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Pasture shade and farm management effects on cow productivity in the tropics

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Abstract

Shade, provided by trees within pastures, can affect cattle productivity through mitigating heat stress and by altering understorey pasture growth and cattle behaviour. Models for daily milk yield and body condition were used to evaluate the effect of pasture shade on dual purpose cow productivity within a silvopastoral system in a dry tropical province of Nicaragua. Daily milk yield and body condition were both negatively affected by pasture shade. Stocking density and age also had negative effects on daily milk yield, whilst night grazing had a positive effect. In addition, body condition was negatively affected by average daily milk yield and was positively affected by feed supplementation. There was a correlation between pasture shade and stocking density in both production models 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.

Keywords: silvopastoral, agroforestry, pasture shade, cattle productivity, heat stress, tropics

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1. 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 found throughout the tropics (Sharrow 1999). 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 and Haber 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 and White 2008, Everson et al., 2009, Pollock et al., 2009). Soil nutrient levels are altered through root competition, facilitative root interactions, leaf- and fruit fall and alteration of animal behaviour influencing the distribution nutrients from animal waste (Powell et al., 1996, Arevalo et al., 1998, Schroth 1999, Xu and Hirata 2005, Michel et al., 2007). Preserved trees, following conversion of native forest into silvopastoral land, can maintain high soil biological activity, soil nutrient levels and organic matter content (Wick et al., 2000). The balance of positive and negative tree effects on understorey growth partly depends on tree species and growth stage (Kumar et al., 2001, Motagnini and Ugalde 2002).

Heat stress, in animals, 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, including; shade seeking, increased water intake, peripheral vasodilation, increased sweating and increased respiratory rate (Blackshaw and Blackshaw 1994, Kadzere et al., 2002). 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, Chaiyabutr et al., 2008, Fisher et al., 2008).

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 et al., 1985). Total daily time allocation for key cattle behaviour 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 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).

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., 2001, Marcillac-Embertson et al., 2009). Cattle seek shade offering radiation protection levels up to 50%, above which no greater preference is shown (Schütz et al., 2009), and increased shade usage when over 9.6m^2 shade cow^{-1} is provided (Schütz et al., 2010). A level of 50 % shading can be attained with most commonly used tree species within 3 years of planting (Kumar et al., 2001).

This study examines the effects of pasture shade (provided by trees) and farm management on cow productivity. Cow productivity is assessed through measurement of milk yield and body condition. Aspects of farm management examined included; night grazing, stocking rates and food supplementation. Based on previous studies we predicted: 1) that availability of pasture shade would improve body condition and increase milk yield (Mitlöhner et al., 2001, Marcillac-Embertson et al., 2009); 2) that stocking density would negatively affect body condition and milk yield (Macdonald et al., 2008) and finally; 3) that increased milk yield would have a negative effect on body condition (Neidhardt et al., 1979, Ezanno et al., 2005).

2. Materials and methods

2.1. Study location

The location for the study was the municipality of Belén, in the Rivas province of Nicaragua, 11°35'N 85°58' W. Biogeographically the region is classified as tropical dry forest and savannah (Gillespie et al., 2001 and Weaver and Lombardo, 2003). Soils are derived from volcanic material, 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 to195 masl.

The regional annual average temperature is 27ºC, annual average humidity is 78% and annual precipitation 1400 mm (INETER 2000). The wet season is between August and October with up to 320mm of rainfall monthly (INETER 2000). The average daily temperature and humidity ranged from 24-30°C and 70-96%, respectively during the study period (Davis Wireless Vantage Pro2™, weather station).

2.2. Farm selection and description

The study was carried out concurrently on six farms between October and November 2009. The majority of the farms' incomes were derived from meat and milk. Other agricultural activity on the farms included crops of rice, beans, wheat, maize, plantain and yucca, grown on a subsistence basis. None of the farms used fodder banks or cut and carry systems and the trees within the pastures represented forest remnants and live fences, with little new planting.

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 farmhouses. All farms practiced partial suckling systems to feed the calves and improve milk let down (Coulibaly and Nialibouly, 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. Pasture composition consisted of natural pasture and "naturalised" pasture with the predominant species being Jaragua (*Hyparrhenia rufa),* Estrella (Star grass, *Cynodon nlemfluensis*), Gamba (*Andropogon gayanus*), Gallina (*Cynodon dactylon*) and 2 paddocks with *Brachiaria brizantha*. No fertilisers were used on the paddocks.

2.3. 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. All tree locations, except those of the riparian areas, were recorded using GPS.

Riparian trees were those trees in clusters around rivers or streams, representing linear forest remnants along waterways. The borders of the riparian areas were recorded by GPS to allow calculation of the area of the paddocks covered by riparian forests and the length of their boundaries with the pasture. The riparian areas were deducted from the field areas to give the pasture areas, as most riparian areas were impassable to cattle and were too dense to allow understorey growth.

Diameter at breast height (DBH), and canopy diameters were recorded for the dispersed trees, clustered trees and live fence trees. DBH was measured using a diameter tape to an accuracy of 1cm. Canopy diameters were recorded in two, perpendicular directions, using a measuring tape or laser measure (Laser Tech® Impulse 200LR) to an accuracy of 10cm. Total diameters for the combined cluster canopies were also recorded. Tree density was calculated per paddock and per farm as the total number of dispersed and clustered trees per area. Live fence trees were not included in tree density calculations but were included in pasture shade calculations.

Canopy cover was calculated as a percentage of the pasture area that was covered by the vertical projections of the tree crowns, as calculated from the measured canopy diameters of the dispersed, clustered and live fence trees. The effective 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 the approximate riparian edge canopy width. The total shade cover for the paddocks, pasture shade, was calculated as the percent of the total pasture area for each farm covered by the canopies of the dispersed, clustered and live fence trees and the canopy cover of the riparian edges.

2.4. Paddock survey summaries

A total of 3650 trees were surveyed and 72 tree species identified. Farm pasture areas averaged 24.3 ha (11.1 to 44.5 ha), with an average paddock size of 6.2 ha (1.00 to 11.15 ha). Average tree density (dispersed and clustered) per paddock was 22 trees ha^{-1} (0 to 66 trees ha^{-1}). Farm tree density ranged from 7 to 63 trees ha^{-1} and farm pasture shade ranged from 9.5 to 28.7 %.

2.5. Cow production measurements

Daily milk yields and body condition scores were used as production indicators for the cows. Recording periods for the farms ranged from 29 to 42 days (37 days average). A total of 121 dual purpose cows were used in this study. 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, allowing calculation of an individual's average body condition score and change in body condition score during the study period.

Individual milk recordings from all cows on the farms were taken a total of 89 times (10 to 21 times per farm, average 15). A total of 1480 individual daily milk yields were recorded. Paddock rotation, feed supplementation and any illness in the cows (e.g. lameness) was noted. Sick cows, cows introduced late, or those who were dried off early in the recording cycle were omitted from the analysis of milk yields but were included in stocking density analysis.

2.6. 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. Supplementary feeding, cattle ages, breeds and parities were gathered from these interviews. Time in milk was determined both by the farmer interviews and checked against estimations of calf ages. Stocking rates were calculated using stock inventories compiled from the interviews. All grazing animals using the paddocks were included in the stocking rate calculations. Pre-weaned calves were not included in the calculations as all farmers kept their calves in corrals.

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 for the cattle: 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). Stocking density was given as LU ha^{-1} pasture.

2.7. Statistical analysis

The statistics software package R, version 2.10.1 by the R Project 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 1. Some dependent variables were also used as independent variables depending on the model in question.

Table 1

Dependent and independent variables used in the data analysis

Variable	Unit
Dependent variables	
Individual average daily milk yield	$lcow^{-1}$ day^{-1}
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 (lactation stage)	months
Farm stocking rate	LU ha^{-1}
Feed supplementation with dried poultry waste	y/n
Corralling by night	y/n
Pasture shade, proportion of pasture area under canopy cover	%
Density of dispersed trees	trees ha^{-1}
Dispersed tree canopy cover	%

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., 2004, 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^{-1} day^{-1}) for lactation stage (time in milk),Y_t = the average daily milk yield of a given cow during the study period. t is taken as the time in milk at the midpoint 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., 2004). Non-parity adjusted and parity adjusted lactation curve coefficients (Table 2) were used in the production models.

Table 2

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

Parameter	Non-parity adjusted lactation coefficients		Parity adjusted lactation coefficients					
	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) for the non-parity adjusted lactation coefficients and Val-Arreola et al. (2004) for the parity adjusted lactation coefficients, 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. 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 analysis. 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 (Jaccard et al., 1990). 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 effects (dispersed tree density, dispersed tree canopy cover and pasture shade), cow factors (breed and age), lactation stage and parity. 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. Lactation stage and parity were included or excluded as independent variables depending on the milk yield adjustment used in the model.

General model for milk yield as the production parameter:

$$MY_{ijklm} = \mu + F_i + T_j + S_k + P_l + TIM_m + E_{ijklm}$$

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, S = cow factors, P= parity, TIM= time in milk (lactation stage), E= experimental error and *i*,*j*,*k*,*l* and *m* 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 over the study period and individual 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 effects, S = cow factors (breed and age), P= parity, TIM= time in milk (lactation stage), MY= individual average milk yield, E= experimental error and *i,j,k,l,m,n,o* and *p* are constants associated with the variables.

3. **Results and discussion**

3.1. General performance

The average, unadjusted, daily milk yield per farm ranged from 2.5 to 5.1 l cow^{-1} day^{-1} with a mean milk yield for all cows of 4.0 l cow^{-1} day^{-1}, with a range of 1.6 to 8.3 l cow^{-1} day^{-1}. This compares favourably to other estimates of milk yield in the tropics of 2.5 to 6 l cow^{-1} day^{-1} (Stobbs and Thompson 1978, Neidhardt et al., 1979, Suttie 2008). Milk yield per hectare, averaged over all farms, was 3.0 l ha^{-1} day^{-1}.

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. The mean change in body condition score, by farm, ranged from -0.1 to 0.6 body condition score points, with a mean change of 0.35 body condition score points for all cows over the study period.

3.2. Milk yield

Daily milk yield was negatively affected by pasture shade, stocking density, age and housing overnight in a corral (Table 3). There was a positive interaction between pasture shade and farm stocking density.

Table 3

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
Pasture shade	-0.03	0.01	-2.43	0.017
Farm stocking density	-0.60	0.18	-3.40	<0.001
Cow age	-0.09	0.02	-5.35	<0.001
Corralling by night	-0.62	0.25	-2.52	0.013
Pasture shade : farm stocking density	0.13	0.05	2.40	0.018
R^2= 0.36, *F*= 11.56 on 5 and 102 *DF*, *P* <0.05				

The log of the parity and lactation stage adjusted average daily milk yield, (l cow^{-1} day^{-1}), was used in this final model.

3.3. Body condition

Body condition was negatively affected by pasture shade and average daily milk yield and positively affected by feed supplementation, with dried poultry waste (Table 4). There was a positive interaction between pasture shade and farm stocking density. Regression analysis failed to show any significant predictor variables for change in body condition score over the study period.

Table 4

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
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
Pasture shade : farm stocking density	0.20	0.08	2.56	0.012

R^2= 0.29, F= 8.329 on 5 and 102 DF, P <0.05

Where; daily milk yield is the log of the unadjusted individual average daily milk yields (l cow^{-1} day^{-1}).

3.4. Pasture shade and stocking density effects on production

Contrary to our prediction one, pasture shade had a negative effect on milk yield and body condition. In line with our prediction two, stocking density had a negative effect on milk yield, which is in accordance with previous findings (Macdonald et al., 2008). The negative correlation between pasture shade and stocking density may show that the farmers are adjusting stocking density in order to maintain milk production and body condition as found by Abdalla et al. (1999). There was an interactive effect between pasture shade and stocking density on both average daily milk yield and body condition score.

The cause for the negative association between pasture shade and cow production parameters is unclear from this study. There are two likely mechanisms for this negative effect of pasture shade on production (Fig. 1). Firstly, the shade may have altered cattle behaviour, both spatially and temporally, leading to a decreased feed intake. This is, however, unlikely, as most previous research suggest no effect or a positive effect of shade on dry matter intake (Mayer et al., 1999, West 2003, Fisher et al., 2008, Hirata et al., 2009). Secondly, the shade may have had direct effects on the pasture, decreasing quantity and/or nutritive quality of the understorey vegetation. The direction of the resulting impact by trees on the forage value of field layer vegetation may vary in time and space. In our case, the mitigating effect of shade on heat stress on the cows was likely present but was not enough to compensate for a decreased nutrient intake. 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 nutrient status (Powell et al., 1996, Arevalo et al., 1998, Schroth 1999, Xu and Hirata 2005, Michel et al., 2007). However, tree distributions and characteristics are also likely determined by the soil parameters themselves and via land management history. 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.

3.5. The effect of milk production on body condition scores

In accordance with our prediction three, average daily milk yield had a negative effect on average body condition score. Previous studies have shown that if a high producing cow's energy demands are not met by an adequate plane of nutrition a loss of body condition results (Neidhardt et al., 1979, Ezanno et al., 2005, Lee and Kim 2006). 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). A reason for the lack of significant effects in this study may be the short monitoring period.

3.6. Corral effect on milk production

Housing the cattle overnight in a corral was used to ease the morning milk routine and prevent cattle rustling. The negative effect of corral use on daily milk yield can be seen as a positive effect of night grazing on daily milk yield. This effect may be due to increased 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 the majority 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).

3.7. Feed supplementation

Two of the six farms used dried poultry waste (DPW), as a daily feed supplement, at a rate of approximately 1 kg^{-1} $cow^{-1}day^{-1}$. Pre-weaned calves also had access to this supplement. DPW can provide around 2000 $kcalkg^{-1}$, equivalent to good quality hay, and 53% crude protein (Bhattacharya and Taylor, 1975). The difference in the mean average body condition score of supplemented to unsupplemented cows in this study was 0.5 (3.0 compared to 2.5), on a 1-5 grading scale. Protein supplementation, irrespective of its type, can lead to decreased grazing time relative to unsupplemented cattle (Krysl and Hess 1993) and may therefore decrease grazing pressure on the pastures.

Supplementation did not affect milk yield, which is consistent with earlier studies which have found that DPW generally 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). Supplementation may have affected milk quality, specifically milk protein and fat, by maintaining a positive energy balance (De Vries and Veerkamp 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.

3.8. The effect of parity, time in milk and age on milk production

The performance of the parity and lactation stage adjusted milk yield model shows that parity had a strong effect, with milk yields increasing from the first parity to the third parity and supports Wood (1967) with milk yield increasing from calving to a peak at 60-90 days and decreasing until the end of the lactation cycle. Average milk yield was negatively affected by age, which is consistent with Wilmink (1987), who also adjusted milk yields for parity and lactation stage. 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).

4. Conclusions

This study has shown that pasture shade is negatively associated with 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 either pasture productivity or cattle behaviour, or both, 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 cause for decreased productivity in the cows corralled at night. It cannot be concluded, however, that the trees themselves are the cause of decreased cow productivity. High tree densities may be acting as markers of land quality, land history and land management decisions rather than the cause of reduced pasture productivity.

The farmers employed management techniques to limit the decreased cattle 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.

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