Research on Forage Trees

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Introduction

Socio-economic aspects

About 50% of the population of Central America consume less calories and proteins than the recommended levels established by many specialist institutions (FAO, 1984; INCAP, 1969; Von Hoegen, 1976). Despite a large increase in the population in Central America, total meat production decreased by 12% between 1980 and 1985, from 457,000 to 400,000 metric tons. Of this, beef production has decreased by 27%, from 303,000 to 221,000 metric tons (FAO, 1987 and 1990b). Between 1981 and 1988, per capita meat consumption decreased (FAO, 1991) and all Central American countries imported milk (FAO, 1990a).

Depending on country, between 45% and 78% of the farmers in the isthmus have farms between 3.5 and 10 ha in area, occupying between 0.4 and 10% of cultivated land (CATIE, 1985). In addition, land and capital restrictions, together with the location of many of these small farms in areas unsuitable for agriculture, make cattle exploitation difficult or impossible. Under these conditions, the energy contained in the food available on most of these farms is barely sufficient to satisfy the animals' maintenance requirements (McDowell and Bove, 1977 cited by Raun, 1982). All these considerations together with small and medium-sized producers' lack of access to appropriate technology, increased demographic growth and other aspects related to the social and economic situation in Central America, imply a need for novel solutions which will allow considerable changes in the currently used production methods. The development of technological alternatives that are more appropriate to the ecological and socioeconomic conditions of the region must play a decisive role in this process of change, so that consumer goods are produced using methods that are more sustainable and more in keeping with the rational use of natural resources.

Livestock production and natural resources

Many traditional land use practices (deforestation, extensive and extractive grazing, absence of erosion control, farming in unsuitable areas, etc.) bring about disturbances in the ecological balance and reduce the productive capacity of soils (Garríguez, 1983; Jiménez, 1983; Heuveldop and Chang, 1981). Moreover, the production and quality of tropical pastures is affected both by climatic factors (Minson and McLeod, 1970; Stobbs, 1975; Cubillos *et al.*, 1975) and land and capital restrictions in most small farms (Avila *et al.*, 1982).

As well as economic and social factors, the above also includes the type of agricultural technologies practiced in Central America since colonial times. The large herbivores of the Pleistocene period had already disappeared by pre-Columbian times (Janzen and Martin, 1982) and ruminants were not exploited as domestic animals. In those days the only native ruminants were deer which are more truly browsers (Sands, 1983; Morales, 1983). Moreover, the predominant vegetation type in all life zones was trees and shrubs. With the exception of corn, there were few grasses present and these were not an important food source for native herbivores (Janzen and Martin, 1982; UNESCO, 1979; National Geographic, 1992; Skerman and Riveros, 1992). This indicates that in most of the region, the natural vegetation of the land is quite different from that currently existing.

The settlement of Spanish colonists in Central America resulted in the introduction of land use technologies more appropriate to temperate climates, including the use of ploughing and livestock rearing along with the establishment of pasture for feed (Meza and Bonilla, 1990; Tosi Jr. and Voertman, 1977). These practices, which still continue, have contributed significantly to the deterioration and elimination of the natural cover with resultant negative effects on the soil and biodiversity. It has also prevented the possibility of rationally utilizing the forest in areas which have doubtful long and medium term production. With respect to traditional livestock rearing "...it is a very discouraging fact for grasslands experts to realize that animals feed more on shrubs and trees or on associations where woody species play an important role, than on true grass or legume species pastures." (Commonwealth Agricultural Bureau Publication, No 10, 1974, cited by Skerman *et al*., 1991).

The establishment of production areas on virgin lands has been part of a process which starts with the sowing of grain crops to take advantage of the fertility present after the forest has been felled. Once fertility starts to decline, the land is abandoned or dedicated to extensive agriculture or livestock rearing which is usually extensive and extractive in nature (Sands, 1983). Since the 1950's, over 50% of the natural forest has been converted to shifting agriculture or pasture (Collins, 1990; UNESCO, 1979; National Geographic, 1992). In the majority of cases these are over- grazed small farms or large areas with a small number of animals per unit area (Collins, 1990). In Central America, high productivity in pastures can only be maintained through the extensive use of inputs and labor due to, among other things, the rapid invasion by native woody species which struggle to establish themselves. "..whilst man persists in trying to maintain the pastures, nature struggles to develop forest." (Skerman and Rivero, 1992).

The questions therefore arise: What would have happened if, instead of introducing the plough and grass species, appropriate technologies had been developed to rationally utilize forest products? Apart from timber, can other forest resources be used to satisfy the demand for consumer goods in Central America's population? The results of research into forage trees and shrubs presented in this book contribute to a partial answer to these questions.

Trees and shrubs as feed for ruminants.

Research into forage trees and shrubs began in CATIE in 1980. Later, the Science and Technology Institute (ICTA), the University of San Carlos in Guatemala and the National University of Costa Rica also became involved. CATIE's Animal Production Area concentrates its efforts on the appraisal of trees and shrubs as sources of forage and on their incorporation in ruminant production systems (Benavides, 1989). The work has an agroforestry focus and is carried out using the farming systems concept. It aims to develop technological alternatives that permit a greater sustainability in animal production systems and a more rational management of soil and forest resources.

The efforts of many professionals in Central America has led to the identification and appraisal of many tree and shrub species with excellent characteristics for foliage nutritional quality, biomass production and adaptability to different agricultural management practices (Benavides, 1991). Woody species with forage potential have been found on the Atlantic slope and Peten area of Guatemala, in the dry, Pacific zones and in the mountains of Guatemala and Costa Rica (Pineda, 1988; Araya, 1991; Benavides, 1991; Mendizábal *et al*., 1993).

Research into forage trees

For a tree or shrub to qualify as a forage species, it must possess advantages in terms of nutritional quality, production and agronomic versatility over other traditionally used forage. The requisites for qualifying are: i) consumption by the animals must be sufficient to expect changes in the response parameters; ii) the nutrient content should be attractive for animal production; iii) the species should tolerate pruning and iv) significant levels of biomass production should be obtained. In addition, native species are recommended since these have the advantage of being adapted to their environment and can be established using cheap and simple agricultural practices.

More than ten years work has enabled the development of a methodology to rationalize and organize the research efforts on forage trees and shrubs. This methodology uses a process of successive elimination to leave only species that show the best forage characteristics.

Most of the work on animal response has been done on small ruminants due to their ability to transform these materials into products that are useful for man, the role they can play in farms where keeping cattle is restricted and the lower costs incurred by working on smaller animals. Nevertheless, the information produced can, in most cases, be extrapolated to larger ruminants in a qualitative sense and verified quantitatively as required.

Apart from a study of individual species using the aforementioned methodologies, studies have been carried out to appraise natural prairies and understories to generate alternatives that allow their rational exploitation and ensure the conservation of their biodiversity.

Identification and characterization of species

The first step consists of identifying and characterizing the species of trees and shrubs that have potential as forage species. This is done by one of three routes. The first uses surveys aimed at producers to find out which woody species are normally appetizing to the animals. The second route is direct observation of animals during grazing or browsing using frequency studies to establish the species that are most often taken. Finally, secondary information is used to work with species that have been mentioned in other studies.

Data obtained from producers and from the literature indicate the presence of species with forage potential in the humid tropics of the Atlantic coast of Costa Rica and the Peten of Guatemala, in semi-arid zones of the Dominican Republic and the Southern coast of Honduras, in mountainous zones of Costa Rica's Pacific coast that have prolonged dry seasons and serious erosion problems and in areas above 1000 masl on the high plains of Costa Rica and Guatemala that have a temperate climate (Table 1).

Direct observation of the animals has resulted in the identification of species that are particularly appetizing and have high in-vitro dry matter digestibility (IVDMD) and high levels of crude protein (CP). These studies have allowed a preliminary appraisal of species which normally have no value and increase the usefulness of others which normally have other functions.

Observations of goats over a four month period in the humid tropical secondary forest of Turrialba showed that of 84 species that were consumed at least once, 9 species represented 54.2% of the total eaten. Furthermore it was found that the two species which were most sought were those with the highest IVDMD and CP. The results clearly showed that dry matter (DM) levels were lower for the more selected species, indicating that the animals select their food on the basis of "succulence" (Table 2).

Table 1. Some species of trees and shrubs with potential for forage identified in Central America.

Trees	Scientific Name	Site
Aliso	*Alnus arguta*	HP/1
Amate, Higueron	*Ficus* sp.	HT/2,DT/3
Bilil	*Polimnia* sp	HP
Brasil	*Haematoxilum brasilleto*	DT
Chaperno	*Lonchocarpus guatemalensis*	HT
Copal	*Stemmadenia donnel-Smithii*	HP
Engorda ganado (?)		HP
Guácimo	*Guazuma ulmifolia*	DT
Guanacaste	*Enterolobium cyclocarpum*	DT
Guarumo	*Cecropia peltata*	DT, HT
Jaul	*Alnus acuminata*	HP
Jicaro	*Crescentia alata*	DT
Jiote, Jinocuabe	*Bursera simaruba*	DT, HT
Jobo	*Spondias mombin*	DT, HT
Jocote, ciruela	*Spondias purpurea*	DT
Madero negro	*Gliricidia sepium*	HT, DT
Nacascolo	*Libidibia coriaria*	DT
Poro	*Erythrina cocleata*	HT
Poro enano	*Erythrina berteroana*	DT, HT
Poro gigante	*Erythrina poeppigiana*	HT
Sacumis	*Buddleia nitida*	HP
Sauco negro	*Sambucus mexicana*	HP
Tiguilote	*Cordia dentata*	DT
Zorrillo	*Roupala complicata*	DT

Shrubs	Scientific name	Site
Amapola	*Malvaviscus arboreus*	DT, DT
Carbon	*Mimosa* sp.	DT
Carbon blanco	*Mimosa platycarpa*	DT
Chaguay, Mongollano	*Pithecelobium dulce*	DT
Chicasquil, Chaya	*Cnidoscolus aconitifolius*	DT
do.	*Cnidoscolus chayamansa*	DT
Chichipince	*Hamelia patens*	HT
Chilca, Sacumis	*Senecio salignus*	HP
Chupamiel	*Combretum sufriticosum*	DT
Clavelon	*Hibiscus rosa-sinenesis*	HT, DT
Espino blanco	*Acacia farnesiana*	DT
Leucaena	*Leucaena leucocephala*	DT
Mano de leon	*Dendropanax arboreus*	HT
Moradillo, Chompipe	*Bomarea nirtella*	HP
Morera	*Morus* sp.	HT, DT
Pintadillo	*Caesalpinea eriostachis*	DT
Ramon blanco	*Brosimun alicastrum*	DT, HT
Ramon colorado	*Trophis racemosa*	DT, HT
Sauco amarillo	*Sambucus canadiensis*	HP
Tora blanca	*Verbesina turbacensis*	DT, HT
Tora Morada	*Verbesina myriocephala*	DT, HT
Zarza	*Mimosa albida*	DT

1/ Highland plains (HP) 2/ Humid Tropics (HT) 3/ Dry Tropics (DT) .
Adapted from: Benavides, 1983; ICTA, 1987; Pineda, 1988; McCammon-Feldman, 1980; Ammour and Benavides, 1987; Hernández and Benavides, 1993.

Table 2. Frequency of consumption and nutrient quality of plant species selected most often by goats in humid tropical secondary forest/1.

Species	Consumption frequency %	DM %	CP %	IVDMD %
Vernonia brachiata	10,1	22,6	29,6	68,4
Acalypha macrostachya	7,9	22,3	30,1	68,0
Heliconia sp.	7,6	23,4	20,0	38,1
Panicum maximum	6,7	22,6	16,9	54,1
Clibadium sp.	4,7	25,7	26,2	47,3
Helechos	4,6	30,7	20,1	26,3
Croton schiedeanus	4,4	32,7	27,1	23,4
Govania polygama	4,4	40,5	20,8	40,8
Trofis sp.	3,8	37,0	15,8	65,2
Other species/2	45,8			

1: Turrialba, Costa Rica. 2: 75 species.
Source: Rodriguez M., 1982, cited by Benavides, 1991.

Table 3. Agricultural management of the woody species that are most used for ruminant feed in San Marcos, Guatemala.

Species	Propagation		Cuttings maturity		Time of planting
	Cuttings	Seeds	Young	Mature	
	------- % of farmers -----				
Miche/1	100	0	0	100	April-June
Sauco/2	100	0	75	25	April-June
Copal/3	86	14	90	10	April-June
Bilil/4	86	14	90	10	April-June
Engorda Ganado/5	100	0	0	100	April-June
Soloj/6	100	0	90	10	April-June
Moradillo/7	100	0	90	10	April-June
Canaque/8	0	100			

1/ *Erythrina* sp. 2/ *Sambucus canadensis* 3/ *Stemmadenia donnel-Smithii* 4/ *Polimnia* sp. 5/ ? 6/ *Palia imperialis* 7/ *Bomarea nirtella* 8/ ?. Adapted from Ruiz, 1992.

During this study, information was also gathered on other uses these species have on the farm and on traditional agricultural management methods. In this way, the study benefits from the producers' knowledge by speeding up the research process.

Many of these species, as well as producing forage, are used for fuelwood, as ornamentals, in living fence-posts, for human consumption and as medicinal plants. A knowledge of these other uses can assist the adoption process when the species are included in feeding systems for ruminants.

In drier conditions, such as the south of Honduras, where precipitation is concentrated in 5 or 6 months of the year, the selection of species is influenced by the time of year, since rainfall affects the type of vegetation. A study carried out over six months was able to identify woody species that were particularly sought by goats and their variation over the time of study.

Information from the field has also helped in learning simple agricultural management techniques that are easy to carry out. In most cases, propagation is done through vegetative material (cuttings and stakes) which results in faster establishment and biomass production than sowing seed (Table 3). It was also found that producers showed a preference for the way the cuttings were taken, their size and the type of cut made (Table 4).

Preliminary information on the biomass production capacity should be obtained by pruning naturally growing trees. In this way, information can be obtained on survival after pruning and production capacity can be calculated over long periods of time, allowing the best to be pre-selected.

An example of this was observations made in the Western Highlands of Guatemala, at an altitude over 1500 masl, where acceptable yields had been obtained from Sauco Amarillo and Chilca species pruned every 180 days (Table 5). However, under these conditions, yields are determined not only by frequency of pruning but also by age of the plant and competition with other nearby plants for light and nutrients.

Table 4.Management of tree and shrub species most commonly used as ruminant feed in San Marcos, Guatemala.

	Type of cut		Type of planting/1		Size, cm	
Species	Bicel	2 cuts	Vert.	Angled	Length	Diam
Miche	X		10	90	100	0,10
Sauco	X		8	92	100	0,10
Copal	X		8	92	100	0,15
Bilil	X		8	92	100	0,10
E. Ganado/3	X	X	14	86	150	0,15
Soloj		X	14	86	100	0,15
Moradillo	X	X	0	100	100	0,10

1/ Percentage of producers. 2/ Bicel = angle cut to avoid rot
3/ Engorda ganado
Adapted from Ruiz, 1992.

In the southern zone of Honduras, almost at sea level and with only irregular rainfall for six months of the year, the best yields have been obtained from Guácimo and Tiguilote. The large yield difference from those obtained in Guatemala may be due, apart from climatic differences, to the fact that in Guatemala the species studied were shrubs whilst in Honduras they were older trees.

Evaluation of nutrient quality

In the second stage, samples of foliage from suitable species are taken to the laboratory for nutrient quality analysis. Initially, an analysis of CP content and IVDMD only are recommended, in order to concentrate efforts on species with the best characteristics. Those with least nutritional content should not be completely rejected, since they may have other interesting properties such as high rate of consumption or high biomass production during dry months, and so play a strategic role in feeding.

Table 5. Total dry matter yield for Sauco amarillo, Engorda ganado and Chompipe by frequency of pruning.

Species	Pruning frequency months	Production/1 kg DM/tree/year
Total DM/2		
Sauco amarillo	3	1,61 +-0,69b
(*Sambucus canadensis*)	6	3,50 +-1,43a
Engorda ganado	3	0,06 +-0,04b
(?)	4	0,21 +-0,16ab
	6	0,36 +-0,28a
Chompipe	4	0,17 +-0,10
(*Bomarea nirtella*)	6	0,17 +-0,11
Edible DM		
Sacumis	3	0,09 +-0,02b
Buddleia sp.	4	0,27 +-0,28a
	6	0,29 +-0,13a
Chilca	3	0,44 +-0,33
(*Bacharis saliciofilia*)	4	0,56 +-0,34
	6	0,56 +-0,37

1/ Values with the same letter do not differ statistically, $p<0.01$.
2/ Adapted from Mejicanos and Ziller, 1990.

Most species show CP content two or three times that of tropical pastures and, in several cases, higher than commercial concentrates (Table 6). In addition, the IVDMD of some leaves may be very high, equal to or greater than concentrates. Two species of euphorbias stand out for their nutritional content: *Cnidoscolus acotinifolius* and *C. chayamansa*, the leaves of which are also used for human consumption (Araya, 1991).

Other species with CP levels over 20% and IVDMD over 70% include *Morus* sp. and a species of *Ficus* from the Peten, Guatemala, two Malvaceae (*Malvaviscus arboreus* and *Hibiscus rosa-sinensis*), two Caprifoliaceae (*Sambucus mexicana* and *S. canadensis*) and three Asteraceae (*Senecio* sp., *Verbesina turbacensis* and *V. myriocephala*).

Table 6. Dry matter, crude protein and digestibility/1 of foliage from woody species with forage potential identified in Central America.

Species	DM%	CP%	IVDMD%
Chicasquil fino (*C. aconitifolius*)/2	16,5	42,4	86,6
Morera (*Morus* sp)	28,7	23,0	79,9
Jicaro (*Crescentia alata*) (flores)	11,0	77,6	
Chicasquil ancho (*C. chayamansa*)2	9,3	30,8	74,8
Tora morada (*Verbesina myriocephala*)	19,8	23,0	71,5
Chilca (*Senecio salignus*)	26,5	23,4	71,5
Amate (*Ficus* sp.)		14,4	71,3
Tora blanca (*Verbesina turbacensis*)	20,6	20,8	70,8
Clavelon (*Hibiscus rosa-sinenesis*)	24,8	21,0	70,0
Sauco negro (*Sambucus mexicana*)	17,9	25,0	69,8
Chaperno (*Lonchocarpus guatemalensis*)		19,5	69,4
Guachipelin	41,7	28,6	68,3
Cassia siamea	26,9	14,4	67,4
Ramon blanco (*Brosimum alicastrum*)		12,7	67,2
Zorrillo (*Roupala complicata*)	26,6	42,5	66,9
Amapola (*Malvaviscus arboreus*)	16,5	22,4	64,5
Sauco amarillo (*Sambucus canadensis*)	18,0	28,5	64,4
Copalchi	31,0	14,3	62,4
Chichipince (*Hamelia patens*)		17,5	61,6
Carbon blanco (*Mimosa platycarpa*)		16,0	60,0
Madero negro (*Gliricidia sepium*)	25,1	21,6	59,2
Nacascolo (*Libidibia coriaria*)		16,0	59,0
Chompipe, Moradillo (*Bomarea nirtella*)	19,0	18,7	58,4
Ramon colorado (*Trophis racemosa*)		12,9	56,5
Poro enano (*Erythrina berteroana*)	22,9	24,3	55,0
Espino blanco (*Acacia farnesiana*)		22,0	55,0
Guácimo (*Guazuma ulmifolia*)	37,6	15,6	54,3
Mano de leon (*Dendropanax arboreus*)		12,1	52,7
Guarumo (*Cecropia peltata*)	19,7	19,8	51,8
Poro gigante (*Erythrina poeppigiana*)	24,0	23,8	51,3
Poro de cerca (*Erythrina cocleata*)	24,3	21,6	51,2
Copal (*Stemmadenia donnel-Smithii*)	19,1	24,4	50,6
Jobo (*Spondias mombin*)	23,6	10,9	49,6
Bilil (*Polimnia* sp)	17,9	22,1	45,2
Tiguilote (*Cordia dentata*)	41,0	16,0	36,0

1/ In vitro dry matter digestibility. 2/ Cnidoscolus. Adaptado from Hernandez and Benavides, 1993; Araya *et al*., 1993; Mendizábal *et al*., 1993; Reyes and Medina, 1992; Godier *et al*., 1991; Medina, *et al*., 1991; Rodriguez *et al*., 1987

Nutrient content is affected by the age of the regrowth, the branch component and the position of the regrowth on it. In Erythrina leaves, under humid tropical conditions, wide variations in CP and IVDMD have been found for all biomass fractions according to their position on the branch (Table 7).

Differences have also been found in data taken by different authors from the same species. This may be due to differences already mentioned, to differences between laboratories or to climatic differences between sampling sites (Table 8). A study of other chemical components such as lignin, tannins and toxins should also be made to detect any potential problems in acceptability, low growth response, milk production or poor animal health. Where there is evidence of negative nutritional factors, samples should be returned to the laboratory to evaluate the factor causing the problem and find possible solutions.

When *Gliricidia sepium* leaves were offered to goats stabled in Turrialba, consumption problems were noticed as the material was younger, with a higher IVDMD and lower DM content. The problem seems to be related to the place of origin of the material since, for the same trial, foliage from two different sites was used and there was a marked relationship between site and level of consumption.

Table 7. Dry matter, crude protein, in vitro digestibility and digestible energy of different foliage fractions from *Erythrina poeppigiana.*

Fraction	%DM	%CP	%IVDMD	DE/a
Apical leaf	17,5	38,4	74,1	3,27
Intermediate leaf	25,5	30,5	33,5	1,48
Basal leaf	26,2	27,1	37,4	1,65
Apical stem	17,0	12,2	54,4	2,40
Intermediate stem	20,1	10,6	47,4	2,09
Basal stem	21,5	9,2	34,1	1,50
Bark	17,0	14,1	78,3	3,45

a/ Mcal/kg DM. Benavides, 1983.

Table 8. Effect of age of regrowth on crude protein content and digestibility of leaves of some Central American woody species.

Species	Regrowth age in months 3	4	6
Crude protein, %			
Sauco Amarillo/1	25,5	23,0	15,6
Engorda ganado/1		24,8	21,9
Chompipe/1		18,3	15,6
Morera/2	23,1	6,9	16,7*
Morera/3	20,9	19,2	
Amapola/4	21,6	20,8	
IVDMD, %			
Sauco Amarillo/1	75,5	67,3	56,2
Engorda ganado/1		66,3	57,3
Chompipe/1		57,5	56,2
Morera/2	90,5	90,5	90,1*
Morera/3	77,2	76,9	
Amapola/4	61,1	58,0	

*/ Cut every 6, 9 and 12 weeks. 1/ Adapted from Mejicanos and Ziller, 1990. 2/ Adapted from Rodríguez *et al*., 1987. 3/ Adapted from Benavides *et al*., 1993. 4/ Adapted from López *et al*., 1993a

As with other forage material, a strong correlation has been found in the foliage of shrubs and trees used between IVDMD and cell wall content, cellulose, tannins and lignins. Information from several species both from cold climates such as the Guatemalan Western Highlands and hot regions in Costa Rica may be useful to develop methods or formulate equations to predict the nutrient quality composition of foliage on the basis of the level of one chemical factor in the material.

Animal response

After testing nutrient quality values, large amounts of material, even plantations of the species, will be needed for the next phase: testing with animals. Tests are carried out to determine the animals' response parameters (acceptability and consumption, milk production, growth) when offered foliage from these species.

Erythrina poeppigiana is the species that has been studied most in the last decade in trials for consumption and production, showing ingestion levels greater than 3%LW in lactating goats (Table 9). Other studies have investigated the level of consumption of species which grow naturally in dryland grasslands, understories and natural forest regeneration sites and which have been selected after observing animals in pastures.

In the southern zone of Honduras, satisfactory consumption levels have been obtained for growing kids feeding on Guacimo and Tiguilote. With some species, a long period of familiarization is needed before the consumption level is established. In the humid sub-tropics of the Peten in Guatemala, the foliage of species that are common on fallow lands and understories have been fed as a supplement to sheep in pasture and have been reported successfully consumed (Table 10). In this way, a normally under-utilized resource acquires a higher value, opening up a way of using non-timber forest products without destroying the forest.

Table 9. Consumption level of *E. poeppigiana* foliage by goats when administered alone or as a supplement to pasture or bananas and plantains.

Type of diet	Intake %LW	Authors
Alone	3,5	Benavides and Pezo, 1986
With green bananas	3,3	Esnaola and Benavides, 1986
With plantain	3,3	Benavides and Pezo, 1986
With green bananas	2,8	Rodriguez *et al*., 1987
With green bananas and pasture	1,5	Esnaola and Rios, 1986

When there is little foliage, either because the plantation is small or because naturally growing plants are used for biomass production, certain observation procedures have been improvised to measure acceptability. In these cases, foliage from different species is offered at the same time and, as the trial proceeds, the most consumed species is eliminated to find out if the rest are also used. It has been observed that species with the highest IVDMD and greatest CP content are selected most initially, and as mentioned earlier, longer adaptation periods are needed than for traditional forage.

On hillsides of the Costa Rican Central Pacific zone, young stabled goats were simultaneously offered foliage from Chicasquil ancho, Chicasquil fino, Jocote and Guacimo. The most consumed species were successively eliminated and it was observed that intake of the species that remained increased. Furthermore, with the exception of a period when only lesser quality foliage was used, it was found that the total consumption for all species increased between experimental periods.

Table 10. Dry matter consumption by penned sheep of foliage from woody species present in secondary forest, Peten, Guatemala.

Species	DM intake % Live weight	Typical deviation
Cecropia peltata	2,1/a	0,4
Brosimum alicastrum	2,0/ab	0,9
Lonchocarpus guatemalensis	1,4/bc	0,4
Hamelia patens	1,3/bc	0,3
Dendropanax arboreus	1,1/c	0,4
Trophis racemosa	1,1/c	0,7
Ficus sp.	0,5/d	0,2
Spondias mombin	0,3/d	0,2

1/ Values with the same letter do not differ significantly, $p<0,05$. Adapted from Hernandez y Benavides, 1993.

Two of the most common woody forage plants are Leguminosae in the genera *Erythrina* and *Gliricidia*. They have high CP contents but medium to low levels of IVDMD. Research results have shown that the energy complement of the feed increases the animals' response parameters noticeably and that the high starch content gives greater productivity than more simple sugars.

An evaluation of the effects of four energy sources on consumption and growth in lambs fed *Erythrina* foliage, in the humid tropics of Turrialba, showed that in all cases where an energy source supplement was given, consumption and weight gain were greater than in animals not receiving the supplement. The greatest responses were found with green bananas and yams (starches) and were greater than with molasses (simple carbohydrates) (Table 11).

Another study in Turrialba on goats fed pasture and green bananas showed significant increases in milk production in goats with mid-range milking potential in proportion to an increased level of supplementation with *Erythrina* foliage. An additive effect was also noticed on the total DM consumption as *Erythrina* consumption increased, whereas the effect on pasture consumption was not very significant.

Table 11. Weight gain and consumption for "Black belly" lambs fed Poro gigante (*Erythrina* sp.) foliage and supplemented with different energy sources.

Parameters	Nothing	Molasses	Green Banana+ Molasses	Green banana	Yam
Mean wt. kg.	22,2	23,0	23,1	20,8	22,8
Gain,g/an/day/1	74,0/c	92,0/bc	91,0/c	112,0/ab	128,0/a
DM cons., % LW					
Erythrina	3,5	3,2	3,3	3,3	3,0
Supplement	0,0	0,8	0,9	1,1	1,3
Total	3,5	4,0	4,2	4,4	4,3

1/ Values with the same letter do not differ significantly, p<0,05.
Benavides and Pezo, 1986.

It is important to have an appropriate proportion of protein source (*Erythrina* foliage) to energy source (plantain) when these are used in the diet. This was found in a study carried out in Turrialba where goats in milk production were offered two levels of *Erythrina* and two of plantain supplements. Highest milk production occurred in treatments with a similar protein/energy ratio. (Table 12).

Higher milk production levels have been obtained with species that have high CP and IVDMD and a very significant response has been observed when increasing amounts of foliage are administered to animals with diets based on pasture.

Table 12. Milk production and dietary protein/energy ratio in goats fed on pasture and different levels of *Erythrina* and green plantain.

Plantain level	High	Low	High	Low
Erythrina level	High	High	Low	Low
Milk, kg/an/day	1,27	1,09	1,09	1,13/1
CP/DE, (g/Mcal)2/	40,0	45,0	35,0	40,0

1/ Interaction between factors significant, $p<0,05$.
2/ Crude protein/Digestible energy (grammes/megacalorie).
Adapted from Castro, 1989.

This is the case with Amapola and Morera foliage, where increased milk yields have been observed in goats in the humid tropics as the amount of foliage in the diet is increased. Milk production levels of 2.2 and 2.6 kg/animal/day have been achieved this way, normally only possible using commercial concentrates.

For both these species, dry matter consumption levels over 5% of live weight were reported. However, for animals with high production potential, there was a marked substitution effect on pasture consumption as well as an important additive effect on total DM consumption, for both species of supplements.

Yields approaching 800 kg milk/animal/300 day lactation have been observed for two goats fed for three years on solely Morera leaves and pasture in a module under humid tropical conditions. Mean production of over 4.0 kg/animal/day have been observed in the same module at peak lactation. In addition, an increased response in weight gain of over 100 g/animal/day has been found for lambs when the percentage of Morera foliage in the diet is increased (Table 13).

Agronomic evaluations

After selecting the species with the best characteristics, agronomic evaluations are carried out. The aim is to develop management techniques that provide high biomass yields in a way that is sustainable over time and involves the minimum use of external inputs. Research has included work on propagation techniques, the most appropriate spatial and temporal arrangements, the use of organic fertilizers (mulches and manures) and the possibilities of association with other crops or forages.

Table 13. Consumption level and weight gain in "Black belly" lambs fed on King grass supplemented with varying levels of Morera foliage

	Morera DM consumption, %LW			
Parameter	0	0,5	1,0	1,5
Starting weight, kg	15,7	15,8	15,8	15,1
Increase, g/animal/day/1	60/b	75/b	85/ab	101/a
DM consumption,kg/an/day				
King grass	0,7	0,6	0,6	0,6
Morera	0,0	0,1	0,2	0,3
Total	0,7	0,7	0,8	0,9
Consumption, % L.W.	3,5	3,7	4,0	4,3

1/ As a percentage of body weight.
2/ Values with the same letter do not differ significantly, p<0.01.
Adapted from Benavides, 1986.

Of all known methods, propagation by cuttings (stakes) is most used since the time taken to establish them is shorter, the technique is easy and well known by producers. The percentage of Amapola and Morera that successfully 'take' is about 90% in the humid tropics (Benavides *et al.*, 1993; Lopez *et al.*, 1993a). In some species it is possible to plant the entire stake horizontally beneath the soil. This gives rise to several plants per stake and saves propagation material. However, there are variations between species that must be taken into consideration before a technique is chosen (Table 14).

Table 14. Effect of planting position on germination and number of shoots for Sauco, Amapola and Morera stakes.

	--- Planting position ---			
	Horizontal		Vertical	
Species	Germ.%	Shoots/ stake	Germ.%	Shoots/ stake
Amapola	58.0	1.0	87.5	4.3
Morera	90.4	2.1	100.0	3.1
Sauco	53.8	1.1	60.4	1.5

Esquivel y Benavides, 1993. Unpublished

Table 15. Dry matter production (mt/ha/yr) for King grass grown in association with *Erythrina* and in monocrop.

Year	Association mean	Check without trees
1	27,0/a	25,8/a
2	17,3/b	19,8/a
Mean	22,1/a	22,9/a

Values with the same letter horizontally do not differ significantly, $p<0,05$.

Benavides *et al.*, 1989.

The association of leguminous trees with grasses can be beneficial in two ways. Firstly, the association provides forage from the associated tree as well as the grass from the pasture. Cut grass production is not affected by the trees since the latter are frequently pruned (2 or 3 times a year) and do not compete for light. Table 15 shows the results of work done in the humid tropical conditions of Turrialba, where King grass (*Pennisetum purpureum* x *P. typhoides*) was grown intercropped with *Erythrina poeppigiana* planted as 2.5 m stakes at 1x3 and 2x3 m (1667 and 3333 trees/ha). No nutrient replacement was given to the soil and all the biomass produced was removed from the site. It was also found that nutrient yields per unit area were three times that of pasture grown in monocrop. Nevertheless, production falls in the short term, in the case of pasture and in the medium term, for *Erythrina*, if material is frequently removed without replacing nutrients.

The other way of utilizing the benefits of the association is to use the *Erythrina* leaves as a green mulch for grasses. In humid tropical conditions with low soil fertility, pasture yields were found to increase when increasing amounts of *Erythrina* foliage (planted at 2x3 m and pruned every 4 months) were applied to the soil. Similarly, it was found that the mere presence of the trees, even without foliage application, stimulated greater pasture production than that for pasture without trees (Table 16).

In livestock rearing, the relationship between animals and the plant component is traditionally one way, the animal benefitting from the plant but not participating in its production. In production systems where animals are managed in stables, a two way relationship can be established by using most of the manure the animals produce as fertilizer. In this way, the system is more balanced and the plant component benefits from nutrients contributed by the animals.

Moreover, those species that have the best forage characteristics are also those which extract most nutrients from the soil and, unlike members of the Leguminosae, cannot fix nitrogen. For this reason they need applications of large amounts of chemical fertilizers. In order to find an ecologically rational solution, goat manure has been tested as a fertilizer in plantations of woody forage species. Sustainably high biomass yields have resulted and, in some cases, the yields have increased over time.

Table 16. *Erythrina* and King grass dry matter deposited, exported and total (mt/ha/yr.) according to amount of foliage added to the soil.

Parameters	Check without trees	Amount foliage added to soil 0%	33%	66%	100%
Produced/1					
Erythrina		9,0	8,6	8,2	9,2
Grass	12,42	21,0/c	20,6/c	26,6/b	30,3/a
Total	12,42	30,0/c	29,2/c	34,8/b	39,5/a
Exported/2					
Erythrina		9,0	6,3	2,2	0
Grass	12,42	21,0/c	20,6/c	26,6/b	30,3/a
Total	12,42	30,0	26,9	28,8	30,3
Erythrina deposited		0	2,3	6,0	9,2

1/ Values with the same letter horizontally do not differ significantly, p<0,01.
2/ Significant differences between check and treatment 0%, p<0,01.
Libreros *et al.*, 1993a

Biomass production in Morera increased significantly in an experiment carried out over three years in Turrialba, using Morera started from 30cm stakes planted at 22,700 plants/ha, with the addition of increasing amounts of goat manure. In fact, for equal levels of nitrogen fertilization, the goat manure produced yields higher than with chemical fertilizer (NH_4NO_3). An increase in biomass production between years was also observed.

With the same planting density and type of stake, positive responses have also been observed in Amapola plantations using the same amounts of manure. However, total yields were less and those with chemical fertilizers were higher (Table 17).

Table 17. Amapola dry matter production (mt/ha/year) by biomass component, according to the amount of goat manure applied to the soil.

	Amount of manure/1			NH_4-NO_3/1	
Component	0	240	360	480	480
Leaves/2	5,8/c	6,2/bc	6,9/b	7,1/b	8,1/a
Soft stem	1,9/b	2,1/b	2,1/b	2,4/ab	2,7/a
Woody stem	6,3/c	6,6/c	7,9/b	7,6/b	8,9/a
Total	14,0/c	14,9/bc	16,9/b	17,1/b	19,7/a
Edible	7,7/c	8,3/bc	9,0/bc	9,5/b	10,/8a

1/ Equivalent in kg N/ha/yr. 2/ Values with the same letter horizontally do not differ statistically, $p<0,05$.
Lopez *et al*., 1993.

In areas with a bimodal rainfall distribution, it is important to evaluate the pruning techniques that will provide adequate biomass levels during the dry months. For this reason, work was done to evaluate the effect of prunings at the end of the rainy season on biomass production during the dry season. In the Dominican Republic, pruning living fence posts of *Gliricidia sepium* in October, November and December, not only delayed flowering, but also produced higher yields and edible biomass growth during the months of less rainfall (Table 18).

Table 18. *Gliricidia sepium* dry matter production (g/tree) during months of dry season.

Component	Pruning month during dry season/1			
g/tree/pruning	February	March	April	May
Leaves/2	288/b	342/b	373/b	528a
Edible stems	66/b	60/c	69/b	96a
Woody stems	118/c	222/bc	315/b	569a
Total	457/c	617/bc	755/b	1192a
Total edible	355/b	402/b	442/b	624a

1/ Mean of initial prunings in October, November and December.
2/ Values with same letter horizontally do not differ significantly, $p<0,02$.
Adapted from Hernandez, 1988

Table 19. Consumption, milk production and in vivo dry matter and crude protein digestibility for Morera and Amapola foliage.

	Goat 1	Goat 2	Goat 3	Mean
Morera				
Intake, g DM/kg$^{0.75}$/day	101,0	109,0	101,0	103,7
Milk, kg/an/day	1,2	1,3	1,3	1,3
In vivo DM digestibility, %	78,4	78,7	80,8	79,3
In vivo CP digestibility, %	99,4	84,6	86,9	89,5
Live weight, kg	34,8	44,9	36,3	38,7
Amapola				
Intake, g DM/kg$^{0.75}$/day	108,0	117,0	102,0	109,0
Milk, kg/an/day	0,8	1,2	1,2	1,1
In vivo DM digestibility, %	64,0	63,9	64,9	64,3
In vivo CP digestibility, %	54,6	51,8	56,6	54,3
Live weight, kg	36,3	44,2	40,8	40,4

Adapted from Jegou *et al.*, 1991

Diet calibration

This stage attempts to generate information to produce diets based on the use of tree foliage. In vivo consumption and digestibility trials must be carried out using metabolic cages and in situ evaluations of breakdown in the rumen. Similarly, metabolic studies and nitrogen balances are done for lactating goats to define more precisely the efficiency with which the nutrients in each type of foliage are utilized. In this way, it has been found that Morera and Amapola foliage have high *in vivo* dry matter digestibility, the Morera showing particularly high digestibility for crude protein (Table 19).

Exploitation of natural prairie and understory

Given that traditional production systems are based on browsing and grazing and the use of natural vegetation in prairies and understories, it is important to study the feeding behavior of herds to find possible ways of improving the system without drastic changes to the producer's methods of exploitation. With this in mind, the work aims to: i) characterize the ways of using vegetation cover and ii) determine the contribution of species taken during browsing on the animals' diets.

Observation of a herd of goats feeding on degraded prairie shows that there is an important variation in the type of vegetation preferred. Whilst in the dry season (March and April) the animals preferred woody species, as soon as the rainy season started, the consumption of herbaceous plants increased markedly.

This type of study has provided an understanding of grazing animals' behavior and not only identified woody species that are most preferred but also which parts of the biomass are used by the animals. It has been found that not only green leaves but also fruits, flowers and dry leaves form important parts of the diet and that each component is taken according to the seasonal variation in availability.

Technology validation and economic evaluation.
The validation of technologies generated by the research process is essential to guarantee their future adoption and to adapt them to real conditions in the production process. The validation process is done in two ways: i) on-farm research in places where much of the work is done, which encourages the chances of adoption and ii) implementing the most promising technologies developed on experimental stations on farms, allowing adjustments to be made according to real-life production conditions.

To date, most of the technologies have been implemented at the level of small farms, for goat production systems designed for family consumption.

Apart from the technology aspect, it is essential to know the economic yield of the alternatives generated, both at the experimental level and at the site of production.

For the economic evaluation, the following have been carried out: a partial budget analysis of the experiments done at field station level, a profitability analysis (cash flow and income) *ex post* of the technologies implemented on the demonstration module and an analysis of family benefit and cash flow and income at farm level.

The analyses carried out to date indicate that applying the technologies with forage trees in farms is profitable and that their presence contributes to an improvement in the economic situation of the family.

In lactating goats fed on a basic pasture diet, the use of *Erythrina* foliage and other agricultural sub-products (rejected bananas) as a supplement gives a better return than using concentrate feed, even though the latter gives greater production (Table 20).

The cost of foliage (from planting to administering as feed) that is nutritionally similar to commercial feeds is much lower than these. This accounts for the greater profitability found in the agroforestry demonstration model run by CATIE, where the goats are fed exclusively on pasture and Morera foliage (Table 21).

Table 20. Milk production, dry matter consumption and economic benefit obtained from two diets fed to stabled lactating goats.

Parameters	Pasture + *Erythrina* + banana	Pasture + concentrate
Milk, kg/animal/day	1,1	1,3/1
Intake		
King grass	0,5	0,5
Ripe banana	0,6	
Erythrina	0,4	
Concentrate		0,7
Total	1,5	1,2
Partial benefit, US$/animal/day	0,6	0,5

1/ $p<0,05$.
Gutierrez, 1985.

Environmental impact evaluation for the technologies.
An attempt has been made to identify and, where possible, quantify the effects of the new and traditional technologies on the soil and vegetation. The aim is to produce recommendations designed to ensure sustainability of production and optimize the use of natural resources. In the case of soil, it is important to find out the effects on chemical and physical characteristics and, although this information is normally detected in the long term, it is useful to monitor changes.

Part of the research into forage trees is to develop techniques for plantations which provide soil conservation in areas suffering problems with erosion. Thus, shrub species can be used to control soil loss since they can be planted at high density, are perennial and can be grown in association with other crops.

Table 21. Cash flow (US$) for the financial analysis of the agro-forestry demonstration model for goats in Turrialba, Costa Rica.

Description	1991/92	Years 1992/93	1993
A. Costs			
A.1 Investment			
Morera and *Erythrina*	4,61	4,61	2,88
Pasture and *Erythrina*	1,66	1,66	1,04
Installations	16,07	16,07	9,37
Breeding stock	50,00	50,00	31,25
Subtotal	72,34	72,34	45,21
A.2 Fixed			
Opportunity cost for land	21,17	21,17	13,23
A.3 Variables, labor			
Pruning, weeding, cutting, transport	182,65	176,19	109,77
Leaf stripping, chopping and feeding	138,45	133,55	83,20
Milking	89,05	85,90	53,52
Goat shed cleaning	54,60	52,67	32,81
Manure fertilization	26,00	25,08	15,63
Salt	30,66	30,66	19,16
Deparasitization	1,40	1,40	1,40
Maintenance	6,50	6,27	3,90
Subtotal	455,31	511,72	319,39
Total cost	527,65	584,06	377,83
Discounted cost stream	610,82	643,92	396,72
B. Income			
B.1 Milk production	672,66	813,99	549,03
Discounted income stream	778,68	897,42	576,48
C. B - A discounted	167,86	253,50	179,76
B/C 1,36	1,27	1,39	1,45
NPV/1 601,12			

Oviedo *et al*., 1993
1/ NPV = Net Present Value

Over a three year period, two types of Amapola plantation were established on a hillside site with serious erosion problems. The two plantations were:Amapola sown in high density along the contours, associated with grass and Amapola sown along the contour with a greater separation between rows and associated with corn. Soil loss was compared with a plot of corn grown in the traditional way (bare soil). A measurement of the amount of soil eroded per year showed that the loss was less in the Amapola plantations.

Impacts of research on agroforestry with goats

One good example of the effect that the technologies developed have had is the changes made in exploiting goats in Costa Rica over the last decade. In this country, at the same time as the use of woody forage species has increased and the use of grasses has decreased there has been an increase in the size of herds and the levels of milk production per animal.

In summary, research into forage trees and shrubs carried out by CATIE has:

i) Demonstrated the feasibility of introducing an agroforestry focus as a non-traditional livestock research alternative.

ii) Developed silvopastoral production technologies which considerably increase sustainability and productivity per unit area and can be transferred to small and medium sized farms and adapted to the conditions of large producers.

iii) Favored the definition and organization of institutional policy and the creation of infrastructure for research and promotion of silvopastoral and forage tree systems in the countries of the region.

iv) For the first time in Central America, trained highly qualified professional personnel on forage trees by means of postgraduate studies, intensive courses and in-service training.

v) Generated knowledge on the alternative uses of natural resources and tropical biodiversity, which can be used for the promotion, formulation and execution of research and promotional projects in Central America.

Conclusions

The research conducted to date in CATIE on forage trees shows that:

i) The foliage of many species of trees and shrubs can improve the quality of diets traditionally used for feeding animals. The crude protein content of this foliage is usually double or triple that of grasses and, in several cases, the energy content is also higher, even when compared to commercial concentrates. Their presence in the diets significantly increases milk production and weight gain in the animals.

ii) Many species of trees produce abundant quantities of edible biomass per unit area, can tolerate pruning and are easily managed, from an agricultural point of view. In associations of pasture with woody forage species, the production of crude protein per unit area can be significantly increased over that obtained from grass in monocrop.

iii) In association with pastures, some tree species have no effect on or even significantly increase the production of the grasses.

iv) During the dry season, trees can produce larger quantities of forage than can be produced by pasture, and in a more sustainable form, where chemical fertilizers are not used.

v) Since forage species can be found in most of the life zones of Central America, silvopastoral systems can be developed in many ecological conditions. Moreover, because of their agricultural versatility, they can utilize places with area limitations without competing with other agricultural activities.

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