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Effects of silvopastoral areas on milk production at dual-purpose cattle farms at the semi-humid old agricultural frontier in central Nicaragua

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Abstract

In extensive cattle production systems, the composition of grazing areas may significantly influence productivity. In dual-purpose cattle production systems in the lowland tropics, pasture lands with trees, so-called silvopastoral areas, are considered as being important, particularly to facilitate the management of crossbred European native cattle. The aim of the study was to quantify the effects of silvopastoral areas on production at dual-purpose cattle farms in the semi-humid lowlands of central Nicaragua. The relationships between seasonal milk production and herd data, and the proportions of land use types were examined for 74 farms by stepwise regression analysis.

The results showed significant positive effects on saleable milk production of areas of degraded pasture (DGPS) ($P < 0.001$), natural and cultivated pastures with moderate tree density (MTCP and MTNP) ($P < 0.05$), and cultivated pasture with low tree density (LTCP). However, negative effects of land use types under natural pasture with low tree density (LTNP) ($P < 0.01$) was also observed, suggesting that on smaller farms, high stocking rates resulted in overgrazing. Analysis by season confirmed the positive effects of DGPS on saleable milk production at the end of the dry season ($P < 0.01$), and of MTNP at the beginning of the wet season ($P < 0.05$). This suggests that degraded pasture may be important as a source of cattle feed at the end of the dry season whilst MTNP are particularly important at the beginning of the wet season. The area of *Brachiaria brizantha* had positive effects on saleable milk production at the end of the dry season ($P < 0.01$), suggesting that the use of this species is an important option for farmers.

The study concluded that silvopastoral systems for dual-purpose cattle production developed in the study area by maintaining useful naturally regenerated trees in grazing areas with relatively low stocking rates and limited amounts of supplemental fodder. Increases in the meat:milk price ratio is likely to reduce tree cover. Further studies are recommended on broadleaf plants in the grazing areas and their nutritional values in the dry season, the feasibility of increasing the availability of supplemental fodder for milk production in the dry season, and the impact of land use types on seasonal grazing decisions.

Keywords: Dual-purpose cattle production; Silvopastoral system; Stepwise regression; Degraded pasture; Milk production

1. Introduction

Conversion of natural forest to pasture in the humid tropics of Central America has been criticized as the main cause of deforestation (Parsons, 1976; Myers, 1981; Kaimowitz, 1996). Cattle managed extensively in tropical pastures with low nutrient values and low labour and capital inputs exploit those nutrients accumulated in the soil by the original vegetation (Kaimowitz, 1996; Sunderlin and Rodríguez, 1996). However, extensive cattle production is an important activity in the rural economy due to its comparative advantages relative to other forms of agricultural production: its low

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requirement for skill and labour, its low risk, and the fact that products can be transferred easily to markets (Hecht, 1992; Muchagata and Brown, 2003). Dual-purpose cattle production systems have been traditionally preferred by family farms in the lowland tropics due to the low risk of price changes, higher economic benefit per unit of area than meat production, adaptation to the climatic conditions in the lowland tropics, and less capital investment and technical support required than for specialized milk production (Sere and De Vaccaro, 1985; Holmann, 1989).

The existence of trees in grazing areas may support cattle production in various ways: (1) improvement of chemical and physical soil conditions (Horne and Blair, 1991; Belsky, 1992; Belsky et al., 1993; Young, 1997), (2) stabilization of soil by protecting the soil surface from intensive rainfall (Pereira, 1989), (3) supporting higher amount of grass production in the dry season by increasing soil water holding capacity and reducing moisture loss (Wilson and Wild, 1991; Young, 1997), (4) improvement of pasture quality (Wilson, 1982; Wilson and Ludlow, 1991; Smith and Whiteman, 1983), (5) increased production by improving the condition of animals and (6) provision of leaves and fruits as fodder for animals (Pezo et al., 1990; Pezo and Ibrahim, 1999). In particular, Zebu and European crossbred cattle, which are the most common cattle types in dual-purpose cattle farms in the lowland tropics, can benefit from shading because they are less tolerant of high temperatures than purebred Zebu cattle (Souza de Abreu, 2002). Common tree species in the grazing areas in the study area, *Guazuma ulmifolia*, *Enterolobium cyclocarpum*, and *Albizia saman*, produce fruits and leaves which are an important source of fodder in the dry season (Zamora et al., 2001).

Published evidence of positive contributions of trees to cattle production have mostly been based on investigations or experiments of limited scale. The effects of silvopastoral areas on production in existing farming systems have not been quantified at the farm level due to the high variation between farms and seasons, and technical difficulties related to obtaining land data for entire farms. The objective of this paper is to quantify the effects of silvopastoral areas on milk production in dual-purpose cattle production systems.

2. Materials and methods

2.1. Site

The study area is located in the Matiguas Municipality in the Matagalpa Department, central Nicaragua: Latitude 12°50′ North and 85°27′ Longitude East. The climate of the study area is semi-humid tropical with a well-defined dry season between February and May. Annual rainfall varies from 1300 to 2000 mm, while temperature fluctuates between 28 and 32 °C. Altitude from sea level is between 200 and 500 m. Topographical conditions are largely flat with modest slopes (0–30%) and small areas with steep slopes (>30%) (INTA, 1998).

The study area is considered to be a part of "the old agricultural frontier" where large immigration occurred in the late 1940s, and land was sought for extensive grazing to meet the demands of the international meat market (Maldidier and Marchetti, 1996). Due to the political pressures during the civil war in the 1980s, large cattle farms were abandoned and divided into small and medium-sized farms in order to make them available to landless farmers by the early 1990s (Levard et al., 2001).

2.2. Farm selection

This study was based on data from an independent survey and the project "Regional integrated silvopastoral approaches for ecosystem management project" undertaken by CATIE and NITLAPAN, under the scheme of Global Environment Facility (GEF) of the World Bank.

The sample farms were selected from two areas (Limas and Piwas) where cattle production is the main economic activity. According to the NITLAPAN database, there were approximately 190 farms in these areas and 130 farms were initially selected by the project at the beginning of 2003 based on the following criteria: (1) farm size (10–140 ha) (2) farms with more than 3 cattle (3) willingness to cooperate with the project and (4) accessibility. Farmers were provided with financial incentives to participate in the project. However, due to difficulties encountered when trying to meet farmers, collection of both land use and herd data was completed for only 74 farms by the end of 2003.

2.3. Land use survey

The satellite images of Quick Bird (Resolution 0.7 m with three natural colours) taken in January 2003 were used for the land analysis. Grazing lands were classified into nine types based on the types and conditions of dominant pastures (natural, cultivated or degraded), and tree densities (Table 1). Hereinafter the four types of land use types, natural and cultivated pastures with low and moderate tree densities are called silvopastoral areas.

A tree density of 30 trees/ha was used as a threshold to distinguish between areas of low and moderate tree density because a density of over 30 trees/ha is generally considered to affect grass cover (Murgueitio et al., 2003). In addition to the pasture in the grazing areas, supplementary forages for cut and carry [King grass (*Pennisetum purpureum* × *P. typhoides*), Taiwan (*P. purpureum*), and Sugar cane (*Saccharum officinarum*)] are sown in forage banks. Types and conditions of pastures and tree densities were verified in 2003 by field observations for all land uses on all the sample farms.

2.4. Herd survey

Data for herd size, changes in herd inventory (numbers of animals sold, bought, born, and died), and daily milk yields were seasonally collected using structured interviews. The interviews were conducted for 74 farms every 3 months

Table 1
Land use types of grazing areas and of specific pasture species

Land use types	Abbreviation[a]	Grass cover	Tree density
Degraded pasture	DGPS	<50%	N.A.
Natural pasture with few trees	FTNP	>50%	Nominal
Cultivated pasture with few trees	FTCP	>50%	Nominal
Natural pasture with low tree density	LTNP	>50%	<30 trees/ha
Cultivated pasture with low tree density	LTCP	>50%	<30 trees/ha
Natural pasture with moderate tree density	MTNP	>50%	>30 trees/ha
Cultivated pasture with moderate tree density	MTCP	>50%	>30 trees/ha
Fallow	FAL	None	N.A.
Riparian forests	FRST	None	N.A

N.A. Not available.

Cultivated pastures: *Panicum maximum*, *Brachiaria brizantha*, *Hyparrhenia rufa*, *Cynodon nlemfluensis*, and *Andropogon gayanus*. Natural pastures: all other pasture species including native and naturalised species.

[a] These abbreviations are used for variables of regression model (proportion of the land use types for grazing area).

for a 1-year period: the beginning of the dry season (between the end of January and the beginning of February), the end of the dry season (the end of April and the beginning of May), the beginning of the wet season (the end of July and the beginning of August), and the end of the wet season (the end of October and in the beginning of November) in 2003.

Herd sizes were estimated based on livestock units (LU) (one livestock unit is equivalent to 400 kg of liveweight). As weighing animals were not possible, 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), 0.5 for weaned calves, and 0.25 for calves before weaning. Herd sizes and compositions were calculated for four seasons with adjustment for cattle movement using the following equation:

$$\text{Annual mean herd size (LU)} = 1/4 \times \sum_{i=1}^{4} \mathit{Herd}\ (i = \text{Seasons},\ 1,2,3,4)$$

where $\text{Herd}_{1,2,3,4}$ (LU) = 3(months) × Actual number of cattle in the farm (LU); − Number of cattle removed (LU) × Removed period (month); + Number of cattle placed (LU) × Placed period (month).

2.5. Tree cover study

Tree cover was recorded for each land use type. Estimation of tree cover was carried out on images with 1:5000 scale by ARC VIEW 3.3 as follows:

(1) Forest areas where lands were totally covered by trees were manually drawn on the satellite image for each farm.
(2) Large dispersed trees or groups of trees as large as 56 m^2 were manually replaced by points based on visual estimation by placing the number of points in proportion to the size of the tree cover (one point for 56 m^2).
(3) The points (one 7.5 m^2 on the images, approximately 56 m^2) were converted into nine 2.5 m square pixels (2.5 m interval grid on 7.5 m^2) so that tree cover overlapping more than two land use types were counted for each land use type by dividing the tree cover by 2.5 m^2 pixels.

2.6. Model specification

2.6.1. Selection of variables

In dual-purpose cattle farms, milk, and live cattle (calves, cows, and steers) are the products. In the study area, 70% of the annual income coming from cattle production was produced by milk sales (Yamamoto, 2004). In the regression model, daily saleable milk production was used as the dependent variable. In order to adjust for differences in land areas between farms, the model was developed on a per hectare basis.

Milk production of a dual-purpose cattle farm is largely determined by (1) number of cattle (particularly lactating cows), (2) types of cattle (breeds, health condition, etc.), (3) feed, and (4) management. It is assumed that feed was adequately covered in the model by having land types as independent variables. Herd structure parameters were accounted for by including stocking rates (SRs, LU/ha) and the proportion of milking cows (MCOWs) as independent variables. In the study area, cattle on the dual-purpose farms were mainly crossbreeds of Brown Swiss and Brahman (mostly 50–70% Brown Swiss); therefore, breed was not included in the model. Regarding management, there was no difference between farms in terms of milk consumption by calves since almost all of the farms practiced a partial-suckling system. Other factors related to management (e.g., milking practices) were ignored since this type of data was not collected during the survey.

Grazing areas were defined as areas that farmers could use for cattle grazing throughout or for parts of the year. For the model, these were composed of pasture lands with different tree densities, fallow, and forest (riparian forest) (Table 1). The proportions of each land use type (i.e, the area of each land type relative to the total area used for grazing) were used as independent variables. In order to maintain independency of land use parameters, the proportion of riparian forests was excluded from the predictors (Table 2). Milk production per hectare per day was averaged across seasons and divided by the size of the grazing area. Stocking rates were estimated by dividing total herd size (LU basis) by the estimated grazing area (pasture lands, fallows, and riparian forests).

In the dual-purpose cattle farms in the study area, several types of supplementary feeds were used, but the amounts were limited except for supplemental pasture (mainly *Pennisetum* spp.) fed by means of cut and carry. Supplementary pastures were sown in forage banks which were outside the grazing areas. In addition, recently sown pasture, *Brachiaria brizantha*, was a feature of the farm. Therefore, the proportions of these two types of pastures for grazing areas were treated as independent variables.

2.6.2. Data analysis

Determining the significance of factors in multivariate regression analyses is often complicated by interactions between predictors. Important predictors can sometimes be eliminated at an early stage of stepwise elimination procedures. Similarly, procedures based on adding variables can lead to final models that do not include variables that are proven to be statistically important (Draper and Smith, 1980). In order to avoid this, two forms of stepwise regression analysis were performed: (1) backward elimination (remove variables one at a time) and (2) standard stepwise regression with forward entrance and backward elimination (add and remove variables) (MINITAB, 2000). The analyses were performed on an annual and seasonal basis. The analysis by season assumed that the proportions of each land type per farm did not change during the study period.

A threshold P value of 0.15 was used for both types of regression analysis. This was the default value in MINITAB and was chosen, rather than $P = 0.05$, in order to minimise the danger of eliminating important variables at an early stage in the stepwise procedure.

Collinearity between independent variables was analysed by cluster analysis with distance based on one minus absolute values of Pearson correlation coefficients. Values smaller than 0.55 are considered to have a collinearity problem (Johnson and Wichern, 1998). In this study, only DGPS and LTNP had a collinearity problem; however, they were not selected together in the final model.

Descriptive statistics of milk production and dependent variables, mean size of grazing areas, and land use parameters (proportions of each land use type) are presented in Table 3 and 4.

3. Results and discussion

3.1. The positive effects of land use parameters on saleable milk production

The regression analysis for saleable milk production with initial variables showed the positive effects of the four land use parameters (DGPS, $P < 0.001$, cultivated pasture with low tree density LTCP, $P < 0.05$, MTNP, $P = 0.005$, and MTCP, $P < 0.05$) (Table 5). Stronger positive effects by DGPS and MTNP were ascertained by smaller P values. The land use types with positive regression coefficients (DGPS, MTNP, MTCP) had moderate tree cover

Table 2
List of selected variables for regression analysis

Variable	Description	Unit
Dependent variable		
MLK_D_H[a]	Daily saleable milk production per hectare	litres/day/ha
Independent variables		
SR[a,b]	Stocking rate	LU/ha
MCOW[a]	Proportion of milking cows in relation to entire herd	
CCF[b,e]	Proportion of area of cut-and-carry forage in relation to total grazing area	
BB[b,d]	Proportion of area of *B. brizantha* in relation to total grazing area	
DGPS[c]	Proportion of area of degraded pasture in relation to total grazing area	
FTNP[c]	Proportion of area of natural pasture with few trees in relation to total grazing area	
FTCP[c]	Proportion of area of cultivated pasture with few trees in relation to total grazing area	
LTNP[c]	Proportion of area of natural pasture with low tree density in relation to total grazing area	
LTCP[c]	Proportion of area of cultivated pasture with low tree density in relation to total grazing area	
MTNP[c]	Proportion of area of natural pasture with moderate tree density in relation to total grazing area	
MTCP[c]	Proportion of area of cultivated pasture with moderate tree density in relation to total grazing area	
FAL[c]	Proportion of area of fallow in relation to total grazing area	

[a] The annual mean of four seasons were used for annual analysis and original data were used for seasonal analysis.
[b] Pasture parameters with recently sown species.
[c] Composition of grazing areas (the sum of these parameters and the proportion of riparian forests for each farm is equal to one).
[d] Included in grazing areas (within cultivated pastures).
[e] Outside of grazing areas. *Pennisetum purpureum* ×*P. typhoides*, *Pennisetum purpureum*, and Sugar Cane (*Saccharum officinarum*) are sown in forage bank.

Table 3
Description of dependent variables and cattle/pasture variables

Variable	Unit	Mean	Standard deviation
MLK_D_H[a]	litres/day/ha	1.382	0.731
MLK_D_H1-2[b]	litres/day/ha	1.334	0.918
MLK_D_H4-5[c]	litres/day/ha	1.198	0.910
MLK_D_H7-8[d]	litres/day/ha	1.647	1.078
MLK_D_H10-11[e]	litres/day/ha	1.350	1.002
SR[a]	LU/ha	0.916	0.337
SR1-2[b]	LU/ha	0.949	0.480
SR4-5[c]	LU/ha	0.903	0.463
SR7-8[d]	LU/ha	0.873	0.376
SR10-11[e]	LU/ha	0.927	0.422
MCOW[a]		0.426	0.144
MCOW1-2[b]		0.391	0.199
MCOW4-5[c]		0.434	0.211
MCOW7-8[d]		0.476	0.220
MCOW10-11[e]		0.401	0.228
CCF		0.0362	0.0451
BB		0.0202	0.0496

$n = 74$.
[a] Annual mean values based on data from four seasons.
[b–e] Mean values based on data in Jan–Feb, Apr–May, Jul–Aug, and Oct–Nov, respectively.

Table 5
Results of regression analysis for saleable milk production with initial variables

Predictor	Coefficient	SE coefficient	T	P
Constant	−2.2989***	0.5047	−4.54	<0.001
SR	1.5475***	0.1603	9.65	<0.001
MCOW	2.5046***	0.3467	7.22	<0.001
CCF	0.765	1.204	0.64	0.527
BB	2.274*	1.038	2.19	0.032
DGPS	1.6018*	0.6051	2.65	0.010
FTNP	1.598	1.345	1.19	0.239
FTCP	1.887	1.629	1.16	0.251
LTNP	0.4271	0.6778	0.63	0.531
LTCP	1.4804*	0.6868	2.16	0.035
MTNP	1.4665*	0.5775	2.54	0.014
MTCP	1.4394*	0.6663	2.16	0.035
FAL	1.0555	0.5492	1.92	0.059

$R^2 = 75.9\%$.
SE: Standard error.
T: T Value.
* $P < 0.05$.
*** $P < 0.001$.

(19–25%), except for LTCP (12.5%) (Table 4). Tree cover can provide positive effects on grass production due to leaf drop better nutrition cycling higher soil organic matter improved physical soil structure and nitrogen fixing (Young, 1997; Wilson and Wild, 1991).

Seasonal analysis by backward elimination suggested that land use types with moderate tree cover tended to have positive effects on milk production at the end of the dry season (Table 7). This suggests that these land use types supported milk production through tree cover (approximately 20%), providing fruits and leaves from trees and/or contributing to maintaining pasture production particularly at the end of the dry season.

Seasonal analysis provided evidence that DGPS had positive effects on saleable milk production at the end of the dry season ($P < 0.01$) (Table 7). This suggests that broadleaf plants which were generally considered to be unpalatable and not consumed by cattle during the wet season, remaining in DGPS, supported saleable milk production at the end of the dry season. Some broadleaf plants are considered to be important forage in the dry season with higher selectivity due to the shortage of grass (Bayer and Waters-Bayer, 1998; Nyaata et al., 2000). In contrast, positive effects on saleable milk production of MTNP were observed at the beginning of the wet season ($P < 0.05$) (Table 7), suggesting that natural pastures grow during this period and support saleable milk production. Moreover, both LTCP and MTCP had positive effects on annual milk production (Table 5), but the effects of MTCP were found at the end of the dry season while those of LTCP seemed to be spread out throughout the year (Table 7). It may suggest increased grass production by shade in the dry season (Wilson and Ludlow, 1991) and fruit production by common tree species found in grazing areas, (e.g., *G. ulmifolia*, *E. cyclocarpum*, and *Albizia saman*) supported milk production in particular in the dry season (Esquivel, 2004).

Table 4
Size, proportion, and tree cover of land use types for grazing lands

Land use types	Proportion		Size		Tree cover (%)
	Mean	SD	Mean (ha)	SD (ha)	
DGPS	0.276	0.274	6.86	1.15	18.8
FTNP	0.019	0.0467	0.50	0.17	7.0
FTCP	0.008	0.0315	0.20	0.09	4.6
LTNP	0.134	0.160	2.21	0.36	12.1
LTCP	0.076	0.138	1.50	0.33	12.5
MTNP	0.183	0.210	3.66	0.57	24.8
MTCP	0.075	0.137	1.47	0.40	19.6
FAL	0.077	0.160	1.36	0.28	42.6
FRST	0.152	0.094	3.59	0.54	84.3
Total	1.000		21.36	1.97	23.3

Source: Data based on Quick bird satellite images, January 2003, $n = 74$.
SD: Standard deviation.

3.2. The negative effects of land use parameters on saleable milk production

According to the stepwise regression analysis by forward and backward procedure, LTNP had a negative effect on saleable milk production ($P < 0.01$; Table 6). In addition, seasonal analysis showed that LTNP had negative coefficients at the end of the dry season and the beginning of the wet season ($P < 0.05$; Table 8). It may suggest that the land use type does not have sufficient pasture to support saleable milk production at the end of the dry season and that the areas were conserved for pasture recuperation at the beginning of the wet season. It should be noted that the correlation between the annual mean SR and LTNP was positive and that the correlation between the size of grazing area and LTNP was negative (Yamamoto, 2004).

These findings suggest that LTNP was overgrazed and is likely to be found in smaller farms, resulting in negative effects on saleable milk production due to lack of biomass at the end of the dry season.

It should be noted that at the beginning of the wet season, MTNP had a positive coefficient ($P < 0.05$; Table 7). This suggests that MTNP had stronger pasture growth under better soil conditions supported by tree cover, and thus did not require pasture recuperation, while LTNP needed pasture recuperation due to pasture degradation caused by overgrazing. It is not entirely clear whether the difference between these two land use types were caused by higher tree cover of MTNP or overgrazing on LTNP because both tree cover and SRs historically formed two land use types over time. The results of the regression analysis suggest that in addition to the effects of actual stocking rates (one of the predictors), the land use types with moderate tree cover contributed to milk production but the land use type with low tree density did not.

3.3. The effects of introduced pasture species on saleable milk production

The regression coefficient of *B. brizantha* was at its largest at the end of the dry season ($P < 0.01$; Table 7). The results suggest that this species is an important forage source particularly at the end of the dry season due its drought tolerance (Peters et al., 2003).

Cut-and-carry forage is provided to cattle in the dry season, but positive coefficients were not observed in the regression analysis. This is probably because the cut-and-carry forage was over-mature and mainly used in limited amounts from February to May. In addition, the proportion of cut-and-carry forage was correlated with SR (Yamamoto, 2004). Hence the results suggest that cut-and-carry forage was primarily used for maintenance of cattle at farms with high SRs rather than contributing to milk production. The positive coefficients of the proportion of cut-and-carry forage (*Pennisetum* spp.) at the end of the wet season are noteworthy (Tables 7 and 8). It seems that supplementary forage was cut and used as cattle fodder at the end of the wet season in order to make it available in the dry season (60 days after cutting – Peters et al., 2003), simultaneously keeping other pasture for grazing in the dry season.

Table 6
Results of stepwise regression analysis for saleable milk production by forward and backward procedures

Predictor	Coefficient	SE coefficient	T	P
Constant	−1.0588***	0.1913	−5.54	<0.001
SR	1.5654***	0.1463	10.70	<0.001
MCOW	2.6054***	0.3226	8.08	<0.001
BB	1.7029	0.9536	1.79	0.079
LTNP	−1.0142**	0.3142	−3.23	0.002

$R^2 = 72.7\%$.
SE: Standard error.
T: T Value.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

Table 7
Regression coefficients of predictors by season (backward elimination)

/Season	Dry		Wet	
Predictor/Month	Jan–Feb	Apr–May	Jul–Aug	Oct–Nov
Constant	−0.7582	−1.145	−1.811	−1.223
SR	1.03***	1.11***	1.67***	1.35***
MCOW	2.36***	1.37**	3.23***	2.74***
CCF	N.S.	N.S.	N.S.	2.5
B.brizantha	N.S.	4.9**	N.S.	N.S.
DGPS	0.43	1.16**	0.57	0.48
FTNP	N.S.	N.S.	N.S.	N.S.
FTCP	N.S.	1.06	N.S.	N.S.
LTNP	N.S.	N.S.	N.S.	N.S.
LTCP	0.99	N.S.	0.88	N.S.
MTNP	N.S.	0.89	1.00*	N.S.
MTCP	N.S.	1.11	N.S.	N.S.
FAL	N.S.	N.S.	0.77	N.S.
R^2	54.68	41.90	72.67	70.24

N.S. Not significant: variables not retained after stepwise procedure.
SR and MCOW are values for each season.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

3.4. Impacts of cattle parameters on saleable milk production

The results show that there were no statistically significant differences in SR and proportion of milking cow (MCOW) by season ($P < 0.05$) (Table 3). Larger numbers of milking cows in the dry season are expected due to higher calving rates (Yamamoto, 2004). However, MCOW were maintained by milking cows brought from neighbouring farms in the wet season and steers introduced in the dry season. The number of steers in the fattening stages at the beginning of dry season was greater than at the end of dry season and the end of wet season ($P < 0.05$).

In the regression model, SR and MCOW were demonstrated to be important variables affecting saleable milk production (R^2 of 68%, 90% of that of final model) (Table 5). However, at the end of the dry season, R^2 for cattle variables was much smaller (33.6%) (Table 7). In addition, saleable milk production per hectare at the end of dry season was significantly lower than the beginning of the wet season ($P < 0.01$, Table 3), suggesting that the impact of cattle parameters on milk production between the seasons were smaller than shown by the difference of R^2. The results suggest that these variables did not contribute to milk production at the end of the dry season as much as they did in the wet season due to the shortage of fodder to sustain the same levels of SR and MCOW. Saleable milk production per cow was significantly lower at the end of the dry season than other seasons ($P < 0.01$), supporting the evidence that supplemental fodder was not utilized sufficiently to maintain the milk yields.

Table 8
Regression coefficients of predictors by season (forward and backward procedures)

/Season	Dry		Wet	
Predictor/Month	Jan–Feb	Apr–May	Jul–Aug	Oct–Nov
Constant	−0.4968	−0.3145	−1.388	−1.223
SR	1.12***	1.10***	1.73***	1.35***
MCOW	2.29***	1.34**	3.28***	2.74***
CCF	N.S.	N.S.	N.S.	2.5
B. brizantha	N.S.	5.1**	N.S.	N.S.
DGPS	N.S.	N.S.	N.S.	0.48
FTNP	N.S.	N.S.	N.S.	N.S.
FTCP	N.S.	N.S.	N.S.	N.S.
LTNP	−0.93	−1.26*	−0.99*	N.S.
LTCP	N.S.	N.S.	N.S.	N.S.
MTNP	N.S.	N.S.	0.53	N.S.
MTCP	N.S.	N.S.	N.S.	N.S.
FAL	N.S.	N.S.	N.S.	N.S.
R^2	54.19	43.44	72.67	70.24

N.S. Not significant: variables not retained or selected after stepwise procedure.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$.

3.5. Impacts of change of milk and meat prices on the composition of land use types

Milk prices at the time of the survey did not encourage supplementary feeding to increase milk yield in the dry season. However, with higher milk price, farmers may invest in cut-and-carry forage in order to increase milk production. On the other hand, with higher beef price, LTCP would be increased since the proportion of steers in the herds was positively correlated with LTCP (Yamamoto, 2004).

Degraded pasture and MTNP are more likely to be replaced for CCF and LTCP since they cover considerable parts of the farms (27.6% and 18.3%, respectively, Table 4). In fact the expansion of CCF, particularly for smaller farms, would be limited due to labour constraints; however, a land use change to increase LTCP for steer rearing, encouraged by higher meat price, is likely to be a stronger option for larger farms that have greater financial resources. It should be noted that land use changes to encourage either higher meat or milk price reduces tree cover. The results suggest that with higher meat price faster loss of tree cover is expected.

3.6. Farm selection and applicability of study results

Sample farms were partly selected by their accessibility which results in sample comprised of farms where milk production is facilitated by milk collection throughout the year. Thus, sample farms are particularly encouraged to produce milk which provides daily cash income. In dual-purpose cattle production systems in the study area, tree cover is particularly needed for shelter for crossbred cattle given the hot climate and reliance in the dry season on fodders from fruits. Farmers mentioned that there were few trees in the farm when they immigrated to the area (Yamamoto, personal communication), suggesting that tree cover in the study areas had increased by introducing dual-purpose cattle production systems. It should be noted that 46% of the basal areas of trees in the grazing areas comprised three species which produce fruits for dry season fodder (Yamamoto, 2004), suggesting farmers' control over the dispersal of trees in the grazing areas (Harvey and Haber, 1999).

Farmers obtained lands which were formerly owned by large meat farms and immigrated to the study area at the beginning of the 1990s (Levard et al., 2001). Farmers are engaged in dual-purpose cattle production in small and medium-sized farmlands with limited equipment, using family labours as the major labour source. Supplementary fodder potentially supports milk production. However, in the study area milk price is maintained rather low due to the remote location away from a large town and the control by middle-men, resulting in low stocking rates which do not allow farms to invest on supplementary fodder.

The results suggest that local-based silvopastoral systems for dual-purpose cattle production developed over time by farmer management based on natural and socio-economic conditions that include: high temperature in lowland tropical climate, semi-humid condition with 4–5 month dry season, sufficient annual precipitation, the length of the dry season, the relatively low stocking rates, no significant reduction of stocking rates during the dry season, commercial milk sales by milk collector throughout a year, and relatively low milk price.

4. Conclusions

This study examined the effects of land use patterns on cattle production on dual-purpose cattle farms in central Nicaragua. Regression analysis demonstrated significant positive effects on saleable milk production of areas of MTNP and MTCP, DGPs, LTCP, and negative effects by LTNP.

The area of *B. brizantha* also made a significant contribution to saleable milk production at the end of the dry season, suggesting that this pasture species is important in this season. Although stocking rates and the proportion of milking cows were important variables for saleable milk production through the year, their importance was smaller at the end the dry season.

The results suggest that silvopastoral areas, especially pasturelands with moderate tree density (tree cover approximately 20%) have significant positive impacts on annual milk production and that the land use change from LTNP to MTCP using *B. brizantha* is the most productive land use change. However, the smaller farms with higher stocking rates, and higher proportion of LTNP were overgrazed and therefore had lowered pasture production, thus having negative effects on saleable milk production at the end of the dry season. If further degradation proceeds, such farms may have to be sold, and farmers would have to move further east into the current agricultural frontier where land is available at a lower price. Such movement would probably cause further deforestation in the Atlantic side of Nicaragua. Further studies are recommended on botanical composition of broadleaf plants in the grazing areas and their nutritional values in the dry season, the feasibility of increasing the availability of supplemental fodder for milk production in the dry season, and the impact of land use types on seasonal grazing decisions.

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