of milk yield and body condition. + and – represent the positive and negative effects identified in the reduced production models. Age, parity and lactation stage also affected milk yield. Breed and temperature (or temperature-humidity index) have been shown in previous studies to influence heat stress. Pasture shade had a negative effect on both milk yield and body condition. It is proposed that this effect was due to either altered grazing behaviour leading to decreased feed intake or a direct effect on pasture productivity, or both. The positive effect of shade mitigating heat stress was likely present but its effect did not compensate for decreased nutrient intake. Pasture shade is dictated by the tree characteristics. Soil fertility can be affected by tree characteristics and land management, but soil fertility can also affect land use and pasture productivity and subsequently tree characteristics. Tree characteristics may be an indicator of land management and soil fertility as well as a determining factor in the primary productivity of the land.

vegetation. The mitigating effect of shade on heat stress was likely present but was not enough to compensate for the decreased nutrient intake of the cows. It is also worth considering the relation between the soil fertility, the tree characteristics and the management of the pastures. Trees can have both positive and negative effects on soil parameters (Powell *et al.* 1996, Arevalo *et al.* 1998, Schroth 1999, Xu *et al.* 2005, Michel *et al.* 2007) but the tree distributions and characteristics are also likely determined by the soil parameters themselves and the land management history (Sanchez *et al.* 2004). Caution must therefore be used in interpretation that the poor productivity, in terms of cow production parameters, associated with higher pasture shade is a direct result of the tree shade itself. Further studies into cattle behaviour, soil parameters, land management and land history must be conducted to investigate these effects further.

The effect of The tf, t me n m lk hn h, e on m lk Teo uct on

Parity and lactation stage adjusted milk yields were used in the final milk production model. This final model had an F-statistic of 11.6 and R^2 of 0.36 (Table 7), compared to 9.1 and 0.26 in the unadjusted yields and 9.6 and 0.22 in the lactation stage adjusted model, and showed an improved normality of errors with model-checking plots. The performance of this adjusted milk yield model shows that parity had a strong effect, with milk yields increasing from the first parity to the third parity as defined by the parity adjusted coefficients used in the final model (Waltner *et al.*1993, Val-Arreola *et al.* 2002, Ji-Yeon *et al.* 2006).

These findings are also consistent with previous studies in which milk yield increases from calving to a peak at 60-90 days and decreases until the end of the lactation cycle (Wood 1967). Average milk yield was negatively affected by age ($p<0.001$). These findings are consistent with Wilmink (1987), who also adjusted milk yields for parity and lactation. It is likely that some of the residual variation in milk yield between cows, not identified in this study, is due to genetic and epigenetic factors (Singh *et al.* 2010).

Corral effect on milk production

Housing the cattle overnight in a corral was used to ease the morning milk routine and prevent cattle rustling. Corral use should be viewed in terms of restriction of access to night grazing. The negative effect of corral use on daily milk yield ($p<0.05$, table 7) can be seen as a positive effect of night grazing on daily milk yield. This effect may be due to increase feed intake in a given 24 hour period or a change in temporal grazing patterns potentially mitigating the effects of heat stress during the day by resting in the shade. Lactating cows in the Summer months have been found to perform ¾ of their grazing activity during the night (Fuquay 1981). Nutrient cycling from the cattle may also play a role as more nutrients will be returned to the pasture, from cattle urine and dung, if they spend a greater proportion of their time in the paddocks (Powell *et al.*1996). A behavioural study investigating variations in time budgets and behaviours with and without night grazing would be required to investigate this corral effect further.

The effect of milk production on body condition scores

Average daily milk yield had a negative effect on average body condition score ($p<0.01$, table 8). These findings are consistent with previous studies which show if high producing cows' energy demands are not met by an adequate plane of nutrition a loss of body condition results (Neidhardt *et al.*1979 and Enzanno *et al.* 2005). There was no effect of time in milk on body condition score in this study, although previous studies have shown that body condition scores vary quadratically with days in milk and that change in body condition score is related quadratically to milk yield within a lactation (Waltner *et al.* 1993, Domecq *et al.* 1997 and Msangi *et al.* 2005).

Modern dairy management aims to have cows in good condition (≥ 3 on a 1-5 scale) prior to the lactation cycle so that they have adequate reserves to meet the negative energy state during the lactation cycle. Increased and accelerated milk yield in the first 120 days of lactation can be expected if body condition score is increased during the dry period (Domecq *et al.* 1997). High condition score cows have been reported to have a 23% increase in milk yield compared to low condition score cows (Enzanno *et al.* 2005). If the higher metabolic load of genetically high yielding cows is not being met by adequate nutrition then body condition will be reduced and also milk yield reduced (Neidhardt *et al.*1979). Higher body condition scores have been linked with higher calving and weaning rates amongst Brahman cows and so additional benefits other than milk productivity can be expected in herds with high body condition scores (Vargas *et al.* 1999).

The lack of significant findings with the change in body condition data is likely due to the short monitoring period of the study. Body condition loss in early lactation has been linked with high milk yields (Ji-Yeon *et al.* 2006). Condition score studies during the dry period and monitoring changes in body condition score over a longer period would be required to investigate possible effects further.

Feed supplementation

All farms gave regular salt supplements to their cows. Two of the six farms used dried poultry waste, DPW, as a daily feed supplement, at a rate of approximately 5.5 kg/cow/day. Pre-weaned calves also had access to this supplement. DPW can provide around 2000 kcal/kg, equivalent to good quality hay, and 53% crude protein (Bhattacharya and Taylor, 1975).

Feed supplementation, with DPW, had a positive effect body condition score ($p<0.001$, table 8). The positive effect of feed supplementation on body condition highlights the link between the plane of nutrition and metabolic state on body condition. Protein supplementation, irrespective of its type, can lead to decreased grazing time relative to unsupplemented cattle (Krysl *et al.* 1993) and may therefore decrease grazing pressure on the pastures.

The difference in the mean average body condition score of supplemented to non supplemented cows in this study was 0.5 (3.0 compared to 2.5), on a 1-5 grading scale. The body condition model accounted for 25% of the variation in average body condition scores. An increase in body condition score of one point, on a 1-10 grading scale, has been equated to a liveweight gain of 31kg in Holstein-Friesian cattle (Berry et al. 2006). This would equate to approximately 0.25 of a body condition score point in a 1-10 grading scale realising a 7.75 kg liveweight increase, equivalent to 3.89 kg dressing meat using a 50% dressing weight conversion (McKiernan et al. 2007). Of this gain in meat quantity, less than 29% could be due to supplementation (R^2= 0.29, table 8). This small increase in meat quantity may not justify supplementation alone.

Supplementation did not affect milk yield and is consistent with earlier studies which have found that DPW has no effect on milk production, but does increase milk production if the diet if deficient in protein (Thomas *et al.* 1972, Bhattacharya and Taylor, 1975). This suggests that the pasture had a quality equivalent to DPW. Supplementation may have affected milk quality, specifically milk protein and fat, by maintaining a positive energy balance (De Vries *et al.* 2000). Milk constituent analysis and economic analysis into the benefit of supplementation on farm meat and milk income should be considered prior to recommendations on the benefit of feed supplementation with DPW.

Conclusions

This study has investigated the effects of trees on cow productivity. It has shown that pasture shade negatively affects the key cow production measures of daily milk yield and body condition. The reasons for the negative effect of pasture shade on cow productivity are not established in this study. It appears that the negative effects of trees on pasture productivity are greater than the mitigation of heat stress in the cows. The finding that night grazing increased milk yield suggests that heat stress may have been a significant cause for decreased productivity.

It cannot be concluded, however, that the trees themselves are the cause of the decreased productivity. Cattle intensification is linked to decreasing tree density as farmers remove trees to reduce the shade effects on improved pasture (Sanchez *et al.* 2004) and so equally, highly productive natural pasture may be treated in the same way by the farmers with a pre-conception that high tree density decreases pasture productivity. High tree densities may instead then be acting as a marker of poor land, land history and land management decisions rather than the cause of decreased pasture productivity.

The farmers employed management techniques to limit the decreased productivity associated with high pasture shade by adjusting stocking densities. Feed supplementation improved body condition but did not increase milk yield, although milk quality may have been affected. In studies where it is not possible to follow complete lactation cycles, parity and lactation adjusted milk yields should be considered for use in milk production models. Future studies should examine the effects of trees on soil properties, pasture productivity, digestibility and cattle behaviour. Consideration should be given to the land development history and seasonality. All findings in relation to tree effects on pasture and cattle productivity should be viewed in the wider context of silvopastoral systems and their potential ecological benefits.

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