Small ruminant management and feeding with high quality forages in the Caribbean




I. Hernández and M. D. Sánchez

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Editorial coordination: Manuel David Sánchez Hermosillo/Ismael Hernández Venereo.
Diagrammed: Saira Morla, IICA.
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Ismael Hernández Venereo

and

Manuel David Sánchez Hermosillo

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ABOUT THE AUTHORS

Ismael Hernández Venereo

Agronomist with major in forage production from Matanzas University, Cuba (1982), M.Sc. in Sustainable Agricultural Systems at the Center for Tropical Agricultural Research and Higher Education (CATIE), Costa Rica (1996), Ph.D. in Agriculture at the Agrarian University of the Havana, Cuba (2000) and Academic Doctorate in Agriculture from the Costa Rica University (2010). Researcher and Director for Research at the Indio Hatuey Grass and Forage Experimental Station of Cuba (1982 to 2005). President of the journal "Pastos y Forrajes" of Cuba. Founding director of Organix S.A., a consulting and technology firm on sustainable agriculture based in San José, Costa Rica (since 2005). He has been consultant in several projects for FAO, IICA, and other organizations in several Caribbean countries, Mexico, Costa Rica, and Panama. He was the main forage consultant for the project "Appropriate Intensive Small Ruminant Production Systems for the Caribbean based on local feed resources" which was implemented in Barbados, Dominican Republic, Jamaica, Surinam and Trinidad and provided funding for the preparation and publication of this book.

Manuel David Sánchez Hermosillo

Agronomist with major in animal production from the Universidad Autónoma de San Luis Potosí, México (1977), with M.Sc. in animal nutrition from the University of Aberdeen, Scotland (1979) and a Ph.D. in nutrition from the University of California, at Davis, USA (1984). He worked in research and development in small ruminant projects in Haiti and Indonesia, and has worked in many countries around the world with feed resources and alternative feeding systems, including from 1993 to 2003 as animal production officer in the Feed Resources Group, Animal Production and Health Division of FAO, Rome, Italy. He was Secretary for Agricultural Development at the State of San Luis Potosí, México from 2003 to 2009, and has been IICA country representative in the Dominican Republic since 2010. He was the technical leader of the project "Appropriate Intensive Small Ruminant Production Systems for the Caribbean based on local feed resources".

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This publication summarizes the experiences and knowledge acquired by the authors on small ruminant and forage production research and development over three decades, thanks to various institutions and projects.

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INTRODUCTION

Small ruminants have been part of the history of the Caribbean since the colonization with arrival of goats from Spain and hair sheep from West Africa. Over the course of the past five centuries, people in the various countries have reared small ruminants, have acquired the taste of their meat and have developed traditional dishes and cooking methods.

The most popular meat is from goats, and although currently much of the meat comes from sheep as well, but it is often sold as goat´s. A butcher in the Dominican Republic said that his costumers were reluctant to buy sheep meat, because it had a “sweet flavor”, and they were cautious when they saw the sheep skin still on the carcass. But as soon as the skin was removed, they could no longer differentiate between the two species, and they did not hesitate to buy if they were told it was goat´s. In fact, once the meat is cooked in the traditional way, very few people can tell the difference between the two species. In most restaurants in the region the menus include dishes of goat meat, seldom of sheep.

One notable exemption is Barbados, where they are proud to have one of the most important breed of hair sheep in the Americas, the Barbados Black Belly sheep. In this case, mutton and lamb are sold by butchers and supermarkets, and local restaurants offer sheep meat dishes.

In the other countries where lamb or mutton are advertised in the menu, the meat is mostly imported and comes from wool or meat-type animals from temperate climates. This is a completely different kind of product, with a distinct flavor given by the intramuscular fat, which hair-type sheep do not have.

In most Caribbean countries, the traditional way to rear small ruminants has been under extensive grazing, with animals free to roam around most of the day, and at night, in the best cases, confined in a corral equipped often with a simple shed. During the day, the animals browse and graze a variety of forages resources in the areas where the natural vegetation and the climate are suitable, using their nutritional wisdom to balance their diet in order to fulfill their nutrient requirements. In parts of the larger islands, and in the whole area of many small islands, goats and sheep are seen going around everywhere, even within the city boundaries. The appropriate conditions and the absence of major predators have allowed the small ruminant populations to remain, despite the frequent attacks by dogs.

These extensive systems, particularly with limited or no managements at all, are productive to a certain extent, depending on the management and the richness of the natural vegetation. But considering that they require minimum investment, they are therefore, very profitable. The most important activity from the animal owner, if not the only, is harvesting the animals, young or adults, when there is a need.

For centuries, this extensive system thrived, and it still does in many areas, satisfying the local meat markets, but with the increase in demand as a result of the growth of local populations and that of the tourist industry, this it is no longer the case, and in many islands the small ruminant population is decreasing. In many others, the extensive systems do not longer satisfy the current meat demands.

With the objective of increasing small ruminant meat offer, there have been numerous attempts to intensify production in various countries in the region. Except in a very few recent cases, most of these initiatives have failed. Various initiatives to raise meat production, or to start milk production from dairy goats, have been short lived, unprofitable or maintained only as a hobby, at very high cost. Two are the main reasons for this overall failure in intensive small ruminant production: internal parasites and nutrition.

In this part of the world, mainly due to the physical isolation caused by the insular nature of the countries and the relative small flock size, there are few diseases affecting small ruminants, and by far, the most important health concern is internal parasites, *Haemoncus contortus*, in particular. Fortunately, once the life cycle of this potentially very harmful worm has been understood, it can be easily controlled by breaking it. The typical approach using anthelmintic drugs does not work in the long run, and the damage to other creatures in the soil is severe.

The most important limitation for successful small ruminant production has clearly been inadequate nutrition. And the main explanation for this has been the failure to recognize that small ruminants have higher nutrient requirements than large ruminants, and that they should not be fed the typical forages used for cattle, which have largely been grasses. Sheep and goats are simply unable to consume, to ruminate and to digest grasses in general, at the rate they require for acceptable levels of production. When the animals are free to move around, they choose the most nutritive plants or parts of them, in order to fulfill their nutrient needs. In these circumstances they might consume some grasses, but always in low proportion compared to other forages with much better quality. The situation gets much worse when small ruminants are under confinement, either in paddocks or in corrals, and they are forced to eat the low quality grass forage. If they have no choice, they will consume it, but adequate performance can only be obtained if the grass diet is supplemented with other feeds, either agro-industrial by-products, crop residues or commercial feeds. Unless these supplements are of very low price, which is often not the case, this supplementation practice seldom pays back.

When both limiting factors are combined, grass pastures with heavy internal parasite load, the results are disastrous: very slow growth rate of young animals and high mortality.

These are the main reasons why the attractive market of small ruminant products has not been satisfied by local production, the causes of the overall failure of goat and sheep production systems in the Caribbean.

However, there many examples where farmers, more than technicians and researchers, have realized that small ruminants benefit from better forages and are already mixing grasses with legumes and other high quality forages, seeing the results in terms of general well-being and productivity.

The purpose of this publication is to explain the most important management practices and forage resources which can contribute towards sustainable and profitable small ruminant production systems based on local feed resources, mainly high quality forages. In some islands, due to labor and land constraints, small ruminant production would not be longer viable at any significant levels, but in other countries, particularly those with extensive unused land resources, there is a tremendous potential to produce small ruminants, to develop very profitable enterprises and to supply the current and future market demands of the region and beyond.

SMALL RUMINANTS PRODUCTION AND FEEDING SYSTEMS

FREE RANGING

By far the most important production system for rearing small ruminants in the majority of the islands is still the free ranging, both in state or private lands. Animals are let loose in the mornings, if they are kept at night in corrals at all, because in many instances animals just sleep outside nearby rural settlements, and spend the day roaming around looking for feed and water.

The small ruminants, similar to wild animals, naturally know what to look for as feed in order to fill their daily nutrient needs for maintenance, growth and reproduction. They learn for their mothers, and from other members of the flock by imitation, what to eat and how, and the also which plants and their parts to avoid, so as order to prevent poisoning or physical discomfort.

Although sheep and goats could thrive in a variety of environments, they tend to do better in semi-arid lands and in island ecosystems with mostly dry weather and with a variety of shrubs and small trees where they find tender leaves, fruits, seeds and flowers. Both species tend to look for and prefer the most nutritious and palatable feedstuffs within their reach. However goats, with their ability to stand up in their hind legs, can reach higher and thus are able to consume more, and sometimes better, feed resources than sheep and they often look physically better.

Goats in the Caribbean and Latin America have not yet learn to climb trees as they do in North West Africa, skill which allows them to ingest leaves and pods unavailable from the ground level.

Free ranging sheep in Jamaica.

Free ranging sheep in Antigua.

Production constraints
Since the introduction of the small ruminants, the free ranging systems, with minimum or no management, have provided the meat that local populations demanded. Nevertheless, in most places it is no longer the case, production levels are insufficient and unable to supply the constantly increasing demands from local and regional markets.

The most important losses in production come from offspring mortality due to starvation, malnutrition, myiasis from screwworm (*Cochliomyia hominivorax*) and parasitism, and unfortunately, also from predator attacks (mainly dogs) and theft. Most, if not all, these production constraints, can be reduced or minimized with adequate installations and proper flock management.

Historical environmental damage
After five centuries of the existence of the free ranging systems, with virtually no management or care of the natural vegetation from the part of livestock owners, there has been the gradual reduction in what it is called, the carrying capacity of rangelands. This was due to the disappearance of the most palatable species from repeating consumption, and the encroachment of undesirable, or less desirable, plant species. In many cases there has been a serious loss of biodiversity, and only unpalatable and/or very spiny species have remained. Some of these remaining plants are members of the Cactaceae family, particularly well adapted to arid ecosystems thanks to their Crassulacean metabolism, which allows for the gaseous exchange to take place at night when there is less loss of water, and to the presence of spines and thorns, which protects them from excessive and repeated consumption by domestic animals.

Improved management opportunities
In free ranging systems there are however some technological interventions which can make them much more productive:

Breeding strategies. The natural year-round mating, which results in births throughout the year, including some of them during the most difficult months when there are shortages of feed and water, can be greatly improved by **seasonal mating**. The ideal situation is to have most, if not all, the offspring born in the best time of the year, that is, well into the rainy season with abundant feed resources. For this to happen, males should only be allowed to breed females around 5 months previous to the best season. Two full estrus cycles are normally required to have all the open females successfully bred. That means, approximately 34 for days for sheep and 42 days for goats, considering that the estrus cycles last, 17 and 21 days, on average, respectively. Males can be left all day with the females during this time, or they can be kept separate, and allowed to breed only when the flock comes back to the overnight corrals.

If there are no restrictions in feed availability throughout the year, a seasonal mating in large flocks can be implemented by keeping the males with the flock for two full heat cycles (around one month) and then three months separated. This means that

all cycling females will get bred in one mating period, and the rest in the next mating season, four months later. In practice, the female flock naturally divides in two similar size groups, which will get bred in alternative breeding periods and results in parturition intervals of 8 months, or 1.5 parturitions per year. This is below the physiological potential of 2 parturitions a year, but it is deemed adequate for large flocks taking into consideration the advantages of a well-defined birth period and the risks and uncertainties of the continuous mating.

An even more sophisticated system is **hand mating**, in which males are permitted to identify, by sniffing, the females on heat, and allowed to breed them just once, either in the evening or in the morning, and then once again 12h later, if the females are still receptive. This way, individual reproduction records can be kept which helps in predicting approximate parturition dates and to prepare with facilities, feed and staff to receive and to take proper care of the new born.

Strategic supplementation. Most natural ecosystems suitable for small ruminant rearing provide all nutrients in enough quantities to meet their requirements. There are however some exceptions. Sodium in the form of salt (Sodium chloride) is normally provided as supplement since naturally most forages and feeds do not contain enough of it. Animals search for sodium when the diet is deficient, which occurs very often. The best way to provide sodium is the form of salt blocks, with or without other minerals, because goats tend to consume salt in excess of their requirements if offered in loose form. Salt blocks can be purchased or easily manufactured on the farm. The blocks can also contain specific minerals, missing in the local soils or in low concentrations, and thus in the forages, which could cause deficiency symptoms in the animals.

If the natural vegetation is seasonally of poor quality, usually meaning with low protein content, then, it is advisable to provide extra nitrogen for optimum rumen functioning (FAO, 1986). That is, for adequate digestion of the basal feed, rumen microbes need to have enough nitrogen. The most common way to provide nitrogen to the animals is in the form of the so-called, molasses or multi-nutrient blocks (FAO, 2007).

In order to increase flock prolificacy, in other words, the number of offspring born per female per *partum*, flushing can be practiced. Flushing means to provide a feed supplement to raise female nutritional level beginning one month prior to the breeding season in order to increase ovulation rates, and consequently, the number of offspring per parturition. If the overall feed availability is inadequate, if animals have to walk long distances to procure their feed, then, it surely better to have only one strong young offspring, than two weak ones. Many small ruminant farmers in fact prefer singles, over twins or triplets, when animals are kept in free ranging conditions. In these cases, flushing is not advisable.

Sometimes feed supplementation, salt blocks and/or water, are provided with the main purpose of getting the flock used to come back to the corrals, or to a certain place, on a daily or regular basis, giving the owner the opportunity to count the flock

and to inspect the animals, in order to be able to detect weak or sick animals and for culling purposes.

Vegetation management. Several practices are employed in order to improve forage availability, seasonally or year around, from natural vegetation. **Fencing** is one of the most practiced methods to restrict the access to forage resources in a certain area, both from own and external animals, in private or leased lands, or to divide grazing fields. For fencing to be effective, the approximate carrying capacities of the land during the various periods of the year need to be known, so as to prevent overgrazing, which can result in deterioration of vegetation and reduction in carrying capacity.

Thinning of vegetation, particularly removing undesirable species, gives the opportunity for the beneficial species to prosper, providing there is a sufficient rest period for them to growth back after grazing.

A very interesting system developed in Brazil (Araujo Filho & Carvalho, 1997) for the Caatinga vegetation in the northeast, which involves the removal of certain trees and shrubs, coppicing of others and the planting of leguminous species, increases overall and seasonal forage availability and quality, and consequently, animal performance. The general strategy and the techniques of this work could easily be used to improve the management of natural ecosystems for small ruminant production in several regions and islands.

Management of natural vegetation in NE Brazil.

Sheep fed tree leaves in the Bahamas

In the Bahamas, farmers practice pruning of tree branches to supplement their animals in times of forage shortages. For certain trees with very palatable foliage, they prune the branches to keep it out of animal's reach in order to prevent frequent consumption and consequently, tree damage.

Rotation of pastures during the year, allows for vegetation to regrowth and the gradual modification of the composition, the increase of the density of a particular species and also the introduction of new species.

INTENSIVE GRAZING

There have been many attempts to develop intensive grazing systems for sheep and goats in the region, but unfortunately most have failed, or have not reached the production expectations. The main reason has been mentioned, the fact that these efforts have had grass species as the main source of forage.

Goats grazing legume pastures in Andros island, Bahamas.

Pelibuey sheep in grass pastures in the Dominican Republic.

The low quality of grasses and the resulting poor animal performance, can be partially compensated by providing supplements, usually agro-industrial by-products or commercial concentrates. However, the profitability of supplementation is often in doubt, unless supplements are acquired at subsidized price or for free.

There have been however, various successful intensive grazing systems targeting small ruminants, mostly based on legumes. Three examples are given.

Fruit tree plantations with legume cover crops. With an initial support from a letter of agreement, when one of the authors, M.D. Sánchez, was working at FAO headquarters in Rome, scientists in the Ciego de Ávila province, Cuba, initiated a series of studies and research trials in order to develop production systems for sheep associated to citrus and other fruit tree plantations using legume cover crops (Borroto *et al*, 2007). One of the most successful species for these systems was *Teramnus labialis*, but other legume species also gave good results. These legumes are more palatable than the citrus foliage and consequently the animals tend to reduce tree damage. It is however, of outmost importance no to leave the animals in the orchards for long periods of time, certainly never beyond grazing times, to prevent vicious behavior during resting times. Other methods, like aversion with Lithium Chloride (Burritt and Provenza, 1990), can be used to persuade the animals not to consume the tree leaves.

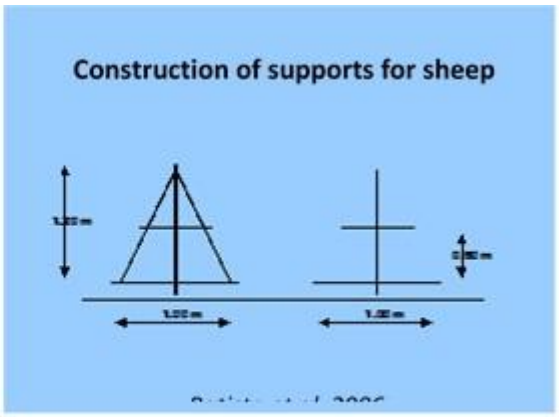
Intensive silvopastoral systems. Following the tremendous success of the leucaena-based systems that have having for cattle both in Colombia and in México, these intensive silvopastoral systems are now starting to be used for small ruminant production, sheep in particular. All the advantages concerning forage (quality and quantity) and animal comfort remain, with very attractive growth rates. These systems have finally demonstrated the vital role of legumes as high quality forages

for small ruminant production in tropical areas and have opened a large opportunity for yield increases and business. The rotational use of paddocks maximizes forage performance, and the combination of better animal nutrition and health, with minimum exposure to larvae virtually eliminates the internal parasite problem. The Cuban version of the intensive silvopastoral systems for bovines, containing climbing legumes in addition to the leucaena in the browsing component, is also being successfully used for small ruminant production in that country.

Sheep in silvopastoral system in México.

Pedestals. An interesting system for ruminants, both large and small, proposed and demonstrated at research level in Cuba, is the so-called “pedestales” (CENPALAB, 2001; Batista *et al*, 2006). It consists of lines of galvanized wire frames sustained by concrete posts of triangular shape, serving as support for climbing legumes (see illustration). Animals walk among the corridors and have access to the forage. This artificial structure resembles the Cuban style silvopastoral system described before, with the wire frames replacing the shrub legumes. Animals can be rotated on a daily basis using electric fences to maximize forage quality and quantity. Several climbing legumes, like *Teramnus labialis*, *Clitoria ternatea*, *Neonotonia wrightii* and *Macroptilium atrpopurpureum*, can be used for this arrangement. The main difference between the pedestal systems for large and small ruminants is the space between the frames, which in the case of cattle allows presence of a grass component, not needed for the sheep and goats.

Pedestals (Photo from CENPALAB, 2001)



Structure of pedestals (Photo from CENPALAB, 2001)

COMPLETE CONFINEMENT

Keeping small ruminants in complete confinement, fed either forages, agricultural residues and/or agro-industrial by-products, has been practiced in South East Asia for a very long time. Population density, intense cultivation and the need for manure, are factors which have influenced the development of this system. Farmers in this region of the world are used to collect forage from public lands (road sides, railway sides, common lands, tree plantations, etc.) to feed their animals, and in return they have animals to sell for religious festivities, at the beginning of school year or for emergencies (weddings, funerals, etc.) and on a daily basis, they have a very valuable fertilizer. In fact, in many instances, manure is the main reason to rear small ruminants in complete confinement, since it is greatly needed and appreciated to fertilize horticultural and fruit crops.

In the Caribbean and tropical Latin America, keeping small ruminants in confinement is a more recent practice, perhaps only for few decades, and it started with dairy goats followed by sheep and meat goats.

The main advantages of keeping animals in complete confinement is that virtually all the production and health constraints can be rather easily overcome, particularly if the housing is well designed and the diet is correct.

Feeding options for complete confinement systems

Crop-residue based diets. Feeding small ruminants with agricultural residues has been practiced in many places and it currently is very important in China. When crop residues are of high nutritive value, like sweet potato vines or mulberry refusals for silkworm rearing for example, there is no need for any other diet supplements, since these forages are a complete feed on its own for sheep and goats. But if the main diet component is a lower quality cereal straw, then a nitrogen source is required for proper rumen functioning. Unless the straw has been ammoniated (with urea, ammonia gas or ammonium bicarbonate) when there is no need for extra nitrogen and only a source of by-pass nutrients (energy and/or protein) is used to boost animal performance (FAO, 2002). The molasses multi-nutrient blocks are very useful supplements when feeding these low nitrogen basal feeds (FAO, 2007).

Agro-industrial by-products based diets. When a variety of agro-industrial by-products, grains and some crop residues are available, then the diets for small ruminants can be specifically designed to meet nutrient requirements. Least-cost formulation is used when many feedstuffs are available, prices vary frequently and technical advice is available to farmers. Otherwise, the system proposed by T. Preston (FAO, 1986) can easily be used and gives excellent practical results. Following this approach, the strategy for feeding small ruminants has five main points:

- Selection of a carbohydrate-rich resource, the most abundant and/or inexpensive feedstuff, locally available and suitable for small ruminants

- Provision of enough fermentable nitrogen (via urea or ammonia) to reach 2.5-3.0% of nitrogen in the diet.
- Addition of other minerals as required. Sulfur is usually the next limiting mineral after nitrogen, for proper rumen functioning.
- Provision of a highly digestible green forage at 10-20% of diet dry matter to further encourage rumen digestion.
- Supplementation with a source of by-pass protein (oilseed meal, fish meal, meat meal, cereal brand or dry tannin-rich legume leaves) and by-pass energy (rice polishing or cracked maize) at 5-10% each of diet dry matter, depending on specific animal responses.

The authors M.D. Sánchez has used this methodology to design research and practical diets for small ruminants obtaining, in most cases, excellent animal performance.

High quality forage based diets. For the last two decades, starting from the studies at the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE, 1994 & 1995), there have been many institutional and private initiatives to rear small ruminants, with cut-and-carry legumes and high quality forages. The emphasis have been on dairy goats, but more recently on sheep and meat goats. The main advantage of the diets, based on highly digestible forage resources, is that animals perform very well without additional feed. However, performance can be further improved when giving an energy-rich complement, since in diets based on high quality forages there is usually an excess of nitrogen, above the rumen microbes needs, that can be taken advantage of with some extra digestible energy.

One of the most popular forage for confinement systems has been mulberry (FAO, 2000), justified by its very high nutritional value and exceptional yields when properly fertilized. Other legumes and high quality forages have also been used successfully, simplifying the task of properly feeding small ruminants.

The description of the most important high quality forage species is a major component of this publication.

HOUSING OF SMALL RUMINANTS

In tropical areas where the animals spend the night, in grazing systems, or live all the time, in confinement systems, becomes a very important factor for their wellbeing, particularly of the young, and thus, for the overall flock performance and productivity.

In most extensive systems, animals are provided with a corral, a pen, to spend the night with a simple shelter to protect them from the rain. This is particularly important for goats, which do not like to get wet, but it is beneficial for both species, because humid conditions are not good for the health of young animals of either species.

FLOORING

Ground corrals. Most holding pens have been built in the dirt, although in some cases have cement floors, and often have a shed to protect the animals from the rain and solar radiation. But, particularly under a roof, the humid conditions caused by urine, feces and rain water, both in dirt or cement floors, do not result in the best environment for small ruminants from the sanitary point of view. These simple corrals seldom have enough slope to facilitate draining and cleaning, and particularly during the rainy season are too humid for a healthy environment.

An option to resolve the humidity problem is the use of bedding. One of the best bedding materials are wood shavings, but others, like rice hulls and a variety of cereal straws can also be used. The bedding is eventually removed, when it becomes saturated, and is utilized as valuable fertilizer.

A goat pen with a dirt floor.

Elevated pens. A good option for animal wellbeing, the permanent solution for the humidity and health problems in animal housing and the best option to recover the valuable nutrients contained in feces and urine, each fraction containing approximately half of the nitrogen excreted by the animal, are definitely the elevated pens with slatted floors.

The type of materials used for elevated pens depends on availability, building traditions and costs. In many places, the slats are made from wood, and the smaller the width, the cheaper it gets because less wood is needed. For instance, using 2-inch slats requires 17% less board-feet of wood than 4-inch slats. Two inches would be the minimum width for adequate animal support and comfort in wooden slats. Other options are concrete, cast iron or plastic slat flooring, similar to swine pens.

In any case, research is needed for the ideal type of material for small ruminant pens from the points of view of animal comfort, hygiene and hoof wearing as it has been done for swine (Pedersen and Ravn, 2008).

In current slat floors, frequent hoof trimming is necessary to prevent leg problems, since animals do not walk much and the surface is not abrasive enough for normal wearing of hooves.

Goats in confinement owned by women producers in the Dominican Republic.

Elevated pens in Saint Lucia

Elevated barn in Suriname

Goats in partial slatted floor.

Slatted floor in Trinidad.

ROOFING

The type of roof for small ruminant elevated pens and corral sheds varies a lot depending on size, design, available materials and economic resources. Factors to be considered are durability, functionality for water collection, storm (hurricane or strong wind) resistance and heat transmission.

The ideal roof is the one that allows rainwater collection separated from feces and urine, that lasts long time and is reasonable cool, in order words, it does not irradiate much heat (infra-red waves) to the animals on sunny days.

Tin roofs are a compromise between functionality, durability and cost, and if properly insulated in the inner side, they maintain an adequate environment as far as temperature is concerned.

Small elevated pens are often covered with palm leaves, which are very suitable for animal comfort, but durability depends on material quality, thickness and slope (The greater the gradient or pitch, the more durable). In small pens, the roof should be high enough to prevent the animals to chew on the leaves. This is particularly important for (large) males which, standing in their hind legs, can reach beyond 7-8 feet, depending of their size.

FENCES AND WALLS

In outdoor pens, fences need to be strong and tall enough to provide adequate protection from predators, dogs in particular. Chain-link (cyclone) fence is often the best option but expensive. For increased security, fences should be buried at least one foot, and barb or electric wire place on top in order to halt dog attacks. Dogs are known to be very smart, particularly in finding ways to get into the small ruminant pens, thus there should be no hesitation in reinforce security measures to prevent their attacks, which could be disastrous event for the flock and the producer.

In raised pens, the main thing to look for is to avoid goats to climb and get out. This is why wall should be preferably made with stick or boards placed vertically, with horizontal boards positioned at heights that can´t be used as support to climb.

FEEDERS

Two kinds of feeders are usually used, the normal troughs for dry feeds (concentrates, agro-industrial by-products, etc.) and the "hay rack" type for fresh and dry forage.

Feed troughs. Several characteristics are important for these feeders to be functional:

- Easiness for cleaning.
- Access that allows only the head and neck to get in, never the feet.
- Access that prevents the young to enter (to step on and contaminate the feed)
- Access that prevents the adults to easily retrieve their heads with forage still in their mouth (to reduce wastage).

Racks. The important characteristics for forage racks are:

- Large enough to hold sufficient forage so as to reduce delivery to once or twice a day.
- Position high enough to simulate browsing (animal performance is better when animals eat with their head pointing upwards).
- Large enough access for the animals to easily consume the forage but small enough to prevent them pulling out the branches.

Access to feeders.

Both feeder types should be ideally located under a roof to prevent feed damages from rain water and should be long enough to allow all the animals present in a particular pen to eat at the same time, this to avoid fighting and injuries. Within the corrals and pens, feeders should be located where there is easy access to deliver the feed/forage and to remove the waste.

Creep feeders. These are feeders specifically designed for access only by the young, and allow special supplementation specifically directed to them. In confinement systems creep feeders should be considered in the original designs to avoid improvisations and space constraints.

WATER

Since potable water should be available at all times, water troughs or dispensers should be easily accessed to animals of all ages. Again, the most important thing is that water does not get contaminated from feed, feces or urine, and for that reason, it should be located at a prudent distance from feeders. Nipples and water troughs with float valves reduce waste and assure availability 24h a day.

Inadequate water container.

Ample pen with adequate drinkers.

Automatic water through and salt-mineral feeder.

Feeder designed to reduce feed wastage.

HANDLING CORRALS

In large flocks, particularly in extensive systems, it is preferable to construct handling corrals specifically designed for adequate animal management without unnecessary stress. Several pens might be needed depending on flock size, but in order to separate the animals by class, sex, size, etc. a circular crowding pen and a sorting alley are convenient. These are constructed 3-feet height with solid or non-see-through fences and gates. The crowding pen has two center pivot swing gates to move and directs the animal to wherever desired pen (Newton, 1983). The construction material could be lumber, exterior plywood, steel or zinc sheets.

In order to quickly move animals in alleys, they need to see light at the end, otherwise it becomes very difficult to make them walk.

MANAGEMENT

This publication is not meant to be a complete treatise on small ruminant production. Only the most relevant aspects and issues regarding management are included, those which can make a difference under practical field conditions in tropical areas.

BREEDING

There are two main aspects regarding breeding of small ruminants, the animal breeds themselves and the breeding system.

Breeds. Being very popular domestic animals everywhere and having been domesticated for thousands of years (> 12,000), there are hundreds of breeds of sheep and goats in the world, particularly in Europe and Asia (Iñiguez, 2005, Iñiguez & Mueller, 2008). However, in tropical areas of the Caribbean and Latin America, there are only few breeds of each species (Devendra & Burns, 1983; Fitzhugh & Bradford, 1983). The early arrivals of small ruminants to the Caribbean came from Spain (goats) and from Africa (sheep). The importation during the last decades have mainly been from North America (USA and Canada).

Goat breeds. The main goat breed in the Caribbean is the Criollo, descendant from the first animals brought by the Spaniards in the XVI Century. It is considered a meat breed since its milk production is low (< 1 liter/day). In the various islands, it has been crossed with other modern breeds, but in general, its traditional characteristics of rusticity and hardiness, especially under the hot and humid conditions prevailing in many islands, have persisted.

Other popular breeds for meat are the Nubian, which also produces milk and thus, can be considered a dual-purpose breed, and more recently, the Boer. Among the dairy breeds, the Alpine and the Saanen (highest milk yielders) are commonly found in most countries. Less abundant are the Toggenburg and the La Mancha.

All goat breeds can do well in the tropics provided they are fed and housed properly since they adapt well to environmental conditions. The choice of breed depends on local availability of breeding stock and on preference. Nevertheless, dairy breeds need better care than meat breeds, and should be kept preferably in confinement, protected from solar radiation and physical dangers, if high yields are expected.

Sheep breeds. The only sheep breeds suitable for the American tropics are the hair-type breeds. Past attempts to bring wool type meat breeds from temperate countries have failed. The presence of wool is a deterrent for heat dissipation which affect ram fertility.

Most of the original hair sheep breeds came from West Africa, like the Pelibuey (Cuban Red), the Barbados Black Belly and the Saint Croix. Both the Pelibuey and

the Saint Croix are much less prolific than the Barbados Black Belly, which can give above two lambs per lambing, and depending on the management and nutrition levels, nearly twice per year. Thanks to this prolificacy and the better overall resistance to parasites, the Barbados Black Belly has been the most popular breed in the Caribbean, and should be the breed of choice for intensive production. Pelibuey and Saint Croix are fine breeds for standard farms, especially in extensive systems, where a lot of walking is involved and feeding is suboptimal.

In terms of carcass meat yield and quality, the Katahdin and the Dorper show much better characteristics. The Katahdin is a breed developed in the USA from the Saint Croix with crosses and selection with other meat wool breeds. The Dorper comes from South Africa from crosses and selection between the Dorset Horn and the Blackhead Persian.

In order to take advantage of the prolificacy of the Barbados Black Belly and the meat qualities of the Katahdin or the Dorper, the **terminal crossing** strategy can be used. This means that the females are Barbados Black Belly and the rams from either of the two meat breeds, but all the resulting offspring, both males and females, are destined to the market, never kept for breeding purposes, otherwise the advantages of the system are lost. Terminal crossing will become more relevant as production is intensified and linked to more demanding markets.

Breeding systems

Continuous breeding. In the most extensive systems, in those with low management and in small flocks under confinement, males are often left with the flock at all times, year around. This has the advantage that all females in heat get bred, without intervention from the farmer. It has however, two main disadvantages, the first is that the farmer never knows exactly when the females are going to give birth, although experience and close observation can give some clues of the proximity of parturition. But the second, and most important, is the fact the young females become usually pregnant at their first estrus, which normally occurs when they are still growing, well before they attain their potential body size. Since physiologically, pregnancy has priority over growth, these young females remain small and in turn, give birth to smaller than average offspring, which have higher mortality risks in early life, both from their smaller size and from the less milk production capacity of their rather stunted mothers.

The only way to avoid unwanted breeding is by keeping apart the adult males from the rest of the flock, or at least from the females, and to separate or to castrate the young males.

Seasonal breeding. In large flocks or when there seasonal variation in forage availability or quality, it is better to breed at pre-determined dates. This way, the farmer with a large flock will know when the season for lambing or kidding will begin, and can prepare for it, with extra labor, pen space and feed resources.

In the production systems section, the seasonal breeding to achieve 1.5 parturitions per year (every 8 months) was explained. The scheme is below the physiological potential, but for large flocks it makes sense so as to reduce mortality. In any case, birth seasons in large groups can be very chaotic, especially when a large group of females comes backs from the pastures to the corrals looking for their young. Farmers need to be well organized to avoid unnecessary stress and injuries among the young.

Artificial Insemination. This technique as well as embryo transfer are helping a lot in the genetic improvement of small ruminants in developed countries and are gradually gaining ground in developing countries. The potential to reduce breeding costs, in particular in regard to the cost of acquiring imported superior males but also by reducing the expenses of maintaining the males in small flocks, are attractive incentives to justify the training of technicians and the purchase of the necessary rather sophisticated laboratory equipment.

In order to benefit from these improved reproductive technologies, animals need to be well managed and properly fed, so they can respond to the better genetics. Animal performance is the result of the genetic x environment interaction. Bringing specialized breeds but keeping the same feeding and management would not give the expected results. Both genetic and management need to be improved in parallel.

Artificial Insemination is more difficult in ewes than in does, due to several factors, including their longer and more complex cervix and the lack of clear estrus signs. The simplest technology is the Vaginal Artificial Insemination, which requires little equipment and skills, but also gives the less reliable results. The Laparoscopic Artificial Insemination, by-passing ewe cervix and depositing the semen directly into the horns of the uterus, gives the best results (75-80% pregnancy rates) but it requires well trained operators and specialized/expensive equipment. The Trans-cervical Artificial Insemination developed by the University of Guelph for example, uses a fiber optic endoscope that goes through the cervix with the help of a speculum with a light source to see during the procedure. Semen is deposited pass the cervix into the uterus. Both ewes and does can be inseminated with this technique (Schoenian, 2004).

Selection. In any small ruminant farm, it is of upmost importance to keep production records to allow selection of the best replacements for continuous improvement of flock performance.

The selection should be based not only on phenotypic characteristics but mainly on production data, that is, milk yield per year or amount of live weight (kg) of lamb/kid weaned by ewe/doe per year.

If selection is exclusively done on size and body appearance, it might go against prolificacy, because the single animals are born heavier and receive more milk than twins or triplets.

REPRODUCTION

The following table shows the basic reproductive parameter for ewe and does.

Table Basic Reproduction Parameters.

Parameter	Doe	Ewe
Age for puberty	5-9 months (weight dependent)	5-12 months
Breeding age	70% of adult weight	70% of adult weight
Estrus cycle	21 days (18-24 days)	17 days (13-19 days)
Estrus duration	24h (12-36h)	30 h (24-36h)
Estrus signs	Mucous discharge, swollen vulva, bleating, frequent tail wagging	Mature ewe look for ram, might wag tail & mount others, muzzle ram around belly/scrotum. Young ewes: often no signs.
Pregnancy duration	150 days	146-147 days (142-152 days)

The mating systems have been described above, but in general, both rams and bucks are generally very efficient in detecting females in heat, and if the flock is united at the end of the day in a grazing system or if the males are mixed with females all day, there would be hardly any female in heat that passes undetected. If allowed, males would mount the females many times, an unnecessary effort particularly for expensive animals. The advantage of hand mating is that males do not waste energy (and semen) by repeated copulation of single females in heat.

ANIMAL HANDLING

Capturing

If catching animals becomes a routine practice, it needs to be done correctly to avoid stress and injuries. There is a natural tendency to grab the animals by the hind legs, however this practice can easily cause injuries. The correct and safe way is by grabbing small ruminants by their rear flank, and then to hold them by keeping their head facing upwards with one hand while pushing from the back with the other hand. The shepherd's crook becomes very handy to capture animals. In this case, animals are caught by the neck and then hold as described before.

Knocking down and holding. If there is a need to knock down the animals for a particular intervention, depending on animal size and operator strength and skills, there are several options, but in any case, the ideal and more comfortable position, for both the animal and the operator, for holding an animal, is simply by sitting it on its lower back (see picture). If properly kept, animals can spent several minutes in this position without discomfort and risk of injury. The knocking down methods are:

Small animal: simply lifting it off the ground with an initial help of the operator's thigh.

Medium size animal: grabbing the leg close to the operator by going above the back and underneath the belly, and then lifting the leg to unbalance the animal and knock down into its lower back.

Large size animal: Twisting the neck and head sideways and upwards until the animal loses balance and falls into its lower back.

Castration

It is a very stressful intervention that should be avoided if at all possible, but if it needs to be done, it should be practiced in very young animals, in order to reduce suffering. The easiest way to castrate young males is to place a rubber band around the scrotum either above or below the testicles. The first option removes the testicles all together, and the second inhibits sperm fertility due to normal body temperature, higher than required for normal development.

Special designed rubber bands for this purpose can be placed with an elastrator or normal (office) rubber bands by tightly twisting them around. Testicles dry up and fall within few days.

For older animals, the best way to castrate them is by using the Burdizzo tool. Each seminal cord should be crushed twice by pulling them sideways, away from the blood supply. It is however, a very painful practice that should be avoided as much as possible.

Dehorning

Removing the horns is recommended in goats to prevent injuries to other animals in the flock and to the operators. It should be performed when the horns are about come out in the first weeks of life. It is easier done with a hot circular iron, either electrically or fire heated, which is placed for two-three seconds around the horn bud. Dehorning can also be achieved with caustic soda paste, but it has more risks for the operator.

Once the horns are grown, they can't be removed altogether, only cut. Cutting them from the base causes a lot of bleeding and a hole that needs to be filled to prevent infection or myiasis. It is preferable to cut only the tips, particularly if they are sharp. An iron saw can be used for this purpose.

Goat Deodorizing

It is a procedure performed on the bucks by removing an area of skin from medially and posteriorly to the horns with the purpose of eliminated the strong buck smell in the premises and to reduce the risk of tainting the milk. The scent is contained in sebaceous cells in areas of wrinkled, folded and hairless skin. There is also a weaker lesser smell in the urine of the buck, thus it is a good idea to keep the bucks far from the milking parlor.

HEALTH CARE

As it was mentioned at the beginning of this publication, the Caribbean region is fortunate for being free of many diseases that affect small ruminants in other areas of the world. This is why, strict quarantine measures should always be kept to prevent bringing illnesses that can jeopardize national's flock health. In this section only the most important diseases will be briefly described.

Caprine Arthritis Encephalitis (CAE)

It is a viral disease which produces chronic inflammation of the joints in adult animals and on occasions, encephalitis. It is widespread in among goats in developed countries and it has not cure. It is transmitted from the infected doe to the kids through the milk, but lambs can also get infected. Care should be taken when importing goats from the North America and Europe, the animals should test negative to CAE, and for this, they need to be reared with heat-treated colostrum and pasteurized milk. Once the flock get infected, it is very difficult to eradicate and culling is the most control practical option.

Caseous Lymphoadenitis

It is worldwide chronic and very contagious and zoonotic disease caused by the bacteria *Corynebacterium pseudotuberculosis*. It is present in most islands in the Caribbean. The external symptoms are the inflammation of the lymph nodes and the eventual rupture if not intervened before, but abscesses also form internally in thorax and abdomen. The pus-like substance is the main means of contamination of skin lesions. The bacteria remains in the premises for a long time and it is difficult to disinfect. The disease is a major cause of carcass condemnation and meat trimming of damaged tissues, but there are also economic losses due to affected growth and performance. It is an important disease that deserves the attention of the regional health authorities. There are vaccines for this disease but their effectiveness in national programs is unknown.

Animals with Caseous Lymphoadenitis

Coccidiosis
Coccidia are species-specific protozoa that parasite the intestinal track causing diarrhea and weakness, especially in young lambs and kids. Most infected animals show no symptoms, but weak and immunocompromised individuals can get severely affected and die. The coccidia multiply inside the epithelial cells of the intestine and the eggs (oocytes) get excreted into the environment via feces. Warmth and humid conditions favor the hatching of the eggs. It is very difficult to prevent infection when offspring are raised on the ground, but much easier in elevated pens.

Internal parasitism
Internal parasites are the most important health problem for small ruminants in the tropics. There are several potential internal parasites, but the most important by far is *Haemoncus contortus* or barber's pole worm. The adults live in abomasum where they suck blood from the epithelium. Adult females produce thousands of eggs a day which are excreted in the feces contaminating the pastures. After a couple of growth stages, larvae are ready to infect new hosts through grass consumption. Experience has shown that the only way to eliminate these worms is by interruption of the life cycle, that is, preventing the intake of the larvae, since in the medium and long term, repeated anthelmintic medication develops resistance. Rotational grazing reduces the risk of contamination, but in certain conditions, of high humidity and shade, it is difficult to attain. Browsing systems and cut-and-carry are the most practical ways of eliminating the internal parasite problem.

Although the overall strategy to control internal parasites should to break the life cycle, sometimes it becomes necessary to treat animals with anthelmintic drugs. In this case, only the individuals being severely affected should be medicated, in order to reduce the chances of development resistance and to save on medicines. The FAMACHA system (Bath, Malam & van Dyk, 1996; Bath and van Wyk, 2001; FAO, 2013) recommends the identification of anemic animals, the ones most affected by the internal parasites, by looking into the bottom eyelid mucous membrane. Only the animals with very pale color receive the drug, the others, less affected, are left to coexist with the parasite.

Closed-flock strategy
Whenever possible, the farm policy should be that of a "closed flock", which means that, efforts should always be made to reduce the exposure of the flock to outside pathogens. The biosafety measures include to prevent bringing outside animals or to take animals back to the farms after being in fairs and expositions, and to avoid visits of people and vehicles, which have been in other small ruminant farms on the same day. All of this is to minimize the risk of bringing new diseases to the farm. For this purpose, artificial insemination and embryo transfer have a great potential in the future, since they reduce the risk of bringing the diseases of live animals.

Efficient microorganisms
Also called mountain or effective microorganisms (EM), are a mix of beneficial microbes developed by the agronomist Teruo Higa from the University of the Ryukyus in Okinawa, Japan, following his concept of "friendly microorganisms" (Higa

and Parr, 1994). The beneficial or positive microorganisms outcompete the pathogenic or negative ones, resulting in healthier overall conditions. EM are made from lactic acid bacteria, photosynthetic bacteria, yeasts and other natural microorganisms found in forests, and are being used for many agricultural scenes, including greenhouses, livestock facilities, water treatment installations, etc. In the context of small ruminants, EM are being utilized to reduce or to eliminate mastitis in dairy goat farms, and should be considered as a routine practice in all confinement livestock operations.

PREDATOR CONTROL

In continental countries, sheep and goats have many natural enemies including, wolves, coyotes, cougars, bears, eagles, etc. and farmers need to take all kinds of precautions to reduce the losses due to predation. In fact, small ruminants can seldom be left alone in pastures without suffering major casualties and even with all measures taken, predators always manage to take some as pray.

Equines (horses and donkeys) and American Camelids (Llamas and Alpacas) are known to chase coyotes and other predators, when they come close to what they consider as their own family group. They can be used as part of the sheep commercial flock, along with shepherd dogs.

Many breeds of livestock guardian dogs, a type of shepherd dogs or sheepdogs, have been developed in the various countries to protect sheep flocks for over thousands of years. They all have particular natural skills to defend sheep (Green & Woodruff, 1998). The Great Pyrenees Mountain Dog is working extremely well in Canada protecting both sheep and shepherds from bear and wolf attacks (Loxton) in the forests. They can even left by alone with the flock and learn how to hunt small mammals to feed themselves.

In the insular states of the Caribbean, the only major predators are the descendants of the wolf, the domestic dogs. Dogs are human best friends, but the worst enemies of the sheep (and goats). In fact, dogs in rural communities have a dual personality. During the day they seem harmless, they spend most of the time laying down, sleeping. They do seem even hungry. But at night, their ancestor instincts come out, they form packs and go hunting. Many dogs show that behavior no only feral dogs, which are real dangerous, even to people.

Small ruminant farmers are well aware of the potential dangers of dog attacks, which often seem to affect the most valuable animals. They take various protecting measures, including reinforced and electric fences, and much more drastic ones like shooting dogs at first sight or poisoning them with tainted food. The latter one being extremely harmful to biodiversity since the poison kills not only the dogs but also many scavengers including opportunistic carrion eaters like squirrels and crows. These kind of actions are not acceptable to most people, particularly to defenders of animal rights, but they are justified by farmers who need to protect their assets.

The ideal situation in this regard would be that there were not significant populations of “free dogs”, particularly at night when most of the attacks happen. Since this is unlikely to occur, because population of dogs and people seem to parallel, some sort

of regulation would seem appropriate to restrict movements by dogs. Simply banning free-dogs by forcing owners to keep them in confinement, fenced or tied up, would seem a reasonably measure. Wild or feral dogs would need to be controlled in some other ways.

In fact, there are dog acts and regulations in some countries that deal with all kinds of issues related to dogs including identification, prohibitions and sanctions. The Western Australia Dog Act, with its regulations, is a good example of a comprehensive legislation (GWA, 1976). All countries interested in developing the small animal industry should have regulations regarding dogs, one of the largest threats.

HIGH QUALITY FORAGE SPECIES FOR SMALL RUMINANTS

Small ruminants have less capacity to consume, to ruminate and to digest low quality and coarse forages, including tropical grasses grown in full sun, compared to large ruminants, cattle and buffalos. Sheep and goats require higher feed quality in order to fulfill their nutrient requirements, to be able to express their genetic production potential.

As a general rule of thumb, small ruminants will consume between 3 to 5% percent of their body weight on a dry matter (DM) basis as feed. The exact percentage varies according to species and animal size, smaller animals needing a higher percentage and better quality feed.

In the Caribbean and in the Latin American tropics, the tradition has been to treat small ruminants like large ruminants, feeding the same forage resources. The high cell wall content (Neutral Detergent Fiber) of grasses prevents enough consumption and makes rumination more difficult for these smaller animals. The high fiber content (Acid Detergent Fiber) limits forage digestibility. The combination of the two above-mentioned factors restrict adequate nutrient intake for acceptable production levels without supplementary feeding.

Sheep and goats requiring a better diet than cattle, under free roaming conditions, they select the most nutritious parts if available vegetation, following their inherent **nutritional wisdom**. High quality forages better meet their feed requirements, without the need of supplementary feeding. Fodder biomass from high quality legume and some non-legume species, has much higher levels of protein and digestibility than grasses. With these high quality forages as the basis of the diet, energy supplementation enhances even further animal performance because most of them have nitrogen levels (crude protein) above the nutrient requirements of small ruminants, and the excretion of the surplus nitrogen, is energetically costly for the animal. Thus, reducing the net energy available for production functions (growth, pregnancy and lactation).

Among the high quality forages there are herbaceous, shrub and tree legumes, and other non-legume species than can be used for grazing (browsing) and for cut-and-carry systems, which do not only provide suitable nutrition but also contribute to better management of natural resources, including larger biodiversity, soil erosion control, improved soil fertility and weed reduction. The three dimensional arrangement of species in various strata for livestock purposes, are known as “agroforestry systems for animal production”, and include silvopastoral systmems, where animals procure their own feed and cut-and-carry systems, where feed is harvested and brought to them.

The ideal agroforestry system for grazing, the silvopastoral system for small ruminants, should have various strata, with appropriate species in each one:

The **very high stratum** for biodiversity and landscape beauty. The suitable species are: various tall palms (eg. *Roystonea hispaniolana*) and the Ceiba tree (*Ceiba pentandra*).

The **high stratum** for shade/micro-environment creation, nitrogen fixing, nutrient recycling, seasonal feed (fruits), wood and firewood. Suitable species are: *Albizia saman*, *Enterolobium cyclocarpum* and *Prosopis juliflora*.

The **medium stratum** for high quality browsing feed. Two kinds of species form this stratum, the shrubs and the climbing plants. Suitable shrub species are *Leucaena leucocephala* and *Tithonia diversifolia*. Suitable climbing species are: *Clitoria ternatea, Teramnus labialis* and *Neonotonia wrigthii*.

The **low stratum** for grazing and soil cover. The appropriate species are: *Stylosanthes guianensis* and *Arachis pintoi*. For cattle, the various grass species are included in this stratum.

For cut-and-carry agroforestry systems, the first two strata remain the same, but the browsing stratum can have additional species, not suitable for grazing, like *Morus alba*, *Gliricidia sepium, Trichantera gigantea* and *Moringa oleifera*. The climbing legumes of the medium stratum, and the grazing species of the low stratum, might not all survive the cutting frequency and the heavy shading of the more dense planting schemes for cut-and-carry purposes.

The above species have been selected from field experiences and research taking into consideration agronomic versatility (basically regrowth capacity after repeated browsing or harvesting), wide-range adaptation, yield and nutritive value for small ruminants. Apart from these features, if there is an option, it is better to select native species to take advantage of their adaptation to the local environment, and species which can be easily established with simple and inexpensive techniques (Benavides, 1991).

Many species are multipurpose plants which provide a variety of benefits complementary to those strictly related to animal production, including nectar and/or pollen producing plants for beekeeping, feed resources for native birds and other wildlife species, firewood for cooking or charcoal, wood, etc. Farmers should choose the best options for their own specific conditions and needs.

There is a lot of information in the literature on these species, and Table 1 compares only two indicators of their high nutritive value.

The foliage of most of these high quality forage species has a crude protein content 2-3 times higher than typical tropical grasses and, in some cases, even superior than commercial concentrates traditionally used for supplementary feed. Crude protein values vary between 12-42%, while in concentrates range between 14-18%. In addition, *in vitro* digestibility of dry matter is very high and comparable or superior to that of concentrates.

It is important to consider that yields and quality depend on many factors, including species, variety, soil type and fertility, climatic conditions (temperature, solar radiation, and rainfall), plant density, fertilizer application and harvesting technique, and the values provided are just indicative.

Table 1. Crude protein (CP) and *in vitro* digestibility of dry matter digestibility (IVDDM) of edible foliage (or pods) of selected forage species.

SPECIES	CP (%)	IVDDM (%)
Non-legume forage trees, and shrubs		
Moringa oleífera	23	71
Morus alba	23	79
Tithonia diversifolia	22	69
Trichantera gigantea	12	52
Legume forage trees, shrubs, and herbaceous		
Albizia saman (pods)	16	70
Arachis pintoi	18	65
Clitoria ternatea	16	80
Enterolobium cyclocarpum (pods)	13	71
Leucaena leucocepahla	25	52
Gliricidia sepium	24	59
Neonotonia wightii	15	60
Prosopis juliflora (pods)	12	75
Stylosanthes guianensis	17	66
Teramnus labialis	17	62

For the last three decades, there has been a very successful movement towards improving the production and feeding systems of ruminants in the tropical areas of Latin America and to some extent, of the Caribbean (CIPAV, 2014). The main objective has been the reconversion of livestock production systems from grass based pastures to agroforestry systems, including the silvopastoral systems. Most of the efforts have been in cattle, trying to reverse the huge damage caused by the deforestation of large amounts of forests and jungles, to establish the so called “artificial pastures”. Agroforestry systems are in simple terms, a win-win situation for everyone, since apart of intensifying and making much more efficient and profitable the production systems, there are also very significant environmental benefits and therefor great possibilities for agro-tourism from biodiversity attractions, renewable energy production and value-added products for niche markets (Hernández and Sanchez, 2004).

A parallel undertaking has been the improvement of small ruminant production by means of replacing partly or totally, the grasses in the traditional diets of small ruminants in the tropics. Although still very far from the development that reconversion occurring in cattle, the more gradual shift towards high quality forage-based systems for small ruminants is steady, with some very successful examples.

In cut-and-carry systems, the leader has been Costa Rica, as the result of the application of the research by CATIE in the 80s and 90s, followed by Panama and more recently other Caribbean countries, led by Cuba. The lead forage species has been mulberry (*Morus alba*) which by the way, it is the best forage in terms of overall quality and potential yield if agronomic conditions are suitable. Complete confinement dairy goat production systems, with animals in elevated corrals and with mulberry foliage as the main feed, have been very successful and productive, as compared with the failed grass-fed systems. An essential element for the sustainability of these farms has been the recycling of nutrients from manure and urine, back to the forages.

In grazing (browsing) systems for small ruminants, the advancement has been much slower, but there are good examples in Cuba, with pedestal systems based on climbing legumes, plantations with legume cover crops and confinement units with Leucaena, Mulberry and Moringa; and in Mexico with Leucaena browsing systems and to a lesser extent confinement systems with high quality forages (mulberry and *Hibiscus rosa-sinensis*).

As a result of the small ruminant project, which supported this publication, several initiatives in various Caribbean countries are under way, that can change the course, the future, of small ruminant in the region.

The reconversion towards agroforestry systems has been mainly a movement led by the private sector and Non-Government Organizations (NGOs), with an initial example and encouragement by research and academic institutions. Except in Cuba, where the government institutions have been behind all research, extension and development. But in general terms, like in other recent/current large agricultural movements (organic agriculture, conservation agriculture, systems of rice and crops intensification, etc.), the academic and research institutions remain sceptic and somehow indignant and outraged because the rapid changes are happening without the strict scientific protocols and validation. In a certain sense, the national and international research institutions are not only contributing little or none at all, but in many cases, blocking the expansion of what they consider “empirical innovations’. Only very few, humble research institutions and their smart investigators, are supporting farmer groups in their reconversion initiatives. Because no matter how successful these new systems have been, the scientific support and the detailed knowledge to refine, fine tune, forage production, overall flock management and individual nutrition, would be most welcome.

Mulberry in association with Erythrina in Costa Rica

Leucaena cultivation in Mexico (photo from E. Murgueitio)

High quality forage species can be integrated in small ruminant farms in different planting arrangements (Sanchez, 1999). Table 2 describes some of these options:

Cut-and-carry plots. They can provide easy access to cut feed and offer the possibility for nutrient recycling.

Grazing/browsing pastures. They seem to be a simple way of feeding animals in most cases, if land is available and conditions suitable. However, very humid conditions are not conducive to grazing systems for sheep due to feet problems, and appropriate fencing is required for animal control and predator prevention.

Living fences. They reduce the long term maintenance costs of fencing, offer habitat for wildlife and provide seasonal high quality feed supplement.

Hedgerows and green barriers. When grown along the contour in sloping lands reduce run-off and erosion. They can also be grown inside pastures or to reinforce fence lines.

Trees in pastures. They can provide environmental services (shelter, shade, nitrogen fixing, etc.), forestry products, like timber and firewood, and additional seasonal feed (pods).

Table 2. Forage species for the Agroforestry Systems.

	Cut and carry	Grazing/ Browsing	Living fences/ Hedgerows	Trees in pastures
Albizia saman				✓
Arachis pintoi	✓	✓		
Clitoria ternatea	✓	✓		
Enterolobium cyclocarpum				✓
Leucaena leucocepahla	✓	✓	✓	✓
Gliricidia sepium	✓	✓	✓	✓
Moringa oleifera	✓	✓	✓	✓
Morus alba	✓	✓	✓	✓
Neonotonia wightii	✓	✓		
Prosopis juliflora			✓	✓
Stylosanthes guianensis	✓	✓		
Teramnus labialis	✓	✓		
Tithonia diversifolia	✓	✓	✓	
Trichantera gigantea	✓		✓	

AGRONOMY OF HIGH QUALITY FORAGES

The fact sheets include detailed information on the main characteristics, establishment, management and utilization of each forage species selected for this publication on small ruminant production. General information on some important agronomical and management considerations is given here.

The data on each of the species comes from the following web sites plus many published articles, PowerPoint presentations in technical and scientific meetings, and a lot of details come experiences of the authors in research, extension and practical work with farmers in many countries during the last three decades:

http://www.tropicalforages.info/ and http://www.worldagroforestrycentre.org/.

Suitable climate

When planning and selecting the suitable forage species for an area, the consideration of climate, soil, topography and future management, is of upmost importance. There is not only one formula for all locations, on the contrary, each farm is unique. Although some species are versatile and growth in many conditions, some will thrive well on poor acid and infertile soils, others need more fertile soils or frequent nutrient applications for optimum performance. Some species withstand cool areas, even mild frost, while others do well under very hot and dry conditions. Plants may survive in areas outside their own range, but they will not grow or regrowth well and might not produce seed. It is important to choose the species, and their combinations, that are adapted to local conditions, but a degree of experimentation is desired, because there are always surprises, unexpected innovations.

Important climatic factors affecting forages include rainfall patterns (length of dry season), temperature and humidity (mainly related to diseases and pests). The most important climate conditions, as well as the suitability of the recommended high quality forage for different agro-ecological regions, are presented in Table 3.

Soil

Important soil factors affecting forage adaptation include overall fertility, pH, and drainage. The suitability of the selected species to three general soil types is shown in Table 4.

It is very important to conduct chemical analysis of representative soil samples, which together with the farmers' experience and the specific characteristics of the forage species, will determine options for soil amendments and fertilization.

Table 3. High quality forage species for three climates situations.

	Wet tropics without or short dry season	Humid or dry tropics with long dry seasons	Cooler tropics of high elevations
Albizia saman	✓	✓	
Arachis pintoi	✓	✓	
Clitoria ternatea	✓	✓	
Enterolobium cyclocarpum	✓	✓	
Leucaena leucocepahla	✓	✓	
Gliricidia sepium	✓	✓	
Moringa oleífera	✓	✓	
Morus alba	✓	✓	✓
Neonotonia wightii	✓	✓	
Prosopis juliflora		✓	✓
Stylosanthes guianensis	✓	✓	
Teramnus labialis	✓		
Tithonia diversifolia	✓	✓	✓
Trichantera gigantea	✓	✓	

Table 4. Suitable forage species for fertile, moderately fertile, and infertile soils.

	Fertile (neutral to moderately acid soils)	Moderately fertile (neutral to moderately acid soils)	Infertile (extremely acid soils)
Albizia saman	✓	✓	✓
Arachis pintoi	✓	✓	✓
Clitoria ternatea	✓	✓	
Enterolobium cyclocarpum	✓	✓	✓
Leucaena leucocepahla	✓	✓	
Gliricidia sepium	✓	✓	✓
Moringa oleifera	✓	✓	
Morus alba	✓	✓	✓
Neonotonia wightii	✓	✓	
Prosopis juliflora	✓	✓	
Stylosanthes guianensis	✓	✓	✓
Teramnus labialis	✓	✓	
Tithonia diversifolia	✓	✓	✓
Trichantera gigantea	✓	✓	✓

Soil preparation

The objective of land preparation is to provide a proper germination and initial development environment to maximize early growth and reduce competition from weeds or companion forage species. For effective germination, it is best to have moist soil pressed closely against the seed, which is best achieved with a fine and firm seedbed.

The traditional way of soil preparation of the Green Revolution Agriculture, including subsoiling (with a subsoiler or a mole plow), plowing (with a moldboard or a disk plow) and harrowing (one pass and crossing) are still performed, but there are not the best practices nowadays, considering costs and above all, impacts on soli structure and fertility (basically organic matter content). No-till direct-seeding and minimum tillage are alternative ways to plant with less or minimum disturbance to soil structure. These alternative methods might require agricultural implements and machinery not necessary readily available in the tropical countries with less advanced agriculture.

Two ways of land preparation for forage establishment, the traditional system with organic matter application (left) and minimum tillage in rows within established pastures.

Soil amendments can improve early forage establishment. Lime application in the case of acid soils corrects pH and improves fertility. Organic matter is always recommended as one of the best ways to amend the soils, especially in exhausted soils after years of annual cropping and repeated plowing. But it is always preferable, to protect and to avoid destruction of the organic matter already present in the soil. It takes many years, even decades, to build up the organic matter in the soil, and only minutes to destroy it with the wrong, but unfortunately, still traditional agricultural practices of plowing and harrowing.

It is preferable to use herbicides, on a single occasion, to temporary suppress grasses and other plants (weeds) in lines for easier and faster establishment of legume species in a pasture, using direct seeding equipment, than to plow and to harrow the complete field destroying the organic matter present, particularly if there is no much of it to start with.

Planting time
In non-irrigated areas, species need to be sown, planted or transplanted, depending on the species, usually at the onset of the wet season, when the soil has received sufficient moisture to support germination and establishment.

The planting period is more important in the dry tropics than in areas with well-distributed rainfall.

Planting material
Establishing forage is a simple agronomic practice, but often livestock farmers have never done it. However, if they are already used to growing crops, they may just need little additional advice on the specific requirements of the different forage species.

High quality forage can be established directly from seed or from vegetative material such as stem cuttings (stakes and micro-stakes), stolon or nursery plants. Suggestions for easier planting for the various species are provided in Table 5.

Seed can be sown directly in the soil or in nurseries first, particularly if seed is scarce and/or the conditions in the field are not optimum for direct seeding, due uneven surface, competition, weather, etc. The preferred method for forage establishment is by (sexual) seed for most conditions, and it is often the most economical and easiest way of planting. Planting by seed assures deeper roots with greater capacity to find water and nutrients, which eventually results in higher biomass production and greater longevity. Seed might also be the most appropriate way of transporting, quarantine, and store selected materials.

Establishing forages by vegetative material is often the most convenient choice for farmers, since it is easy and reliable. It does not require much land preparation and above all, the planting material is usually locally available.

Vegetative planting material can be prepared just using a machete or with pruning scissors. It should be planted as soon as possible after collection, kept moist and cool until planted, preferably on wet soil. Collection of planting material from many plants maximizes genetic variation and reduces susceptibility to disease and insect damage.

Stem cutting, for example from Tithonia and Mulberry, should be 20 to 30 cm long and with at least 3 buds, for most common conditions. Stakes are frequently planted in a vertical position into the soil. However, long Gliricidia pieces (around 1.5m) can also be placed horizontally and sprouting occurs along the buds.

Table 5. Ways of planting forage by species.

	Stems Cutting	Stolons	Transplanted Seedlings	Direct seeding
Albizia saman			✓	✓
Arachis pintoi		✓		✓
Clitoria ternatea			✓	✓
Enterolobium cyclocarpum			✓	✓
Leucaena leucocepahla			✓	✓
Gliricidia sepium	✓		✓	✓
Moringa oleifera	✓		✓	✓
Morus alba	✓		✓	✓
Neonotonia wightii		✓		✓
Prosopis juliflora			✓	✓
Stylosanthes guianensis		✓		✓
Teramnus labialis				✓
Tithonia diversifolia	✓		✓	✓
Trichantera gigantea	✓			

Planting in nurseries

Both seeds and vegetative material can be planted first in nurseries before transplanting to the field. In a greenhouse or in a nursery, plants can be sown in plastic bags of different size depending on the species. In addition, they can be sown in trays, like the ones used for vegetables (Figure 3), or other containers like recycled containers including bottles and tetrapacks.

Nursery trays and young plants.

The planting substrate could be peat-moss or whatever substrate commonly used for vegetables like rich soil, humus, river-sand or organic substrates, usually in mixes. It is important to maintain the appropriate humidity with irrigation, but always preventing direct exposure to rainfall, especially with small seeds which can be uncovered easily.

Inoculation of legume seeds

The majority of the forage species being recommended in this publication belong to the family Leguminosae (Fabaceae), and are commonly called legumes. The species of this family are notorious for being able to fix atmospheric nitrogen through an association with bacteria of the genus *Rhizobium* and *Bradyrhizobium,* which form root nodules. Legumes are easily recognized by their fruit shape or pods and their compound (stipulated) leaves. Table 1 lists legume and non-legume forage species.

Some legumes do not form effective nodules unless particular strain of nodule forming bacteria are present in the soil, while others are less specific and form nodule with a variety of bacteria. Symptoms of nitrogen deficiency are yellowing of leaves, weak seedlings and poor survival. It is possible to overcome nodulation problems by applying to the seeds the correct *Rhizobium* bacteria. However, the offer of commercial inoculum is limited and many times only research institutions have the specific nitrogen-fixing bacteria for a particular forage species. For practical purposes, if legumes growth well and do not show evident signs of deficiency, it is probably because the nodules are there and functioning.

Scarification

Seed of some forage species, particularly legumes, will not readily germinate because they have a protecting hard coat which prevents water from entering the seed, a phenomenon called dormancy. Under these conditions germination is poor, unless the seeds are scarified, the seed coat softened or broken.

Some of the legumes easily germinate, such as *Arachis pintoi* and *Gliricidia sepium*, without any treatment. Others, like *Leucaena leucocephala*, *Albizia saman* and *Enterolobium cyclocarpum*, need scarification.

The seeds can be scarified by either physical or chemical methods. Abrasion, with sand or sandpaper, makes the seed coat thinner and allows water penetration. Treatment with hot water or with concentrated acid dissolves or softens the coat, achieving similar results. For large quantities of seed mechanical scarification can be done by rotating drums with abrasive surfaces or mixing the seed with sand.

An easier method for smaller amounts of seed is the hot water treatment. Few minutes (2-3) in hot water (60-80 °C) and the soaking for 24 h works for most legumes.

Moringa seed only requires soaking in room-temperature water for 24 hours.

Seeding depth

The depth of seeding is critical for forage establishment. Too deep would not allow plants to emerge, and to shallow would exposed the seeds to birds and insects, or to get dry from solar exposure. Seed size and soil texture are important in determining sowing depth, the smaller the seed and the heavier the soil, the more superficial is the required placement of the seed. Small forage seeds (e.g.

Teramnus, Stylosanthes and *Clitoria*) need to be sown within the first centimeter of the soil. Larger seeds (e.g. *Gliricidia, A. saman, E. cyclocarpum*) can got to soil depths of 2-5 cm.

The other critical factor is the contact of seeds with surrounding soil. Proper germination is obtained if fine soil closely encloses the seed and transmits the humidity required.

Seeding methods

The amount of seed required for direct seeding depends of seed size, viability and whether the species will be in monoculture or in association with other species. The planting scheme basically depends on the harvesting method, either grazing/browsing or cut-and-carry, mechanically or by hand. In general terms, smaller seeds are sown at lower rates and larger seeds at higher rates, just because of size. The fact sheets provide information on the amount of kg of seed that need to be planted per unit area.

Direct seeding is done either in rows, manually or with drill seeders, or by broadcasting. In any case, seeds needs to be placed at the right depth or covered with soil for a successful germination.

Sowing in rows has the advantage of facilitating weeding by hand, chemical, or mechanical means and eventually grazing/browsing and harvesting.

When planting forages in slopes, the rows should be perpendicular to the slope, ideally at leveled contour lines. In flat surfaces, tree forages should be planted east-west, to obtain maximum solar radiation.

Fertilizer application

In most situations, forage can be successfully established without manure or fertilizer, although obviously, they will grow better from the beginning if nutrients are available. In any case, the recycling of nutrients is essential for long term sustainability of forage production. Some of the forages can be very productive, and thus, continuously extract large of amounts of nutrients from the soil.

Legumes might be fixing its own nitrogen, but the rest of the mineral nutrients come mostly from the soil. In grazing/browsing systems, nutrients are naturally recycled to the soil via feces and urine, but in cut-and-carry systems efforts should be made to return nutrients either by directly spreading the fresh slurry or mixing it with irrigation water, or by passing feces/urine through a biodigester. The fermentation occurring within the biodigester releases methane which is normally burnt to generate heat for cooking or other purposes, but most important, it incorporates the mineral nutrients into bacteria, which can then release them for plant absorption. The issue here is that, biodigester effluent has a greater fertilizer value than the mixture of feces and urine from which it comes from. This is because there are great loses of nitrogen when fresh feces or slurry are spread in the fields, as a results of the action of ureases naturally present in the soil. On the contrary, effluent nutrients are contained

with bacteria cells, and thus, much more stable. Bacteria releases nitrogen and other nutrients, slowly without major loses by evaporation or leaching.

Manure and other organic materials, apart from providing valuable nutrients, also improve soil structure and soil capacity to retain and exchange nutrients. The recycling of manure is easier if forage plots, at least the most valuable ones, the highest quality species, are nearby the stables.

Soils in tropical areas vary in their fertility and thus in their capacity to growth forages. In any case, forages will perform depending on nutrient availability, in most circumstances linearly with the contents of the limiting nutrient, which it is normally nitrogen, but sometimes phosphorus, potassium or another micro-mineral (sulfur or molybdenum for example).

Table 7. Nutrient content (%) in biodigester effluents, manure, and compost.

	N (%)	P (%)	K (%)
Biodigester effluent – liquid	1,45	1,10	1,10
Biodigester effluent – solid	1,60	1,40	1,20
Manure	1,22	0,62	0,80
Compost	1,30	1,00	1,00

Plant competition at establishment

The most critical time for forage establishment is the first few weeks, when most species have difficulty in competing with grasses or other species present in soils. In order to reduce competition and to achieve rapid growth, several agronomic practices are used. Direct seeding is often accompanied by clearing vegetation in rows with mechanical means or with herbicides. The objective is to temporarily suppress the growth of competing species to give sufficient time for the forage plants to get established. Once the forages have surpassed in height the competitors, they normally do fine. Although much more expensive, transplanting has the advantage over direct seeding that plants are normally stronger and larger, for overcoming the difficult initial phase. However, care should be taken not to lose the main root advantage provided by seeds. The plants grown in nurseries should never allowed to get taller than the container that holds them. This is to prevent that the main root gets twisted and loses its ability to grow vertically and to penetrate deep into the soil. It is preferably to transplant smaller seedling with straight main roots, than larger plants, apparently stronger, in which the main root has been bent by insufficient vertical space within the holding bag or container.

Containers with a lot of holes or specially designed to allow air to penetrate to the substrate limits, reduce or eliminate stress at transplanting. This occurs since surface roots are already in contact with air, and do not die when the plant is taken out of the bag or container. This phenomena is called **self-pruning** of roots. When roots reach the edge of the growing substrate, adapt or self-prune, and when

transplanted into the soil, they keep growing as they were doing it, virtually without stress.

Transplanting is often a good option for establishing trees, the species of the tall stratum, particularly if natural reforestation is not possible due to scarcity of seeds or distance from forests where that particular species is present. The main challenge is to prevent animals to damage them by consumption or trampling. Protection by fencing is often used to restrict animal access. But as it was mentioned before, trees would naturally reforest pastures if they are not eliminated by farmers, as it has been the normal practice, unfortunately.

FORAGE MANAGEMENT AND CONSERVATION

Some simple forage management principles will help farmers to improve quality, yield, persistence and animal performance.

HARVESTING

The harvesting of forage biomass, can be broadly divided into cutting and grazing/browsing. Frequency and intensity are important aspects of forage harvesting. Frequency refers to how often the trees are cut or grazed, while intensity relates to the amount of leaf and stem remaining in the plant.

In general terms, the best way to feed the animals is to offer freshly cut forage or to allow them to direct harvest the forage, that is, to let them graze or browse. In this manner, forage has normally its best nutritive value.

Timing for first harvest

Before forage is harvested/grazed for the first time, it is essential to allow sufficient time for the plants to get well established. Many failures in forage duration upon establishment occur by overlooking this simple principle.

The right time for the initial utilization is determined by species, soil, climate and agronomy. When dealing with herbaceous legumes it is important to take into account the botanical composition of the stand (area covered by the legume), the height and the number of anchor points of the plant.

It is a common to leave forage shrubs until they reach a height of at least 0.90-1.5 m. However, age at the first harvest is also important since it is positively correlated to yield at subsequent harvests. Obviously, there are differences between species. The establishment period can be greater than one year in some cases.

Grazing/Cutting frequency

The decision on how often to graze/cut forage is not based simply on yield and feed quality. It also depends on the needs of the farmer at a given time, which may override any other considerations.

Harvesting should be done as regularly as it is feasible to obtain the highest feed quality and dry matter production. For the first few days after cutting, forage regrows slowly as it has few leaves to photosynthesize and it greatly depends on root reserves. This period is followed by a few weeks of rapid growth and production of good quality feed. If left uncut for long intervals, forage quality drops as plants produce more lignin and digestibility of leaves and young stems decrease.

The recovery of forage plants depends on the availability of buds and leaves left after defoliation. Subsequently, how fast the forage comes back also depends on soil humidity, dry or wet season, and on soil fertility. Although the ideal criteria for harvesting is plant height, under drier conditions cutting frequency should be determined by site-specific rainfall patterns, with more frequent cuttings during the rainy season, and less frequent in the dry season.

When grazing, it is very important to use a rotational system, since legumes (both trees and climbing species) are more palatable than grasses and if they are repeatedly consumed, they tend to disappear from the paddock. The grazing period (occupation time) should be short (maximum 1-2 days) to allow faster recovery. Rotation time (days until animals return to a particular paddock) should be enough to allow complete fodder recovery. Numbers of days to full recovery vary according to species and rainfall, faster in rainy areas, but usually vary between 35 to 45 days.

Cutting height

Most forage can tolerate low cutting, but some will produce higher yields and live longer if cut a little higher (Table 8). There are no fixed rules and farmers need to develop their own cutting management as they gain experience with a new species or variety.

Low cutting, i.e. severe defoliation with little or no leaf remaining, produces a longer lag phase before regrowth starts. A lighter defoliation, leaving some leaf area, will result in a faster recovery.

Table 8. Suggested cutting height for different forages types

High nutritive value plants cutting	**Cutting height (cm)**	**Examples**
Stoloniforous legumes	5-10	*Arachis pintoi*
Bushy Legumes	20-30	*Stylosanthes guianensis*
Shrubs and trees	30-100	*Morus alba, Gliricidia sepium*

Grazing/browsing is often less severe for the plants than cutting, as animals remove mainly the leaves, while cutting removes whole branches. Reserves within the stems and branches, and the fact that they are still there, that there is no need to rebuild them again, favors a faster regrowth.

Harvesting methods

For ruminant feeding, the preferred method to harvest forage has been hand cutting, although mechanical harvesting could be employed for large areas, either to be offered fresh or for conservation (mixing, drying or ensiling).

Manual harvest. In small and medium size farms, harvesting is done with machetes, scissors or small mowing machines. The cuts should be performed as clean as possible, with an upward movement preferably, which reduces cortex tearing on the stumps, favors healing and reduces the chances of infection. Other cutting implements (e.g. sickles) are used in some countries for herbaceous forages.

Manual harvesting of mulberry with machete in Costa Rica.

Mechanical harvest. There are not many examples of mechanical harvest in the region. However, in the case of herbaceous legumes it would not be difficult to adapt the grass harvesters as the one showed in Figure 5.

Grass harvester in Suriname.

For woody perennials, like mulberry or leucaena, there is no much experience in the region neither. In Australia, sugarcane harvesters have been adapted to cut leucaena (Figure 6), more to cut it back and allow better use by animals, rather than for cut-and-carry systems.

With these woody plants, it is customary to chop the whole forage, including branches and young stems, into small fractions. This operation facilitates handling and mixing, but it prevent the animals to choose the most nutritive fraction of the forage and also complicates the consumption of the bark, which animals enjoy pealing from the woody stems after they have finished with the leaves. What is better for the farmer, in this case, might not be the best for the animals.

Mechanical harvest of leucaena harvester in Australia (Photos from M. Shelton)

In some Central American and Caribbean farms, it is common to pass all harvested through a chopper before feeding it to the animals. There are dairy goat farms in Costa Rica where they harvest mulberry and King grass, chop them and then mix them in a proportion of 75-80% mulberry and 20-25% grass.

FORAGE CONSERVATION

One of the most serious problems of tropical livestock production is insufficient feed during the dry season. Forage conservation is an option to overcome periods of feed shortage. The main objective is to preserve the nutrients present in the forage as much as possible, to lose the least amount of leaves or forage quality. There are two options to conserve forage and feeds in general: ensiling and drying.

Ensiling

In the tropics, grasses have been, by tradition and for practical reasons, the main forage used for conservation. Recently, however, herbaceous and woody legumes have become an important part in livestock feeding.

During the ensiling process, the acidity (pH 3.5 – 4.5) resulting from the lactic acid production from carbohydrate fermentation, stops any further enzymatic destruction of nutrients. When the silo is well made, it has pleasant odor and taste (slightly acid) and has conserved most of the nutritive value of the original fresh forage. The ensiled forage will not have better nutritive value than that of the fresh forage it was made of. The only case where final feed turns out better than the original stuff, is when there is a chemical treatment, as in the case of ammoniation of crop residues, but this a different process all together.

Ensiling techniques and species

The key aspects for good silage production are: a good forage to start with, fine chopping and excellent compaction (air exclusion). When there is no experience of ensiling a particular forage, it is always a good advice to add some easily fermentative material, like molasses or a starch source, to ensure that the pH drops quickly. Normally young plants will produce better silage than older ones.

The first thing is to chop the forage as fine as possible to allow good compaction, to expel the maximum amount of air to avoid aerobic decomposition or fungal growth. Depending on the size of the container, compaction can be done by hand, by feet (standing or jumping on top) or with machinery (tractor). Once the material is well compacted, the container is sealed trying to leave the minimum amount of air on top, again to prevent aerobic processes.

The ensiling process lasts few weeks to achieve the desired acidity, and once that happens, the material is stable and lasts in good condition for many months, even years, provided that not air or water gets in (that the cover does not get perforated).

Once the farmer proceeds to use the silo, the area exposed to air should be as small as possible to prevent oxidation. Preferably, a particular silage batch should be used as quickly as possible, in few days, to avoid deterioration of the feed (Ojeda, 2000), and for this reason, several smaller containers are preferable than a large one. However, if the silo can be properly sealed again after every use, a larger container has the advantage, in many circumstances, of less labor required for unit of feed conserved.

Apart for forages, other feeds can be preserved by ensiling. For instances, reject bananas, make excellent silage, since they contain abundant carbohydrates and can be easily compacted. Brewers' grains are also candidates for ensiling, since after few days of open-air storage, they grow mold readily.

Herbaceous legumes can be ensiled with grasses. The optimum ratio is between 20-30% herbaceous legumes, and 70-80% grasses. The best way to obtain a uniform mix of the two components is to simultaneously introduce them into the chopper. If the forage is to be wilted, it is recommended to first cut the grass and then the legume because legume drying is generally more crucial as leaf loss may occur if the material becomes too dry.

Ensiling trees and shrubs has been successfully done for some species. Silage can be done with green fodder, but pre-wilting (4-6 hours under full sun) can reduce protein degradation during conservation. Cutting thin particles (2 cm or less) improves compaction of lignified stems and leaf, and plasmolysis can be artificially accelerated. Conservation also may reduce anti-nutritive factors.

Figure 5. Conservation of *Gliricidia sepium* and *Moringa oleifera* by ensiling in Rivas, Nicaragua. (Photos by Enrique Murgueitio).

Forage drying

The other option to preserve forages is drying. In few cases the whole harvested material can be dried, for instance with the herbaceous legumes, but in others, only the leaves, as in the case of shrub forages. The drying of tender stems and branches can be speeded up if the material is first pressed by passing through hay conditioning equipment, which crimps and crushes the stems facilitating water loss.

It is more convenient to dry forages, especially leaves in flat surfaces away from the field, simply to avoid losses. Some of the leaves, for instance those of Leucaena, are too small and get detached from the branches very easily shortly after harvesting. They make, however, an excellent leaf meal. Gliricidia and mulberry leaves can also be dried in paved surfaces, canvas or plastic sheets, or in solar driers.

Drying in the shade has the advantage of preserving forage color and nutrients much better than under the direct sun. An important consideration to always keep in mind is that what dries the forage in the wind, the air, no the sun. For this reason, solar driers often have two components: a heat accumulating device that gets heated by the solar radiation, and the drying device itself, where the material gets dehydrated by the contact with air. Hotter air dries more because it holds more water per unit of volume.

Once the leaves are dry, they can be compacted to reduce volume and facilitate transportation and storage.

Pelleting, cubing or baling, are options for compacting hay or dry leaves. The method of choice depends on available equipment, volume and storage/handling needs.

Recent developments show great promise for both biomass production and industrial processing of high value forage into meals. Some of the plants have low content of fiber and minimum percentage of anti-nutritive factors (e.g. Moringa and Mulberry). Several institutions in Cuba, are obtaining good results in the utilization of dried foliage in feeding monogastric (rabbits, chicken, ducks, etc.), and ruminants (goats, sheep, and cows).

The comparison between fodder trees and commercial concentrate is presented in Table 9. Trees have higher content of crude protein, but lower metabolizable energy, than cereal concentrates.

Goats on low quality hay.

Table 9. Comparison of nutrient composition between fodder trees and commercial concentrate.

	DM (%)	CP (%)	ME(MJ/kg DM)
Leucaena leucocephala	90.4	20.1	8.88
Gliricidia sepium	97.7	24.7	9.26
Albizia lebbeck	95.7	23.9	8.92
Morus alba	96.7	24.9	10.17
Commercial concentrate	86.2	18.2	11.55

DM = Dry matter; CP = Crude protein; ME = Metabolizable energy.
Adapted from Savón *et al*, 2005.

Pelleting of fodder plants represents a good option to substitute cereal concentrates. The technology for processing and treating forage in the tropics must take into account the following parameters of the raw materials before entering the pelleting factory: mill-sieve diameter, humidity content and meal density. Recent research suggests that in the tropics it is possible to obtain good results with a mill-sieve diameter of 2-5 mm, a moisture content of 12 to 20%, and a density of 90-115 kg/m^3. These parameters may vary according to the plant species.

Moringa pellets produced in Cuba.

Particle size and humidity of the material, in addition to press parameters (roller speed, die diameter and cutting blade speed), determine the characteristics of the final product (pellet diameter, length and density).

FORAGE FACT SHEETS

High Stratum Species

Albizia saman

Scientific name
Albizia saman F. Muell.

Synonyms
Enterolobium saman Prain. ex King; *Inga salutaris* Kunth; *Inga saman* Willd; *Mimosa saman* Jacq., *Pithecellobium saman* Benth; *Samanea saman* Merr.

Family/tribe
Family: Fabaceae. subfamily: Mimosoideae, tribe: Ingeae

Common names
English: saman, acacia, cow bean tree, cow tamarind, monkey pod, rain tree. **Spanish**: samán, algarrobo del país, carreto negro, delmonte, árbol de lluvia. **French**: samán, gouannegoul.

Morphological description
A conspicuous, semi-deciduous tree with common height below 30 m with 4.5 m of diameter at breast height; dense crown, spreading up to 30 m across; bipinnate compound leaves, 15-40 cm long, velvety. White flowers below, pink above, solitary or in small clusters in the leaf axils or clustered at the ends of shoots. Pods more or less straight with distinct thickened edges, black with brownish pulp, 12-20 cm long, containing various seeds.

Distribution
Native to: northern South America and naturalized throughout the tropics, where it is a component of dry forest and grass savannahs.

Uses/applications
Shade/shelter: Trees provide a microclimate for plants growing underneath. The common name ‘rain tree’ comes from the observation that grass is often greener under the tree’s canopy. At night and on cloudy days, branches hang down and the leaves fold down and inward, allowing rain to fall directly on the ground and promoting ground cooling. In the morning the leaves unfold giving full shade and helping to preserve moisture. It is used as a shade for tea, coffee, cocoa, nutmeg and vanilla, and provides shade for pasture and grazing animals.
Nitrogen fixing: Forms symbiotic relationships with many strains of nitrogen-fixing Rhizobium. Thus, tree´s deciduous habit is a major mechanism of pasture fertilization.
Feed. Animals browse the growing trees, consume forage from pruning and relish the nutritious fallen pods.
Food: Edible pod pulp.
Fuel: Wood produces 5,200-5,600 kcal/kg when burnt and it regrows vigorously after lopping or pollarding making it a valuable source of high-quality firewood and charcoal.
Timber: Wood with attractive dark-and-light pattern, highly prized for carvings, furniture and paneling.
Medicine: A decoction of the inner bark and fresh leaves is used as diarrhea treatment.
Ornamental: Commonly planted at avenues and parks for its majesticness and beauty.


Ecology

Soil requirements. Normally found on neutral to moderately acid soils (pH as low as 4.6). It grows on light or heavy soils, and tolerates infertile or waterlogged conditions.
Moisture. Mean annual rainfall: 600-3000 mm.
Temperature. Mean annual temperature: 20-35 °C.
Altitude. 0-1300 meters above sea level (masl).

Agronomy

Establishment. If animals consume the ripe pods, some of the seeds are not ruminated and pass intact through the gut while being scarified. The easily germinate once deposited on the soil with the feces. Most of the small plants get tramped or eaten by animals, but some survive and grow to become trees. In practice, the only enemy for natural regeneration of Saman trees is the machete.

For nurseries, seeds need to be scarified in hot water for 3 minutes and then soaked in water for 24 hours before placing in pots.

The ideal density in pastures is 15 trees/ha, thus, depending on the planting system is the number and distance of transplanting.

Pests and diseases. In most places, is free from pests and diseases. However, some defoliators, including the Leucaena psyllid, *Heteropsylla cubana*, may attack the tree, but usually without serious damage.

Feeding value

Nutritive value. Fallen ripe pods have a crude protein content of 12-18% of dry matter and 41% digestibility. They are avidly eaten by all domestic animals. Although leaves are nutritious, they are not considered an important fodder.

Seed

Seed viability is maintained for more than 3 years in hermetic storage at room temperature with 11-15% humidity. The number of seeds/kg is 4,000-6,000.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Enterolobium cyclocarpum

Scientific name
Enterolobium cyclocarpum (Jacq.) Griseb

Synonyms
Albizia longipes Britton & Killip; *Inga cyclocarpa* (Jacq.) Willd; *Mimosa cyclocarpa* Jacq.

Family
Family: Fabaceae, subfamily: Mimosoideae, tribe: Ingeae.

Common names
English: ear pod tree, elephant ear, enterolobium, Mexican walnut, pitchwood. **Spanish:** guanacaste, algarrobo de orejos, dormilon, framboyán extranjero, orejón. **French:** bois tanniste rouge. **Creole Patois:** Bwa tanis wouj.

Morphological description
One of the largest trees in dry forests, reaching up to 40 m in height and 3 m in diameter, with a huge crown. Older trees develop small buttresses and produce large roots that run along the surface of the ground for 2-3 m. Sidewalks, roads, or foundations may be cracked or raised by trees growing close by. The bipinnate compound leaves have 5 opposite leaflets. The small white flowers occur in compact, round heads. Pods are distinctive ear shaped, thickened and indehiscent. Seeds are 20 x 15 mm, ovate, reddish-brown. An adult trees produce around 2,000 pods, each with 10-16 seeds (900-1200 seed/kg).

Distribution
Native to tropical America, from Mexico to northern South America. Exotic to the Caribbean islands where it is quite common. Colonizing a wide range of habitats with 1-6 month dry seasons. It is a climax species in subtropical dry forest and restricted

to disturbed areas in wetter forests. It is the dominant species in all the tree associations in which it is found.

Uses/applications

Shade/shelter: The wide-spreading canopy and nitrogen fixing ability make it ideal shade for livestock in pasturelands.
Food: Immature pods are cooked as vegetables, seeds are toasted and ground.
Fiber: Excellent for quality paper production.
Timber: the heartwood is reddish-brown, coarse-textured and moderately durable. The wood is resistant to attack by dry-wood termites and *Lyctus*, and can be used in house construction, interiors and boats.
Medicine: Bark extracts are used against colds and bronchitis.

Ecology

Soil requirements

Soil type: tolerates alkaline, calcareous, and even acidic soils. Medium-textured soils are probably best, but eroded Ultisols, deep moist clays, shallow sandy clays, and porous limestone all allow good development.
Moisture. Mean annual rainfall: 750-2500 mm
Temperature. Mean annual temperature: 23-28 °C.
Altitude. 0-1,200 m.a.s.l.

Reproductive behaviour

The small, white flowers are borne in clusters or heads at the leaves base. Flowering takes place in March and April during new leaf regrowth after the leafless dry season. There is no knowledge about first flowering age. Seed dissemination is mainly by cattle, horses, and wild ungulates, attracted by the fruits syrupy pulp.

Agronomy

Establishment. Propagated through seeds which are collected from fallen pods. Seeds require scarification. A suitable treatment is soaking in very hot water for 30 seconds, followed by 24 hours in water at room temperature. Natural regeneration is infrequent in grazed pastures since only few seeds are spread by grazing animals, and after germination they are browsed off. It regrowth vigorously after coppicing or lopping, but no information is available on its response to repeated cutting.

Pests and diseases

Has no widespread or serious disease or pest problem. Parrots often prey on the green pods, and the gall-forming moth*, Asphondylia enterolobii*, may disrupt fruiting. Occasional attack by a fusarium fungus may cause the affected limbs to fall from mature trees.

Feeding value

Nutritive value and palatability

It produces large quantities of highly palatable and nutritious pods, which are consumed readily by livestock. Pods nutritive value is high, with 13% of CP and 71% of IVDDM. The foliage is less palatable.

Seed production
Seeds tolerate desiccation to 10.7% humidity. Seeds remain viable for several years under cool, dry conditions.

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Prosopis juliflora

Scientific name

Prosopis juliflora (Sw.) DC.

Synonyms *Acacia cumanensis* Humb. & Bonpl. Ex Willd. ; *Algarobia juliflora* Sw.; *Mimosa juliflora* Sw.; *Prosopis bracteolata* DC. ; *Prosopis cumanensis* (Humb. et Bonpl. ex Willd.) Kunth. *Prosopis chilensis* (Mol.) Stuntz

Family/tribe

Family: Fabaceae. subfamily: Mimosoideae, tribe: Mimoseae

Common names

English: mesquite, honey mesquite, mesquite bean, algarroba, ironwood

Spanish: mezquite, cambrón, bayahonda, algarrobo, algarroba, algarrobo cují

French: bayahonda, chambron, bayarone, bayahonde francais

Morphological description

An evergreen tree with a large crown and an open canopy, growing to 5-10 m. Brown or green brown, sinuous and twisted, with axial thorns situated on both sides of nodes and branches. Bark somewhat rough. The root system includes a deep taproot. Leaves compound; leaflets in 13-25 pairs, oblong (3 x 1.7 mm) and dark green, bipinnate with 1 or sometimes 2 pairs of rachis, almost pendulous. Flowers lateral to the axis with a tubular, light greenish-yellow, 1.5 mm wide calyx with hooded teeth; corolla light greenish-yellow, composed of 5 petals with 3 mm wide pubescent along its edges. Fruit a non-dehiscent pod, straight, linear, falcate to annular, with a coraceous mesocarp in one or segments; seeds compressed, ovoid, hard, dark brown, with mucilaginous endosperm surrounding the embryo; cotyledons flat, rounded.

Distribution

Native to North America (Mexico, US), Central America (Guatemala to Panama) and South America (Colombia, Ecuador, Peru, Bolivia and Argentina) and naturalized in many the Caribbean islands. Exotic to Brazil, Africa, Asia and Australia.

Uses/applications

Shade/shelter: Trees provide a microclimate for plants growing underneath. It is one of the most important species for the stability of semi-arid ecosystems.

Nitrogen fixing: Forms symbiotic relationships with nitrogen-fixing cowpea-type *Rhizobium*. Its deciduous habit is a major mechanism of pasture fertilization. The root form mycorrhizal association with *Glomus* fungi increasing nitrogen fixation.

Feed. Animals avidly consume the nutritious fallen pods. Pods can be fractioned to obtain several kinds of feeds and foods. Pods need to be ground to prevent insect damages in storage. Leaves are not normally consumed by animals due to high tannin content, but goats eat them to certain extend.
Food: A flour is made from the pods with the seeds removed, for bread and sweets.
Apiculture. It is a major source for nectar. High quality honey, very light nice color.
Fuel: The wood is a preferred firewood for its high calorific value. It makes excellent charcoal, famous for grills and barbecues.
Timber: Very hard and durable wood, requiring special tools to work it. Preferred wood for doors and furniture, but rare due to scarcity of large pieces. It is used a lot for fence posts, crafts and tools.
Medicine: Syrup made from pods used for various home remedies.

Ecology

Soil requirements. It grows in a variety of soils, including sandy and unfertile. It prefers deep soils of neutral to slightly alkaline (pH 6.5 – 8.3) but it grows in some places sodic soils.
Moisture. It grows best in semi-arid and arid lands (250 – 1,000 mm), but thrives even at higher rainfall (1,500 mm).
Temperature. It tolerates a wide range of temperatures, including below cero and frosts since it drops its leaves during the winter.
Altitude. From sea level to 2,000 m.a.s.l.

Agronomy

Establishment. When animal consume the ripe pods, seeds pass through the gut while being scarified. The readily germinate once deposited on the soil with feces.
Management. The tree normally grows to a height of about 10 m, but under favorable conditions it may reach 20 m. Spacing depends on the use intended for the trees. In South America when grown for firewood, a spacing of 2 x 2 m or wider is used. In rangeland in association with grasses and other crops, the spacing may be up to 10 x 10-15 m. When the emphasis is on pod production, the spacing used is usually 5 x 5-10 m. Young plants benefit from weeding around the stem and need protection from grazing animals.
Weed. In Africa it has become a weed in dense communities where it is not used.
Pests and diseases. In South America, the wood sawyer insect (*Oncideres saga*), causes considerable damage. Other pests reported there are the lycainid butterfly (*Hemiargus ramon*), which damages the flowers, and the lonchaeid fly (*Silba pendula*) and *Bruchus* beetles, which attack the pods.

Feeding value

Nutritive value. Ripe pods are highly palatable, on dry matter basis they contain 12-14% crude protein and a high level of energy (75% TDN). Seeds contain 31-37% protein. Pods should be finely ground before feeding as grain replacement.

Seed. Seed storage behaviour is orthodox; 60% germination following 50 years storage; viability can be maintained for several years in hermetic storage at 10 deg. C with 5-9% mc; no loss in viability following 24 hours of immersion in liquid nitrogen for seeds at 7% mc and 5% mc. There are 20 000-26 000 seeds/kg.

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Medium Stratum Species

Shrubs

Leucaena leucocephala

Scientific name
Leucaena leucocephala (Lam.) De Wit (subsp. glabrata (Rose) Zárate; ixtahuacana C.E. Hughes; Leucocephala).

Synonyms
Acacia leucocephala (Lam.) Link; Leucaena glauca Benth; Mimosa glauca sensu L.; Mimosa leucocephala Lam.

Family/tribe
Family: Fabaceae (alt. Leguminosae), subfamily: Mimosoideae, tribe: Mimoseae.

Common names
English: leucaena, wild tamarind, lead tree, jumby bean.
Spanish: leucaena, guaje, ipil-ipil, lino criollo; granolino.

Morphological description
Shrub or tree up to 18 m tall, forked when shrubby and branching strongly after coppicing. Bipinnate leaves with 4-9 pairs of pinnae, up to 35 cm in length. Numerous flowers, white to slightly yellowish. Pods 14-26 cm x 1.5-2 cm, pendant, brown at maturity. Brown seeds, 18-22 per pod, 6-10 mm long.

Distribution
L. leucocephala occurs naturally in southern Mexico, and is widely distributed throughout the tropics including Africa, Southeast Asia and Australia.

Uses/applications
Forage. It is the most important ruminant forage in agroforestry systems for animal production, including for the intensive silvopastoral systems, thanks to its unusual high capacity for regrowth after browsing/ cutting and a lifespan of several decades.
Shade. It is also used as a shade tree for coffee and cocoa and for alley farming.
Food. Unripe pods have been used as food and medicine since ancient times.
Fuel. It gives excellent results for energy production.

Ecology
Soil requirements. In its native range, grows on shallow limestone soils, coastal sands and seasonally dry Vertisols with pH 7.0-8.5. In exotic locations requires well-drained soils with pH above 5.5, or above 5.0 where aluminum saturation is very low. Intolerant of soils with low pH, low phosphorus, low calcium, high salinity, and waterlogging. Tolerant of moderate salinity and alkalinity.

Moisture. It prefers sub humid and humid climates of 650-1,500 mm and up to 3,000 mm annual rainfall and tolerates up to 7 months dry season. It does not tolerate waterlogged soils or extended periods of flooding (>3 weeks).
Temperature. It requires 25-30 ºC for optimum growth. Growth ceases at 15-16ºC. Frosts will kill leaf or stems depending on severity and growth stage.
Light. Grows readily with up to 50% shade. Productive under mature coconuts.

Reproductive behaviour
All subspecies will flower and set seed throughout the year under adequate soil moisture and temperature.

Agronomy
Establishment. Relatively slow to establish, particularly in competition with weeds. For best results plant on deep, well-drained soils with pH >5.5 and maintain a weed-free area of at least 0.5 m either side of the establishing plants. Fresh seed has good germination, but after some time, seed must be scarified to break the impermeable testa. Scarification can be done by soaking seeds for 3 minutes in water just before boiling at 80 °C. Mechanical scarification, using coarse sandpaper (for small seed lots) or abrasive-lined rotating drum scarifiers, is possible. Specific rhizobium is required but it is normally present where Leucaena has grown previously.

Traditional complete land preparation has been used in the past but it is preferable to do direct seeding after temporary control of competitors. In Australia they plant rows 4-9 m apart at seeding rates of 1.5-3.0 kg/ha. In Cuba for direct grazing systems the recommended density is 1 m within rows x 3 m between rows, but in Colombia is planted at high densities, 1 m x 1 m. In fodder banks, density could be 0.4 m within rows, and 1.0 m between rows.

Post-plant herbicides can be used to control emerging weeds between the rows. Rolling cultivators can be used to control very young weeds and to break soils crusts to allow the emergence of Leucaena seedlings.

Small areas can be planted using seedlings, normally raised in poly bags for plug planting at 3-4 months old. Seedlings can also be raised in beds and removed for planting as bare-rooted seedlings.

For cut-and-carry systems all the *L. leucocephala* varieties are fine, but for browsing (grazing) systems the varieties “Cunningham” or “Perú” are preferred, due to the flexibility of their branches, which do not break while browsed by cattle and to their resistant root system to animal trampling.

Fertilizer
Normally no fertilized under most conditions with normal Rhizobium association. Starter nitrogen and phosphorus may be used when establishing into depleted soils. On acid infertile soils it is essential to add lime, phosphorus, and potassium at planting, and then after each cut.

Compatibility
It is compatible with a range of grass species, but it can be difficult to establish into existing grass pastures without complete opening rows or previously removing the grass. In the dry tropics, can be difficult to establish grass into mature Leucaena plantations due predominantly to moisture competition. It is recommended to seed Leucaena first, and shortly afterwards introduce the grass.

Companion species
Grasses: In sub-humid and humid conditions it can be grown in association with a variety of grasses: *Cenchrus ciliaris, Panicum maximum, P. coloratum, Chloris gayana, Digitaria eriantha, Brachiaria humidicola* and *B. decumbens*.

Pests and diseases
Main insect pest is the psyllid (*Heteropsylla cubana*), an aphid-like sucking insect that reduces production of all cultivars and accessions. Psyllid population outbreaks are generally episodic, depending on climatic conditions. In the humid tropics, outbreaks are most severe at start and end of wet season. Populations can be almost permanently high where moderate rainfall and temperatures occur throughout the year.

Soil insects such as earwigs, scarab beetles, termites, and cut worms can cause serious damage to emerging seedlings and should be controlled.

Weed potential
It has considerable weed potential in ungrazed disturbed lands, such as roadsides and stream banks, particularly where soils are limestone based. No weed potential under continuous grazing as trees rarely set seed, and seedlings are removed by grazing or grass competition. Without a rotational grazing, Leucaena can´t survive within pastures due to continuous intake by livestock. Leucaena will never invade intact forests since it does not tolerate shade when young.

Feeding value
Nutritive value. Foliage is noted for its very high nutritive value for ruminant production. Typical values for the edible fraction are 55-70% digestibility, 3-4.5% nitrogen, 0.8-1.9% calcium and 0.23-0.27% phosphorus. Leaves also contain 2-6% condensed tannins, phenolic compounds which bind and protect dietary protein from degradation in the rumen.

Palatability/acceptability. Highly palatable to most grazing animals especially compared to other forage tree legumes.

Toxicity. It contains mimosine, a non-protein aminoacid that has antimitotic and depilatory effects on animals. Mimosine concentrations in young leaves can be as high as 12%, and the edible fraction commonly contains 4-6%. Mimosine is acutely toxic to animals but is normally converted to 3-hydroxy-4(IH)-pyridone (DHP) upon ingestion. DHP is goitrogenic and, if not degraded, can result in low serum thyroxine

levels, ulceration of the oesophagus and reticulo-rumen, excessive salivation, poor appetite, and low liveweight gains. DHP is metabolized by the microbe *Synergistes jonesii*, which is present in the rumen of animals in the Americas, from where it has been taken to other continents. Since *S. jonessii* is normally present in the rumen of most animals in tropical America, toxicity in ruminants is mostly a myth, coming from its negative effects on monogastric animals to which it should never be fed.

Production potential

Dry matter. Forage yields up to 15 t/ha/year depend on soil fertility, rainfall, altitude, density, and cutting frequency. Leaf yield is maximized by cutting at 6-12 week intervals during the growing season. Yields in extensive hedgerow plantings in the dry tropics, and subtropics generally range from 2-6 t/ha/year. Firewood yields compare favorably with the best tropical trees, with height increments of 3-5 m/year, and wood increments of 20-60 m^3/ha/year.

Animal production

Excellent cattle growth rates have been reported from Autralia, where thousands of hectares have been established. Large areas have been planted in Cuba and México as a strategy to increase animal production throughout the year, increasing cattle daily weight gains from 0.4 to 0.8 kg/head/day and milk production from 7 to 11 kg/animal/day. In Colombian farms, milk production has reached 17,026 kg/ha/y. A great feature of Leucaena is that it maintains its foliage during the dry season when the grasses seasonally dry out, so it virtually eliminates the dry season for forage production. It provides enough nutrients to sheep and goats, resulting in good weight gains and good reproductive performance.

Seed production

Seed production is strongly moisture dependent and producers report minimal seed set in dry years. Seed yields of 250 kg/ha are common from mechanically harvested dryland crops, but wide-spaced manually harvested trees under irrigation can produce up to 2 t/ha.


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Shrubs

Tithonia diversifolia

Scientific name
Tithonia diversifolia (Hemsl.) A. Gray

Synonyms
Mirasolia diversifolia Hemsley.

Family/tribe
Family: Asteraceae (Compositae), tribe: Heliantheae.

Common names
English: Tree marigold, tithonia, Mexican sunflower
Spanish: Jalacate, guasmara, árbol maravilla, girasol mexicano.

Morphological description
It is a woody herb or succulent shrub, 1-3 m tall. Opposite leaves (3-5), attenuate base, acute apex and crenate margin. Its height varies between 1.5 and 4.0 m with erect and branched stem. Leaves are alternate petiolate, up to 20 cm long and wide.

The inflorescence appears in flower heads and it is formed by small sessile flowers. The flowers are brilliant yellow or orange. The fruit is dry and indehiscent. The seeds known as achene; are oblong, up to 6 mm long.

Distribution
Present in all tropical and subtropical areas with almost 15,000 species distributed all over the world. Tithonia genus has 10 species in Central America, and it is commonly accepted that its center of origin.

Uses/applications
Feed. For the last three decades has been used as forage in agroforestry systems for animal production, including silvopastoral systems, with great success thanks to its high nutritive value, abundant production and wide range of growing conditions.
Green manure: In Costa Rica has been used at experimental level for increasing bean production in improved fallow lands; in other countries also used as green manure in rice and corn crops.
Pest control: Used as insecticide, but specific compounds unknown. Also used against leaf-cutter and other ants.
Medicinal: Infusion used for constipation, stomach pains, indigestion, sore throat, liver pains, and malaria. Leaf infusions, which contain bitter oil, are sometimes used for treating the eczema in the skin of domestic animals.
Ornamental: Widely cultivated and appreciated as ornamental in the tropics.

Ecology

Soil requirements. It grows in deep soils with good drainage, tolerates low acidic pH values (5.0), and low levels of phosphorus.

Moisture. Annual rainfall of 100-2000 mm.

Temperature. Mean annual temperature of 15-31 ^{0}C.
Altitude. It grows from sea level to 1950 m.a.s.l.

Reproductive behavior

Flowers and produces seed throughout the year and at different times, but mainly during rainy seasons. It is a prolific seeder which retains its seeds until the plant dries in the dry season when the seeds are spread by wind, water, and the movement of people, livestock, and vehicles.

Agronomy

Establishment. Can be propagated from seeds, and cuttings. Seeds germinate readily when sown fresh, all year round. Seeds are sprinkled directly on soil, or barely covered with soil at densities up to 40,000 plants/ha. Stem cuttings of 20 to 40 cm length establish readily. Cuttings buried horizontally in the soil will sprout, but they are less effective than cuttings inserted either upright, or at an angle. Cuttings should be planted into moist soil immediately after collection.
Harvest. It can be cut or grazed as soon as 7 weeks, but regrowth depends on fertilization, responding very well to biodigester effluent and poultry manure.

Fertilizer

It has a great root volume, recovers scarce soil nutrients effectively, and has a wide adaptation range. Grows rapidly and demands low inputs. It has the unique ability to absorb soil phosphorus quite efficiently, making it a very valuable source of phosphorus fertilizer.

Weed potential

Due to its rapid vegetative reproduction and significant yields of lightweight seeds, it can quickly invade disturbed habitats. It forms dense stands that prevent the growth of young native plants. It is considered invasive in some parts of Africa and Australia, and in many Pacific islands.

Feeding value

Nutritive value. Accumulates as much nitrogen in the leaves as legumes, in addition to presenting high phosphorus content. Nutritional quality varies with vegetative status. Leaves contain 24.3% protein in dry matter and low fiber values, and in general shows fast degradability and fermentation at rumen level. The rapid nitrogen digestion requires a readily available energy source for optimum utilization. It should not be fed as only feed, because excessive nitrogen excretion causes poor performance.

Palatability/acceptability. Fresh forage can be initially rejected, but quickly animals get used to it and even seem addicted.

Production potential

Dry matter. Good biomass production capacity and quick recovery after pruning, which depends on planting density, soils, and vegetative status. Forage potential production is between of 21-31 t of DM/ha/year.

Animal production. It can be used to feed a variety of animals, monogastrics and ruminants. Pigs gained more than 600 g/day in a ration containing sorghum complemented with 30% pre-dried and ground Tithonia. Widely used in Colombia and other tropical countries for fattening animals and pastures. Fresh foliage is mixed with concentrate and cut grasses. Cattle, goats, sheep, guinea pigs and rabbits consume it well when fresh. It is a source of carotenoids to pigment egg yolks. Popular in apiculture as a source of nectar.

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Clitoria ternatea

Scientific name
Clitoria ternatea L.

Synonyms
Clitoria albiflora Mattei, *C. bracteata* Poir, *C. mearnsii* De Wild

Family/tribe
Family *Fabaceae* (*Leguminosae*), subfamily *Faboideae,* tribe: *Phaseoleae*.

Common names
English: Butterfly-pea; blue-pea. **Spanish:** azulejo, papito, zapatico de la reina, zapotillo, conchita azul, campanilla, choroque, lupita, bejuco de conchitas.
French: cordofan-pea, honte.

Morphological description
A vigorous, strongly persistent, herbaceous perennial legume. Stems fine twining, sparsely pubescent, suberect at base, 0.5-3 m long. Leaves pinnate with 5 or 7 leaflets; leaflets elliptic, ovate or nearly orbicular, 1.5-5 cm long, 0.3-3 cm wide. Flowers axillary, single or paired; color ranges from white, mauve, light blue to dark blue; pedicles 4-9 mm long, twisted through 180º so that the standard is inverted. Pods linear-oblong, flattened, 4-13 cm long, 0.8-1.2 cm wide, sparsely pubescent when mature, pale brown, dehiscent when dry. Seeds 8-11/pod, oblong, somewhat flattened, 4.5-7 mm long, 3-4 mm wide, olive brown to almost black, shiny, often mottled. Number of seeds/kg: 23,000.

Distribution
Native to Africa. Now widespread throughout humid and sub-humid lowlands of Asia, the Caribbean, Central and South America, and more recently in semi-arid tropical Australia.

Uses/applications
Fodder. Good for short and medium-term pastures and protein banks, and in mixtures for silvopastoral systems. Excellent for hay making.
Green manure. Increases soil fertility to improve yields of subsequent crops when grown as green manure or ley pasture.
Cover crop. A good species as cover crop in fruit orchards and tree plantations.
Food. Used in infusions and to dye rice in Asia.
Ornamental. Widely planted in gardens and fences for the beauty of its flowers.

Ecology

Soil requirements. Adapted to a wide range of soil types (from sands to heavy clays) of moderate fertility, but extremely well adapted to heavy clay alkaline soils, and especially on clay soils which are too shallow for Leucaena. Adapted to pH 4.5-8.7 but prefers medium to high pH. It tolerates very unfertile soils.

Moisture. Requires summer rainfall of 500 mm over 3 months but grows best between 700-1,500 mm. Drought tolerant, even under heavy grazing will survive in years which have only 400 mm rainfall and a dry season of 5-6 months or longer. Some tolerance of short term flooding, but not prolonged inundation or waterlogging.

Temperature. Warm (wet) season growth up to 2,000 m.a.s.l. in equatorial Africa, and up to 24 ºS latitude. Tolerates average daily temperatures down to 15 ºC but not frosts. Production is limited more by low average daily temperatures or a short growing season than by light or even heavy frosts.
Light. Normally grown in full sunlight but moderately shade-tolerant.

Reproductive behaviour

Flowers can develop in 4-6 weeks after sowing and continue to flower while temperature and moisture are adequate. Flowering can occur throughout the year given sufficient soil moisture and frost-free conditions. Predominantly self-fertile, but with some out-crossing.

Defoliation

Tolerant of heavy rotational grazing, but not constant heavy defoliation. Frequent trampling by cattle will damage the stems. Growing tips and axils of stems must be left to develop new leaves. Because of its high palatability, it is better managed as short-term pasture under rotational grazing. Optimum cutting interval of 56 days at heights of 5 or 10 cm for best DM and protein yield.

There is one report of persistence for 14 years under heavy dry season grazing in infertile Vertisols. It must be allowed to set seed to guarantee persistence. In protein banks, cattle should be allowed to graze for only 2-3 hours each day.

Agronomy

Establishment. Best results are achieved by planting into moist soil (2-6 cm), in narrow rows (15-50 cm apart), at about 2-4 kg/ha for long-term pastures and 6 kg/ha for short-term pastures to achieve plant densities of 5-10 plants/m². Excellent results can be achieved when sown as a crop using conventional planters and presswheels to achieve good soil/seed contact.

For optimum yield as a green manure crop, the seeding rate is 12 kg/ha. As a component of grass-legume pastures, it can also be planted behind a blade plough or using a "crocodile seeder". Soil temperatures between 16 and 36ºC are required for good establishment. Weed competition will delay establishment but, once established, Clitoria can smother most weeds.

Seed should be inoculated with Tropical Group M rhizobium. Mechanically scarify seed with a high hard seed content (>30%) when soil conditions favor immediate germination, or use unscarified seed with a high hard seed percentage when staggered germination is desired, e.g. planting behind a blade plough or when using a crocodile planter. Establishment is considered a much lower risk on heavy textured soils because of large seed size and greater weed tolerance than alternatives such as Leucaena. The use of pre-emergent herbicide 2-8 weeks prior to sowing is desirable to achieve successful weed control during establishment.

Fertilizer
Not normally needed when sown on suitable soils, but phosphorus, sulfur and potassium may be required on infertile soils.

Compatibility with other species
Rapid climbing growth suggests that Clitoria will combine better with tall grasses than with creeping ones. It has been used as leguminous mulch within elephant grass (*Pennisetum purpureum*) to improve grass protein levels. When grown together, Clitoria increased total forage protein content and total DM without reducing grass yield. It can be sown as a pure stand for short-term (2-3 year) rotation with crops.

Companion species
It has been grown successfully with elephant grass (*P. purpureum*), forage sorghums (*Sorghum bicolor*), and millets, as well as *Panicum maximum*. Also sown with pangola (*Digitaria eriantha*), *Andropogon gayanus, Dichanthium aristatum. Cenchrus ciliarus,* and *Chloris gayana*.

Pests and diseases
Fungal leaf diseases (e.g. *Cercospora, Colletotrichum, Odium* and *Rhizoctonia*) have been recorded in cool-wet weather but rarely a serious problem. Minor susceptibility to various leaf-eating caterpillars and grasshoppers. Most lines susceptible to root nematode *Meloidgyne incognita*.

Feeding value
Nutritive value. Excellent nutritive value with high protein and digestibility (up to 80%) with nitrogen concentrations of 3.0% for leaf, and 1.5% for whole plant. Leaf had consistently low acid detergent fiber (ADF, 20%).

Palatability/acceptability. Very palatable thus requiring grazing management to maintaining it in pastures.

Toxicity. Seeds are a strong purgative.

Production potential
Dry matter. Yields up to 15 t of DM/ha/year and 4,200 kg of DM/ha at 4 month. In dryland conditions in the sub-humid tropics, it normally produces 2-6 t/ha/year DM.

Animal production. Liveweight gains of 0.7-1.3 kg/ha/day recorded for steers grazing pure Clitoria pastures. Cattle grazing para grass (*Brachiaria mutica*), and *C. ternatea* pasture gained 0.68 kg/head/day.

Seed production. Hand harvest where economical, but can achieve 700 kg/ha by mechanical harvesting methods. Irregular pod maturity affects best time of harvest as some pods will have shattered while flowers and green pods are still present.

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Teramnus labialis

Scientific name
Teramnus labialis (L. f.) Spreng and subspecies *arabicus* Verdc; *labialis* var. *abyssinicus* (Hochst. ex A. Rich.) Verdc; *labialis* var. *labialis*

Synonyms
Glycine labialis L. f.

Family/tribe
Family: Fabaceae (Leguminosae or Papilonaceae), tribe: Phaseoleae.

Common names
English: blue wiss, rabbit vine, horse vine. **Spanish:** Teramnus.

Morphological description
Extremely variable perennial, twining or prostrate, trailing, some forms stolons, sometimes woody at the base. Stems 0.3-3 m long, slender, often covered with white to ferruginous hairs. Rounded leaflets, elliptic, ovate, obovate, narrowly oblong or lanceolate; Inflorescence a slender raceme, with few to many flowers along the 0.3-10 cm long rachis. Linear pods, 2.5-6 cm long, 2-4 mm wide, glabrescent to densely covered with spreading hairs; 7-12 seeds/pod. Seeds yellow-brown to dark purplish-brown, oblong or almost cylindrical, smooth or covered with a granular encrustation; 110,000-370,000 seeds/kg. It has a distinctly curved tip on the pod.

Distribution
Native to or naturalized in Africa, Western Indian Ocean, Asia, Pacific. Mesoamerica, Tropical South America and most Caribbean islands. Found in grasslands with scattered trees, thickets, bushland, forest clearings, and along road edges.

Uses/applications
Fodder. Component of permanent pastures, with potential for agroforestry applications due to moderate shade tolerance. It can be grazed fairly intensively or cut-and-carry.
Food. Seeds used as food.
Medicine. Plant extracts used in natural medicines.

Ecology
Soil requirements. Found in well drained sands to clays with pH 6.0-8.0. Although originating from mostly near neutral to alkaline soils, some types have performed well on soils with pH 5.0-5.5. Others have been collected in areas with sodic soils.

Moisture. Mostly collected in run-on or moister areas, optimal growth in regions with average annual rainfall 750 to 1,500 mm. It sheds its leaves during dry periods and killed off by the prolonged dry periods.

Temperature. It occurs at latitudes between 25 ºN and 29 ºS, representing a range in average annual temperatures between 14-27 ºC, sometimes with frost.
Altitude. From sea level to 3,000 m.a.s.l.
Light. It grows well under citrus (*Citrus sinensis*), banana (*Musa* spp.) and coconut (*Cocos nucifera*).

Reproductive behaviour
It appears to flower in response to shortening day length. Flowering time varies markedly among provenances, some flowering in about 70 days from a spring planting and others 200 days.

Defoliation
Tolerance of defoliation varies according to growth habit, low growing stoloniferous varieties normally being more tolerant than more upright types.

Agronomy
Establishment. Generally, seed does not require scarification. However, levels of hard seed can be high and scarification may be necessary in some instances to achieve at least 50% germination. Although *T. labialis* appears somewhat promiscuous in relation to rhizobial requirements, inoculation may be beneficial. Seed can be broadcast or sown at 2-3 kg/ha in rows 50-75 cm apart, and no more than 3 cm deep. Stands take 6-8 months to become established.

Fertilizer. It requires moderately fertile soil. Application of 20 kg/ha of phosphorus and 40 kg/ha of potassium is recommended on deficient soils.

Compatibility
It grows well in mixed pastures, persisting and producing considerable bulk without smothering the grasses. It is probably not sufficiently aggressive to combine with more competitive grasses such as *Paspalum notatum*, nor does it twine to a sufficient height to combine with unmanaged tall grasses such as *Panicum maximum*.

Companion species
Grasses: *Axonopus fissifolius*, *Bothriochloa pertusa*, *Stenotaphrum secundatum*.
Legumes: *Macroptilium atropurpureum*, *Neonotonia wightii*, *Vigna parkeri*.

Pests and diseases
It is not affected by pests and diseases to any great extent, although leaf damage caused by *Fusarium* and *Alternaria* has been recorded, particularly in the wet season. Some leaf damage has also been caused by the banded cucumber beetle.

Ability to spread
It has become naturalized outside its native range.

Feeding value
Nutritive value. It maintains a high leaf to stem ratio, with crude protein levels of 21% in leaves and 10% at stems. Calcium levels were 1.2% in leaves and 1% at stems, and phosphorus 0.3 and 0.2%, respectively.

Palatability/acceptability. It is well eaten by sheep and cattle.

Production potential
Dry matter. While more productive types can produce 10-16 t of dry matter/ha, many produce much lower annual yields.

Animal production. It combines well under citrus plantations, with good results in sheep growth.

Seed production. Pod-set often occurs beneath the foliar canopy, and close to ground level, making mechanical harvesting difficult. The general recommendation is to harvest 3-4 weeks after commencement of ripening, when 90-95% of pods are ripe. While seed yields of >1 t/ha have been recorded, 0.2-0.5 t/ha are more common.

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Neonotonia wightii

Scientific name
Neonotonia wightii (Wight & Arn.) J.A. Lackey, var. longicauda (Schweinf.) Verdc.

Synonyms
Glycine javanica auct.

Family/tribe
Family: Fabaceae (Leguminosae), subfamily: Faboideae, tribe: Phaseoleae.

Common names
English: Glycine, perennial soybean. **Spanish:** soya perenne, soya forrajera, **French:** soja pérenne.

Morphological description
Trailing, climbing or twining perennial vine with strong taproot, and woody base of 25 mm in diameter in large plants, climbing to 10 m on appropriate support. Herbaceous slender stems (mostly 2-3 mm diameter), glabrous to densely pubescent (hairs whitish to reddish brown), well branched, redeveloping from underground crown if main stem severed; ability for prostrate stems to develop nodal roots varies with ecotype. Pinnately trifoliolate leaves, deciduous, petiole 2.5-13 cm long. Axillary inflorescence, dense or lax racemes, 2-35 cm long on peduncles 3-12.5 cm long, comprising 20-150 flowers; standard white to mauve-blue, sometimes with obscure small violet streaks on lower part, yellow to orange on senescence. Brown pods, linear-oblong, straight or slightly curved at the apex, 1.5-4.0 cm long and 2.5-5.0 mm wide, containing 3-8 seeds, shattering at maturity. Oblong seeds with rounded corners, laterally compressed, light olive-green to dark and reddish-brown, occasionally mottled; 50,000-170,000 seeds/kg.

Distribution
Native to Africa and it may also be native to South and Southeast Asia. It is found in grasslands, shaded conditions in bushlands and woodlands. Naturalized in in Subtropical Australia and in many other parts of the tropics.

Uses/applications
Fodder. For grazing in pastures and for cut-and-carry. It makes good hay and silage. Suitable for agroforestry, although twining habit can be a problem in the latter.

Ecology
Soil requirements. It occurs on wide range of soils from red sands to heavy black clays, mostly well drained and with pH from 6-8. Under cultivation, it grows best on fertile, deep, freely drained, near neutral clays and clay loams, usually of alluvial

origin or derived from basic igneous rocks (basalt, andesite). Performance is less reliable on soils with pH lower than 6 unless heavily limed, or those with a hard-setting A horizon. More demanding than most tropical legumes for molybdenum. Very sensitive to manganese and aluminum toxicities, both of which are alleviated by lime additions. Moderately tolerant to salinity, depending on variety. Of the twining legumes, it is best adapted to neutral fertile soils.

Moisture. It originates from areas with average annual rainfall from 550-1,650 mm. Most cultivars are grown in areas with mean summer rainfall between 800 and 1,500 mm. It is not successful in areas of much higher rainfall. Some ecotypes are drought tolerant. It grows best in well-drained soils, but tolerates a degree of waterlogging, some accessions being collected in depressions and on swamp margins.

Temperature. Mean annual temperatures vary from 15 to 25 ºC, sometimes with a lowest average monthly minimum of 5-6 ºC, and subject to frosts. Optimum day/night temperature for growth 30/25 ºC, slow growth at 16 °C and no growth at 13 °C.

Light. Moderately shade tolerant, growing successfully under trees in open forest and woodland. Twines towards the light when growing among taller grasses.

Defoliation

Relatively slow to establish, it should not be grazed too early. Under normal conditions, mixed grass/legume pastures can be grazed 7-8 weeks after sowing if there is sufficient grazing pressure to reduce initial grass competition. Once the legume is fully established, pastures are rotationally grazed. It is advisable to exclude livestock towards the end of the growing season every few years to facilitate flowering and seeding to encourage legume persistence.

Agronomy

Establishment. Hard seed levels, in manually harvested seed, are frequently of the order of 80-90%. Larger amounts can be mechanically scarified, and small amounts treated with concentrated sulphuric acid for 25 minutes, or hot water. Commercial seed has usually been sufficiently scarified during the harvesting and threshing process. It is fairly promiscuous in its rhizobial relationships and can be inoculated with different commercial inoculant. Seed can be broadcast onto the surface of a well-prepared seedbed, or drilled to 1-2 cm at 1-5 kg/ha seed, and rolled with a heavy roller. Germination is best at moderate temperatures, and declines markedly above 37 °C. Young seedlings growth slow, but vigor improves with effective nodulation. With good conditions, ground cover can be achieved at about 2 months after sowing.

Fertilizer. It requires fertile soil, and deficiencies or toxicities must be corrected, including liming. Main nutrients to consider are calcium, phosphorus, sulfur and molybdenum. On very fertile soils, no fertilizer may be required, but as a guide, a suitable establishment dressing is 40 kg/ha of phosphorus, and molybdenum. Follow-up dressings of 20 kg/ha of phosphorus every 1 or 2 years, and molybdenum every 3 years may be necessary. Need for copper should be monitored in deficiency areas, antagonistic with molybdenum.

Companion species
Grasses: *Chloris gayana, Digitaria eriantha* (pangola grass), *Panicum maximum, Pennisetum clandestinum, P. purpureum, Setaria sphacelata, Brachiaria decumbens.* Legumes: *Leucaena leucocephala, Vigna parkeri.*

Pests and diseases
Generally few problems with pests and diseases. Under very wet conditions, leaf blight (*Rhizoctonia solani)* can cause leaf damage. It is an alternative host for halo blight caused by Pseudomonas a serious disease of beans (*Phaseolus vulgaris*), but not seriously affected itself. During moist and mild, temperature conditions, webworms can severely defoliate plants. Several Coleoptera attack the roots of young plants, causing losses.

Ability to spread
A prolific seeder, with appropriate space and environment, seedlings establish readily. Some varieties can also spread vegetatively, rooting down at the nodes.

Feeding value
Nutritive value. Crude protein values in leaf dry matter up to about 26%, 20% in the whole plant. Dry matter digestibility varies between 55-62% depending on age of regrowth and moisture regime.

Palatability/acceptability. Well grazed throughout the whole year.

Production potential
Dry matter. Yields vary according to soil and environmental conditions, variety and defoliation management. They generally range from about 3-8 t of dry matter/ha.
Seed production. Day/night temperature of 27/22 to 16 °C is most suitable for seed production. Seed formation is reduced at high temperatures. Seed may be hand or machine harvested. The crops is ready when pods become dark and hard and start shattering. Yields of up to 1 t/ha seed have been recorded, but commercial producers consider 300 kg/ha satisfactory.

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(Photo from Dayami Fontes y C. Mazorra)

Morus alba

Scientific name
Morus alba. L.

Family
Family: Moraceae

Common names
English: Mulberry. **Spanish:** morera or mora. **French:** mûrier.

Morphological description
A handsome deciduous tree, 10-25 m tall, that forms a dense and wide spreading head of branches usually wider than the height of the tree, springing from a short, rough trunk. The simple, alternate, stipulate, petiolate, light green leaves are cordate at their base but very variable in form, even on the same tree. Flowers are unisexual, borne in the axils of leaves or on spurs on separate spikes. Fruits are collective, fleshy, white, deep red to black.

Distribution
Native to Asia, area China-Japan and Himalayas´ foothills.
It has now spread all over the world, from northwest and central Asia, to Europe and to America and to Africa. There are mulberry varieties for many environments, from sea level to altitudes of 4,000 m, and from the humid tropics to semi-arid lands.

Uses/applications
Fodder. Leaves have been the traditional feed for the silkworm (*Bombix mori*) since the onset of sericulture some 5,000 years ago. In China, mulberry residues from silkworm rearing have traditionally fed to small ruminants and it has also been part of the dyke-pond system. For the last three decades mulberry has been used to feed other domestic animals, ruminants in particular in various parts of the world, taking advantage of its high quality and production.
Food. It is appreciated for its fruit, which is consumed fresh, in juice, wine or in preserves. Young leaves and stems are delicious vegetables.
Medicine. Mulberry leaf tea is used as remedy for a variety of diseases. Dry leaves are used for diabetes since the compound 1-deoxynojirimycin reduces the rate of sugar absorption.
Ornamental. Common in parks and gardens.
Wood. The wood is used for making sporting equipment and for furniture.

Ecology
Soil requirements. It grows better in a well-drained neutral soil, preferably a deep loam. The white mulberry is quite tolerant of drought, pollution and poor soil, growth depends on solar radiation, nutrients and water.

Temperature. Grows well in temperate areas but loses its leaves in the winter. In the tropics it grows all year around.

Light. Requires full sun for good production. Maximum yields have been obtained in areas with plenty of sunlight.

Defoliation
Responds well to coppicing. In the tropics the most appropriate cutting interval is 45-90 days, varying with the season.

Agronomy
Establishment. The most common planting method worldwide has been by stem cuttings, but in certain places seed is preferred. Stakes should be 20 to 30 cm long, and each stake ideally should have at least 3 buds. Usually, stakes are planted vertically into the soil. For cut-and-carry it can be planted at 0.4 m within rows x 1 m between rows. Micro-stakes, with only one bud, take well in humid and warm conditions.

Mulberries can also be grown from seed. Seed should be sown as soon as extracted from the fruit, although white mulberry seeds germinate better after storage for one to three months. Seeds should be planted near the soil surface with a thin layer of soil and ashes spread over them in moist soil. They can also be planted first in a nursery with common substrates (soil, peat moss, humus, etc.). Seed germinate in 9-14 days, depending on the season. When seedlings are about 7.5 cm tall, they are thinned and weeded.

As is the case with other tropical perennial forages for cut-and-carry systems, planting by seed assures deeper roots with greater capacity to find water and nutrients, which eventually results in higher biomass production, and greater longevity. Seeds are easier to transport, to quarantine and to store.

Fertilizer
For both higher yields and better quality leaves the application of balanced fertilizer is imperative. Responses of mulberry to nitrogen fertilizers (250-350 kg of nitrogen/ha) have been clearly demonstrated, with better responses from organic sources. The nutrients extracted by the high production need to be replenished for sustainable production.
The association with legumes with effective nitrogen-fixing rhizobium can reduce N inputs. Nevertheless, in extremely poor soils, in very rainy areas, or under irrigation conditions, additional chemical fertilizer may still be needed.

Compatibility
Mulberry has been tried for direct browsing in combination with grasses and clovers in some temperate countries with acceptable results. In the tropics, it combines well with *Gliricidia sepium* under cut-and-carry systems, and grows well under *Erythrina spp*, and Leucaena.

Pests and diseases
Literature describes many pests and diseases of mulberry in silk producing temperate areas, but generally mulberry is a very healthy crop in the tropics.

Ability to spread
Mulberry trees are very easy to propagate and transplant. Fruit (seed) bearing plants can be spread through birds.

Feeding value
Nutritive value. Crude protein values in leaves vary from 15-28% depending on variety and growing conditions. Crude protein in edible biomass (leaf and young stem) averages 12-15%, with essential amino acids representing 45% of total aminoacids. Fiber fractions are low in mulberry leaves compared to other foliage. Acid detergent lignin contents are 8% for leaves and 7% bark. A striking feature of mulberry leaves is the mineral content, with ash values up to 25%. Typical contents are calcium 1.8-2.4%, phosphorus 0.14-0.24%, potassium 1.90-2.87% and magnesium 0.47-0.63% in leaves.

The most notable characteristic of mulberry foliage is its very high digestibility values, much superior to common forages and equivalent to commercial feed. Leaf digestibility *in vivo* for goats 78-81% and *in vitro* 89% have been reported

Palatability
An important feature of mulberry forage is its high palatability. Small ruminants avidly consume the fresh leaves and the young stems first, even if they have never been exposed to it before. They even consume the bark Cattle consume the whole biomass if finely chopped. Animals prefer mulberry to other forages when offered simultaneously, and even dig through a pile of various forages to look for mulberry.

Production potential
Dry matter. Total biomass production 25-47 t/ha/year and edible 15-35 t/ha/year.

Animal production. Evaluations carried out with ruminants show high intake levels and high animal responses in weight gain and milk yield. In Central American and Caribbean farms it is used to replace grain-based concentrates in lactating cows and goats in confinement and semi-confinement with excellent results. In cows, production of 12-14 kg of milk per day have been reported without using concentrates. Goats can produce between 11,000-12,000 liters of milk/ha in mulberry based feeding systems. Fresh and dried edible biomass have been used in sheep with excellent results.

Fresh fodder has been used in feeding pigs, rabbits, and guinea pigs. Dried foliage (mill and pellets) have produced good outcomes in pigs, rabbits, and poultry. Other small herbivores: guinea pigs, iguanas, and snails, could also be fed mulberry leaves.

Seed production

In some mulberry varieties, seeds should be removed from the fruit as soon as ready by squashing with plenty of water to separate seeds from pulp. Seeds can be dried and stored for several months although immediate sowing is recommended.

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Gliricidia Sepium

Scientific name
Gliricidia sepium (Jacq.) Kunth ex Walp.

Synonyms
Robinia sepium Jacq.

Family/tribe
Family: Fabaceae (Leguminosae, Papilionaceae), subfamily Faboideae tribe: Robinieae.

Common names
English: Gliricidia, Nicaraguan cocoa shade, quick-stick. **Spanish:** cocuite, madre de cacao, madriado, mataratón, madero negro, piñón cubano.

Morphological description
Small to medium-sized, leguminous tree up to 10-12 m high. Branching frequently from the base with basal diameters reaching 50-70 cm. Trees display spreading crowns. Leaves are odd pinnate, usually alternate, sub-opposite or opposite, approximately 30 cm long. Inflorescences appear as clustered racemes 5-15 cm long. Flowers bright pink to lilac, tinged with white, according to the variety. Pods are green, 10-17 cm long, sometimes tinged reddish-purple when unripe. Seeds 4-10/pod, oblong, yellow-brown to brown and almost black, shiny, minutely pitted. Seed size varies with provenance between 4,700 y 11,000 seeds/kg.

Distribution
Native to dry forest areas of Mexico and Central America. Widely common in the Caribbean.

Uses
Fodder. From lopping and protein banks. Leaves are dried for leaf meal.
Live fence. Widely used as live fence.
Shade. Common shade for coffee and cocoa.
Support. For pepper and vanilla plants.

Ecology
Soil requirements. Adapted to a wide range of well-drained soils. In its native range, often found on highly eroded soils of volcanic origin with pH 4.5-6.2, but is also found on sands, heavy clays and slightly alkaline, calcareous limestone soils. However, also suitable for acid, infertile soils. Not tolerant to high aluminum saturation. It does not grow well on wet or waterlogged soils.
Moisture. Drought tolerant and adapted to an annual rainfall regime of 650-3,500 mm. Largely deciduous where dry seasons are moderate to severe, but evergreen where there is sufficient moisture throughout the year.
Temperature. Mean annual temperatures across the native range vary from 21-29ºC. Leaves abscise when night temperatures fall below 15ºC.
Altitude. It grows to an altitude of 1,200 m.a.s.l., and in its native range possibly to as high as 1,600 m.a.s.l.
Light. It does not tolerate medium to heavy shade.

Reproductive behaviour
Strongly self-incompatible despite having hermaphrodite flowers pollinated by insects. Flowering begins at the start of the dry season at about 6-8 months of age. A tree can produce vast numbers of flowers (up to 30,000) that attract a wide variety of insects. Pod ripening takes 45-60 days. In very wet areas, plants may flower but produce little if any seed.

Defoliation
It tolerates repeated cutting. For forage, first cut 8-12 months after sowing at 0.5-1.0 m above soil level, and thereafter every 2-4 months depending on rainfall and temperature.


It is largely deciduous in the dry season. To prevent leaf loss at this time, it is cut at the end of the rains and again at 8 weeks into the dry season. A final cut at 16 weeks into the dry season may be possible. Normally used as a cut-and-carry forage and is rarely directly grazed. Under grazing, goats accustomed to Gliricidia will eat the bark, as well as leaves and small stems, and may kill young trees.

Agronomy

Establishment. Sowing depth is 2 cm for seeding in field or nursery beds Scarification is unnecessary and germination rates of >90% are typical. Seedlings establish rapidly, generally reaching a height of 3 m before flowering at 6-8 months of age.

Trees can also be established rapidly from cuttings, using stakes of 5-6 months old, 1.5 m long and with a diameter of 3.5-4.0 cm. If moisture is adequate, foliage will appear in four weeks. For living fences, stakes 1.5-2.5 m long with diameters of 5-10 cm, are planted 1.5-5.0 m apart to 20 cm depth. For densely planted protein banks, seed is preferred. Various planting patterns can be used e.g. double rows or triangular. Plant populations range from 4,000-10,000 trees/ha. Very high densities are used in small protein banks. Planting direction should be east to west to maximize sunlight interception.

Fertilizer. As green manure, 15 t/ha/year of leaf biomass can provide the equivalent of 40 kg of nitrogen/ha/year to companion crops and pastures. Tolerant to low soil fertility, but it will respond to lime on soils with high aluminum saturation.

Compatibility

Compatible with shade tolerant grasses such as *Stenotaphrum secundatum,* and *Paspalum notatum*.

Companion species

It has been planted in association with mulberry, providing the required nitrogen.

Pests and diseases

It has remained relatively free of serious diseases, probably due to its tendency to be leafless seasonally. Several incidences of insect problems have been noted in exotic environments. For example, aphids, mealy bugs and scale insects occasionally attack trees in Indonesia and the Caribbean.

Feeding value

Nutritive value. Crude protein content 18-30%, and in vitro digestibility of 60-65%. Yields and nutritive value depend on provenances.

Palatability/acceptability

Some palatability problems occur with ruminants depending on prior experience and sometimes provenance. Sometimes, naive animals refuse leaves on the basis of

smell, often rejecting them without tasting. Wilting leaves for 12-24 hours before feeding increases intake.

Production potential

Dry matter. Annual leaf dry matter production varies from 2-20 t/ha/year, depending on many factors. In fodder plots, annual yields of 5-16 t/ha of leaf dry matter have been obtained. Severe leaf fall occurs following flowering in seasonally dry environments. Harvesting of leaf in the early dry season will delay flowering, preventing or limiting losses from leaf fall and maximizing regrowth.

Animal production. Normally used as green forage, protein supplement to low-quality tropical forages and by-products for cattle, sheep and goats. It may be used as the sole feed in the dry season. Feeding levels have been 1-3% of body weight for cattle and goats, indicating a supplementation level of 30-100%, although a 20-40% level is more common. Increases in liveweight gains of approximately 25% have been reported for steers grazing gliricidia-grass pastures, compared with steers grazing grass alone. Results from experiments with dairy cows and buffaloes reported similar or slightly increased milk yield and milk fat yield when concentrates were replaced by Gliricidia forage up to 25% of intake.

Seed production. It produces abundant seed in native land. Seeds are shed from pods through explosive dehiscence with seed dispersal distances of up to 40 m. Seed production varies with provenance, ranging from 75 kg/ha up to 180 kg/ha, based on 7 seeds/pod and a seed weight of 8,000 seeds/kg.

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Moringa oleifera

Scientific name
Moringa oleifera Lam.

Synonyms
Guilandina moringa L., *Moringa pterygosperma* Gaertn.

Family
Family: Moringaceae

Common names
English: Moringa, ben-oil tree, clarifier tree, drumstick tree, horse-radish tree
Spanish: Moringa, libertad. **French:** ben ailé, neverdie, pois quenique.

Morphological description
A small, deciduous tree with sparse foliage, often resembling a leguminous species at a distance, especially when in flower, but immediately recognized when in fruit. The tree grows to 8 m high and 60 cm in diameter at breast high. Wide and open crown, typically umbrella shaped and usually a single stem. The wood is soft. Alternate leaves, the old ones soon falling off. Each leaf is large (up to about 90 cm long), with opposite pinnae. Leaflets dark green above and pale underneath. Flowers, produced throughout the year, are creamy white in color, with yellow stamens in loose axillary panicles up to 15 cm long, with very sweet odor. Fruit large and distinctive, up to 90 cm long and 12 mm broad, slightly constricted at intervals, light brown. It splits along each angle to expose the rows of rounded blackish oily seeds.

Distribution
Native to India, Malaysia and Arabian Peninsula.
Exotic to tropical Americas and other countries around the world, from humid tropics to semi-arid lands.

Altitude. There is Moringa from sea level to altitudes of 1,000 m.

Uses
Fodder. Moringa is commonly cultivated in hedges and backyards because of its usefulness as a fodder tree and its remarkable capacity to stand maltreatment. It is cultivated in many tropical countries for animal feed with good results in poultry, swine, sheep, goats, and apiculture. Also used in meat, eggs, and milk production. High in protein, vitamins, and minerals. Branches are occasionally lopped for feeding ruminants.
Food: All parts of the plant are edible: the green pods, leaves, flowers, seeds, and roots. The leaves, a good source of protein, vitamins A, B, and C, and minerals such

as calcium and iron. However, they are mainly used for human food, and not to any great extent for livestock. They are an excellent source of the sulphur-containing amino acids methionine, and cystine, which are often in short supply. Seeds from mature pods can be cooked in different ways. Seeds contain a pleasantly flavoured edible oil. Flowers edible or used for tea.
Fiber: Bark can be used to make small ropes, and mats.
Gum: When the tree is injured, the stem exudes a gum that is used in calico printing, as a condiment, and for stomach and bladder ailments.
Lipids: Oil extracted from mature pods is used as a lubricant, in cosmetics and perfumes.
Medicine: Different parts of the plant are effective against skin infections and fungus. It is also used as a cold remedy, diuretic, astringent, and for cardiac and circulatory, and kidney, and bladder problems. Other uses include control of cholesterol, diabetes, high blood pressure and even prevent and treat certain cancers. Moringa extract contains seven times more vitamin C than oranges, so it can boost the immune system and decrease susceptibility to colds, cough, and the flu.
Ornamental: Widely planted as an ornamental.
Water treatment: Ground seed can clarify water of any degree of visible turbidity, if a small cloth bag filled with the powdered seeds is swirled round in the turbid water

Ecology
It readily colonizes stream banks and savannah areas where soils are well drained and the water table remains fairly high all year round. Quite drought tolerant, but yields much less foliage where it is continuously under water stress. It can be killed back to ground level by a freeze, but it quickly sends out new growth from the trunk when cut.
Soil requirements. Adapted to a wide range of soil types, but it does well in well drained clay or clay loam without prolonged waterlogging. It prefers a neutral to slightly acidic soil reaction, but can tolerate pH as high as 8.5.
Moisture. It prefers sub humid and humid climates of 500-1,500 mm.
Temperature. Mean annual temperature from 12 to 40 °C.
Altitude. It grows from sea level to 1,000 m.a.s.l.

Reproductive behaviour
The bisexual, flowers are highly cross-pollinated by bees and some birds.

Defoliation
It coppices and pollards well. An extremely fast-growing tree, within 1-3 months reaches 2.5 m. Constant pruning of up to 1.5 m/year is suggested to obtain a thick-limbed and multibranched shrub. Trees are commonly grown for their leaves, and topping-out is useful to keep an abundant supply of leaves, pods, and flowers within easy reach.

Cutting tender shoots for food and forage will increase production of branches, flowers, and fruits. Tree pruning should be performed when the plant has achieved a reasonable height, between 1.2 -1.5 m depending on the characteristics of each location.

Agronomy

Establishment. Easily established by cuttings or by seed. Seeds can be sown either directly or in bags. Usually, no seed pretreatment is required, and they sprout in 1-2 weeks. However, in some cases, introducing seed in room temperature water during 24 hours can increase germination.

It should be planted in soil with good drainage and full sun light. Planting distance varies depending on the purpose of the stand. For seed production trees can be sown between 1 and 3 m apart.

Fertilizer. It responds well to mulch, water, and fertilizer. Growth is stunted in areas with a high water table. Nutrient requirements per hectare for high biomass production are approximately of 280 kg nitrogen, 380 kg phosphorus and micro-nutrients

Pests and diseases

Recent studies indicate attacks by some fungi and bacteria, like root rot and papaya powdery mildew. Ants and crickets attack new shoots, and the hairy caterpillar *Eupterote mollifera* causes defoliation.

Feeding value

Nutritive value. Foliage is noted for its very high nutritive value for ruminant and monogastric production. Typical values for the edible fraction are 57-79% digestibility, 17-23% crude protein, calcium 2.64% and phosphorus 0.26% of dry matter.

Palatability

It is well eaten by ruminants and monogastrics.

Production potential

Dry matter. Forage yields of 4-15 t/ha/year vary with soil fertility, rainfall, altitude, density and cutting frequency. Leaf yield is maximized by cutting at 6-8 week intervals during the growing season.

Animal production. Fresh biomass improves feed intake and animal performance in cattle, sheep, and goats as supplement in basal diet grasses. Recent major developments show great promise both for biomass production and for industrial processing of Moringa leaf meal. Excellent results obtained from the utilization of dried foliage (mill and pellets) in monogastrics (rabbits, chicken, ducks, etc.) diets as substitute of commercial concentrates. In rabbits it supplies high nutrient content, and can substitute between 50-70% of commercial concentrate.

Seed production. Seed viability can be maintained for several years in hermetic storage at 3 °C with 5-8% humidity. Seeds should be collected from well-developed pods.

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Trichantera gigantea

Scientific name
Trichanthera gigantea Nees

Synonyms
Ruellia gigantea Bonpl.

Family/tribe
Family: Acanthaceae subfamily: Acanthoideae tribe: Trichanthereae.

Common names
Spanish. Nacedero, cajeto, madre de agua, cenicero, tuno, palo de agua.

Morphological description
A shrub or small tree to 5 m, occasionally up to 15 m, with a rounded crown. Leaves ovate to oblong, narrowing at both ends and concave approaching the apex, 26 x 14 cm; hairless or pubescent along the venation; petioles 1-5 cm long. Inflorescence is a compact terminal panicle 5-15 cm long. Fruits contain 35-40 seeds each, and there are 4,000,000 seeds/kg. Wood is light, with pith large and septate.

Distribution
Native to streams and swampy areas and wet forests of Central America and tropical countries of South America.

Uses/applications
Forage. For cut-and-carry systems in forage banks and life fences.
Shade. In plantations and to protect water springs from stream bank erosion.
Medicine. Farmers in Colombia use it as an indigenous medicinal plant to treat human medical conditions (blood tonic, nephritis, lactogenic drink for nursing mothers), and animals (colic and hernia in horses, and retained placenta in cows).

Ecology
Soil requirements. Well adapted to acid infertile soils of pH down to 4.5.
Moisture. Adapted to 1,500-3,000 mm annual rainfall, with outer limits of 1,000 mm and over 5,000 mm. Although common to stream banks, it requires well-drained soils. It will drop its leaves during dry periods, but regrow rapidly after rain.
Temperature. A lowland species from the humid tropics, performs best at mean temperatures of approximately 30 °C. It does not tolerate frost.

Light. It has considerable shade tolerance. Yields over 30% under banana shade, compared with sun-grown plants. Grows under Leucaena, and other agroforestry species. Stem cuttings will readily form roots in full sun or in light shade.

Reproductive development

Obligate outcrossing species pollinated by bats, birds, ants and large bees. Germination percentage is very low, at 0-2%. Propagation is generally by stem cuttings.

Defoliation

Tolerant of regular defoliation by cutting. No information on direct grazing was cited. Plants should not be cut at heights below 1.0 m. This height ensures plant regrowth if buds are not damaged; it also reduces weed competition.

Agronomy

Establishment. Generally established from stem cuttings that strike roots easily. Cuttings 20 cm long and with at least 3 leaf buds, and 2-3 mm in diameter, were most effective in striking roots (92% of cuttings). Larger and longer cuttings were less successful. Cuttings should be selected from the basal part of young stems. Strike rate has been improved by storing cuttings in a shaded place for one day prior to planting into a nursery bed. Cuttings produce shoots in about one month, and can be planted into the field after about 50 days. Spacing varies from 0.5 to 1.0 m apart, and can be planted in a block or as a twin-hedgerow along fence lines.

Fertilizer. It responds well to fertilizer application despite being adapted to acid infertile soils. In Vietnam, DM yield increased from 5 to 9 t/ha when manure application was increased from 15 to 30 t/ha. In low fertility soils, produces an almost linear response to N fertilizer of up to 240 kg/ha, with an optimum return on costs at 160 kg/ha N. Regrowth well under heavy cutting regimes when fertilization and ideal conditions occur.

Companion species

It can be grown in association with a range of over-story agroforestry species due to its shade tolerance. Has been grown underneath bananas, Leucaena, and Gliricidia.

Feeding value

Nutritive value. Moderate to high nutritive quality depending on provenance. Contains high concentrations of water-soluble carbohydrates and starch, and low NDF. CP content ranges from 12-22%, IVDMD ranges from 45-60% and 24 hr in sacco DMD ranges from 50-70%. Contains comparatively high ash and calcium concentrations at 16-20%, and 2.4-3.8% of DM, respectively. Suitable as a feed for non-ruminants.

Palatability/acceptability

Well accepted by a range of domestic animals, including pigs and other monogastrics, after a period of familiarization. Palatability may change with provenance.

Toxicity

None reported. Contains no saponins or condensed tannins, but contains varying concentrations of steroids and other phenolic compounds, possibly including hydrolysable tannins. Concentrations depend on provenance.

Production potential

Dry matter. It produces 3-6 t of DM/ha n acid-infertile soils at spacing of 10,000-40,000 plants/ha. Yields of up to 12 t of DM/ha/year have been reported in environments more conducive to growth. As living fence in twin hedgerow at 1 x 1 m spacing, it has produced approximately 0.7 t of DM/linear km/month.

Animal production. Some report good response in rabbits, replacing 30% of concentrate. For feeding pregnant pigs, it can replace up to 30% soybean meal without affecting reproductive performance. Edible biomass is accepted for pigs and creole chickens.

Seed production. Seed is very small (4,000,000/kg) and is produced in small fruits weighing about 0.9 g each and containing 35-40 seeds. Seed germination is very poor at 0-2%. Propagation is almost exclusively by stem cuttings.

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Stylosanthes guianensis

Scientific name
Stylosanthes guianensis (Aublet.) Sw. var. guianensis

Synonyms
Stylosanthes gracilis H.B.K Kunth

Family/tribe
Family: Fabaceae (Leguminosae, Papilonaceae), tribe: Aeschynomeneae.

Common names
English: Brazilian stylo, brazilian lucerne, common stylo. **Spanish:** Alfalfa de Brasil, lengua de rana, tarbardillo. **French:** luzerne brésilienne, luzerne tropicale.

Morphological description
A robust, erect to semi-erect, short-lived perennial herb or sub-shrub growing to 1.2 m. Leaves and young stems glabrous to densely pilose, or with scattered bristles. Trifoliolate leaves with lanceolate leaflets, 0.5-4.5 cm long and 0.2-2 cm wide. Flowers yellow to orange, with standard 4-8 mm x 3-5 mm; borne in clusters on a capitate spike. Seeds mostly pale brown (varying from yellow to almost black) in single-seeded pods; 260,000-400,000 seed-in-hull/kg.

Distribution
Native to Mesoamerica and tropical South America. Naturalized in many parts of the tropics and subtropics.

Uses
Fodder. For pasture, for cut and carry, hay, leaf meal and pellets.
Cover crop. In orchards.

Ecology
Soil requirements. It prefers well-drained, open-textured soils from sands to light clays (e.g. tropical latosols, gleys, loams, and sandy podzolic soils). Found on soils with pH from 4.0-8.3. Moderately tolerant of high aluminum and manganese, but not of high salinity. It can extract phosphorus very efficiently, but responds to phosphorus applications, as well as potassium, calcium, sulfur and copper.
Moisture. It occurs in areas with rainfall from 700-5,000 mm/year, mostly 1,000-2,500 mm/year. Although cultivars survive in lower rainfall areas and long dry periods, they are generally best adapted to regions with >1,500 mm. Tolerance to flooding and short term waterlogging vary with ecotype.

Temperature. It occurs from about 20 ºN in Mexico to 32 ºS in Argentina. This means to a range in average annual temperatures from about 19-27 ºC. Primarily adapted

to the hot humid tropics, although some ecotypes grow satisfactorily in the humid subtropics.
Altitude. From sea level to 2,200 m.a.s.l.
Light. It does not have shade tolerance, or at best, fair shade tolerance.

Reproductive development
Mostly a short-day flowering response with critical photoperiod between 11.5-14 h depending on ecotype. Ecotypes vary in their ability to seed under different day lengths. In tropical America and Asia the most common ecotype is CIAT-184.

Defoliation
Cutting/grazing when plants are tall and woody can kill them, since there are few growing points close to the ground on mature plants. It is best to stimulate lower branching early by grazing or cutting to 10-20 cm in the first few months. Rotational grazing, 1 week on and 4-8 weeks off, or cutting at 2-3 month intervals favor it.

Agronomy
Establishment. It can be planted from seed or vegetatively. Freshly harvested seed may have >70% hard seed, but can be scarified to reduce this level by soaking in water at 55 °C for 25 minutes, or at 85 °C for 2 minutes. Alternatively, it can be mechanically scarified with an abrasive disc or rice polisher, or treated with concentrated sulphuric acid for 10 minutes. Mechanical harvesting normally has a scarifying effect on the seed. Fairly promiscuous in its rhizobium requirements, often nodulating adequately on native rhizobium, but can respond to commercial inoculum. Seed sown at 2-5 kg/ha. Where seed is scarce, about 80% strike has been achieved with cuttings, 15-20 cm long with lower leaves removed, taken in the wet season and half of the stem buried horizontally to 3-5 cm.
Fertilizer. Stylo responds well to improved soil fertility, particularly phosphorus, but it can grow on infertile soil (partly due to endomycorrhiza found in roots). In deficient soils, 10-20 kg of phosphorus/ha is recommended.

Compatibility
It can be shaded out by taller grasses such as *Panicum maximum*. It suppresses weeds under correct management. It dies out under excessive cutting or grazing.

Companion species
Grasses: *Andropogon gayanus, Chloris gayana, Digitaria eriantha, Heteropogon contortus, Hyparrhenia rufa, Melinis minutiflora, Panicum maximum, Pennisetum purpureum, Setaria sphacelata, Brachiaria brizantha, B. decumbens and, B. ruziziensis*.

Pests and diseases
The main diseases are anthracnose and head blight. The former causes "tar spots" on leaves and stems, and may kill the plant. Botrytis head blight becomes a problem in seed crops during damp weather.

Ability to spread
Spreads by seed, by virtue of surface water movement, or following ingestion by livestock.

Feeding value
Nutritive value. 12-20% crude protein, 52-60 % *in vitro* digestibility, 0.2-0.6% phosphorus, 0.6-1.6% calcium.

Palatability/acceptability
Not readily eaten by cattle early in the growing season, but becomes relatively more palatable than associated grasses later into the dry or cool season. It is also of great value for small ruminants. With rotational grazing, animals graze the leaves first, successively taking more stem, ultimately damaging the woody main stem.

Production potential
Dry matter. Commonly 5-10 t/ha, but as high as 20 t of dry matter/ha, depending on cultivar, growing conditions and management.
Animal production. Grazing cattle gains of 250-600 g/ha/day and 300-500 kg/ha/yr.
Seed production. Maximum measured seed production ranges from 700 to 1,350 kg/ha, although machine harvest recovery is only 50-60% of this amount since pods shed on maturity. Flowering varies through the tropics depending on seasonality. Under certain conditions, seed remaining in seed heads is dislodged by beating the crop with sticks, then swept-up and cleaned, yielding over 1 t/ha on occasions.

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Arachis pintoi

Scientific name
Arachis pintoi

Family/tribe
Family: Fabaceae (Leguminosae or Papilionaceae), tribe: Aeschynomeneae

Common names
English: Forage peanut, pinto peanut. **Spanish**: Maní forrajero, maní perenne.

Morphological description
Stoloniferous, perennial herb with a strong taproot on the older crowns and a dense mat of stolons. Stems initially prostrate, becoming ascendant up to 50 cm in height depending on environment and provenance. Tetrafoliolate leaves, with ovate leaflets up to 4.5 cm x 3.5 cm. Flowers on short axillary racemes, 12-17 mm wide, yellow. Terminal pods with 1 or 2 seeds. Seed size varies markedly with provenance, average 7,000 seeds/kg (4,000-9,000).

Distribution
Native to: South America: Brazil (Bahia, Goiás, Minas Gerais states). Generally occurs under low (open) forest native vegetation. Now grown throughout the wet tropics and subtropics, and the upland tropics up to 1,400 m.a.s.l.

Uses/applications
Fodder: Integrated into permanent pasture for intensive grazing systems. Some provenances are used for cut-and-carry.
Cover crop: in fruit orchards, in coffee and other trees.
Ornamental: used in gardens as lawn.

Ecology
Soil requirements. Generally found on red, sandy loam river-bottom soils of low to moderate fertility and high aluminum saturation, particularly in wet or flooded lowlands during the wet season. Not restricted by soil texture. Successful on soils with pH ranging from 4.5-7.0, although growth reduced below pH 5.4. It prefers moderate to high fertility, but can survive in infertile soils. Low requirement for copper, molybdenum and calcium; moderate requirement for phosphorus and zinc. Tolerant of high levels of Manganese. Low to moderate tolerance of salinity.

Moisture. It grows best when receiving annual rainfall between 1,500-2,000 mm, but it will survive with 1,000 mm or less. It survives dry seasons of up to 4 months. Tolerant of flooding, but not to permanent inundated or waterlogged situations.
Temperature. It grows best between 22 and 28°C.
Altitude. From sea level to 1,100 m.a.s.l.
Light. Amongst the most shade tolerant warm-region legumes, may grow more in shade than in full sunlight.

Reproductive behaviour
It flowers throughout the growing season, although limited by moisture, low temperatures or day-length in the subtropics. Flowering apparently stimulated by dry-wet cycle. Seed is produced on pegs (gynophores) in the soil´s top 7 cm. Pegs do not penetrate on hard, dry ground. Pegs vary in length from 1-27 cm long. In the upland tropics, it normally takes 6 weeks or less from flowering to mature pods.

Defoliation
Extremely tolerant to low and regular defoliation.

Agronomy
Establishment. It can be established from cuttings or from seed, although plants established from seed develop an effective root system faster. The moderate levels of dormancy in fresh seed can be reduced by drying at 40 ºC for 10-14 days prior to planting. Once dried, seed should be stored in a cool dry environment since large reductions in viability of inadequately dried and inappropriately stored seed have been experienced within 10 months of harvest. Seed should be inoculated with *Bradyrhizobium* strains. Seed should be sown at 10-30 kg/ha depending on quality and price. It should be sown at 2-5 cm deep, surface sowings result in poor germination and high seed losses to birds and rodents.
Fertilizer. It does not require high levels of fertilizer in most situations. In very infertile soils an establishment application of 20 kg/ha of phosphorus, 100 of calcium, 20 of potassium, 14 of magnesium and 22 of sulfur plus maintenance dressings every two years, of half this amount, have given good results. Applications of molybdenum may be necessary in 2-3 year-old stands on very acid soils.
Compatibility
It grows well with both sward forming and tussock grasses. Regular defoliation might be necessary when grown with aggressive grasses to maintain high proportion of legume. It grows well under trees.

Companion species
Grasses: Creeping species such as *Brachiaria decumbens*, *B. humidicola*, *Paspalum maritimum*, *P. notatum*, *Axonopus fissifolius*, *Digitaria eriantha*, *Cynodon dactylon*, and *C. nlemfuensis*. It also forms stable mixtures with bunch grasses such

as *Panicum maximum* and *Paspalum atratum* where it colonizes the inter-bunch spaces.

Pests and diseases
Diseases do not cause long-term or serious damage, but rats and mice are attracted to the nuts. It is susceptible to the root-lesion nematode (*Pratylenchus brachyurus*). Peanut mottle potyvirus can cause chlorotic ringspots in leaves. It can be infested by spider mites (*Tetranychus sp*.), without causing major damage.

Ability to spread
It spreads by stolons up to 2 m/year in the wet tropics and 1 m/year in the subtropics.

Weed potential
Once established, it is very difficult to eradicate. It generally spreads by cultivation, and favored by regular grazing/mowing. It is tolerant of many common herbicides. It can be controlled by ceasing defoliation in the presence of taller aggressive species.

Feeding value
Nutritive value. Crude protein: 13-25% and dry matter digestibility: 60-70%. Relatively low levels of condensed tannins.

Palatability/acceptability. Well eaten by all classes of animals, including chickens, ducks and pigs. Selected by cattle if animals exposed to the legume previously.

Production potential
Dry matter. It produces between 5 - 24 t of dry matter/ha/year depending on where it is grown, and whether grown alone or in association with some grasses.

Animal production. In Colombia, annual liveweight gains up to 200 kg/head and 920 kg/ha, depending on companion grass and dry season stress. In Costa Rica, liveweight gains of cattle in a mixed pasture with *Brachiaria brizantha* nearly 1,000 kg/ha/year. Improvements in liveweight gain of 20-200% and milk production 17-20% over grass-only.

Seed production. Seed is produced below ground, and separates from peg soon after maturity. It may need to mow regularly during the growing season to encourage seed set and to reduce rodent attacks. Seed is produced throughout much of the growing season, under adequate moisture, so harvest is at end of rainy season. Seed (in pod) yields of over 1 to 4 t/ha although some provenances are less productive. Seed should be dried and stored under low humidity to avoid rapid mortality.

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CONCLUSIONS

The production of small ruminants in the tropical areas of Latin America and the Caribbean can be sustainable and sufficient to supply the current and future market demands of the region and beyond, and considering the attractive prices, it can also be a very good business. All the main factors are potentially in place: animal breeds, suitable forage species, appropriate technologies and market demands.

Nevertheless, in order to take advantage of this opportunity, it is essential that sector leaders, technicians and above all, small ruminant farmers, understand the key factors to be able to maintain a sustainable, profitable and competitive production.

Although small ruminant production started very soon after the arrival of the European colonizers, it has been only during the last few decades that the extensive production, prevalent for five centuries, has not been able to satisfy the growing market demand, particularly for meat.

There are few farms in various countries in the region, which are showing that intensive small ruminant production is not only possible but also profitable.

Evidence from diverse institutions and commercial enterprises suggests that alternative feeding systems using high quality forage species for small ruminants in tropical Latin America and the Caribbean are technically viable and sustainable from economic and ecological perspectives.

Sustainable technologies exist to be applied to a variety of farm sizes, intensification and mechanization levels, depending on local resources. Integrated systems combining animals and highly quality forages can very productive per unit area, provided that the necessary mineral nutrients are there from the beginning and are continuously replenished. Perennial species have advantages from the energy point of view, since once established, they last for many years.

Detailed information has been generated on the potential of various high quality forage species in terms of their characteristics, establishment and management needs, and innovative options for their utilization. Mulberry, Moringa, and Leucaena are the most promising multipurpose forages, attracting considerable attention.

If one day, pelleting and cubing of tropical forages, particularly of high quality leaves, becomes a practical commercial option, because equipment and processes had been worked out, it would be a great leap forward to animal production, not only in

the tropical areas but worldwide. Some of these forage, like mulberry for example, can easily substitute cereals within commercial feeds.

Some production technologies have been around for a while and are commonly used by farmers, like composting earthworms and biodigesters. However, there are newer technologies like the use of biochar, efficient microorganisms, mycorrizhal fungi and anaerobic fermentations, showing a lot of potential for agricultural production.

It is clear that the future of sustainable livestock relies on a deeper comprehension of interactions between animals, plants, soil and microbes.

However further education, research, and extension are needed to ensure continuous improvement of production systems, urgently required to meet the growing market demands and ever changing biological and business environments. Public and private investment to encourage innovation, is pivotal for the future of agriculture, including small ruminant production.

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Oficina del IICA en la República Dominicana

Av. George Washington, #601, 3era. Planta Edif. Banco Agrícola,
Santo Domingo, R.D.
Tel.: 809-533-7522/ Fax: 809-532-5312
Sitio web: www.iicard.org