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REVIEW

The potential of silvopastoral systems for cattle production in Cuba

Tania Sánchez-Santana, Onel López-Vigoa, Jesús Manuel Iglesias-Gómez, Luis Lamela-López and Mildrey Soca-Perez

This paper presents a review of relevant literature and research on the potential of silvopastoral systems for milk and meat production in Cuba. This work emphasizes the contribution of trees in pasture systems, which are known to improve the plant community as well as increase the productive efficiency of steers, reproductive females and dairy cattle. Results from this research suggest that, due to the association effect, both the availability of dry matter and the total protein content of gramineous plants is increased in pastoral systems that incorporate trees while also maintaining pasture. In systems of gramineous plants that have been mixed with *Leucaena leucocephala* and that support cows of average potential, it is possible to obtain milk production of 10 kg/cow/day in addition to live-weight gains of 0.500–0.600 kg/animal day^{-1} in Cebú cattle. This work concludes that the use of silvopastoral systems is a viable option for the production of milk and meat under low-input conditions, such as those in Cuba. *Please refer to Supplementary Materials*, DOI: https://doi.org/10.1525/elementa.334.s1, *for a full text Spanish version of this article.*

Keywords: Silvopastoral systems; Cattle and milk production; Cuban agroecology

El objetivo del trabajo fue evaluar las potencialidades de los sistemas silvopastoriles para la producción leche y carne en Cuba a través de la reseña grupo de investigaciones realizadas en el país sobre el tema. Se hizo énfasis en la contribución de los árboles al mejoramiento de la composición de la comunidad vegetal; así como el incremento de la eficiencia productiva en toros de ceba, hembras en desarrollo y vacas lecheras. Los resultados sugieren que en los sistemas con árboles se incrementa la disponibilidad de la materia seca y el contenido de proteína bruta de la gramínea por el efecto de la asociación. Además, se logra mantener la persistencia del pastizal. En sistemas de gramíneas mejoradas con *Leucaena leucocephala* y vacas de mediano potencial es posible lograr una producción de leche de 10 kg/vaca/día; mientras que, en la ceba se puede obtener ganancias en peso vivo de 0,500–0,600 kg animal día^{-1} en ganado Cebú. Se concluye que el empleo de sistemas silvopastoriles constituye una opción viable para producir leche y carne con bajos insumos en las condiciones de Cuba. *La versión en español de este articulo se puede encontrar en Materiales Suplementarias*, DOI: https://doi.org/10.1525/elementa.334.s1.

Palabras Claves: Sistemas agrosilvopastoriles; Producción de carne y leche; Agroecología cubano

Introduction

In the past, Cuba's national economy consisted of two main activities: cattle production and the sugarcane agroindustry. Presently, although the contribution of cattle production at the national level has diminished, it still represents an important economic activity and legacy due to the value of its assets and its repercussions on food security for the Cuban population (Nova, 2014). Cuba has approximately 4 million heads of cattle. Of these, 64.6% are females, and 103.6 thousand are from breeds with enhanced genetic value, of which the state sector possesses the majority. Recently, there has been a noteworthy increase in heads of cattle in the cooperative sector (ONEI, 2015). Cooperatives make a large contribution to food production at a national level, generating 72.7% of the country's total milk production (MINAG, 2015). The greatest participation in cooperatives is from small-scale *campesino* farming families organized into Credit and Services Cooperatives (CCS is the Spanish acronym) or working in

Indio Hatuey Pastures and Forage Experimental Station (IHPFES). University of Matanzas, Central España Republicana, Matanzas, CU

Corresponding author: Tania Sánchez-Santana (tania@ihatuey.cu)

the private sector, with those two groups accounting for 68% of national milk production (Nova, 2016).

In livestock areas, a number of environmental problems such as soil degradation, deforestation, ground water pollution and the loss of biological diversity threaten the long-term sustainability of these systems, regardless of who owns the land (Alonso, 2011; CITMA, 2012). Not only does this make them unsustainable, it also leaves them vulnerable, especially to large-scale climatic change. The causes for degradation of livestock environments are multiple. The most common include deforestation, gramineous plant monocultures, consistent decreases in plant biodiversity, inadequate pasture management, inappropriate water use, and a lack of awareness of sustainable agriculture practices among producers (Milera, 2011; Milera, 2013). The present challenge is to transform the traditional model of cattle production used and to establish more sustainable production systems.

Silvopastoral systems (SPSs) are part of this transformation; they represent an alternative model for achieving the restoration, maintenance and sustainability of natural resources in livestock areas. These systems offer socioeconomic and ecological benefits, as evidenced by a number of scientific studies, as well as the successful experiences of cattle farmers (Ibrahim *et al.*, 2006). SPSs are agricultural ecosystems in which a tree and a grass component (either natural or improved pastures) are associated with a livestock component at the same site. These associations increase biological interactions between the components with the objective of maximizing the use of the land. In other words, these systems temporally and spatially combine the maintenance of natural or cultivated pastures, tree growth, and cattle-rearing activities (Russo, 2015).

Various multidisciplinary studies on tree species in silvopastoral systems have shown the favorable influence of these systems on both milk and meat production, as well as in the productive efficiency of developing animals. These silvopastoral systems thus achieve very good productive and health results through the integration and stability of the soil-plant-animal associations. Integrated studies on the environmental impacts of silvopastoral systems have also been conducted, and have provided insights into, for example, the impacts of shade on the production and quality of pasture, positive nutrient recycling, soil biology, insect equilibrium, and pruning as a management technique (Murgueitio *et al.*, 2008; Murgueitio *et al.*, 2015).

Silvopastoral systems (SPSs) offer an option to produce food without using chemical fertilizers. They are also a way of preserving the environment since they contribute to the maintenance of tree cover on cattle-producing lands and trees provide a number of ecosystem services and benefits. Ecologically, SPSs also function as carbon sinks, provide habitat for different organisms, and serve as biological corridors creating connectivity between more stable ecosystems (Ibrahim and Mora, 2006; Harvey, 2006). Furthermore, Rois *et al.* (2006) argue that SPSs have three dimensions of benefits – economic, environmental and social – because they favor rural development, protect the environment, and help maintain biodiversity.

The presence of legumes is necessary for sustainable milk and meat production systems in which pasture is the main food source. Not only do legumes improve the nutritional value of animal diets, but they also establish symbiotic relationships with nitrogen-fixing soil microorganisms, thereby allowing plants to have better nitrogen uptake. This characteristic not only benefits legumes, but also gramineous and other plant families that grow next to them (Sierra and Nygren, 2006; Jalonen *et al.*, 2009). Such characteristics represent some of the main reasons why incorporating legumes in SPSs is essential for cattle production in Cuba, a place where the lack of imported inputs has resulted in the increased use of legumes as valid substitutes for nitrogen fertilizers.

The carrying capacity of SPSs can range from 1.0 to 1.7 Units of Large Cattle (ULC) per hectare, depending on: a) the type and fertility of the soil; b) the species of plant grown in the pasture; c) the species and density of the trees; d) the management of the system, and e) the productive potential of the animals. Optimal non-grazing periods for the pasture to rest range from 25–40 days in the rainy period (RP) to roughly 50–70 days in the less rainy period (LRP) (Simón, 2011). In the past 20 years, questions about silvopastoral systems have attracted the attention of Cuban scientists, and a number of studies on the topic have been carried out. This article provides a general review of these studies and highlights the most valuable results of the research on Cuban SPSs to date. It also evaluates the future potential of SPSs for bovine production in Cuba.

Review of the methodologies used in SPSs research

The results presented in this article summarize more than 20 research projects conducted between 1991 and 2016 by the Indio Hatuey Pastures and Fodder Experimental Station (IHPFES) at Matanzas University. These projects were conducted on the Station's productive areas or on farms in the province of Matanzas, and they are compared with results obtained by other scientific institutions elsewhere in Cuba. The following is a summary of the characteristics of the sites where research was carried out as well as a summary of the methodologies used in each study.

Indio Hatuey Pastures and Fodder Experimental Station. IHPFES is in Perico Municipality, in the province of Matanzas, Cuba, located between 22° 48′ 7″ North latitude and 81° 2′ West latitude; it is 19.01 meters above sea level. The soil at the experimental station is classified as red ferralitic (Hernández *et al.*, 2006) and has relatively flat relief. The climate is warm tropical (Climate Center, Meteorology Institute, 2013) with an annual mean temperature and relative humidity of 24.4°C and 82.6%, respectively. The average annual rainfall is 1300 mm.

The Matanzas Genetic Company. This study was conducted using a dairy operation on the Triunvirato farm which belongs to the Matanzas Genetic Company, located at 23° North latitude and at 80° 30′ West longitude; it is 70 m above sea level. It located adjacent to the municipality of Matanzas in Matanzas province. The annual mean temperature is 23°C, with a mean of 21°C in winter and 27°C in summer. The annual mean rainfall is 1300 mm, with a variation average of 1000–1200 mm in the RP

and of 200–400 mm in the LRP. The soil type on which the experiment was carried out is classified as brown with carbonates (Cambisol), and there is slightly hilly relief.

Victoria de Giron Citrus Enterprise. The study was carried out at the El Rancho dairy of the Victoria de Girón Citrus enterprise, located in the town of Agramonte in the municipality of Jagüey Grande in Matanzas province, Cuba (at 81° 6′ North latitude and 22° 40′ West longitude). The soil is classified as lixiviated red ferralitic (Hernández *et al.*, 2006), on flat ground relief. The agricultural area of the farm is 65 ha, of which 2 ha were planted with an association of *Cenchrus purpureus* CT-115 and the arboreal plants *Morus alba* and *Leucaena leucocephala.* For the study, irrigation was applied every 15 days during the LRP. The remainder of the area (63 ha) was left with natural pasture in rain-fed conditions. Planting of the experimental SPS plot started in June 2006. *M. alba* was planted at a depth of 8–10 cm and with 30 cm between each plant. The distance between double rows of *Leucaena leucocephala* and *Morus alba* was 1 m, and 1.2 m within the rows of *Leucaena leucocephala*. *Cenchrus purpureus* cv. CT-115 was planted in series of 5 rows at a width of 4 m, at 70 cm spacing between each row and at a depth of 15 cm.

Pasture measurements

Grazing availability in Leucaena leucocephala. To estimate the grazing availability of *Leucaena leucocephala,* edible leaves and tender stems (up to 3 mm diameter) were collected by hand from 10 of the trees established in the quarter section, simulating the grazing done by animals up to a height of 2 m (Lamela, 1998, quoted by Sánchez-Santana, 2007).

Pasture availability. Pasture availability was estimated using an alternative method proposed by Martinez *et al.* (1990), in which samples were taken when animals entered and left each quarter section, with 80 observations made per hectare.

Proximate chemical analysis. A homogeneous sample of 300g of *L. leucocephala* as well as 300g of pasture, collected according to the methodology proposed by Herrera (2006), was sent to the laboratory for analysis. The indicators measured in this analysis were: dry matter (DM), ashes, gross protein (GP) and calcium, according to the techniques described by the Association of Official Analytical Chemists (1995).

Floristic composition of pasture. The floristic composition of the pasture was estimated using the step method described by Anon (1980), which consists of walking along the diagonals of each quarter section. Every three steps, the observer classified the species of pasture that he/she met with the tip of his/her shoe. This measurement was taken twice a year (in June and December) in all of the quarter sections that make up the experimental unit.

Livestock measurements

Bodily condition. The bodily condition (BC) of animals was monitored weekly on a scale from 1 to 5 points, according to the methodology described by Alvarez (1997).

Milk production and quality. Milk production was monitored by individually weighing all the cows included in the experiment to determine total milk production. Additionally, milk quality was evaluated by means of the FIL-141: B, 1997 infrared method, using a MilkoScan 104 A/S Foss Electric device, in order to determine the fat, protein, lactose, total solids and non-fat solids percentage of the milk.

Beneficial effects of SPSs on the plant community

The most commonly utilized SPSs in Cuba are either protein banks, associations of trees with gramineous plants in the entire pasture area, or living fences (Sánchez-Santana *et al.*, 2011). Protein banks consist of arboreal and herbaceous legumes in 20–30% of the pasture area, which limits the benefits brought about by these plants to only the area they take up, while with other types of associations, the whole pasture area benefits (Simon, 2012). For that reason, associations of trees with improved pastures are the most widespread SPSs in the country. They represent a promising alternative for animal production in Cuba, since they contribute to improving the biological quality of soils, increasing the nutritional value of pastures, increasing meat and milk production, as well as favoring agricultural health and the protection of the environment.

The tree species used most commonly in these systems are *Leucaena leucocephala*, *Gliricidia sepium* (Jacq.) Kunth, *Albizia lebbeck* (L.) Benth. (Milera *et al.*, 2014), together with *Bauhinia purpurea* L. *Megathyrsus maximus* (Jacq.) B. K. Simon & S. W. L. Jacobs and *Cynodon nlemfuensis* Vanderyst are the most common pasture species used in SPSs due to their capacity to be associated with these tree species. Other pasture species, such as *Cenchrus ciliaris* L. and *Cenchrus purpureus* (Schumach) Morrone CT-115 may also be found (López *et al.*, 2015a).

The floristic composition of pasture, the availability of dry matter and the nutritive value of the plant community are indispensable elements in evaluating a silvopastoral system for raising developing female cattle, as well as for milk and meat production. These elements play a fundamental role by providing available food for animals. The interactions established among soil, plants and animals in SPSs have a positive influence on the components that make up the plant community of the system. The magnitude of this effect depends on the species present, the characteristics of the soil, and the conditions of the climate where the system is located.

Sanchez-Santana (2007) characterized the plant community of an association of improved gramineous plants and *Leucaena leucocephala* cv. Cunningham as having carrying capacities of 1.5–1.8 ULC/ha. During a five-year evaluation period, they found that the presence of improved pasture was above 50%, demonstrating the feasibility of tree-pasture association for ensuring the persistence of pasture. Improved gramineous plants were represented by *Megathyrsus maximus* cv. Likoni and *Cynodon nlemfuensis* cv. Jamaicano, with predominance of *Cynodon nlemfuensis* in the first three years. However, *Megathyrsus maximus* increased its percentage in the floristic composition to match that of *Cynodon nlemfuensis* in the fifth year of the evaluation (Sánchez-Santana, 2007). It is necessary to point out that *Megathyrsus maximus* shows significantly more tolerance in the areas shaded by trees.

Hernández *et al.* (1998) estimated the total dry matter availability of a multi-association with the following species: *Leucaena leucocephala* cv. Cunningham, *Stylosantes guianensis* cv. CIAT-184, *Neonotonia wightii* cv. Tinaroo, *Teramnus. labialis* cv. Semilla Clara, *Centrosema pubescens* cv. SIH-129 and *Megathyrsus maximus* (a mixture of cvs. Likoni and SIH-127). They obtained an edible biomass yield of 7131.9 and 4594.8 kg of DM ha rotation^{-1} for the RP and LRP respectively, without using fertilization. In an association consisting of a mixture of improved and natural gramineous plants with *Leucaena leucocephala* cv. Cunnigham, a dry matter availability of 5.0 and 3.6 t of DM ha rotation^{-1} for gramineous plants and 0.6 and 1.1 t of DM ha rotation^{-1} for legumes was obtained in the RP and LRP respectively, without using chemical fertilizers and while reaching a carrying capacity of 0.9 ULC/ha (Iglesias, 2003). In turn, Sánchez-Santana (2007), characterizing the availability of dry matter in an association of *Megathyrsus maximus* cv. Likoni and *Leucaena leucocephala* cv. Cunningham under production conditions of 1.5–1.8 ULC/ha, obtained total availability values higher than 3 t of dry matter per hectare during the five years of this study. These results show the importance of associations of improved gramineous plants with *Leucaena leucocephala* in order to reach stability in the total yields of edible biomass. Nevertheless, it must be pointed out that pruning is a necessary management practice in order to ensure stable availability of *Leucaena leucocephala* over time.

Seasonal variation of the total availability of gramineous plants (2.7 and 3.4 t of DM ha rotation^{-1} for the RP and LRP, respectively) was also detected in the evaluation. However, the imbalance in the production of food between the RP (70%) and the LRP (30%) that characterizes treeless systems is still minimized (Sánchez-Santana, 2007). The results from the measurements of the dry matter availability of gramineous plants in systems associated with trees demonstrate that yields higher than 3 t of DM ha rotation^{-1} can be obtained. Even higher values may be reached depending on the species present, the density of trees, and the conditions of management. In all cases, however, the silvopastoral systems in the study have higher dry matter availability than those obtained in gramineous plant systems without trees (Hernández, 2000; Hernández *et al.*, 2001; Iglesias, 2003). When Hernández *et al.* (2001) evaluated four different systems (gramineous plant monoculture, and each of *Albizia lebbeck*, *Bauhinia purpurea* and *Leucaena leucocephala* associated with *Megathyrsus maximus* cv. Likoni), they found that gross protein (GP) percentages were higher in the systems with trees. Similar results were noted for the species *Megathyrsus maximus*, *Cynodon nlemfuensis* and *Paspalum notatum*, which presented an increase of between one and three percentage units in GP content when *Leucaena leucocephala* or another legume tree formed part of the plant community in the quarter section or plot (Hernández *et al.*, 1987; Guevara *et al.*, 1996).

The increase of GP content in pasture is a consequence of the presence of leguminous trees, which have the capability of fixing atmospheric nitrogen in the soil by symbiosis with rhizobia. In turn, N is used by the gramineous plants in the system according to reports by Sierra and Nygren (2006), who studied nitrogen fixation by leguminous trees in silvopastoral systems. Results suggest a direct transfer of the nitrogen in trees to gramineous plants through the roots. For this reason, it is important to include improved pasture in SPSs in order to achieve a higher quantity and quality of animal diet in terms of DM and GP, particularly when feeding cows of average to high milk producing potential. The increase of nitrogenous substances in gramineous plants in systems where arboreal species are present may also be a result of the plants adapting to reduced light caused by trees casting shade, which can have an influence on plant physiology (Pentón, 2000).

An important advantage of SPSs when compared to gramineous plant monocultures is that they minimize the imbalance in food production that characterizes treeless systems (Sánchez-Santana *et al.*, 2011). An example of this is found in the study carried out by Swaby *et al.* (2013), who found a total availability of biomass of 25.3 t of DM ha year^{-1} (of which 38% was produced in the LRP) in a silvopastoral system integrated with a multi-association of *Megathysus maximus* Tobiatá-Mombaza and the arboreal plants *Leucaena leucocephala*, *Bauhinia variegata* and *Albizia lebbeck.* In terms of soil life, the edaphic macrofauna shows a larger number of microorganisms with predominance of earthworms in the SPSs (specifically *Leucaena Leucocephala* + *Megathyrsus maximus*) than in pastures with only improved gramineous plants. The diversity and uniformity indexes are also higher, indicating that the presence of trees improves the biological activity of the soil and ensures the stability of the system over time (Sánchez-Cárdenas *et al.*, 2011).

With regard to plant protection, SPSs, (specifically of *Leucaena leucocephala-Megathyrsus maximus)* provide a number of adequate shelters and habitats as well as a microclimate favorable to the development of beneficial and entomopathogenic insects. This permits the establishment of complex interactions that imply a larger balance between phytophagous and bioregulator insects, favoring the latter, as well as other beneficial insects like pollinators, coprophagous insects and decomposers of organic matter that are responsible for maintaining the biological stability of these systems at the pasture level (Alonso *et al.*, 2011a). The ways in which SPSs favor beneficial insect populations partially explains why, in those systems, populations of harmful organisms do not express the full magnitude of harm that they can potentially cause to crops of *Leucaena leucocephala* in the country, as has happened with *Heteropsylla cubana* Crawford. Because of this, we suggest there is value in the association *Leucaena leucocephala-Megathyrsus maximus* when soil conditions and farm type allow it, since with the counterbalancing obtained in regard to the entomofauna present, it would be possible to ensure that these plantations endure over time (Alonso *et al.*, 2011b).

Developing females in systems associating gramineous plants with trees

At present in Cuba, female Holstein heifers and their crosses are incorporated into production at between 270 and 280 kg of live weight (LW). Typically, this weight is

not reached until 27–28 months (and sometimes up to three years), which is later than desired, and also later than the usual 19–20 months that normally fed heifers generally take to reach that weight. This is due to the large food shortage experienced by cattle, mainly in the LRP, together with poor animal management in the early stages of developing females.

With regard to the use of legumes to feed replacement females, Simón *et al.* (1993) obtained gains of 0.477 y 0.431 kg/animal/day^{-1} in a silvopastoral association of *Leucaena leucocephala* with common *Megathyrsus maximus* fertilized with 150 kg of N ha year^{-1}. No differences were observed in individual gains between systems. On account of these results, the determination of the productive possibilities of the system "association in the whole pasture area" (Iglesias *et al.*, 2003, 2009) was proposed in order to raise females of genotypes characteristic of Cuban commercial dairy herds. The use of inputs in this research was minimal, since pastures were not fertilized or irrigated, and animals did not receive any supplementary food during the less rainy period. The high availability of pasture, in addition to the contribution of creeper legumes and *Leucaena leucocephala* via grazing and pruning, allowed female calves to satisfy their nutritional requirements and obtain the gains expected for this category (**Table 1**).

Type F_1 hybrid animals obtained weight gains greater than 0.500 kg daily, both in the less rainy and rainy periods, with an accumulated gain of more than 0.520 kg at the end of the livestock farming cycle, which differed significantly ($p < 0.01$) from the gains reached by the Siboney genotype females. There were also significant differences ($p < 0.05$) in favor of the Type F_1 animals in regards to the final weight reached for the mating season (294.9 vs 280.8 kg), although these were slightly less heavy at the beginning of grazing. The incorporation age was similar in both groups of animals, with values close to 23 months.

For their part, Lopez *et al.* (2010) evaluated the productive behavior of developing females of F_1 genotypes (Holstein × Cebú) and native hybrids under production conditions in systems having an association of gramineous plants with *Leucaena leucocephala.* F_1 animals were incorporated for reproduction with weights of 308.8 kg at 28.6 months of age, while native hybrids were incorporated with weights of 336.8 kg at 26.9 months of age. The live weight gain was from medium to low and was similar in both genotypes (0.361 and 0.383 kg animal day^{-1}, respectively). According to these results, both genotypes had similar behavior with respect to the indicators analyzed for these production conditions.

In the eastern part of the country (the Cauto Valley), Vega-Albi *et al.* (2014) evaluated different grazing systems with *Charolaise* heifers from Cuba and demonstrated that when *Leucaena leucocephala* was used in association with *Cynodon nlemfuensis* in 100% of the pasture area, gains of 0.55 kg/animal/day were obtained and the animals were incorporated for reproduction at 19.93 months. On the other hand, in monoculture grazing systems, despite adequate management practices, gains of only 0.31 kg/animal/day and an incorporation age of 25 months were found.

Sánchez *et al.* (2010) evaluated the effect of supplementing with distilled corn residues on the behavior of grazing heifers in a silvopastoral association of gramineous plants and *Leucaena leucocephala.* Significant differences ($p < 0.05$) were found when analyzing daily gain according to treatment. The highest value (0.805 kg/animal/day) was detected using a treatment that was supplemented with 20% of required protein in relation to live weight. The result of 0.572 kg/animal/day was found for the group supplemented with 10% of required protein, while a gain of 0.479 kg/animal/day was obtained in the group without supplementation. The authors of this study reached the conclusion that the use of distilled corn residues at 20% of gross protein had a positive influence on mean daily gain. As well, this work showed that the hematocrit values were maintained within those recommended for this bovine species.

In order to complement this work, and taking into account that Cuba has an important germplasm of arboreal forage species, Simón *et al.* (1995) conducted an experiment to determine the possibilities of *Albizia lebbeck* associated with natural pasture for raising 5/8 Holstein × 3/8 Cebú hybrid females. Significant differences ($p < 0.01$) were found for the daily live weight gain in favor of the

Table 1: Behavior of female calves during the cycle of livestock farming. DOI: https://doi.org/10.1525/elementa.334.t1

Indicator	Association	Protein bank	ES±
	Type of animal		
	F_1	*Siboney*	
Initial live weight (kg)	164.2	170.9	2.47
Final live weight (kg)	294.9	280.8	3.67*
Incorporation age (months)	22.7	22.8	1.05
Accumulated average gain (g/animal/day)	0.524	0.440	20.08**
Average gain in the less rainy period (g/animal/day)	0.508	0.421	18.68**
Average gain in the rainy period (g/animal/day)	0.584	0.495	18.08**

* $p < 0.05$; ** $p < 0.01$; F_1 (½ Holstein × ½ Cebú); *Siboney* (5/8 Holstein × 3/8 Cebú).
Source: Iglesias *et al.* (2003).

system with *Albizia lebbeck* when compared with animals grazing on natural pasture only for the two periods estimated (0.415 vs 0.371 and 0.337 vs 0.160 kg/animal/day^{-1}). The availability of DM and GP in the treatment of *Albizia lebbeck* was determinant in the final LW (335 vs 308 kg) and in the accumulated gain (0.397 vs 0.296 kg). The results of the above-mentioned research, conducted under low external input conditions, confirm that the behavior of female replacement calves relative to live weight gain (over 440 g per day) is acceptable in these systems.

Milk production in systems associating gramineous plants with trees

Research conducted for more than 25 years in Cuba on SPSs with predominantly improved pastures and medium fertility soils has shown carrying capacities between 1.1 and 1.7 ULC/ha. These systems were evaluated using cows of medium productive potential with genotypes obtained from crossing Holstein and Cebú (**Table 2**). This research has confirmed that there is the potential to achieve milk production between 7.0 and 10.0 kg/animal/day with adequate nutrition. A production per hectare of 2800–6000 kg/year was also obtained (Sánchez-Santana, 2007; Hernández *et al.*, 2011; López *et al.*, 2012). Sánchez-Santana (2007) reached a production of 9.6 kg, 8.7 kg y 8.6 kg per milking cow in the first, second and third year of the study, respectively. No significant differences were found when the effect of seasonality on the weight of newborn calves was analyzed. The values were higher than 37.5 kg for both periods (Sánchez *et al.*, 2008). These results in milk production are similar to those found by Lamela *et al.* (2010), who obtained a milk production of 10.0 kg/animal/day in cows of medium productive potential (Holstein × Cebú) that fed on an association of *Leucaena leucocephala*, *Morus alba* and *Cenchrus purpureus* CT 115 with irrigation.

When SPSs, such as the associations of improved gramineous plants (*Megathyrsus maximus* and *Cynodon nlemfuensis*) with *Leucaena leucocephala,* are used along with cows of medium productive potential (either Siboney [5/8 Holstein × 3/8 Cebú] or Cuban Mambí [¾ Holstein × ¼ Cebú] genotypes) without the feed supplementation, it is possible to obtain milk production of 10 kg/animal/day with adequate nutritional quality (4.1% fat, 3.2% protein, 4.6% lactose, 8.6% non-fatty solids and 12.7% total solids) (López *et al.*, 2015b).

Another important aspect of these systems is the fact that in such multi-associations (intensive SPSs) with gramineous plants, herbaceous and arboreal legumes with high density (15 000 plants/ha), there is a significant improvement in the nutritional quality of animal diets because there is a great variety of plants that are offered and eaten as well as a larger component of legumes than provided in systems with gramineous plants alone. This improvement is of such magnitude that with only 25 kg of DM cow/day, the results obtained are similar to those obtained in systems with irrigation and fertilization, and this is achieved without concentrated supplements that offer between 30 and 50 kg of DM/cow/day (Hernández *et al.*, 2011). Moreover, carrying capacities of up to 2.5 ULC/ha can be used, and individual milk production can be maintained around 10 kg/animal/day^{-1}. This allows increasing milk production per hectare from 3000 to 6000 kg/year. Nevertheless, at a similar time of year, when cows in these systems are offered a level of supplementary concentrate representing 20% of the diet as well as the probiotic Sorbifauna in doses between 60 and 90 g/cow/da, an average milk production of 12.0 kg/animal/day^{-1} with 3.9% fat and 3.4% protein is obtained (Sánchez-Santana *et al.*, 2015).

In systems consisting of a silvopastoral association of *Megathyrsus maximus* and *Cynodon nlemfuensis* with *Leucaena leucocephala,* when cows give birth to offspring with a bodily condition (BC) between 3 and 3.5 (on a scale from 0 to 5), their milk production is from 20–25% higher than those that give birth to offspring with a BC lower than 2.5 or higher than 3.5 (López *et al.*, 2012). Reproductive efficiency, measured by the birth-gestation interval and the number of services per gestation, is higher in cows having a BC between 3.0 and 4.0 when compared with a BC inferior to this (López, 2002).

Meat production in systems with an association of gramineous plants with trees

Cattle fattening in SPSs with *Leucaena leucocephala* and natural and/or improved pastures, mainly with Cebú and Cebú mix genotypes, allows average individual gains between 0.420 and 0.780 kg/animal/day^{-1} with carrying capacities ranging from 1.1 to 5.5 animals/ha (Simón *et al.*, 1990; Cardona and Suárez, 1996; Hernández *et al.*, 1996; Hernández, 2000; Castillo *et al.*, 2002; Hernández *et al.*, 2003). In one of the first studies on cattle fattening initiated in SPSs with *Leucaena leucocephala* and natural pasture, individual gains of 0.715 kg/animal/day^{-1} and a 51% increase in meat production per hectare were obtained over the control group (Hernández *et al.*, 1986). The LW gains for Cebú cattle (0.419 kg animal day^{-1}) were 73% higher than those obtained with natural pasture (0.242 kg animal day^{-1}) and did not differ from the system with supplementation (0.409 kg animal day^{-1}) (Hernández *et al.*, 1987).

The evaluation of SPSs with Cebú cattle that began grazing with a LW of 220–230 kg in four systems having *Megathyrsus maximus* and woody tree species (including *Leucaena leucocephala*, *Albizia lebbeck*, and *Bauhinia purpurea* at concentrations of 600–900 trees/ha), as well as a control group with improved gramineous plants, indicated that systems having trees surpassed the control significantly (0.541 vs 0.758 kg/animal/day^{-1}) (Hernández, 2000). Grazing started when trees were between 1.3–3.0 m high with a density between 600–900 trees/ha and gramineous plants covered around 65% of the area. Results show that, in terms of daily gain, systems having trees significantly surpassed the control based on *Megathyrsus maximus.* Results also demonstrate that *Leucaena leucocephala* combined with *Megathyrsus maximus* was the best system. This was a result of the high quality of the gramineous plant in that system and a greater total availability within the system. These results confirm similar work reported previously (**Table 3**).

Table 2: Milk production in different types of silvopastoral systems. DOI: https://doi.org/10.1525/elementa.334.t2

Author	Location	Date	System	Treatment	Behavior (kg animal day^{-1})	Soil	Carrying Capacity (*ULC/ha)	Breed
Sánchez-Santana, (2007); Sánchez-Santana *et al.*, 2008 and López *et al.* (2012)	*Matanzas Genetic Enterprise*	2002–2006	*L. leucocephala* + *C. nleunfuenis* + *Megathyrsus maximus*	Two month period of production and rainfall effect (LRP and RP)	9.0–10.0	Brown with carbonates	1.5–1.8	Mambí de Cuba
Hernández *et al.* (1998); Hernández *et al.*, 2011	IHPFES	1991–1998	*Leucaena leucocephala* cv. Cunningham, *Stylosantes guianensis* cv. CIAT-184, *Neonotonia. wightii* cv. Tinaroo, *Teramnus. labialis* cv. Semilla Clara, *Centrosema pubescens* cv. SIH-129 and *Megathyrsus maximus* (a mixture of cvs. Likoni and SIH-127)	Three treatments: A High exploitation level B Medium exploitation level C Low exploitation level in a randomized block design with three replications	10.0–11.0	Red Ferralitic	1.1–4.7 (depending on the treatment)	Holstein × Cebú cross
Lamela *et al.* (2010)	Victoria de Girón Citrus Enterprise	2006–2008	*Leucaena leucocephala* + *Morus alba* + *Pennisetum purpureum*	Two month period of production and rainfall effect (LRP and RP)	9.9–10.0	Lixiviated Red Ferralitic	10	Holstein × Cebú crossed cows
López *et al.*, 2014; López *et al.*, 2015b	IHPFES	2014–2015	*Leucaena leucocephala* + *Cynodon nleunfuenis* + *Megathyrsus maximus*	A Switch Back design with two treatments: (WOS) without supplementation and WS (0,5 kg of concentrate per kilogram of milk produced, starting from the eighth liter).	9.7 y 9.8	Red Ferralitic	1.2	Holstein × Cebú creole cows
Sánchez-Santana *et al.* (2015)	IHPFES	2014–2015	*Leucaena leucocephal* + *Megathyrsus maximus*	Switch Back design and three treatments: 60, 90 and 120 g of Sorbifauna additive.	12	Red Ferralitic		Holstein × Cebú creole cows

* ULC: Units of Large Cattle is equivalent to one bovine of 450 kg of live weight in Cuba; Source: self-elaborated.

Table 3: Meat production in agrosilvopastroal systems. DOI: https://doi.org/10.1525/elementa.334.t3

Author	Location	Date	System	Treatment	Behavior (kg animal day^{-1})	Soil	Carrying Capacity (*ULC/ha)	Breed
Hernández (2000); Hernández *et al.* (2001)	IHPFES	1993–1997	Four productive systems: pasture only and *A. lebbeck, Bauhinia purpurea* and *Leucaena leucocephala* associated with pasture	A) pasture only and B) *Albizia. lebbeck* associated with pasture, C) *Bauhinia purpurea* associated with pasture and D) *Leucaena leucocephala* associated with pasture	0.541 vs 0.758	Red Ferralitic	3 animals/ha	Comercial Cebú
Iglesias (2003); Iglesias *et al.* (2006) and Iglesias *et al.* (2011)	IHPFES	1998–2003	A. Protein bank of *Leucaena leucocephala* cv. Cunningham, with *Megathyrsus maximus* likoni and creeper legumes + *Megathyrsus maximus* likoni fertilized with 80 kg of N/ha in 75% of the remaining area B) Association of *Leucaena leucocephala* cv. Cunningham with *Megathyrsus maximus* cv. Likoni and creeper legumes 3. Traditional grazing system with *Megathyrsus maximus* in the whole área, fertilized with 80 kg of N/ha.	Three treatments: A) Protein bank system and/or B) Association system in 100% of the area, compared with C) control of fertilized gramíneous plants	0.538; 0.555–0.623, B and A, respectively	Red Ferralitic	2.5 ULC/ha	Commercial Cebú bulls
Sánchez-Santana *et al.* (2016)	IHPFES	2015–2016	*Megathyrsus maximus* cv. Likoni with *Leucaena leucocephala* cv. Cunningham	24 Holstein × Cebú cross bulls were used (365 kg of LW and 24 months of age), distributed in two groups of 12 animals at random: a control group that did not receive supplementation	1.0	Red Ferralitic	1.1 ULC/ha	Holstein × Cebú bulls

Animal behavior showed the superiority of associated systems over traditional systems with inputs. It is important to acknowledge that the inclusion of arboreal species, particularly *Albizia lebbeck* and *Bauhinia purpurea,* in similar studies indicated their high potential for bovine fattening. According to Iglesias *et al.* (2006), Cuban-based studies on the use of SPSs for meat production with Cebú hybrids, without the use of supplementary feed, produced accumulated gains between 0.492 and 0.623 kg/animal/day^{-1}, with a final weight at slaughter of 357 to 414 kg/animal and an age ranging from 24 to 28 months.

On the other hand, a live weight (LW) of 448 kg and an age of 29 months at slaughter as well as average gains of 0.487 kg/animal/day^{-1} were obtained when *Andropogon gayanus* was used in grazing and a protein bank of *Leucaena leucocephala* and *Neonotonia wightii* was used in fattening Cebú bulls. Gains of 0.429 kg/animal/day^{-1} in the LRP and an accumulated gain higher than 0.620 kg/animal/day^{-1}, with LW over 400 kg at 26 months of age were obtained in a silvopastoral system with *Leucaena leucocephala* and *Megathyrsus maximus* (without supplemental feed) (Iglesias *et al.*, 2011). An accumulated daily mean gain higher than 0.800 kg/animal/day^{-1} and a weight of 445 kg and 22 months of age at slaughter with a 57.2% carcass yield was found in a study conducted by Díaz (2008) in a silvopastoral system with predominance of *Cynodon nlemfuensis* in association with *Leucaena leucocephala* and access to a biomass bank of *Pennisetum purpureum* cv. CT-115 with a genotype specialized for meat production (Charoláis de Cuba). Iraola (2013) found an accumulated daily gain of 0.718 kg/animal/day^{-1} when evaluating productive indicators of Cebú hybrid bovines in a system based on improved pastures (*Cynodon nlemfuensis*, *Pennisetum purpureum* vc. CT-115 and *Brachiaria hibrido* vc. Mulato) with *Leucaena leucocephala* covering 50% of the area. This represented an increase of more than 65% compared to the gains obtained from a system of degraded pastures in that same area. In addition, the age and weight at slaughter were 24 months and 416.2 kg/animal, respectively, whereas production per hectare was 749.1 kg, which is in the range of the 0.500 to 0.800 kg/ha result posed by Iglesias *et al.* (2011) using these systems in Cuba. This shows their potential for meat production using SPSs.

Sánchez-Santana *et al.* (2016) did research on a silvopastoral system consisting of an association of *M. maximus* cv. Likoni with *L. leucocephala* cv. Cunningham established 20 years before, with a spacing of 5 m between rows and a density of 236–364 plants/hectare. To do this, they evaluated the effect of a mixture of corn and residues enriched with torula yeast as an energy-protein supplement (at 20% of the raw protein required) in diets for Holstein × Cebú bulls in the final fattening phase. As a result, weight gains higher than 1.0 kg/animal/day^{-1} (1.08) were obtained in animals receiving 1.0 kg of the supplement, while the animals that were not supplemented showed a mean daily gain of 0.846 kg animal day^{-1}. In this case, energy was the limiting factor in obtaining higher gains. These gains are higher than those obtained in previously described research conducted in Cuba; nevertheless, the inclusion of SPSs has been proven to have beneficial effects on productive behavior and, in all cases, it is superior to monoculture systems despite the differences based on the cattle breed used, carrying capacity, management and the edaphic-climatic conditions of the study.

Conclusions

Research conducted in the last 25 years shows that SPSs have great potential for bovine production in Cuba. Associations of improved gramineous plants with trees show high availabilities of dry matter and pasture persistence, with GP values two percentage points higher in improved gramineous plants systems than in monoculture systems, without irrigation or the application of chemical fertilizers. These results show that through the use of adequate energy-protein supplements or associations of gramineous plants and legumes – planted throughout a pasture or in protein banks – it is possible to create silvopastoral systems for developing females which result in satisfactory live weight gains up to their incorporation for reproduction, and consequently, result in earlier deliveries as well. In this sense, the use of silvopastoral systems with legumes, whether creeper, shrubby, or both, contributes to saving on supplements and nitrogenous fertilizers. This makes SPSs more viable systems from an economic standpoint. Results obtained in this study show milk production increases in cows of medium potential, implying greater food availability for the population, which is important in terms of food security in Cuba. At present SPSs are a viable option in bovine production in Cuba because they have greater plant diversity than pastures in monoculture, and they obtain satisfactory results in meat and milk production.

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Competing interests

The authors have no competing interests to declare.

Author contributions

- Contributed to conception and design: T Sánchez-Santana, O López-Vigoa, JM Iglesias-Gómez, L Lamela-López, M Soca-Perez
- Contributed to acquisition of data: T Sánchez-Santana, O López-Vigoa, JM Iglesias-Gómez, L Lamela-López, M Soca-Perez
- Contributed to analysis and interpretation of data: T Sánchez-Santana, O López-Vigoa, JM Iglesias-Gómez, L Lamela-López, M Soca-Perez
- Drafted and/or revised the article: T Sánchez-Santana, O López-Vigoa, JM Iglesias-Gómez, L Lamela-López, M Soca-Perez
- Approved the submitted version for publication: O Alonso-Amaro [not an author]

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