

Organización Comemorativa
Unión - IICA - CATIE

**RESEARCH PROGRAM ON SUSTAINABILITY
IN AGRICULTURE (REPOSA)**

- 1 NOV 1996

RECIBIDO
Turrialba, Costa Rica

**Report No. 104
Field Report No. 149**

TREES IN GRASSLAND

*The Influence of Trees on Grass Production within Sylvopastoral
Systems of the Atlantic Zone of Costa Rica*

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July 1996

**CENTRO AGRONÓMICO TROPICAL DE
INVESTIGACIÓN Y ENSEÑANZA (CATIE)**

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REPOSA es financiado por la UAW bajo su Programa del Uso Sostenible de la Tierra en los Areas Trópicos. La sede de REPOSA está ubicada en la Estación Experimental Los Diamantes del MAG en Guápiles.

Preface

PREFACE

This thesis has been written in relation to the PhD-forestry research project titled: "Integration of trees and forest in farming systems. An intertemporal linear programming model on farm level as a tool for land use planning in the Atlantic Zone of Costa Rica". The project is part of the research conducted by the Atlantic Zone Programme, a cooperation between the Wageningen Agricultural University, the Centro Agronómico Tropical de Investigación y Enseñanza (CATIE) and the Ministerio de Agricultura y Ganadería (MAG). The programme has a long term objective to carry out research toward rational natural resources use in the Atlantic Zone of Costa Rica with emphasis on the small land owner.

This thesis is concerned with the influence of trees on grass production within the sylvopastoral systems of the Atlantic Zone. The empirical research of the present report has been carried out in Río Jiménez, one of the three research areas of the PhD-forestry research project in the northern part of the Atlantic Zone. The present thesis is done as a 'afstudeervak bosgebruiks systemen' with a duration of 21 study points (840 sbu) and an 'open vak bosbouw', 3 study points (120 sbu).

Ir. A.C.J. van Leeuwen, PhD researcher at the Department of Forestry of the Wageningen Agricultural University, was the main supervisor during the research in Costa Rica and the writing of the report afterwards in Wageningen. Additional and final supervision came from drs A.M. Filius and Prof. Dr. Ir. M. Wessel, also affiliated to the Department of Forestry.

I also want to thank the Costarican field assistants who helped during the research in Costa Rica. The many days in field, to set up the trials and later on carrying out the measurements were not a piece of cake. Sun and rain brought their stress, but the friendship, joy and jokes we had in the field made of this period a time to be remembered. Don Mario Solano, Luis and Enrique Alfaro thanks.

The last one I want to thank is Louise, who accompanied me during my stay in Costa Rica and helped all the time. Remembering this, working and living together will be a great pleasure while fulfilling our new jobs in Nepal.

July 1995, Wageningen

*Green is the grass
Blue is the sky
but the Tree gives the shade
in which I lie*

Anonymous

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SUMMARY

This study on the influence of trees on grass production within the sylvopastoral systems was carried out in Río Jiménez, a sub-region in the northern part of the Atlantic Zone of Costa Rica.

Sylvopastoral systems are widely practised land use systems in the Atlantic Zone of Costa Rica and are mostly established after forest clearing. The area of sylvopastures in the Atlantic Zone is still increasing. The Atlantic Zone has a tropical humid climate. Three soil use classes are distinguished, sylvopastures mostly occur on infertile soils with good drainage.

The main purpose of the sylvopastoral systems in the Atlantic Zone is cattle breeding and meat production. Tree products of the systems, like fruits, fodder or timber are only by-products, nevertheless they can represent a substantial value for the farm households. There is no deliberate management aiming at a certain tree stocking rate within the sylvopastoral systems in the Atlantic Zone. In general the farmers regard trees positive in the sylvopastoral system, but this is not based on exact data on the effect of trees on pasture. Therefore optimal tree stocking rate and best species to be used are not known.

In this research interactions between trees and pasture and the effects of these interactions on the grass production within the sylvopastoral systems in the Atlantic Zone of Costa Rica are analyzed. The research is started with a literature review on the theoretical background of the interactions between trees and pasture in sylvopastoral systems. After this, field research was done in the Río Jiménez area in the Atlantic Zone. The field research was restricted to two tree species, *Pentaclethra maculosa* (Gavilán) and *Cordia alliodora* (Laurel) and two pasture types, Pasto Natural (a mixture of local grass species) and *Ischaenum ciliare* (Ratana).

A sylvopastoral system, an agroforestry system, is comprised of three components, i.e. trees, pasture and cattle. The different components influence each other. A relational diagram is used to analyze the production side of the system. The different relations between the components are derived from system analysis and elaborated further using other researches. Within the tree-grass relation the available amount of light under trees is seen as the main factor to determine grass production under trees. Grass production can be higher compared to the open field production, caused by an improvement of the understorey micro climate. When light saturation is not reached, increased light intensities result in an increased grass production until other factors, like temperature and water stress become more limiting to grass production.

For the empirical research four trials were set-up, combining the two tree species and two grass types. Every trial consisted of five isolated trees with a north-south transect of ten meter at both sides of the tree with ten measure plots and two reference plots (open field situation). Tree parameters, monthly grass growth, grass quality and composition, soil properties and light intensities were measured.

Tree parameters showed the difference in shape between the tree species. Gavilán has a large and densely foliated crown, Laurel is the opposite with a small and open crown.

Grass production (dry weight) showed clear differences between the tree species. There are no pronounced differences in grass production between the two grass types. Grass production is reduced significantly under Gavilán, up to 70% in the case of Pasto Natural and 50% for Ratana. Grass production is increasing with the distance to the tree. At an 8 meters' distance from the trunk grass production reached about the level of the reference plots. Although not significant, in the case of Ratana, grass production is even a

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little more than in the reference plots at an 8 meters' distance from the trunk. The average grass production under the trees is for Pasto Natural 77% of the reference plots and for Ratana 105%. Under Laurel no reduction of grass production is measured. For Pasto Natural grass production varies from 100-120% on all the plots, Ratana varies from 95-105%. The average grass production is for Pasto Natural 119% of the reference plots and for Ratana 104%. The difference between average grass production of Pasto Natural under Gavilán and Laurel and the reference plots is in both cases significant. This is not the case for Ratana.

Grass quality (digestibility and proteins) is not influenced in relation to the distance of the tree. However there are too few samples to give a reliable prediction. In relation to the distance of the tree, composition changes only in the case of Pasto Natural. With an increasing distance to the tree the occurrence of *Paspalum conjugatum* is increasing and the occurrence of *Panicum laxum* is decreasing.

In all cases top soil layers are positively influenced under Gavilán and Laurel. Resulting in a thicker top soil layer under the trees.

Light intensity in the case of diffuse and direct light is reduced significant under Gavilán for all plots. Under Laurel only a slight influence is noticed close to the trunk for diffuse light. In the case of direct light, light reduction is more pronounced.

Grass production is significantly correlated to light intensity. Correlation is higher for Pasto Natural than for Ratana. Grass production increases when light intensity increases up to a light level of about 80% to open field. When light intensity increases further grass production is not increasing further. Probably other factors become more limiting (temperature and water stress). A light level of 80% seems to be the optimum. Below this light level grass production decreases, a higher light level does not result in an increased grass production, it might even decrease a little.

1 INTRODUCTION

This research on the influence of trees on grass production is done in the Atlantic Zone of Costa Rica. In this chapter a description is given of the context of the research and what the role is and function of the trees in the sylvopastoral systems in the Atlantic Zone. Therefrom the research question is defined and the demarcation of the study is discussed. After this the objectives of this study and the used methodology are described. Also a short overview is given of the research region. The chapter ends with an outline of the report.

1.1 Research context

The research is carried out within the framework of the forestry PhD research: "Integration of trees and forest in farming systems. An intertemporal linear programming model on farm level as a tool for land use planning in the Atlantic Zone of Costa Rica" (van Leeuwen, 1991).

The linear programming model will calculate optimal land use plans under different conditions. Effects of decisions on land use can be indicated by the linear programming model. For this model, which is computer based, both physical data on for example soils, trees and crops, and socio-economical information on goals of farmers, farmers' relations with markets and banks, farm sizes, income, etc, are used (van Leeuwen, 1991).

The research of this report, the influence of trees on grass production in the sylvopastoral system, contributes to the first part, the physical aspects.

One of the main criteria in land use analysis and planning is sustainability. It is supposed that trees and forest can have an important role in sustainability of land use (van Leeuwen, 1991). Research on farm level must make clear how far this assumption is in agreement with the farmers' point of view regarding trees and forest. The research of Paap (1993) has contributed to this, giving insight how the farmers are dealing with the tree component in the sylvopastoral system. Underlying research is focused on the production side: The effect of the trees, within this system, on the grass production.

1.2 Sylvopastures in the Atlantic Zone

The sylvopastoral system, in which three components are combined, i.e. trees, grass and livestock, is a widely practised land use system in the Atlantic Zone of Costa Rica, see 1.6. In chapter two the theoretical basis of this system will be discussed. In this section sylvopastoral systems in the Atlantic Zone are introduced briefly, to get an impression of the system and the role of the trees within the system and the relevance of this research. For an extensive description of the sylvopastoral system in the Atlantic Zone see Paap (1993).

1.2.1 Establishment of sylvopastures

Sylvopastures are mostly established after forest clearing. After the clearing grass is sown. Very big trees which could not be sold or easily felled are left standing (Paap, 1993).

One can distinguish three tree categories based on their origin in the

sylvopastoral systems in the Atlantic Zone. Trees which are left standing after forest clearing, secondary regrowth after interventions in the forest, and trees that are planted by the farmer (Zambon, 1989). Most of the trees originated from spontaneous secondary regrowth in the pastures. Fruit trees are mostly planted. Hardly other trees are planted in the sylvopastures. In a few cases timber species, like *Cordia alliodora* (Laurel) are planted (Paap, 1993). The dispersion of the trees is very irregular and highly varying. Often trees are clustered in small groups, and one finds dispersed isolated trees.

1.2.2 Management practices

The main purpose of the sylvopastoral systems in the Atlantic zone is cattle breeding and meat production. Animal production of cattle ranching in the sylvopastoral system is being practised on a very extensive scale, with low levels of inputs and managements (Ibrahim, 1994). Dairy farming is not practised a lot. The majority of practices within the sylvopastoral systems are focused on cattle (Paap, 1993).

The management of the pasture is usually rather extensive, it mainly consists of clearing it from unwanted vegetation and mowing. This is done twice a year with a machete, sometimes herbicides are used. No manuring is practised (Nobbe, 1988; Paap, 1993).

The management of the trees is limited to maintaining regeneration of wanted trees in the pasture, when the pasture is cleaned. Often the area around small trees is cleaned to stimulate its development. In some cases farmers plant trees, mostly fruit trees (Paap, 1993). Other activities in relation to the trees are hardly made. In a few cases farmers mentioned activities like pruning of trees that give too much shade. Also fruit trees are pruned to avoid fruit eaten by cows or the cattle is scared off. The trees in the pastures are not used for fodder.

The borders of the pastures are often made of living fences. They are very characteristic in the Atlantic Zone. When the living fences are pruned the pruned material is used as fodder (Zambon, 1989; Paap, 1993).

1.2.3 Grass and tree species

About 30 different grass species are found per farm unit in the research area, Río Jiménez, which is on the average 51 ha (Paap, 1993). Two types of grass species are used, the natural and the improved species. The most used improved grass species is *Ischaenum ciliare* (Ratana), an exotic grass species introduced about 15 years ago. Other introduced exotic grass species are *Cynodon nlenfluensis*, *Echinochloa polystaechya* (Alemán) or *Panicum maximum* (Guinea). Research is done on better producing improved species like *Arachis pintoi* and *Desmodium spp.* (Nobbe, 1988; Paap, 1993).

The group of natural species, locally called 'Pasto Natural', is a mixture of species which occur naturally in the Atlantic Zone. Some natural species in the Atlantic Zone are *Digitaria sanguinalis*, *Homolepis aturensis* (Arozilla), *Panicum laxum* (Zacatillo Suampo), *Paspalum conjugatum* and *Paspalum fasciculatum* (Gamalote). They are less productive than the improved grass species. In the more swampy pastures *Brachiaria mutica* (Para) and *Echinochloa polystaechya* occur the most (Nobbe, 1988; Paap, 1993).

A lot of different tree species can be found within the sylvopastoral system in the Río Jiménez area. Paap (1993) found in total 52 different tree species, with an average of 6 species per farm unit. The most occurring timber species are: *Cordia alliodora* (Laurel), *Cedrela odorata* (Cedro amargo) and *Pentaclethra macroloba* (Gavilán). The latter is also an important shade tree. *Citrus spp.*, *Annona muricata* (Guanábana) and *Persea americana* (Aguacate) are the most common fruit species. *Erythrina spp.* (Poró) and *Gliricidia sepium* (Madero negro) are the most used species within the living fences (Paap, 1993).

1.2.4 Functions of the trees

The function and use of the trees in sylvopastoral systems depends on the main purpose of the system. Tree products, like timber, fruit or fodder are therefore mostly regarded as by-products by the farmers. Nevertheless the by-products of sylvopastoral systems can represent a substantial value for the farm households (Paap, 1993).

Other functions of the trees are for instance the provision of shade to the cattle. Trees provide shelter in the hottest hours of the day and during heavy rain. Shade is mentioned as important by the farmers, but a shade tree is mostly a double purpose tree, which also provide timber or fruit. The farmers scarcely mention typical shade trees (Paap, 1993).

The relation between trees and grass/soil is perceived differently among farmers. Farmers reported a worse, equal or better grass growth under trees. The influence of the trees on the grass is related to the growth, freshness and colour of the grass, depending on the amount of shade. Evenly dispersed trees with a fair distance were reported by the farmers to have no influence or a beneficial effect on the pasture. To avoid a too high shade regime by the trees, the farmers prefer a certain density of 20-25 trees ha⁻¹. This density is only based on the impression the farmers have of the effect of trees on pasture (Waaaijenberg, 1990; Paap, 1993).

1.3 Problem analysis

The investigation of Paap (1993) was focused upon the way in which the farmers use the trees in their pastures and the problems they encounter while using trees. Some of the results of his study have served as a basis for this research.

Because tree products are regarded mere by-products within sylvopastoral systems in the Atlantic Zone, there is no deliberate management aiming at a certain tree stocking rate within the sylvopastoral system. The research of Paap (1993) showed that most of the trees within sylvopastures in the Atlantic Zone are secondary regrowth or natural regeneration from existing trees in the pastures. The occurrence of trees is more or less natural.

In general the farmers regard trees positive in the sylvopastoral systems, not only because of their products and shelter for the cattle, but often also in their relation to pasture. The view of the farmers on the tree-grass relation is based on the impression they have on the effects of the trees on the pasture (Paap, 1993).

No precise data are available about the interactions between trees and pasture. The influence of trees on the grass production (quantitatively and qualitatively) is not known. Is there a higher or lower grass production under trees? In which way is the quality of the grass influenced by the trees? And how are these influences on quantity and quality related to the distance of the tree? Also different effects between different tree species on the pasture are not known.

Because of this lack of knowledge on the effect of trees on the other components, especially the effect on grass production, no specific management practices can be given to an optimal tree stocking rate and the best species to be used.

1.4 Objectives and research question

In general, research on agroforestry is to obtain more knowledge about the relations between the components of the agroforestry system and the way in which land use managers can influence the relations to produce and control the desired outputs on their specific piece of land, with or without scientific

intervention (Reintjes et al., 1992).

The objective of this research is to get more insight in the interactions between trees and pasture within the sylvopastoral system. This is specified to the effect of the tree-grass relations on grass production. This leads to the following research question:

What interactions exist between trees and pasture and what are the effects of these interactions on the grass production within the sylvopastoral systems in the Atlantic Zone of Costa Rica.

Knowledge on the tree-grass relation can be translated to certain management practices. This gives the following explicit research objectives:

- What is the effect of the presence of trees on grass production
- What recommendations can be given on the tree densities in the sylvopastoral system.

1.5 Demarcation and methodology

The research is restricted to two tree species, *Cordia alliodora* (Laurel) and *Pentaclethra maculosa* (Gavilán) and two grass species, *Ischaemum ciliare* (Ratana) and Pasto Natural (a mixture of local grass species). This study is also restricted to the production side of the sylvopastoral system, the sociological and economical sides of the sylvopastoral system are not incorporated.

The field research is carried out in the Río Jiménez area in the Atlantic Zone of Costa Rica (see figure 1.1). The tree/grass combinations resulted in four different trials. Every trial consists of five isolated trees. Under every tree a north-south transect was set up with ten measuring plots. Also two reference plots were allocated for every tree. The empirical research of this study lasted for nine months. The data were obtained from July 1993 up to April 1994. During nine months measurements of grass production under trees were made. Also measurements were carried out on trees (tree height, lowest trunk height, dbh and crown projection), soil (thickness and percentage of organic matter of the topsoil) and pasture (composition and quality). In July and August light intensities were measured, under and beside the trees. The experiment is elaborated more extensive in chapter 3.

Before the empirical research started, a literature review on the theoretical background of the interactions between trees and grass in sylvopastoral systems was made. In this literature review much emphasis was put on research in other situations on grass production under trees. Especially the light relation is discussed in more detail.

1.6 The Atlantic Zone

The Atlantic Zone coincides with the Limón province (fig. 1.1), the eastern part of Costa Rica. The Limón province consists of several cantons. In the cantons Guápiles and Guácimo the forestry research area Río Jiménez is located. This is one of the three areas described in the PhD forest research, i.e. Río Jiménez, Neguev and Cocori. In or close to the Río Jiménez area the trials of this research are located.

The total area of the Atlantic Zone is about 10,000 square kilometres, with a population of about 180,000 people and a growth figure of more than 3% per year. The main source of income of the inhabitants of the Atlantic Zone is agriculture. Of the total labour force 45% is working in agriculture (\pm 26,000 persons). About 6,500 of them are farmers, the others are labourers especially on banana plantations (Waaijenberg, 1990).

1.6.1 Land use

The natural vegetation in the Atlantic Zone is the low land tropical rainforest or tropical swamp forest. Typical species are *Carapa guianensis* and *Pentaclethra macroloba*. The Atlantic Zone was covered for 99% with forest (Romeijn, 1987). Unless deforestation, still about 30%, 161,205 ha, of the northern part of the Atlantic Zone is covered with natural vegetation (Leeuwen van and Hofstede, forthcoming). However these forests are cleared more and more due to an expanding area of (sylvo)pasture. The increase of deforestation gives an increasing ecological degradation (Romeijn, 1987).

The area of (sylvo)pastures increased rapidly. In 1982 about 35%, 232,900 ha, of the total farm area in the Atlantic Zone was (sylvo)pasture (Leeuwen van and Hofstede, 1994). In 1987 over 50% of all the agricultural land was used as pasture. Near all pastures were created by conversion of forests (Romeijn, 1987). Most of the pastures are used for extensive cattle ranching (Paap, 1993).

The tendency to more intensive sylvopastoral systems leads to soil degradation, giving an unsustainable land use when the present grass species are used (Baltissen, 1987). The prevailing grass species in the pastures are not capable of higher productivity by improved management. Better producing grasses and legumes are necessary to sustain a more intensive animal production (Ibrahim, 1994). The conversion of forests into another land use system also leads to a change in morphological characteristics of the soil. This can lead to water stagnation, which can cause air and water stress for plants. Another change is a decrease in organic matter in the soil, also the biological activity in the soil decreases, having a negative effect on recovering of the soil after degradation. (Baltissen, 1987; Romeijn, 1987).

1.6.2 The climate

Based on the system of Holdrige (1967) the Atlantic Zone has a tropical humid climate. The average annual rainfall is 4,500 mm yr⁻¹, ranging from 3,000-6,000 mm yr⁻¹. The wettest months are June, July and August as well as October, November and December. Relatively dry months are March, April and May. The difference between the average monthly rainfall in the dry months with the other months is small. The average monthly rainfall in dry months is 210 mm per month, the average monthly rainfall is 305 mm per month. Dry spells of a few days or weeks without any rain can end in days of intensive rain (Baltissen, 1987).

The average annual temperature is 25° C, the potential evapotranspiration is 2,500 mm yr⁻¹ and the relative humidity is very high (over 80%),

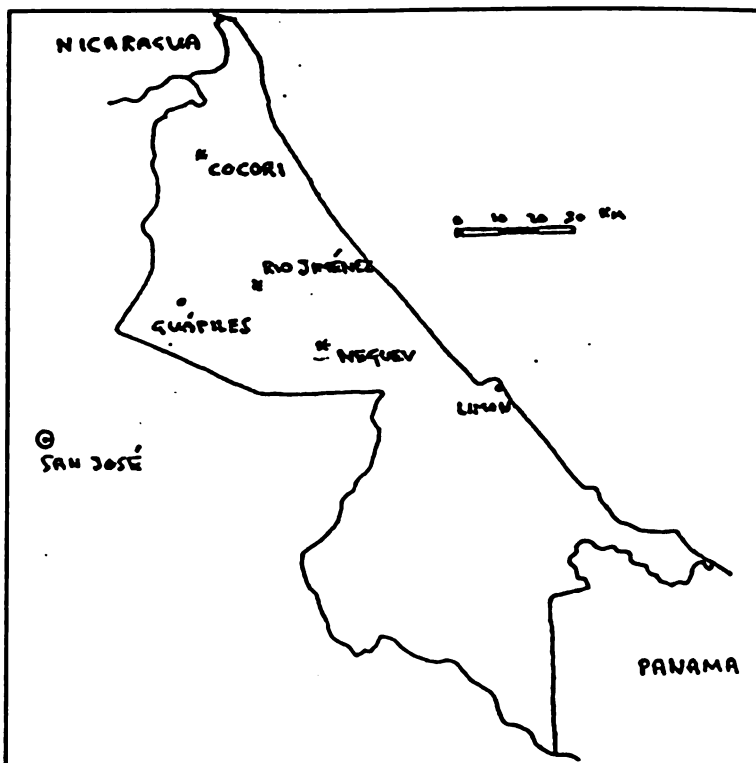


Figure 1.1 Map of the Atlantic Zone, Costa Rica. Scale 1:2,000,000

throughout the year. The figures are from the weather station 'El Carmen' in the Atlantic Zone (Baltissen, 1987).

1.6.3 Geology and soils

A part of the Atlantic Zone is formed by lahar (volcanic mudstreams), deposits of different ages from the north east section of the Turrialba volcano, part of the Cordillera Central, the great mountain massif in the centre of Costa Rica. This part of the Atlantic Zone is a smoothly undulated landscape strongly dissected by many rivers. The strong weathering has resulted in clayey soils. The sediments have a fluvial origin. Most recent are the deposits of the river Parismina and Destierto (Veldkamp et al., 1992). The research is located in this part of the Atlantic Zone.

Further to the coast and in the north east of the Atlantic Zone, the Limón basin, is very deep. It consists of a thousand or more meters deep tertiary and quaternary sediments from the Cordillera Central (Brouwershaven, 1993; Veldkamp et al., 1992).

In general three classes of soil use can be distinguished. The classes are based on fertility and drainage status of the soil. The three classes are fertile soils with good drainage, infertile soils with good drainage and soils with bad drainage (Koster, 1993).

Sylvopastoral systems occur on all kinds of soils in the Atlantic Zone, but mostly on the infertile soils with good drainage. The longer ago the colonization took place the more the occurrence of sylvopastoral systems on the fertile soils is diminishing. Land use is changing into only pasture (Verbraeken, 1988; Waaijenberg, 1990). On infertile soils and soils with a bad drainage sylvopastoral systems become more important when colonization began longer ago. Also within the classes better fertility and drainage tend to favour pasture at the expense of sylvopastoral system (Waaijenberg, 1990).

Because sylvopastoral systems occur mostly on infertile soils with good drainage and also the research trials are all located on these soils, this soil is described in more detail. The infertile soils are Andic Humitropepts (Waaijenberg, 1990), also called, 'tierras rojas' (red soils) (van Uffelen, 1990). These Andic Humitropepts (tierras rojas) are subclassified, with the local names Milano, Neguev and Silencio (Waaijenberg, 1990). The subclassification is based on fertility. In a decreasing fertility:

Milano : tierra bermeja o café

Neguev : tierra colorada

Silencio: tierra muy roja (Wielemaker and Vogel, 1993).

The occurrence of sylvopastoral systems in the Río Jiménez area on these soils is: Milano 33,3%, Neguev 42,4% and Silencio 72,0% (van Uffelen, 1990). Showing a decrease of the sylvopastoral systems with a increasing fertility.

The characteristics of the Andic Humitropepts (red soils) are; clayey, with high phosphor fixation, a risk for soil compaction and occurring on slopes. Especially the soil Neguev is susceptible to soil compaction. The soils have a cambic B soil layer with andic properties to poor developed andic properties and are well drained. The soils are old and well developed out of pyroclastic material of volcanic mudstreams. A high percentage of amorphous clay is transformed in crystalline halloysite. The soils are relatively infertile and for this, agroforestry (sylvopastures) and forest are serious options for these soils (Waaijenberg, 1990).

1.7 Outline of report

In this report the following is discussed. Chapter one contains the introduction. The second chapter deals with the theoretical background, a literature review and study of comparable research. It describes the interactions between the different components, with emphasis on the relation between trees and pasture. The second chapter ends with the impact of shade on the

grass production. The empirical research, materials and methodology are described in the third chapter. The obtained research data and analysis of the data are presented in the fourth chapter. The last chapter contains the discussion, conclusions and recommendations.

2 INTERACTIONS BETWEEN TREES AND PASTURE: A LITERATURE REVIEW

In this chapter relations between trees and pasture in sylvopastoral systems are discussed. The chapter starts with a general introduction to sylvopastoral systems, with respect to definition, structure and relations between components. Then, the grass production in relation to the tree cover will be focused in more detail. Especially the light relation will be emphasized.

2.1 The sylvopastoral system: Definition and concept

Several land use systems are gathered within the collective name agroforestry. A land use system will be an agroforestry system when it meets several criteria. These criteria are mentioned in a lot of the existing definitions on agroforestry. The definition of the ICRAF, which is adopted in this report is:

"Agroforestry is a collective name for land use systems and technologies in which perennials (trees, shrubs, palms, bamboos, etc.) are deliberately combined on the same management unit with herbaceous plants (crops, pasture) and/or animals, either in some form of spatial arrangement or temporal sequence, and in which there are both ecological and economical interactions among different components." (Young, 1987).

Depending on the components they encompass, one can divide agroforestry into three major systems, i.e. agrisilvicultural systems, sylvopastoral systems and agrosylvopastoral systems (Nair, 1985). Sylvopastoral systems include tree, pasture and livestock components (Combe, 1982).

The definition mentions a deliberately combining of different components. As is made clear in 1.2.2 in sylvopastoral systems in the Atlantic Zone hardly trees are planted, only some regeneration of trees is maintained in the pastures. Especially when this is almost the only activity with regard to the tree component one can argue if the tree components are deliberately combined with the other components. Paap (1993) however concluded that the sylvopastoral systems in the Atlantic Zone are agroforestry systems.

One can distinguish two items in an agroforestry system, practices and technologies. Agroforestry practices are: 'A distinctive arrangement of components in space and time, and the management of these components.' (Reintjes et al, 1992). This research is done within the sylvopastoral practices as they occur in the Río Jiménez area in the Atlantic Zone of Costa Rica.

The research of this report is focused on sylvopastoral technologies in this zone. To obtain knowledge about the interactions of trees and pasture and the effect of the relations between trees and grass production. An agroforestry technology can be described as: 'The accumulated knowledge about the working of the relations between components of the agroforestry system and the way in which land use managers can influence the relations to produce and control the desired outputs on their specific piece of land, with or without scientific intervention.' (Reintjes et al, 1992).

The difference between the terms, system, practice and technology is not always clear. The interpretation of the definitions and the practical use of them is difficult. This problem is only mentioned here, but it is beyond the scope of this report to discuss this here in detail.

2.2 Structure of sylvopastoral systems

The structure of a system is shaped through the different components used in the system and the way they are arranged. Sylvopastoral systems comprise three major components: trees, grass and livestock (fig. 2.1).

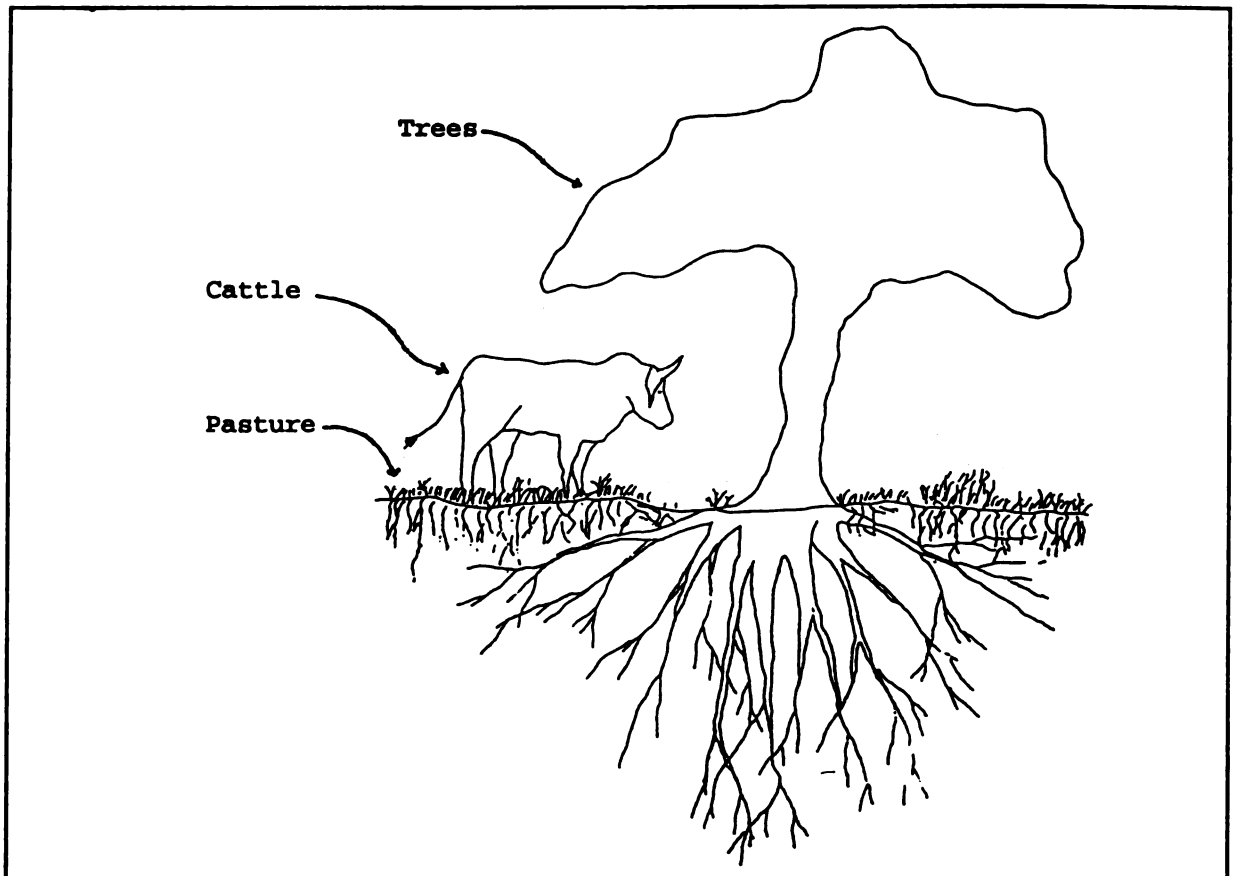


Figure 2.1 The sylvopastoral system and its components.

The structure can be divided in the vertical stratification, the different storeys, and the spatial arrangements of the tree component in relation to the grass component (Beets, 1989; Montsma, 1988). Sylvopastoral systems in the Atlantic Zone generally have a simple vertical stratification. They exist of two storeys, the upperstorey and the understorey. The upperstorey is formed by the trees and the understorey is formed by the grass layer. The spatial arrangement of the trees is irregular. The trees are scattered in the pasture, in groups or isolated. Because the irregular spacing of the trees there are also spots where only the grass layer is left and no tree storey exists.

2.3 Relations between the components

In sylvopastoral systems the various components influence each other. Between the components different relations exist. The relationship between the

components can be competitive, complementary, supplementary or some composite of these relationships (Raintree, 1983; Montsma, 1988). Components are complementary when the presence of one increases the output of the other, supplementary when there are no mutual interactions between the components and competitive when the presence of one reduces the output of the other (Young, 1989). Which of these relationships predominates in a given sylvopastoral system depends not only on the genotype, number and spacing of components, but also on which growth factors (light, water and nutrients) are limiting for the respective components under realistic field conditions (Raintree, 1983; Kessler, 1992). There will be no competition as long as the soil water content, nutrient level and the amount of light are in excess of the needs of the components. When the availability of a single factor falls below the plants' combined demands competition begins (Beets, 1982). The nature of the relation between the components, whether they are competitive, complementary or supplementary, is based on the needs for light, water and nutrients (Garrison and Pita, 1992; Lövenstein et al., 1992; Russo, 1984; 't Mannetje, personal communication).

Trees are often regarded the dominant component in the agroforestry system, and compete with the understorey, especially for light. The result of this competition will be depressed understorey yields. No doubt trees have a competitive advantage in the form of their greater stature, but particularly in agroforestry systems, they may be competitive with the understorey and if so are they reducing the net yield of the understorey? These are questions which require closer analysis (Raintree, 1983).

2.3.1 Relational diagram of sylvopastoral systems

In order to get a better understanding of the different components and relations in the sylvopastoral system a relational diagram is used. Relational diagrams are very helpful in system analysis. It is used a lot in theoretical production ecology where this method is derived from (Leffelaar, 1992). This method is not used much in forestry because it is mainly developed for simulation modelling. It is focused on production. Working with this system one should bear this in mind. It leaves other aspects, like sociological, ecological or economical aspects untouched. Because this research is focused on grass production this method is used.

Relational diagrams may be especially helpful at the start of research to facilitate the formulation of rate and state variables. They also make the contents and characteristics of a model easily accessible. A system is defined as a limited part of reality that contains interrelated elements and a model is a simplified representation of a system (Leffelaar, 1992).

In figure 2.2 a relational diagram is given which shows the state and rate variables and their relations in the sylvopastoral system. This relational diagram is not showing every detail of relations and their effects, but it shows the most important relations and how the different state variables (cattle, grass and trees) are related to each other. The relative growth rates (rgr) and the relative decrease rates (rdr) are different for the distinguished state variables. The system is also subject to external biotic and abiotic factors, like radiation, temperature, precipitation, soil characteristics, and management. This is not explicitly shown in the diagram, for clearness sake, but is supposed to be incorporated in the different rgr's and rdr's. It are all constants or parameters. The extra incoming and outgoing arrows of the state variables 'cattle' and 'trees' represent the sudden change of these state variables through human influence like planting or logging of trees and moving, buying or selling of cows.

To which aspects of the sylvopastoral system the underlying research is converged is shown in figure 2.3. The relational diagram of figure 2.2 represents the sylvopastoral system as a whole, the relational diagram of figure 2.3 only the research. Only the state variables 'trees' and 'grass' are incorporated. The influence of the livestock component on the other components

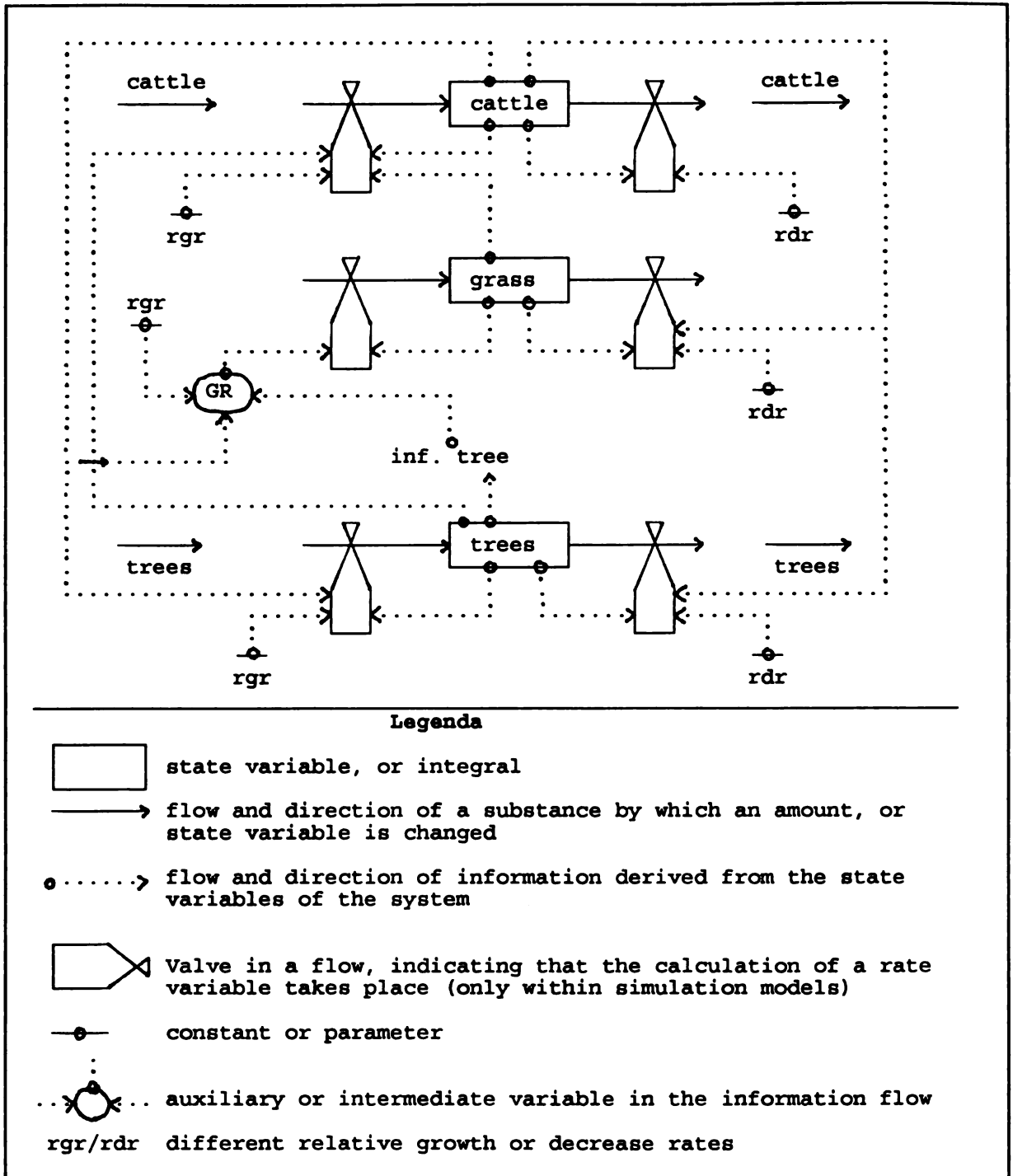


Figure 2.2 Relational diagram of a sylvopastoral system.

is kept out of the research. The state variable 'cattle' is removed, having no longer a relation in the practice of the research with the 'tree' and 'grass'

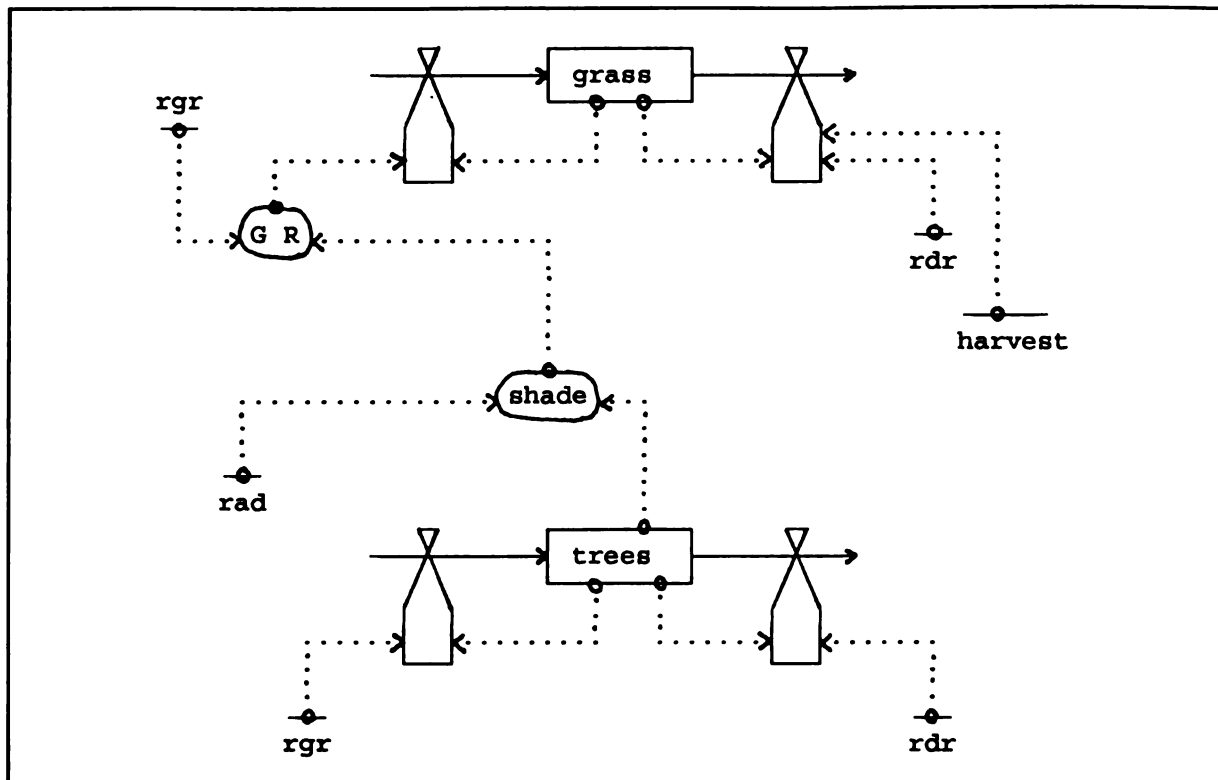


Figure 2.3 The relational diagram of the research for shade influence. See for explanation of symbols figure 2.2.

state variables, because of fences around the transects (see 3.3).

No division is made between the various relations between the trees and the grass in figure 2.2. Only the total influence of the trees on the grass (inf. tree) is shown. In figure 2.3 the tree influence is shown in more detail, in this case for shade. The growth rate (GR) of the grass is influenced by the rgr (representing the relative growth rate and other external parameters) and the intermediate variable 'shade'. Which on its turn depends on the state variable 'trees' and radiation parameter.

Also other relational diagrams could be drawn in which other tree influence is shown. For example the tree influence on the soil. The intermediate variable shade changes than into an intermediate variable 'soil', dependent on the state variable 'trees' and parameters/constants of soil characteristics. Also the influence of the state variable 'grass' on the intermediate variable 'soil' can be incorporated.

The relational diagram is helpful in thinking about which parameters have to be measured for the research and how they are related to the state variables in the sylvopastoral system.

2.3.2 Different aspects of relations between the components

In the first part of 2.3 the nature of the relations is discussed and in 2.3.1 the relational diagram showed how the different components are linked together. Where the different relations consist of, different aspects of the relations, as reported in literature, will be summarized here.

The tree-grass relation:

- a. Root competition
 - b. Nutrient pump
 - c. Soil penetration
 - d. Nitrogen fixation
 - e. Competition for light
 - f. Wind velocity reduction
 - g. Space occupation
-
- ad. a: Tree roots compete with roots of herbaceous plants for water and nutrients in the soil (Daccarett and Bleydenstein, 1984).
 - ad. b: Trees function as a nutrient pump. Trees have a deeper root system than grass and take up nutrients which are not available to the grass roots. These nutrients come available to the pasture through decay of the leaf layer (Russo, 1984; 't Mannelje, personal communication).
 - ad. c: Tree roots can penetrate indurated layers, resulting in a better soil structure, benefiting grass (Young, 1989).
 - ad. d: Leguminous trees and grasses enrich the soil through nitrogen fixation (Daccarett and Bleydenstein, 1984; Wiersum, 1988).
 - ad. e: Trees have a strong influence on the micro climate. The tree crown diminishes the light for photosynthesis of the understory (Daccarett and Bleydenstein, 1984). When trees are in their sapling stage, there can be also a strong competition for light with the grass. When there is a close grass cover, especially in the case of natural regeneration or direct seeding of trees, it can be hard or impossible to regenerate trees (Evans, 1992).
 - ad. f: The decrease of solar radiation together with a reduction of wind velocity result in a decrease of evapotranspiration of the understory and provides a more humid micro climate. This can change the vegetative growth and promote a change in vegetative patterns (Garrison and Pita, 1992).
 - ad. g: Obviously there is a reduction in pasture area and yield through the space occupied by the basal trunk of the tree and the surrounding root mass (Reynolds, 1988).

The tree/grass-cattle relation:

- a. Grazing
 - b. Treading
 - c. Manuring
-
- ad. a: This includes not only grazing of the pasture, but also eating natural regeneration of trees and forage from the trees (Evans, 1992; Montsma, 1988).
 - ad. b: Treading causes destruction of the superficial roots of the trees as well as of the roots of the grass. Treading causes also soil compaction. Soil compaction gives an increased infiltration time (Braggio, 1984).
 - ad. c: Through the manure the livestock enriches the soil. This is not regular spread, but some concentration occurs where the livestock rest. This is often under trees where they find shelter against sun or heavy rain (Braggio, 1984).

2.4 The relation between trees and grass with regard to light

In the case of a sylvopastoral system the first question to be considered is, if a certain combination of the components, trees, grass and livestock, has an advantage over systems in which they are kept separately (Montsma, 1988). Research can give an answer to this question and help to

decide what the optimum combination of components is, under the given conditions.

For continued growth plants require continuous and balanced access to the resources light, water and nutrients (Conor, 1983). Within the tree-grass relation the available amount of light under trees, is seen as the main factor which determines the dry matter production of grass under trees (Daccarett and Bleydenstein, 1968; Kessler, 1992; Montsma, 1988; Willems and Wisse, 1984). That light is the main factor showed the research of Wong and Wilson where shade has been provided by shade cloths and not by tree canopies, and influenced grass production. In that research, with a limited amount of shade even an increased grass growth has been reported (Wilson, 1990).

As mentioned in chapter one in the description of the sylvopastoral system, the farmers of the Atlantic Zone mentioned worse, equal or better grass production as compared to grass without trees. Also in literature these three effects are mentioned. In temperate areas grass has a reduced production under trees, see e.g. the research of Willems and Wisse (1984) on grass production under poplar in the Netherlands. In areas with a higher influx of solar radiation grass growth may be better under a tree than without tree canopy. Several experiments have shown a higher grass production under trees as compared to the unshaded situation, e.g. Kennard and Walter (1973) and Bosch and Van Wijk (1970) with *Panicum maximum* in Rhodesia (both mentioned in Montsma, 1988), Belsky et al. (1993) in tropical savannas in Kenya and Wilson (1990) with *Paspalum notatum* under *Eucalyptus* in Australia. Comparing results from these researches with the situation in the Atlantic Zone is difficult, because most research is done under very different climatic conditions.

Also the climatic conditions of a research in Turrialba, Costa Rica differ too much to translate the results to the Río Jiménez area. Nevertheless, it helps to give a direction where this research should be focused on. The research in Turrialba with four different trees (*Erythrina poeppigiana*, *Pithecolobium saman*, *Gliricidia sepium* and *Cordia alliodora*) did not show a proved negative effect on the grass production. The reduction of the dry matter production of the herbaceous vegetation under the trees in comparison with the unshaded control plot was not significant. The quality of the shaded grass proved to be better compared to the unshaded grass (Daccarett and Bleydenstein, 1968).

An increased grass production under trees may be caused by the improvement of the understorey micro climate, a lower radiation rate under trees, which decreases temperature and evaporation. Another positive factor on grass production is a better soil fertility caused by the tree as a mineral pump (Belsky et al., 1993; Montsma, 1988). In a nitrogen poor environment where nitrogen is limiting grass production, a reduced radiation rate showed an increase in grass production, because there is an increased mineralisation by bacteria, giving a better use of the nitrogen ('t Mannetje, personal communication; Wong and Wilson, 1980).

Budowski (1983) mentions a positive effect of trees on grass palatability. A better palatability under shade conditions is caused by a reduced lignification in the grass due to the reduced light influx.

As explained above the most determining factor is light. In the following the effects of light are treated in more detail.

2.4.1 Light availability

The amount of light under the trees depends on different factors. The first is the tree species. The global radiation, the radiation which reaches the earth's surface, is divided in three parts by the trees. One part is reflected by the tree and one part is absorbed. The remainder, the radiation reaching the understorey is called transmission (Lövenstein et al., 1992). Every tree species has a specific crown development and hence a certain light transmission. This transmission is also dependent of the extent of canopy closure. This is determined by the age and shape of the trees and the number

of trees per hectare (Willems and Wisse, 1984). The development of the canopy results in a certain leaf area index, which shows the number of leaf layers per unit for a certain condition (Lövenstein et al., 1992).

Global radiation reaching the trees is also a variable. The incoming radiation is the radiation reaching the earth's atmosphere and varies with latitude, season (day of the year) and daily time course (time of the day). The weather conditions also influence light availability. The presence of water vapour, clouds or dust in the atmosphere reduces the incoming radiation reaching the earth's surface by scattering and absorption. The global radiation consists therefore partly of direct radiation (incoming radiation) and partly of diffuse (scattered) radiation (Bartelink, personal communication; Lövenstein et al., 1992; Willems and Wisse, 1992).

2.4.2 Light intensity

The effects of light intensity will be treated on the basis of the results of the research of Kennard and Walter (1973 in Montsma, 1988). The total dry matter production of the grass in the research of Kennard and Walter (1973 in Montsma, 1988) is measured in three situations (table 2.1). Under a high shade regime (closed canopies) the total dry matter production is less than open grassland, but under a medium shade regime (open canopies) there is more grass production as compared to the open grassland.

Table 2.1 Yield of herbaceous layer, average light intensity and mean surface temperature under closed tree canopies, open canopies and in open grassland in Rhodesia (after Kennard and Walker, 1973 in Montsma, 1988).

	Total dry matter (g m ⁻²)	Average light intensity (lumen)	Mean surface temperature (°C)
Closed ca- nopies	276	3.9	23.1
Open canopies	447	5.8	24.6
Open grassland	302	15.8	30.2

Grass production is related to the assimilation rate of the grass. Assimilation minus respiration for maintenance and growth gives the production. The assimilation rate increases proportionally with light intensity¹ until light saturation is reached (Lövenstein et al., 1992). In the situation of the closed canopies light is the constraining factor for assimilation. Changing from the closed canopies to the open canopies into open grassland the light level increases (table 2.1). Also the assimilation rate increases, until

¹ In this report light intensity represents not the total global radiation, but the radiation between the wavelengths of 400 and 700 nm (visible radiation). Only this radiation is used in the photochemical process and therefore denoted as PAR (photosynthetically active radiation) expressed in Jm⁻²s⁻¹. Light levels are a certain amount of available PAR and not a certain level of wavelengths (Lövenstein et al., 1992).

light saturation is reached.

At higher light levels, assimilation rates approach a maximum level, that is independent of light intensity, as other factors have become limiting. Limiting factors can be CO₂ concentration, temperature, water status of the leaf, nitrogen status of the leaf and pests, diseases or air pollution (Lövenstein et al., 1992). In the situation of the research showed in table 2.1 grass production in the open grassland is less than under an open canopy. Probably in the open grassland light is not the limiting factor (light saturation is reached) and other factors become limiting to assimilation and thus production. Shade provides a better understorey environment (Belsky et al., 1993) having a positive effect on the factors temperature and water status of the leaves. The result is a higher assimilation rate under the open canopies as compared to open grassland. The factors temperature and water status of the leaf will be elaborated shortly.

Temperature influences assimilation. Part of the biochemical processes of assimilation are regulated by enzymes, whose activities are temperature-dependent. At high temperatures aminoacid composed enzymes start to disintegrate. Hence at temperatures below the disintegration point, the assimilation rate is more controlled by light limitation, because not the enzymes are restraining assimilation, but light. In this case the light use efficiency (expressed in kg CO₂ha⁻¹h⁻¹ or Jm⁻²s⁻¹) is only little affected by temperature. At high temperatures this efficiency declines rapidly due to disintegration of the enzymes. This is shown with a situation of continuous light saturation, assimilation increases with increasing temperatures until an optimum temperature. When temperature exceeds the optimum temperatures assimilation declines again (Lövenstein et al., 1992).

A higher light intensity and temperature gives faster and more severe drought stress. Drought stress causes fall in the water potential in the leaves and the stomata close. This gives an increased stomatal resistance which hampers the CO₂ diffusion, a sub-process of assimilation (Lövenstein et al., 1992).

Also other factors, not related to the light relation, have an influence on the production, but light is seen as the most important. Looking at the results of several experiments (Belsky et al., 1993; Daccarett and Bleydenstein, 1968; Bosch and Van Wijk, 1970 and Kennard and Walter, 1973 in Montsma, 1988; Wilson, 1990) one can suppose a higher grass production under a slight reduced light intensity in situations where light is no longer a constraining factor for grass production, but other factors (temperature and water stress) have become limiting grass production. This situation seems to occur in tropical regions especially in arid areas. Question is how far this situation occurs in the Atlantic Zone with a very humid climate.

3 THE EMPIRICAL RESEARCH, MATERIALS AND METHODS

In order to determine the effects of trees on grass production in the Atlantic Zone of Costa Rica four trials are executed on existing sylvopastoral fields. The organisation and methods and the parameters measured are described in this chapter.

3.1 Site description

For a description of the study region chapter 1 is referred to, where a general overview is given of the Atlantic Zone. The research sites are all located in the surrounding of Guácimo, the Río Jiménez area (see appendix 1, map of location of research sites).

The decision which sites are chosen for the experiment is made in co-operation with an agronomist and forester from the Atlantic Zone Programme and a field assistant who is familiar with the local situation. The Río Jiménez area was chosen, because this is one of the three areas of the PhD forestry research (Research of van Leeuwen, 1991) and an extensive research of Paap (1993) was made on the sylvopastoral systems in this area. Data are available on the farming systems and contacts with some farmers existed already.

3.2 Experimental design

In this paragraph the way the trials were set up and how the experiment was carried out will be discussed. After a general observation of the area and using the available data about the farms, two grass types i.e. *Ischaenum ciliare* (Ratana) and Pasto Natural and two tree species i.e. *Pentaclethra macroloba* (Gavilán) and *Cordia alliodora* (Laurel) were chosen for the experiment. All trials have as much as possible the same conditions with regard to altitude, climate, soil and pasture management.

The trees were selected according to four criteria: an association with one of the selected grass types, standing on the soil type Andic Humitropepts, relatively homogenous site conditions (altitude, climate and management), and a location far from other trees. This last criterion appeared to be difficult, most of the trees of the selected species (Gavilán and Laurel) grow in groups. The distance to the nearest trees from the research tree is measured and the nearest trees are drawn on the maps (Appendix 2). The trials are located on the same soil type, Andic Humitropepts, infertile soils with good drainage (Wielemaker and Vogel, 1993). It showed impossible to locate all trials on a soil with the same subclassification. The trials 1, 3 and 4 (appendix 2a, c and d) have all soil 'Neguev' and trial 2 (appendix 2b) has soil 'Silencio'. For a more detailed description of the soils see chapter 1.1.3.

In total 20 trees were selected, 5 Gavilán and 5 Laurel trees on two Ratana fields and 5 Gavilán and 5 Laurel trees on two Pasto Natural fields. Resulting in four different trials, i.e. Ratana with Gavilán (Santa Rosa), Ratana with Laurel (Africa), Pasto Natural with Gavilán (Adrimaga) and Pasto Natural with Laurel (Adrimaga). See for the maps of the trials appendix 2a-d. The research is limited to this number due to the limited availability of time and money. Combining the trials is problematic because they are located on different sites and on fields with different pasture management. The influence

on grass production and the differences between the trials caused by this are not known.

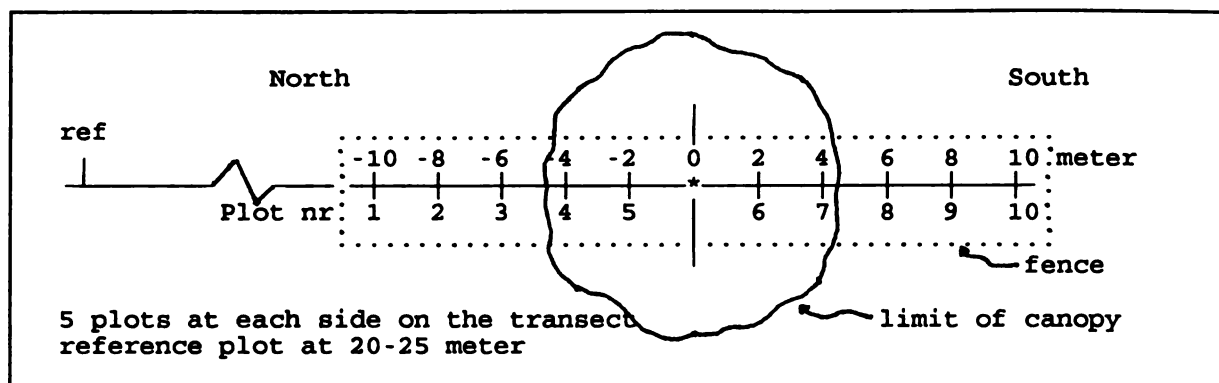


Figure 3.1 The experimental set-up of transects and plots around a research tree.

Under each tree a north-south transect of 20 meters was made, 10 meters at each side of the tree (fig. 3.4). In a research of Kessler (1992) four transects were used, in each wind direction one, to investigate influence of the sun position, but no significant difference appeared between the transects. In this research only a north-south transect is used, to cut down the expenses of the fences, instead of decreasing the replicates or the number of species used. On each transect 10 plots are situated, 5 plots at each side of the tree with 2 meters distance between them (fig. 3.4). A reference plot is situated without tree influence at 20 to 25 meters distance of the tree. The surface of each plot is 0.25 m^2 . The transects and the reference plots are protected from livestock interference through fences made of poles and barbed wire.

On each trial the same measurements were carried out. Tree characteristics, grass production and site characteristics were investigated in order to determine the effect of trees on the grass production.

3.2.1 Tree parameters

To get an impression of the shape (which is related to shade regime) of the trees used in the trials and be able to compare the shapes of the two tree species the following parameters were measured on all twenty trees:

- * tree height
- * diameter breast height
- * height of the lowest branches
- * width crown and canopy projection

3.2.2 Grass growth, quality and composition

The dry weight production of the grass was measured every four weeks. Before the start of the research the grass was cut in the whole transect and in the reference plots to provide a similar initial grass level in all the plots. Four weeks after cutting, the first measurement was carried out in July 1993. The research should last for 12 months, but in this report data up to April are used. The interval of four weeks was chosen similar to the time most farmers use for regrowth of the pasture after a period of grazing. Although in some cases a different management is used.

The grass was cut at 7 centimetres height (limits 5-10 cm.), an iron

square and a grass-shears were used. After the grass samples were taken the surrounding grass between fences was also cut. Before drying the grass samples the fresh weight production was measured. The grass samples were dried at 105 °C for 48-62 hours after which the dry weight production was measured of each sample. After this for each trial the average production of each plot was calculated and of each plot the percentage of the production of the reference plot.

To investigate the quality of the grass some samples were analyzed on digestibility and protein. The samples of plot number 1, 3 and 5 were used from every first, third and fifth tree of each trial (see fig. 3.4). The samples were analyzed in the laboratory of CATIE in Turrialba.

The composition of the pastures was examined to see which grass species occur in the different fields and if there is a change in composition related to shade regime. Also the percentage of bare soil was examined.

3.2.3 Soil properties

Some soil samples were taken from the top soil layer. For every tree the thickness of the top soil layer was measured under and beside the tree crown. The percentage of organic matter of the top soil was measured of the trees numbered 1, 3 and 5 of every trial. The percentage of organic matter is obtained by the glow loss method (personal communication Stoorvogel). The soil samples were dried at 105 °C for 12 hours and weighed. After this the samples were glowed at 550 °C for 3 hours and weighed again. The glow loss is obtained after which the percentage of organic matter can be calculated. The glow loss should be corrected for the percentage of soil parts smaller than 2 µm and the percentage of free iron (Fe₂O₃) to obtain the exact percentage of organic matter. The necessary data were not available to make these corrections. Because only a comparison of the percentage of organic matter under and beside the tree crown is used, the percentage of glow loss without this correction gives a good indication too (Soil laboratory University of Wageningen).

3.2.4 Light intensities

For the two different tree species the light intensities were measured on all the plots. The measurements resulted in data of the changes of light intensities at different distances of the trunk. Light intensities were measured for two situations, i.e. for diffuse light (on an overcast day with a homogenous cloud cover) and for direct light (on a bright sunny day). When direct light was measured it was done on three different times, at 09.00 hours, 12.30 hours and 15.00 hours. All measurements were taken in July and August. For both tree species the average light intensities were calculated for each plot and the percentage of the light intensity of the reference plots.

A normal photometer (Quantum) was used, with a point light cell measuring Microeinsteins m² sec⁻¹. The light cell was placed directly above the grass layer at 40-50 cm.

3.3 Plant species studied

In sylvopastoral systems in the Atlantic Zone different kind of grass species are used. The most common are *Ischaenum ciliare* (Ratana) and Pasto Natural. The grass type Pasto natural is a mixture of natural occurring grass species in the Atlantic Zone. Species which occur in the pastures of the trials are *Digitaria sanguinalis*, *Homolepis aturensis* (Arozilla), *Panicum laxum* (Zacatillo Suampo) and *Paspalum conjugatum*. *Ischaenum ciliare* belongs to the improved species (Paap, 1993). There are by breeding improved species introduced in the Atlantic Zone which produce better, but they are not much

used up to now (Nobbe, 1988).

Ratana (*Ischaemum ciliare*) and Pasto Natural are chosen for this research, although producing less than the improved species, because they are very common and most used in the Atlantic Zone. See for a species description appendix 3.

The research of Paap (1993) showed a wide variety of dispersed tree species occurring in sylvopastoral systems in the Atlantic Zone. In total the farmers mentioned 52 different species, with an average of 6 (5.4) species per farm unit. The figures between brackets are from the Río Jiménez area. The size of an average farm unit is 51 (36.4) hectares, from which 29.2 (32.1) hectares is pasture. The most used tree species are *Cedrela odorata* (Cedro amargo), *Cordia alliodora* (Laurel) and *Pentaclethra macroloba* (Gavilán).

For this research Laurel (*Cordia alliodora*) and Gavilán (*Pentaclethra macroloba*) are chosen. Laurel is a tree with a small crown and moderate foliage resulting in a high light transmission. The species Gavilán is the opposite. This species has a large and heavy crown and a dense foliage resulting in a low light transmission. Because of their common use in pastures and their difference in light transmission and shape these species are used. Gavilán and Laurel are used as a timber trees, Gavilán also for its shade (Paap, 1993). See for a species description appendix 4.

4 THE EMPIRICAL RESEARCH, RESULTS

In this chapter the results obtained from the research are presented and have been analyzed. The results of the different trials are compared and the shade effects on the grass production are analyzed.

4.1 Tree characteristics

In table 4.1 the tree characteristics, tree height, diameter breast height and height of lowest branch are presented for four combinations of tree species and sites.

Table 4.1 Gavilán and Laurel trees with parameters: height, diameter breast height (dbh) and height lowest branch (means and standard deviations).

Site and species	Number of trees	Height (m)		Dbh (cm)		Height l.b. (m)	
		Mean	σ	Mean	σ	Mean	σ
Pasto Natural-Gavilán	5	14.8	3.1	86.3	15.1	2.0	0.6
Ratana-Gavilán	5	16.5	5.5	90.3	29.9	1.9	0.2
Average Gavilán	10	15.7	4.3	88.3	22.4	1.9	0.4
Pasto Natural-Laurel	5	23.8	4.2	40.0	8.2	10.5	4.7
Ratana-Laurel	5	19.9	2.0	32.9	10.1	6.7	3.1
Average Laurel	10	21.9	3.7	36.5	9.4	8.6	4.3

The differences between heights, diameters and heights of lowest branch are not very large for both tree species when the sites are compared. No significant ($P < 0.05$) differences occur for Gavilán and Laurel for the tree characteristics between the different sites. When the height or dbh is larger the standard deviation is in almost every case higher. This is the case for the Gavilán trees with Ratana in Santa Rosa, they are larger and bigger, but more variable in size, compared to the Gavilán trees with Pasto Natural in Adrimaga. The differences between the two species are, as expected, large. There is a significant difference for height, diameter breast height and height of lowest branch ($P < 0.05$ and $n=10$). The Laurel trees are higher with a smaller dbh than the Gavilán trees.

The mean canopy projection of the Gavilán trees is larger than the mean canopy projection of the Laurel trees (fig. 4.1 and appendix 5), also with a significant difference for all directions. The standard deviation between the larger Gavilán canopies is higher than of the Laurel trees for the canopy width. The crown position, the height of the bottom of the crown, is much higher for the Laurel trees (table 4.1, lowest tree branch). Besides a

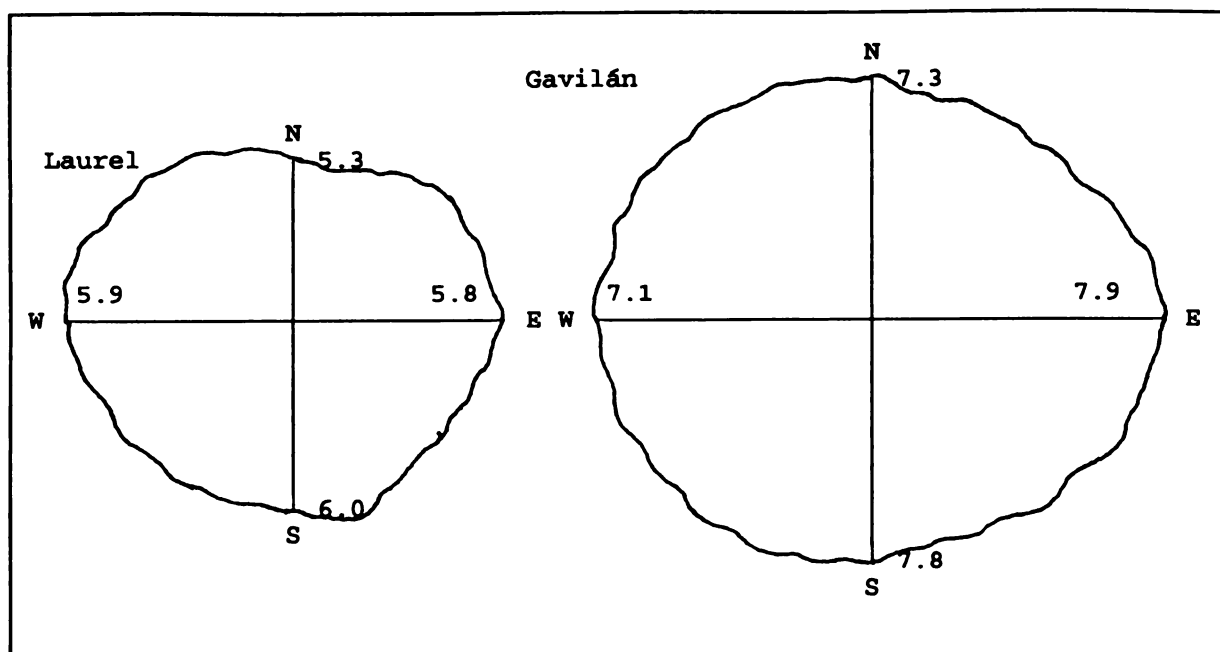


Figure 4.1 Average (n=10) canopy projection of Gavilán and Laurel.

difference in crown width and position there is also a difference in foliage. Gavilán has a dense foliage while Laurel has a open crown. Foliage is only visually observed, it is not measured.

All these figures clearly show the difference between the shapes of the two tree species, one of the reasons why these species were chosen (see 3.2).

4.2 Grass production

Per 'tree-site' combination grass production is evaluated. Dry matter grass production as a relation to the distance from the trunk is measured and expressed as a percentage of the grass production of the reference plots. For this analysis always dry matter weight is used. Fresh weight was also measured, but is only used to control the measurements. Students t-test and a 'difference analysis' is used to test whether significant differences occur between adjacent plots at the different distances from the trunk and the reference plot. The exact standard deviation is not known, Students t-test is used because it works with an estimated standard deviation (σ). The T-distribution is used for difference analysis. When possible 'pooled variance' is used to increase the accuracy of the prediction. In that case F-distribution is used to test if the different variances can be treated as equal. In all cases a reliability interval of 95% is used. When the transect is taken as a whole, number of data (n) is 5 for both, the reference plots as well as the different plots under the trees. It is doubled when the north and south transects are combined (n=10). The same statistical methods are used for the light and soil data.

Grass growth of Ratana and Pasto Natural is influenced under Gavilán trees resulting in significantly lower grass production (fig. 4.2 and appendix 6, fig. a-d). Pasto Natural is influenced the most. It is significantly influenced up to 6 meters' distance from the trunk, Ratana is only significantly influenced up to 2 meters' distance from the trunk ('pooled variance' with

$P < 0.05$). For Pasto Natural at a 2 meters' distance from the trunk a grass production of 25-30% of the reference plots is reached. For Ratana this is 45-55%. In table 1 and 2 of appendix 6 the exact values of the fractions are presented for the total transect and the combined north-south results. For both grass types, with an increasing distance from the tree trunk the grass production is increasing until a maximum, which is about the level of the reference plots. The grass production increases sharply until about an 8 meters' distance from the trunk, which is also about the crown width of the Gavilán trees. At an 8 meters' distance from the trunk the grass production is 90-95% of the reference plot in the case of Pasto Natural, for Ratana even a grass production of 110-115% at an 8 meters' distance from the

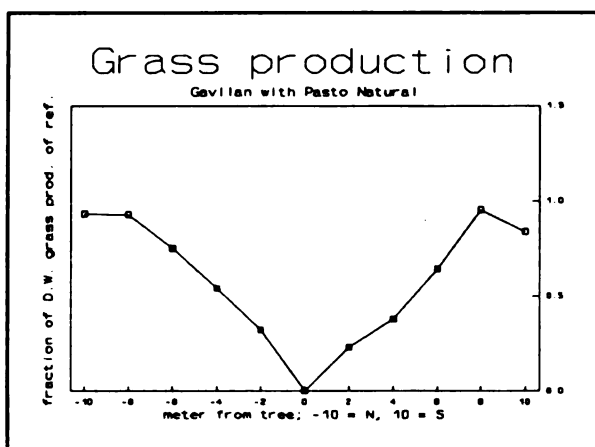


Figure 4.2 Grass production, Pasto Natural under Gavilán, expressed as a proportion of the values on the reference plots, in relation to the distance from the trunk.

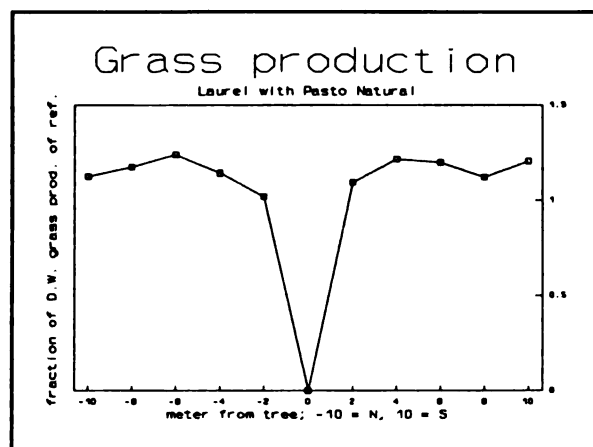


Figure 4.3 Grass production, Pasto Natural under Laurel, expressed as a proportion of the values on the reference plots in relation to the distance from the trunk.

trunk occurs. This higher grass production of Ratana however is not significantly higher compared to the reference plot.

Grass production of the two grass types under Laurel trees gives a quite different result (fig. 4.3 and appendix 6, fig. e-h). No reduction of the grass production is measured under Laurel trees, it even resulted in a slightly higher grass production compared to the reference plots. For Pasto Natural the grass production on all the plots varies from 100-120% and from 95-105% for Ratana (appendix 6, table 1 and 2). Ratana has only a slightly decreased grass production for the plots at a 2 and 4 meters' distance from the trunk. The grass production of Ratana is not significantly influenced under Laurel. Pasto Natural however has except for the plot at 2 meters' distance from the tree significant higher grass production than the reference plots ('pooled variance' with $P < 0.05$).

In table 4.2 the average grass production per four weeks is presented. The average dry weight grass production is calculated for the surface of the circle under the trees formed by the transects (diameter 20 meters). The effects on grass production between the two grass types under Gavilán and Laurel are the same, but intensity is quite different. Grass production of Pasto Natural is reduced more than grass production of Ratana under Gavilán. The average grass production of Pasto Natural is significantly reduced under Gavilán, 78% of the reference plot. Ratana is also reduced close to the trunk, but the average grass production under Gavilán is even a little higher (105%) compared to the reference plot, although not significant. Also for the

Table 4.2 Average dry weight grass production. D.W. (gm² per cut) and fraction expressed as a proportion of the values on the related reference plots. Time between every cut was four weeks.

		Gavilán		Laurel	
		plots	ref.	plots	ref.
Pasto Natural	D.W.	44.7	57.6	73.5	61.9
	fraction	0.78		1.19	
Ratana	D.W.	48.4	46.3	49.1	47.2
	fraction	1.05		1.04	

situation with Laurel the intensity of the effect is larger for Pasto Natural. In this case Pasto Natural has a more increased grass production than Ratana. Pasto Natural has a significantly increased average grass production under Laurel, 119% of the reference plot. Average grass production for Ratana under Laurel is also a little bit higher (104%), but not significantly higher.

4.3 Grass quality and composition

In table 4.3 the data on grass quality are presented. No significant differences occur between the grass qualities as a relation to the distance of the tree. In all cases no influence is shown on digestibility or proteins. The

Table 4.3 Grass quality per tree-site combination. D: digestibility % of D.M., P: proteins % of D.M.

Distance to tree		2 m.	σ	6 m.	σ	10 m.	σ
Pasto Natural - Gavilán	P	17.4	1.3	16.8	1.6	14.3	2.9
	D	39.7	6.7	46.4	1.2	44.7	5.0
Ratana - Gavilán	P	17.6	1.6	16.3	0.8	16.5	2.8
	D	40.0	7.5	35.5	0.0	44.3	5.8
Pasto Natural - Laurel	P	15.1	2.9	13.8	1.1	15.1	2.0
	D	46.2	2.2	48.8	3.3	45.2	4.2
Ratana - Laurel	P	15.1	1.7	14.7	2.8	16.8	4.1
	D	53.7	0.8	49.9	3.3	58.5	2.5

data on grass quality of the two grass types are only an indication of the

grass quality. There are too few samples and a limited number of reiterations, resulting in a variance which is too high to give a reliable prediction of the grass quality under and beside the tree crown.

Also the grass composition for the different tree/site combinations is examined. Of course Ratana dominates in the two trials with Ratana grass type, with a rare occurrence of some other species. In the trials with Pasto Natural a mixture of all different kind of grass species exists (appendix 7).

Only in the case of Pasto Natural under Gavilán the composition alters with the distance to the tree. In the other three cases no change is noticed. The occurrence of the grass species *Paspalum conjugatum* is increasing in relation to the distance of the tree. The opposite goes for *Panicum laxum*, the occurrence of *Panicum laxum* is decreasing in the case of an increasing distance to the tree (appendix 7).

4.4 Light intensity

Due to the smaller canopy (fig. 4.1) Laurel has a smaller shade projection than Gavilán. Laurel also has a lower shade regime because of the difference in canopy width and a higher crown position (table 4.1, lowest tree branch), but also because a difference in foliage of the crown. Hence the light interception for Laurel is much lower than for Gavilán.

As explained in paragraph 3.3.4 light is divided in diffuse and direct light. In figure 4.4 the available amount of diffuse light is plotted as a relation to the distance of the tree. The difference between Gavilán and Laurel is obvious (fig. 4.4, 4.5 and appendix 8, fig. b,d). Under Laurel only a slight influence is noticed, about 15-20% (diffuse light) less radiation close to the trunk. The light interception of Gavilán is severe, only 20% of the light intensity is left close to the trunk increasing to 85% at a 10 meters' distance from the tree. Light reduction for Laurel is only significant at 2 and 4 meters' distance from the tree. Light is significantly reduced on every plot, however, for Gavilán.

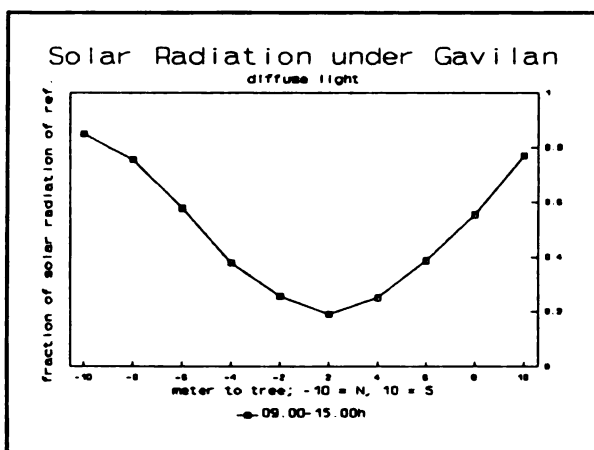


Figure 4.4 Diffuse light (% of ref. plots) under Gavilán.

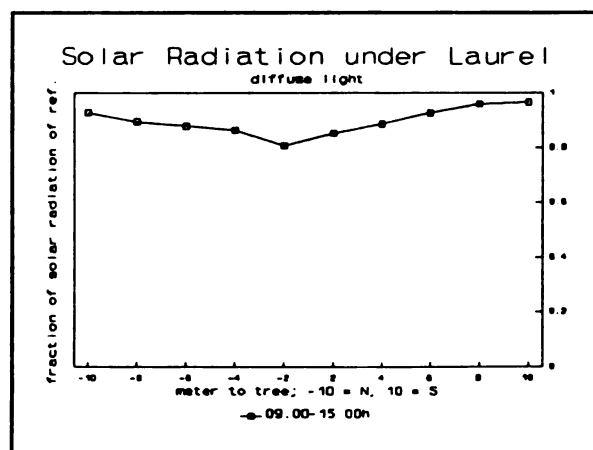


Figure 4.5 Diffuse light (% of ref. plot) under Laurel.

The situation for direct light is a little different (appendix 8, fig. a,c). With diffuse light there is no direct change from sun into shade, it is a gradual transition. With direct light there is a clear difference between sun and shade. The difference between the unshadowed situation (the reference

plots) and the minimum under the trees is larger in the case of direct light compared to the minimum in the case of diffuse light. For Laurel 60% radiation is left at noon, dropping to 30% in the morning and afternoon (appendix 8, fig. c). Gavilán drops even to 10-15% (appendix 8, fig. a). For Laurel also the position of the shade changes during the day. The shade position of the Gavilán does not change much between 09.00 hours and 15.00 hours, because of the low position of the tree crown of the Gavilán.

4.5 Soil characteristics

Only the results of top soil layers are presented in table 4.4. Also the organic matter was measured, but the data could not be used, because of a mistake in handling the samples. The soil is not studied in detail, the results are therefore just an indication of the soil quality in relation to the trees. The variance would be too high, because the limited number of samples, resulting in unreliable prediction.

In spite of the limited research in every case the thickness of the top soil layer under the tree is higher than the top soil layer beside the tree.

Table 4.4 Top soil layers (cm). Under the tree at half the width of the crown and beside the tree at a 10 meters' distance from the trunk and standard deviation (σ).

Tree		under	σ	beside	σ
Pasto Natural - Gavilán	top soil	4.7	2.0	2.4	0.9
Ratana - Gavilán	top soil	5.9	3.1	4.1	1.6
Pasto Natural - Laurel	top soil	5.7	1.5	4.0	1.7
Ratana - Laurel	top soil	5.7	1.6	3.5	0.6

The differences between the values for the Laurel trees are a little smaller than for the Gavilán trees, having a much smaller tree crown than the Gavilán.

4.6 Tree-grass interrelations

In this paragraph the different results, presented above, are combined to describe the tree-grass interrelations. The difference in grass production under the two tree species is clear (see 4.2). Grass production is strongly reduced under Gavilán (from 2 to 8 meters). At an 8-10 meters' distance from the tree the grass production has reached the level of the reference plots or a little more (appendix 6, fig. a and b). At that distance diffuse and direct light intensities have reached about 80% of the level of the reference plots (see 4.4 and appendix 8, fig. a and b). Grass production increased even a

little under Laurel, although only significant for Pasto Natural (appendix 6, fig. c and d). Under Laurel average light intensity varies from 80-85% (appendix 8, fig. c and d). Under both trees at a light level of about 80% grass production reaches its maximum (at an eight meters' distance from the trunk for Gavilán and more or less on the whole transect for Laurel). Both tree species show that in this situation a light level of 80% is sufficient to reach or even outreach grass production with a 100% light level. In the case of Gavilán grass production decreases after an eight meters' distance from the trunk (appendix 6, fig. e and f), while light intensity is still increasing (appendix 8, fig. a and b). This can be caused, because measurements of grass production may have been influenced negatively because sometimes cows sneaked through the fence at the edges. However this influence is regarded not significant (see 5.3). It is supposed that other factors are more limiting, although it is not proved, no research is done on temperature and water stress.

The laps of especially the diffuse light intensity curves under Gavilán and Laurel resemble to a great extent to the grass production curves under Gavilán and Laurel. A linear regression is made for the light-grass production relation. Grass production is significantly correlated to light intensity (fig. 5.1 and appendix 9). Correlation is higher for Pasto Natural ($r^2 = 0.92$) than for Ratana ($r^2 = 0.52$). Correlation does not necessarily mean causation. Not only light but also other factors like soil, temperature and water influence tree-grass interrelations. Gavilán and Laurel showed a positive influence on the soil, like a thicker top soil layer (see 4.5) by which the grass layer is influenced. However, in other research (see 2.4) light is regarded the main factor which determines the dry matter production of grass under trees.

With a low light reduction of about 20%, grass production is a little higher than in the open field, which is the case under Laurel. Further increasing light intensity does not result in a higher grass production. Apparently some shade results in better growth conditions, i.e. lower temperature and higher humidity, having a positive influence on grass production.

The higher grass production under Laurel is not as pronounced as mentioned in some other research (Kennard and Walter, 1973; Bosch and Van Wijk, 1970 (mentioned in Montsma); Wilson, 1990, Belsky, 1993). Although not the same species are used in the other researches, it is possible to compare in general the results, because shade is seen as the main influence on grass production. All these researches are in more arid areas. There grass production is limited more by drought than in the Atlantic Zone, where rainfall throughout the year is abundant. The effects of shade, higher humidity and lower temperature, are less in the Atlantic Zone. Probably water stress and a too high temperature are not limiting grass production much in the open field in the Atlantic Zone.

Research in Turrialba (Daccarett and Bleydenstein, 1968) did not result in a proved negative grass production under trees, but compared to the unshaded grass the quality of the shaded grass proved to be better. In this research no significant influence on grass quality appeared, but there were very limited data. However, the composition of the Pasto Natural is influenced

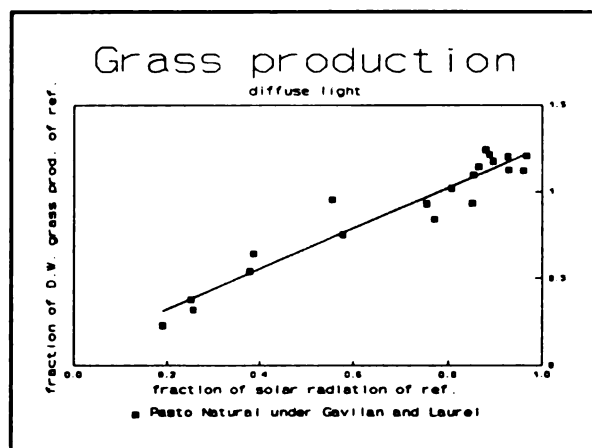


Figure 4.6 The relation between light intensity and grass production.

by shade. A higher shade regime is in favour of *Panicum laxum* at the expense of *Paspalum conjugatum* (appendix 7). Perhaps the possibility of Pasto Natural to change its composition with changing light conditions, is why Pasto Natural gives a relative higher increased grass production under Laurel than Ratana. This assumption however, conflicts with the results under Gavilán, where Pasto Natural has a relatively lower grass production than Ratana.

5 DISCUSSION AND CONCLUSIONS

In the former chapter the results were presented, in this chapter the discussion and conclusions which proceed from the results are discussed. Also some restrictions and problems influencing the results are described. The chapter ends with a number of recommendations for further research.

5.1 Discussion

During the research the trials were protected from livestock influence by fences. This includes that during the research no longer grazing, treading and manuring occurred. It is not known in what way this influenced the research. It can be supposed that the livestock pressure under trees, especially Gabilán, is higher than in the open field. After fencing the trials the grass could recover from treading and having at least in the start a profit from the manure under the trees. If and how this influenced the grass production is not known.

In spite of the effort put in making the fences, during the research they seemed not as cow-proof as they should be. This is especially the case for the edges. The sudden decrease in grass production for the plots at a 10 meters' distance from the tree (see e.g. appendix 6, fig. a at 10 meter) may have been totally or partly caused by cows that sneaked through the fence.

Another problem is the isolated trees. It proved to be very difficult to find trees with totally no influence of others. In the early morning (before 09.00) or late afternoon (after 15.00) in some cases another tree gave some shade on a transect.

A critical remark must be made on the design of the transects. In this design the plots are related to the distance of the tree, when repeating the experiment it is perhaps better to relate the plots to the crown width, especially when the standard deviation of the crown width is high. Canopy influence will be more equal for the linked plots than for plots related to the distance of the tree.

5.2 Conclusions

The main objective of the research, as formulated in chapter 1, was to investigate which interactions exist between trees and pasture and what the effects are on grass production within the sylvopastoral systems in the Atlantic Zone of Costa Rica.

The first part, the interactions, is discussed in chapter 2. The relationships between trees and grass are based on the resources light, water and nutrients. Within the tree-grass relation the available amount of light under trees, is seen as the main factor which determines the dry matter production of grass under trees. This assumption is used in this research. The relation between trees and grass with regard to light is therefore discussed in more detail at the end of chapter 2. When light intensity increases assimilation and hence growth increases. At higher light levels grass growth approaches a maximum level, that is independent of light intensity, as other factors become more limiting.

The results of the experiments showed the effect of trees on grass production, the second part of the research question. Under Gabilán light intensity increases with an increasing distance from the tree, at the same

time grass production increases. Under Laurel diffuse light intensity varied only a little and is reduced about 20%, grass production is stable and is slightly increased. The light level under Laurel seems to be more or less optimal. Also under Gavilán grass production reached the optimum at diffuse light level of about 80%.

Below the optimum light level an increased light level results in an increased grass production, light is limiting grass growth. Beyond the optimum light level an increased light level does not result in an increased grass production, it might even decrease a little. It is assumed that other factors become more limiting. This is not proven, because no research is done after temperature and water stress.

5.3 Recommendations

The optimum diffuse light intensity seems to be at about 80% of the open field. With 80% diffuse light intensity grass production is equal or more compared to grass production in the open field. Management should be aiming at a diffuse light reduction of about 20%. It is difficult to translate this to a certain tree stocking rate, because light reduction under trees is species and shape dependent. In the case of Laurel there is about an overall 80% light level under the trees. At an 8-10 meters' distance from the tree light intensity is close to 100%. A tree stocking rate of 40 trees ha⁻¹ (tree distance of 16 meters) seems reasonable.

For Gavilán light intensity changes with the distance to the tree. Up to 8 meters from the tree a decreased grass production occurs for Pasto Natural. Ratana resulted even in an increased average grass production under the trees compared to the reference plots. The influence of the crown can be reduced by pruning in order to let more light through. Besides grass production losses should also be compared to yield of trees. Trees can have a substantial value and may exceed the grass production losses.

Further research on tree density and costs-benefits analysis is necessary. In this research isolated trees were used, further research on grass production under a group of trees or in a plantation must be done to give the optimum tree density. Trees used in the research were also mature. Light reduction and influence on grass production during their growth should be investigated.

This research showed the correlation between light and grass production, but not the exact causation. Especially when light level approaches light saturation and light is not limiting grass production, which factors are limiting grass production then? Also further research is necessary on the influence on the grass quality. Quality within a grass species and between different grass species (*Panicum laxum* versus *Paspalum conjugatum*) in relation to light intensity.

This research was focused on the production side, also sociological and economical aspects must be judged. Research on cost-benefits ratios can give an answer to the best tree-grass combination. Other relevant aspects are, sociological aspects such as, are the farmers willing to plant and manage more trees or will they clear their fields more and more?

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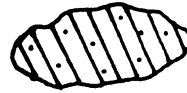
Appendixes

APPENDIXES

APPENDIX 2 MAPS OF THE TRIALS

Legenda

Group of trees or forest :



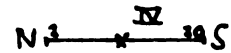
Solitaire tree :



Farm house :



Transect :

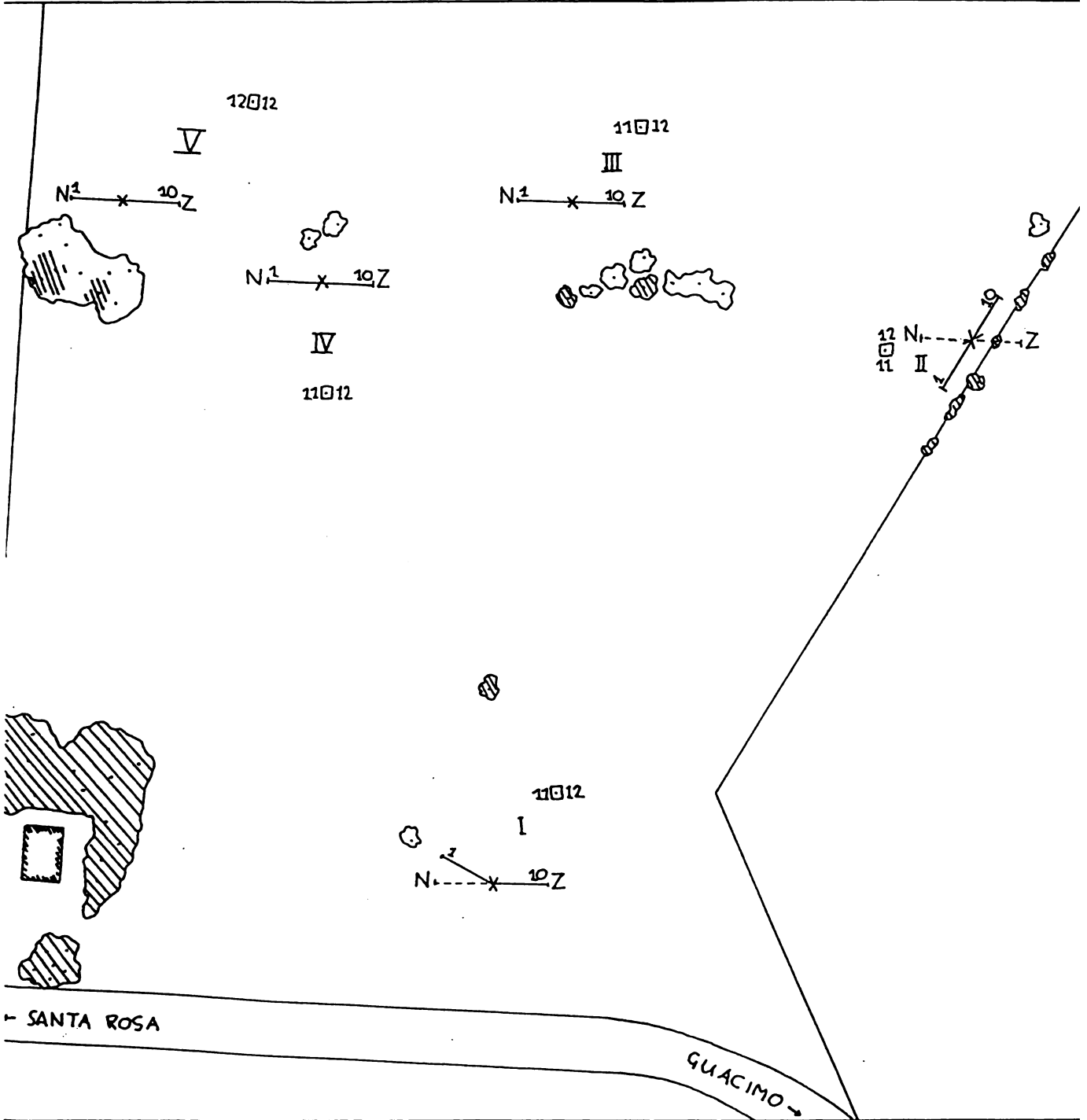


with, tree number : IV
 norht, south direction : N, S
 plot numbers : 1
 tree : x

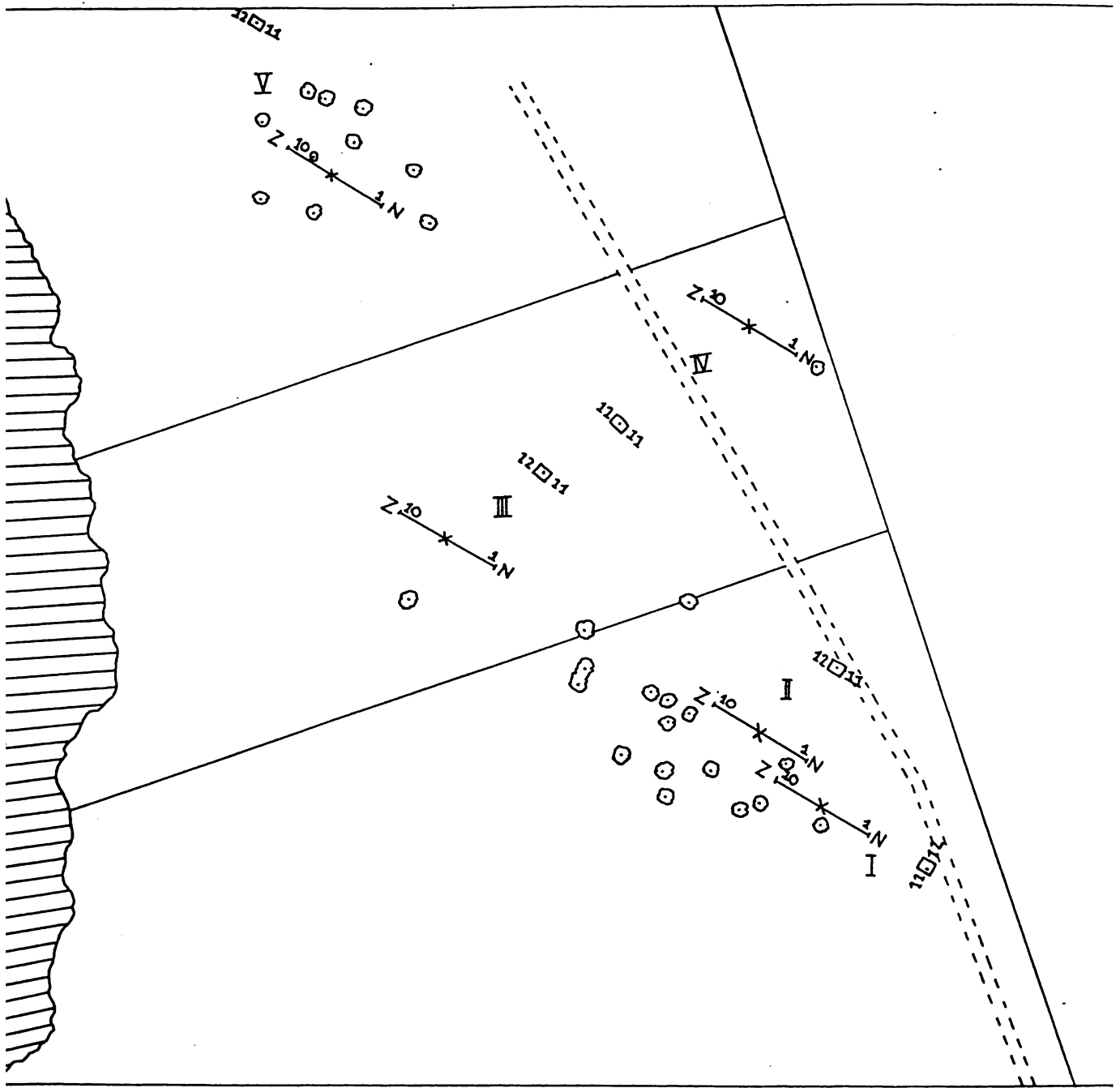
Reference plot with plot numbers :



Appendix 2a

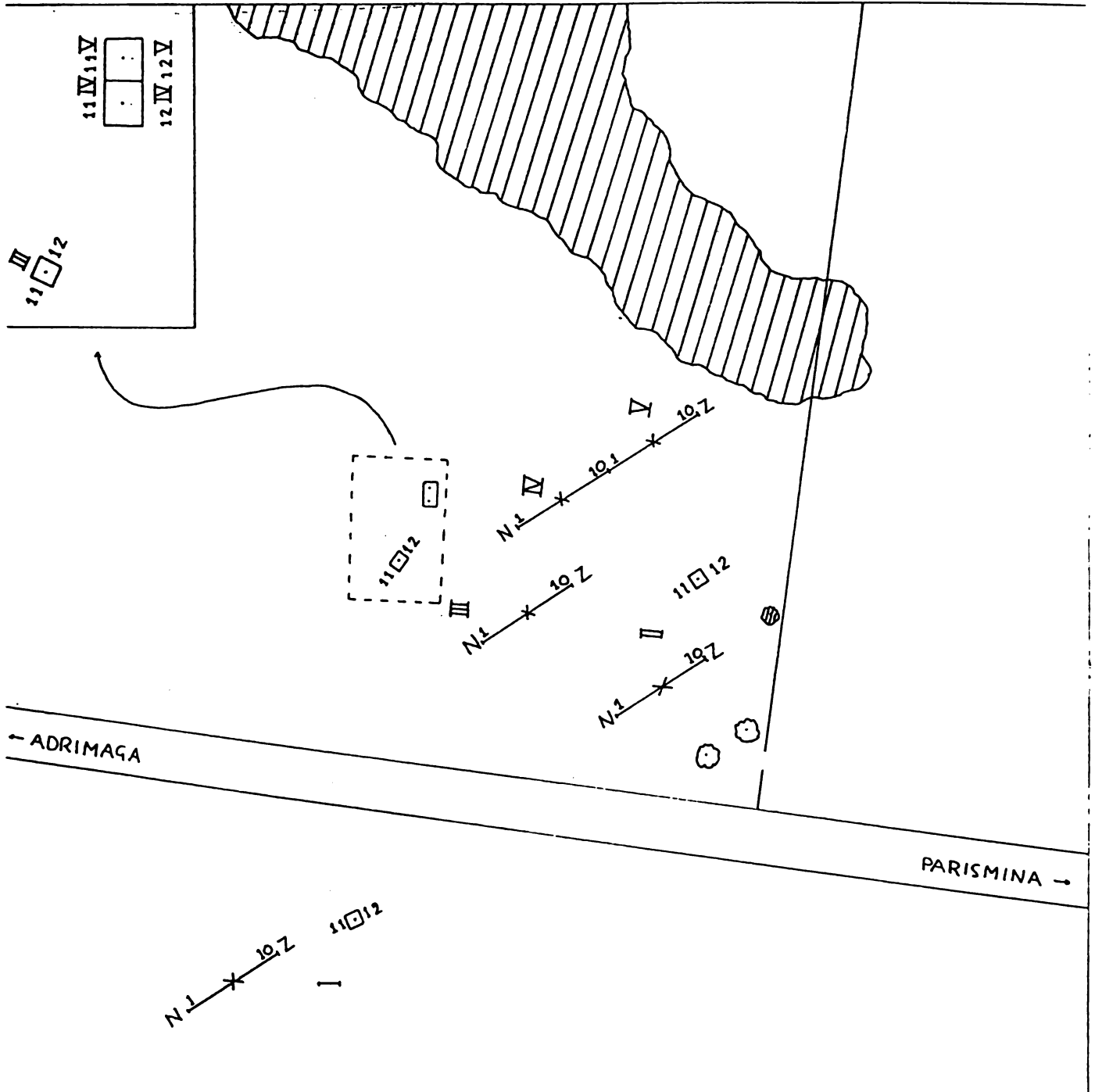


Santa Rosa: Ratana with Gavilán

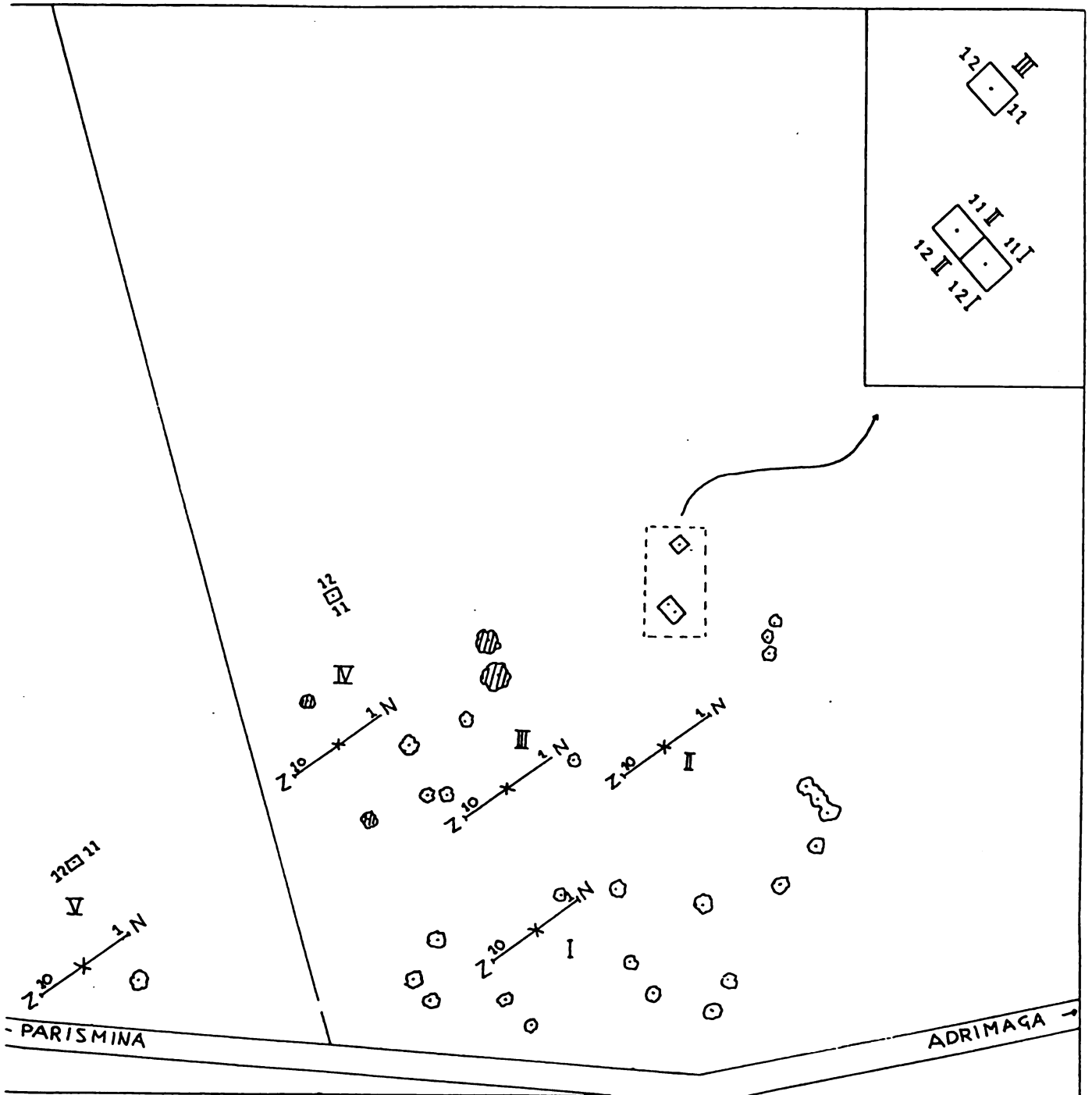


AFRICA →

Africa: Ratana with Laurel



Adrimaga: Pasto Natural with Gavilán



Adrimaga: Pasto Natural with Laurel

APPENDIX 3 DESCRIPTION GRASS SPECIES

ISCHAEMUM Linnaeus

Annual or perennial grasses; inflorescence of 2-many digitate racemes or rames borne at the apex of a terminal peduncle; individual rame or raceme composed of many internodes, each bearing 2 similar spikelets; disarticulation at the base of each internode, which falls with the 2 attached spikelets; one spikelet of each pair sessile or subsessile, the other pedicellate, the 2 similar, but the pedicellate one often somewhat smaller or reduced. First glume flattened, usually rigid and often cross-wrinkled below, thin and veiny above, its marginal flanges clasping the boat-shaped second glume of equal or slightly longer length; florets 2, concealed by the glumes; lower floret hyaline, awnless, with a staminate flower; upper floret shorter, the lemma hyaline, deeply bifid, the twisted awn arising at the juncture of the lobes; palea usually longer than the lemma. Pedicellate spikelet equal or smaller, often somewhat reduced and shorter-awned, in some species disarticulating from the pedicel.

The genus is unusual in the Andropogoneae in having a well-developed, staminate lower floret. About 50 species, almost all native to the Old World, a few of these occurring as weeds in the American tropics. (Panicoideae: Andropogoneae.)

KEY TO SPECIES OF *Ischaemum*

- 1a. Rames 2, closely appressed to each other, appearing as a single cylindrical spike; lower part of first glume of sessile spikelet strongly transversely corrugated
I. rugosum
- 1b. Racemes 2-many, spreading apart; first glume of subsessile spikelet stiff but smooth, not corrugated 2
- 2a. Racemes 3-many; nodes and leaf blades glabrous; blades 10-33 mm. wide
I. latifolium
- 2b. Racemes 2; nodes upwardly bearded; blades pubescent, less than 10 mm. wide *I. indicum*

Ischaemum indicum (Houtt.) Merrill, J. Arnold Arbor. 19:320. 1938. *Phleum indicum* Houtt., Nat. Hist. II: 13:198. t. 90, f. 2. 1782. *Ischaemum ciliare* Retz., Obs. Bot. 6:36. 1791. FIGURE 102

Duration indefinite; plants sprawling, the lower parts of the culms long decumbent and rooting at the lower nodes; upper portions of culms ascending, branching freely; prophylla 2.5-6 cm. long; internodes ca. 1 mm. thick, hollow, glabrous; nodes wide, dark, upwardly bearded; sheaths keeled, papillose-pilose on the margin and on the surfaces, especially toward the apex; ligule a thin, brownish membrane, 0.5-1.0 mm. long; leaf blades flat, 4-9 cm. long, 4-8 mm. wide, papillose-pilose on the surfaces, with a few stout hispid hairs at the base. Peduncles slender, glabrous, exserted 5-15 cm.; inflorescence a conjugate pair of diverging racemes, 6-8 cm. long. Spikelets paired at each node of the disarticulating rachis, one subsessile, on a pedicel ca. 0.5 mm. long, the other on a pedicel ca. 3 mm. long; rachis internode and pedicel similar, triangular in cross section, stiffly ciliate on the external angles. Disarticulation at the base of the internodes, the spikelet pair falling together with the internode. Subsessile spikelet biconvex, ovate 3:1, tapering to a short, narrow base; first glume ca. 4 mm. long, its basal third stiff, yellow, smooth, very broad, its marginal flanges covering the base of the second glume; upper two-thirds of the first glume thin, with many green nerves, most of them paired; apex bidentate; surface with numerous stiff spreading hairs; second glume longer than the first, bulging near the base, slightly winged near the tip, 5-nerved, tapering into a short straight awn; lower lemma ovate, acute, hyaline, ca. 3.5 mm. long, with a similar palea of about equal length; lodicules 2, truncate; stamens 3, the anthers yellow, 1.6-2.2 mm. long; pistil absent; upper floret perfect-flowered; lemma thin, hyaline, apex bifid to the middle, the awn arising between the teeth; basal segment of awn brown, tightly twisted, 3-4 mm. long; upper segment thin, only slightly twisted, purple, 6-7 mm. long; palea thin, hyaline, acute, longer than the lemma; lodicules 2, truncate; stamens 3, the anthers similar to those of the lower floret but longer; pistil with 2 separate naked style branches; stigmas purple. Pedicellate spikelet: Similar to the subsessile one, but usually smaller, the flower sometimes abortive. Chromosome number $n = 9$.

The only Costa Rican collection is the following: Puntarenas, Golfito; very common on sand along a stream, elevation 2 m., 11 December 1968, P. & D. 11571. Introduced from the Old World; reported from Panama and Guyana.



FIG. 103. *Ischaemum* species. *I. latifolium*: A, inflorescence; *I. indicum*: B, portion of a raceme; *I. rugosum*: C, spikelet pair and rachis internode.

Ischaemum latifolium (Spreng.) Kunth, Rév. Gram. 1:168. 1829.
Andropogon latifolius Spreng., Syst. Veg. 1:286. 1825. Figure 103.

Perennial; plants sprawling or erect, the culms 45-150 cm. long, sometimes rooting at the decumbent lower nodes, freely branching; internodes solid, pithy, glabrous; nodes wide, glabrous; sheaths glabrous except for the bearded collar, keeled toward the apex; ligule a brown membrane, 0.5-2.0 mm. long, tipped with cilia 0.5-2.0 mm. long; leaf blades flat, broad, 6-10 × longer than wide, 6-24 cm. long, 10-33 mm. wide, narrowed abruptly to the base, bearded on the collar and lower side at the base, otherwise glabrous. Peduncle slender, glabrous, exerted 3-10 cm.; uppermost leaf blade reduced; peduncle forking once or twice at the tip, the branches bearing a fan-shaped cluster of 5-17 racemes, each 6-12 cm. long. Spikelets paired, one sessile, its pedicel ca. 0.3 mm. long, the other on a pedicel ca. 3 mm. long; rachis internodes and pedicels bearded on the angles and at the tip; disarticulation at the base of the internodes, the spikelet pair falling; sometimes the pedicellate spikelet disarticulates from its pedicel. Sessile spikelet: 4.5-7.0 mm. long; first glume narrowly ovate, 4.5:1, acute, flat to convex on the back; margins slightly keeled and ciliate near the bifid tip; basal portion firm, smooth; upper portion herbaceous, 5-7-nerved, some of the nerves forking; second glume convex,

awn-tipped, slightly longer than the first; lower lemma nearly as long as the first glume, 4.0-5.5 mm. long, hyaline, acute, ciliate above, its palea slightly shorter; lodicules 2, truncate; anthers 3; upper floret with a hyaline, bifid lemma 3.5-4.0 mm. long, bearing an awn 5.0-9.5 mm. long from the sinus; palea about as long as the lemma; lodicules 2, truncate; anthers 3, yellow, 2.1-2.3 mm. long; caryopsis 1.5 mm. long, clear amber, with a large embryo. Pedicellate spikelet: Similar to the sessile one, but becoming laterally compressed by the folding of the first glume along one keel, the other scarcely developed; florets similar to those of the sessile spikelet, but somewhat reduced and the fertile lemma shorter-awned.

Brushy roadside, Canton de Dota, 1,400-1,800 m.; Buenos Aires; stream banks, northern Guanacaste. September to February. Mexico to Ecuador and Brazil. Chromosome number $n = 18$ from a Costa Rican specimen (*P. & D. 11067*) that is smaller and has narrower blades than most specimens of this species.

Ischaemum rugosum Salisb., *Icon. Stirp. Rar.* 1, pl. 1. 1791. Figure 103.

Caespitose annual; culms 55-130 cm. tall, erect or the bases decumbent and rooting; branching freely from most nodes; prophylla prominent, 4-8 cm. long, with several accessory nerves on each lateral flange; culms 2-3 mm. thick, hollow, glabrous; nodes wide, dark, bearded at the lower margin with a circle of appressed, ascending, silky, white hairs; sheaths shorter than the internodes, glabrous except on the margin below the apex, slightly keeled above; ligule a thin brown membrane, 2.0-5.5 mm. long, adnate to the erect sheath auricles; leaf blades flat, 8-20 cm. long, 7-15 mm. wide, softly papillose-pilose on both surfaces; base of blade usually contracted into a short, woolly pseudopetiole. Peduncle glabrous, erect, exerted 3-11 cm.; inflorescences several, borne on the culm apex and from the upper leaf axils, consisting of a pair of conjugate rames, closely appressed to each other and appearing as single cylindrical spike ca. 5 mm. in diameter, 3-10 cm. long, the 2 rames at maturity somewhat spreading apart near the apex. Spikelets paired, one sessile and one pedicellate at each node; rachis internodes thick, 2.5-3.5 mm. long, triangular in cross section, the external faces yellowish, rigid, the inner side hyaline, thin, the interior hollow; external angle of the surface with a line of stiff appressed hairs; base of the internode and callus of the sessile spikelet bearded with short ascending hairs; pedicel similar to the rachis internode, usually shorter, 1.5-2.5 mm. long; rames disarticulating freely at the base of each internode, the rachis internode, pedicel, and the 2 spikelets falling as a unit. Sessile spikelet: First glume 3.3-5.0 mm. long, ovate, acute, 2.5:1, slightly convex, the lower three-fifths rigid, yellowish, very strongly transversely corrugated, the upper two-fifths flat, herbaceous, longitudinally striate with many fine green nerves; margins of the glume bearing 2 inflexed flanges that clasp the margins of the second glume; second glume keeled, boat-shaped, slightly longer than the first, acute; lower lemma thin, ovate, acute, faintly nerved, awnless, its palea a hyaline nerveless scale, shorter than the lemma; stamens 3, the anthers 1.5-1.8 mm. long, pink; pistil rarely present; upper floret perfect-flowered or pistillate, its lemma hyaline, 3-4 mm. long, bifid to the middle, the awn attached on the outer side at the junction of the acuminate teeth; awn 1.5-2.0 cm. long, bent, the basal half brown, strongly twisted, the upper segment thin, white, loosely twisted; palea hyaline, nerveless, shorter than the lemma. Pedicellate spikelet: Similar to the sessile spikelet but smaller, the first glume asymmetric, ovate 2:1, the lower half yellow, rigid, sometimes slightly undulate, the upper portion green, herbaceous, finely striate; flower usually staminate. Chromosome number $n = 9$ from Costa Rican specimens. A base number of $x = 10$ is also reported for this genus.

Occasional but locally abundant; *Curatella-Byrsonima* savannas in northern Guanacaste, in road ditches, pastures, sometimes in shallow water; sea level to 600 m. elevation; also collected at Los Angeles (Río Peñas Blancas), Chomes, and Turrialba. This Old World species is apparently a recent introduction in Costa Rica, the earliest collection dating to 1960. Panama, Venezuela, Trinidad, Cuba, and Jamaica.

HOMOLEPIS Chase

Stoloniferous grasses; inflorescence a terminal panicle. Disarticulation below the glumes; spikelets lanceolate, acuminate, dorsally compressed; glumes concealing the florets, subequal or the first somewhat longer than the second, its margins covering the edges of the second; first glume 7-9-nerved, ovate; second glume 7-nerved; sterile lemma 7-nerved, strongly ciliate between the marginal nerves, its palea small, membranaceous; fertile floret chartaceous, acuminate, the lemma obscurely nerved, glabrous and shining, with thin exposed margins overlapping the margins of a palea of similar length and texture. (Panicoideae: Paniceae.)

Homolepis aturensis (H.B.K.) Chase, Proc. Biol. Soc. Wash. 24:146. 1911. *Panicum aturense* H.B.K., Nov. Gen. & Sp. 1:103. 1816. Figure 93. **Arrocillo**

Duration indefinite; plants extensively stoloniferous; erect or ascending floriferous branches 20-50 cm. long arising from the stolons; culms glabrous, hollow, 1-2 mm. thick; nodes glabrous; sheaths usually shorter than the internodes, glabrous or pilose, silky-ciliate on the margins, keeled; ligule a minutely ciliate membrane, 0.4-0.7 mm. long; a puberulent line across the collar; blades cordate above a brief pseudopetiole, flat, 4-12 cm. long, 7-20 mm. wide, glabrous to pilose or velutinous on the surfaces; peduncle included or exerted up to 12 cm.; uppermost leaf blade much reduced; panicles terminal on the culms or on leafy branches, narrowly elliptical, 6-9 cm. long, 2-5 × longer than wide; spikelets on slender pedicels, rather crowded, 7.0-7.7 mm. long; first glume 7-9-nerved, ovate, the margins overlapping the edges of the second; second glume 6.4-6.8 mm. long, 7-nerved, the margins ciliate near the base; sterile lemma 7-nerved, 5.2-6.8 mm. long, 7-nerved, strongly silky-ciliate between the marginal pairs of nerves; fertile lemma 4.8-6.0 mm. long, lanceolate, the nerves faint, its palea similar; anthers 3, purple, 1.3-1.6 mm. long. Chromosome number $n = 10$ from Costa Rican material.

Moist pastures, shaded roadsides, sea beaches, from sea level to 1,200 m. elevation, on both Caribbean and Pacific slopes. June to March. Southern Mexico to Bolivia and Brazil.

PANICUM Linnaeus

REFERENCES: S. T. Blake, New criteria for distinguishing genera allied to *Panicum* (Gramineae), Proc. Roy. Soc. Queensland 70:15-19. 1958. Agnes Chase, Notes on genera of Paniceae-IV, Proc. Biol. Soc. Wash. 24:103-160. 1911. R. W. Freckmann, Taxonomic studies in *Panicum* subgenus *Dichanthelium*, Unpubl. Ph.D. Diss., I.S.U. Library. 175 pp. 1967. F. W. Gould, Nomenclatural changes in the Poaceae, Brittonia 26:59-60. 1974. A. S. Hitchcock & Agnes Chase, The North American species of *Panicum*, Contr. U.S. Natl. Herb. 15:1-396. 1910; and Tropical North American species of *Panicum*, Contr. U.S. Natl. Herb. 17:459-539 + XII. 1915. Chien-Chang Hsu, The classification of *Panicum* (Gramineae) and its allies with special reference to the characters of lodicule, style-base and lemma, J. Fac. Sci. Univ. Tokyo, Sect. 3, Bot. 9:3:43-150. 1965. M. G. LeLong, Studies of reproduction and variation in some *Panicum* subgenus *Dichanthelium*, Unpubl. Ph.D. Diss., I.S.U. Library. 228 pp. 1965. L. R. Parodi, Estudios sistemáticos sobre las Gramineae-Paniceae argentinas y uruguayas, Darwiniana 15:65-111. 1969.

Plants annual or perennial, caespitose, rhizomatous, or decumbent and rooting at the base; inflorescence an open or contracted panicle, sometimes with rather simple branches and the spikelets unilaterally disposed along them. Disarticulation below the spikelets. Spikelets more or less flattened on the first glume side and convex on the second glume side, sometimes biconvex or even somewhat laterally compressed; first glume usually much reduced, rarely as much as three-fourths as long as the spikelet, mostly 1-3-nerved, membranaceous; second glume and lower (sterile) lemma subequal, ca. as long as the spikelet, membranaceous, 3-11-nerved; sterile lemma often containing an abortive or well-developed palea, and rarely a staminate flower; upper (fertile) floret stiff or rigid, awnless, the lemma usually smooth and shining, its margins inrolled over the edges of a flat or somewhat convex palea of similar length and texture; lodicules 2, truncate; anthers usually 3; ovary with 2 separate style branches, these naked near the base; stigmas plumose; caryopsis elliptical or obovate, dorsally flattened, with a large embryo.

Panicum is an enormous genus, primarily distributed in warm climates of both eastern and western hemispheres. Early authors used the name in a very inclusive sense, involving most of the species of the subfamily, but a general tendency has been to remove groups of species as segregate genera. Related or segregate genera in our flora include *Brachiaria*, *Digitaria*, *Echinochloa*, *Homolepis*, *Hymenachne*, *Ichnanthus*, *Isachne*, *Lasiacis*, *Leptocoryphium*, *Oplismenus*, *Paspalum*, *Pseudechinolaena*. The genus *Panicum* is generally recognized by the spikelets, which are borne in panicles and are awnless, dorsally compressed, and with a short first glume and subequal second glume and sterile lemma that conceal the rigid floret. A recent proposal has been made by Goudot to remove the subgenus *Dichanthelium* as a genus; however, these plants lose their distinctiveness in the tropics, and I have continued to include them in *Panicum*. (Panicoideae: Paniceae.)

KEY TO SPECIES OF *Panicum*

- 1a. Spikelets more than 3 mm. long 2
 1b. Spikelets less than 3 mm. long 11
 2a. Fertile lemma rugose *P. maximum*
 2b. Fertile lemma smooth 3
 3a. Spikelets (at least those in axillary inflorescences) pubescent 4
 3b. Spikelets all glabrous (see also *P. cordovense*) 5
 4a. Sheaths, blades, and internodes densely papillose-hispid; spikelets acuminate, all pubescent *P. rudgei*
 4b. Sheaths, blades, and internodes sparsely pubescent; spikelets blunt, only those in axillary inflorescences pubescent *P. cordovense*
 5a. Leaf sheaths and blades densely papillose-pubescent 6
 5b. Leaf sheaths and blades glabrous or only slightly pubescent on collar and edges 7
 6a. Spikelets 3.5 mm. or less long, usually reddish toward base *P. ghiesbreghtii*
 6b. Spikelets 4.5-5 mm. long, stramineous or marked with purple . *P. parvum*
 7a. Spikelets glutinous, often with adhering particles *P. glutinosum*
 7b. Spikelets not glutinous 8
 8a. Plants with slender rhizomes; panicles 10-15 cm. long; lower floret staminate *P. aquaticum*
 8b. Plants not rhizomatous (submerged nodes sometimes rooting); panicles large, 35 cm. or more long 9
 9a. Panicle branches simple, conspicuously whorled; spikelets blunt; sterile lemma inflated by large palea *P. mertensii*
 9b. Panicle branches rebranched, not conspicuously whorled; spikelets acute or acuminate 10
 10a. Leaf blades elliptical, glabrous, 50 cm. or more long, up to 6 cm. wide; first glume more than half as long as spikelet *P. grande*
 10b. Leaf blades linear, less than 2 cm. wide; first glume very short; dewlaps deep purple *P. elephantipes*
 11a. Glumes and sterile lemma pubescent 1
 11b. Glumes and sterile lemma glabrous 2
 12a. Leaf blades ovate, less than 4.5 × longer than wide 1
 12b. Leaf blades narrowly ovate to linear, at least 5 × longer than wide 1
 13a. Panicle very diffuse, spikelets diverging on slender pedicels; spikelets 1.3 mm. or less long, without glands on sterile lemma *P. trichoides*
 13b. Panicle slender, of up to 15 short, drooping, 1-sided spikeletlike racemes; spikelet-subessile along their lower sides, at least 1.8 mm. long, usually bearing 2 circular eyelike glands on sterile lemma *P. pulchellum*
 14a. First glume at least half as long as spikelet 1
 14b. First glume one-third to one-fourth as long as spikelet 1
 15a. Fertile lemma rugose, becoming brown when mature *P. sellowii*

Panicum laxum Swartz, Prodr. Veg. Ind. Occ. 23. 1788. Figure 136.

Duration indefinite, probably perennial; culms 15-90 cm. long, rarely up to 120 cm., the bases often decumbent and rooting at the nodes, branching from the rooted portion or the middle nodes of erect culms; internodes 1.0-1.5 mm. thick, hollow, glabrous; nodes glabrous or rarely retrorsely pilose; prophylla ca. 2 cm. long, ciliate on the keels; leaf sheaths shorter than the internodes, the overlapping margin ciliate; surface glabrous or papillose-pilose toward the apex; ligule a thin ciliate membrane, 0.3-0.6 mm. long; leaf blades flat, 6-15 (23) cm. long, 4-12 mm. wide, rather thin, rapidly folding or rolling when the plants are uprooted; dewlap sometimes pilose; upper surface sometimes pilose above the ligule. Inflorescences terminal on leafy culms; panicles usually 5-15 (33) cm. long, open, cylindrical or ellipsoidal, with numerous straight primary branches, densely covered to their bases with spikelets; spikelets short-pedicellate, borne on the lower sides of the triquetrous rachis, in pairs or small groups; larger panicles sometimes with evident secondary branches. Spikelets 1.4-1.8 mm. long, ovoid ca. 2:1, rather blunt, biconvex in lateral view, distended by the enlarged palea of the sterile lemma and often gaping almost to the base; first glume broadly ovate, acute, 3-nerved, 0.7-1.0 mm. long; second glume 1.3-1.8 mm. long, 5-nerved; lower (sterile) lemma similar but 3-nerved, 1.2-1.7 mm. long, with a membranaceous palea 1.3-1.6 mm. long; upper (fertile) floret ovate, 1.2-1.4 mm. long, stramineous; lodicules 2, truncate; anthers 3, yellow or spotted with purple, 0.8 mm. long; styles 2, separate; caryopsis 0.8 mm. long, elliptical, tan. Chromosome number $n = 20$ from numerous Costa Rican specimens.

Common in wet open or partially shaded sites; widespread from sea level to 1,200 m. elevation, rarely higher. Blooming April to October, occasionally during the rest of the year. Southern Mexico to Paraguay; West Indies.

Panicum laxum is a member of the intricate Laxa group. The species of this assemblage are poorly defined and much in need of careful biosystematic study. *Panicum boliviense* may be only a large form of *P. laxum*. *Panicum polygonatum* is also closely related, but has more pointed spikelets lacking a palea in the sterile lemma.

PASPALUM Linnaeus

REFERENCES: D. J. Banks, Taxonomy of *Paspalum setaceum* (Gramineae). Sida 2:269-284. 1966. Agnes Chase, The North American species of *Paspalum*. Contr. U.S. Natl. Herb. 28:1-310 + XVII. 1929.

Caespitose, rhizomatous, or stoloniferous annual and perennial grasses of extremely diverse size and habit. Inflorescence of 1 or more one-sided racemes, the spikelets short-pedicellate, borne in rows on the lower side of the rachis; spikelets mostly paired, the pairs alternating on opposite sides of the midrib, and the racemes hence 4-rowed, or solitary by absence or abortion of one member of each pair, and the racemes hence 2-rowed. Intermediate conditions also occur, resulting in racemes in part 3-rowed. Rachis triquetrous, or flattened and sometimes winged, the midrib often prominent. Spikelets oriented with the first glume away from the midrib of the rachis and the second glume and the upper (fertile) lemma toward it. Spikelets more or less plano-convex, ovate, elliptical, or obovate in outline, blunt or acute; first glume present on some or all of the spikelets in some species, but absent in most; second glume and lower (sterile) lemma membranaceous, usually equal and as long as the spikelet, covering and concealing the upper (fertile) floret; second glume covering all or most of the convex back of the fertile lemma, entirely absent in a few species; sterile lemma flat, covering the palea of the fertile floret, occasionally with a rudimentary or well-developed membranaceous palea and rarely with a staminate flower; fertile floret usually nearly as long as the spikelet; lemma stiff or rigid, its margins thick and more or less inrolled over the edges of a palea of equal length and similar texture; lodicules 2, truncate; anthers usually 3; styles 2, separate, naked below; stigmas plumose; caryopsis elliptical or obovate, strongly dorsally flattened. The basic chromosome number in the genus is $x = 10$.

Paspalum is a very large genus of grasses of warm climates, its center of diversity being in the American tropics. Relatively few species occur in the temperate zone. Estimates of the number of species range from 200 to 400. The ecological diversity of the genus is extreme. Some species are xeromorphic plants of dry savannas, while others occur in fresh water and salt marshes or as floating aquatics. The Central American species are all confined to low and moderate elevations, rarely above 2,000 m. Some species, as *P. notatum* and *P. dilatatum*, have forage value or are used for erosion control. *Paspalum conjugatum* is a common weed and is regarded as a poor forage species. *Paspalum paniculatum*, *P. candidum*, and *P. plicatulum* are also common and weedy. The genus is related to *Panicum*, differing in its racemose rather than paniculate inflorescences. It is also similar to *Paspalidium* and *Urochloa*, which differ in having transversely corrugated fertile lemmas, and to *Axonopus* and *Brachiaria*, which have the back of the fertile lemma turned away from the midrib of the rachis. Polyploidy and meiotic irregularities occur frequently. (Panicoideae: Paniceae.)

Paspalum conjugatum Bergius, Acta Helv. Phys.-Math. 7:129. 1762. Figure 150.

Strongly stoloniferous perennial; flowering culms arising from the rooted stolons, 20-100 cm. long, simple or branching from the lower nodes; internodes 1-3 mm. thick; glabrous, shrunken in drying; nodes mostly glabrous or rarely appressed-bearded; leaf sheaths more or less compressed, usually glabrous except for the finely ciliate overlapping margin; sometimes both margins hyaline and glabrous; ligule a hyaline membrane, 0.3-1.5 mm. long; leaf blades 7-20 cm. long, 7-14 mm. wide, the upper surface sparsely to densely pilose; collar minutely bearded; blades of stolons ovate, blunt, 2-4 cm. long, 5-8 mm. wide. Peduncles terminal on leafy culms, included or exerted up to 7 cm.; inflorescence of 2 conjugate slender divergent or reflexed racemes, rarely a third raceme borne below them on vigorous plants; individual racemes 6-16 cm. long; spikelets solitary, in 2 rows, closely placed; rachis 0.7-0.9 mm. wide, the tip often bearing several minute abortive spikelets; pedicels 0.3-0.4 mm. long. Spikelets strongly flattened, 1.3-1.9 mm. long, elliptic-ovate 1.2-1.4:1, scarcely pointed; first glume absent; second glume and lower (sterile) lemma equal, as long as the spikelet, hyaline, both with 2 marginal nerves, lacking midribs; second glume finely ciliate with hairs up to 1 mm. long; lower lemma similar but not ciliate; upper (fertile) floret ca. as long as the spikelet, whitish, firm but not rigid, the lemma slightly convex, the palea flat; anthers 3, yellow, sometimes purple-spotted, ca. 0.6 mm. long; styles 2, separate; stigmas dark; caryopsis 1.0-1.1 mm. long, elliptical 1.3:1, tan, the persistent styles reflexed along the sides of the caryopsis. Chromosome number $2n = 40$ from Costa Rican specimens.

A common weed in moist pastures, road ditches, marshes, beaches, cafetales, etc. On both Pacific and Caribbean slopes, from sea level to 1,200 m. elevation. Blooming yearlong. Southern United States to Argentina; naturalized in the tropics of the Old World.

This species is weedy and aggressive in wet pastures. It is almost universally regarded with disfavor and said to be rejected by livestock and to increase under grazing conditions. Common name *Turruud* or *Turbará*. Our slides showed no pairing in meiosis, and it may be that the species, which is highly uniform in aspect, is completely apomictic. Several minor variants have been described, but my measurements show complete intergradation in spikelet and leaf blade size. Such variation as occurs appears to be related to fertility and moisture supply.

Some authors have ascribed the name of this species to Swartz, on the basis that the original publication by Bergius was a phrase name. However, Bergius gives the name as "PASPALUM (conjugatum) spicis conjugatis." His usage differs from that of Linnaeus, who placed the "trivial" name in the page margin, whereas Bergius placed it after the generic name but in parentheses. His intent seems clear, and there is no reason to reject his authorship. The identity of the plate accompanying the description is conclusive.



150. *Paspalum conjugatum*. Blooming plant with a stolon, two views of a spikelet, fertile floret.

APPENDIX 4 DESCRIPTION TREE SPECIES

Pentaclethra macroloba

Family: Mimosaceae (Leguminosae).

Name: *Pentaclethra macroloba* (Willd.) Kuntze.

Local names: Gavilán, Quebracho.

Description:

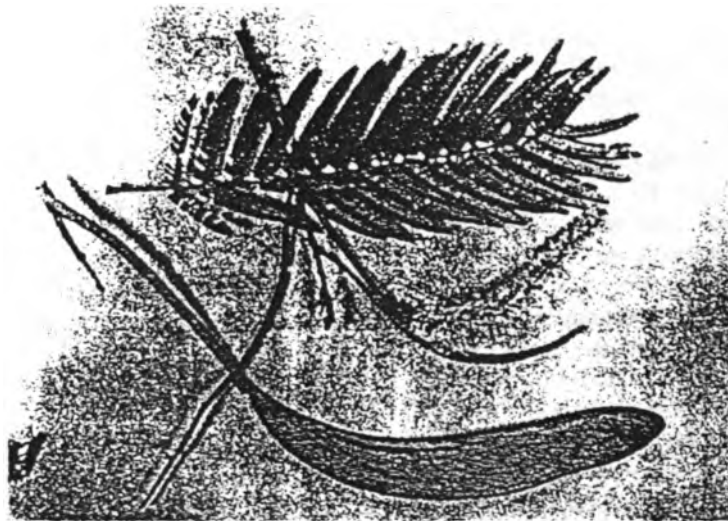
An abundant tree in the forests of the 'tierra caliente' from Nicaragua to the Guayanas (Standley, 1983). It is the dominant tree of the lowland Atlantic tropical rain forest of Costa Rica. It is reported to tolerate stagnating water fairly well (Hartshorn, 1972). It is a tall tree up to 40 m. height, with bipinnate leaves and numerous leaflets and a wide spreading crown. Its flowers are small in racemose spikes. The legume (pod) is woody and elastically dehiscent, 20-30 cm. long and 3-4 cm. wide. The seeds are big and probably bachochorous.

The seeds and pods contain nitrogenous toxins, so seed predation is unlikely to occur (see also Hartshorn, 1972). Additionally, Hartshorn suggested that ants, attracted by the nectaries, may protect the new shoots and leaves from herbivorous insects.

According to the ecological classification used by GSBN, *P. macroloba* belongs to the group of 'esciofitas parciales' (partial shade bearers). It was indicated as late-successional (Richards, 1952; Hartshorn, 1972).

After Hoogveld, 1990.

**BIPINNADAS – ALTERNAS – SIN ESPINAS
HOJUELAS ANGOSTAS, MENOS DE 5 MM
PINNAS DOS O MAS PARES**



Mimosaceae

“Gavilán”, “Quebracho”

PENTACLETHRA MACROLOBA (Willd.) Ktze.

- Arbol:** Grande.
- Hojas:** Generalmente con 15 a 20 pares de pinnas y muchos pares de hojuelas, de 1 a 2 mm de ancho y hasta 10 mm de largo, tocándose a todo lo largo de la pinna.
- Flores:** Blancas, en espigas largas.
- Frutos:** Unas legumbres linear-espatuladas, de 20 a 30 cm de largo y 3 cm de ancho, levantadas hacia arriba de la rama como en el género *Calliandra*.
- Hábitat:** En elevaciones bajas, con climas muy húmedos. Crece en lomas y también en ciénagas.
- Ambito:** Nativo desde Nicaragua hasta Brasil.
- Nota:** Las vainas se abren elásticamente y tiran las semillas varios metros. Las hojas se cierran de noche. Dicen que el árbol indica suelos pobres. La madera es dura, pesada y resistente, utilizada como madera de cuadro. En La Selva de Sarapiquí, Costa Rica, el 39 por ciento del volumen total de madera fue de esta especie.

CORDIA ALLIODORA (Ruiz-Lopez & Pav.) Oken
BORAGINACEAE

SYNONYMS:

Cordia gerecanthus (Jacq.); *Cerdana alliodora* (Ruiz & Pav.).

COMMON NAMES:

Salmwood (En.); faux bois de rose (Fr.); pardillo, laurel, laurel negro, laurel blanco (Sp.); louro, louro amarello, uruazeiro (Brazil); capa, capa prieto (Dom. Republic, Puerto Rico); hormiguero, bojon (Mexico); cyp, cypre (Trinidad); (Dominika-) Rosenholz (German).

NATURAL OCCURRENCE:

Central Mexico to Argentina, fairly common in Central America, the West Indies, Venezuela and Ecuador.

Latitudes: 25 °N -25 °S

Altitudes: 0-1900 (close to the equator) m.

INTRODUCED:

W. Africa (Nigeria, Sierra Leone); Uganda; Mauritius.

VEGETATION TYPE:

Cordia alliodora is a pioneer species of evergreen and seasonal rainforest. Especially in secondary rainforests. In Ecuador in pure stands on abandoned lands. Otherwise in pure groups or in companion of *Cedrela odorata*, *Swietenia macrophylla* and *Bombacopsis quinata*.

HABIT:

30-40 m high deciduous-evergreen tree, with diameters from 60-100 cm. Straight stem, cylindrical, clear for close to half of the total height. On superficial

soils may develop small buttresses, of up to 2 m (when adult). The bark is yellow-brown to dark brown and fissured. The inner bark is light brown, fibrous, and tasteless, but has a slight odor of garlic. The trunk is with whorled branches appearing in horizontal layers. The crown is relatively small and open, becoming leafless during the dry season. The twigs are green and with star-shaped hairs when young, becoming brown. The tips of the twigs develop swellings that house ants (nearly absent in West Indies and S. America).

The alternate leaves are oblong to lanceolate, 4-8 by 10-20 cm, pubescent to almost glabrous above and stellate-tomentose beneath. The leaves are slightly shiny yellowish-green, thin, the lower surface paler and more or less finely hairy with minute star-shaped hairs, with odor of garlic when crushed. The petiole is 1-3 cm long.

The strong smelling flowers occur in large showy terminal panicles, are white coloured, and well visible as the tree flowers before turning out new foliage. The flowering is in the dry season when the tree is leafless. The flowers are fragrant, about 1-1.5 cm long and broad. The fruit is 3-5 mm long. Annual fruiting after 5-10 years.

Tree model: Fagerlind.

ECOLOGY:**Climate:**

Köppen: Af, Aw

Description: (sub)humid tropics
Rainfall regime: uniform
Mean annual rainfall: 2000-5000 mm
Min. annual rainfall: 1000 mm
Max. dry period: 0-4 (Costa Rica 6-7) months
Mean annual temperature: 20-27 °C
Mean max. hottest month: 26-32 °C
Mean min. coldest month: 16-25 °C
Remarks:

Soil:

Texture : medium; (heavy)
Soil types: wide range of soil types
Reaction : (neutral); alkaline
Drainage: well drained; seasonal water logging
Fertility: not on poor, degraded soil
thers : deep soils are preferred; no steep terrains

Light : Strongly light demanding

PRODUCTIVE USES:

Food : -
Fodder: leaves; seeds
Wood : fuelwood; charcoal; timber; furniture; veneer/plywood
Other : -
Remarks: The wood is good in appearance, easy to work, light, strong and fairly durable.

SERVICE USES:

Agricultural shade; mulching; N-fixation; ornamental; wind-break.

REPRODUCTION:

Coppicing; direct seeding (seldom successful as a result of weed competition); seedlings (potted or bare-rooted); natural regeneration.

NURSERY:

Seeds per kg: 20-30,000 (60-70,000?)
Storage : dry, cold, airtight

Viability : short-lived: best sown within 2 weeks after seed collection.

Pretreatment: none

Germination : 80% fresh seed; in 15-30 days.

Plantable size: in 9-10 months

Remarks :

ESTABLISHMENT:

Because of the fast growth and good natural pruning the espacement can be 3x3 m or more. In Costa Rica taungya systems the espacement is at least 3x3 m. The average of trees as shade trees over coffee is 220 trees/ha.

MANAGEMENT/TREE MANIPULATION:

Coppicing (requires wide spacing); self-pruning of the tree is excellent.

Rotation period: 25-35 years.

AF-SYSTEMS:

Agrisilvicultural systems: taungya (Costa Rica, CATIE), intercropping, shade trees;

Silvopastoral systems: intergrazing.

Remarks: Shade tree in coffee, tea and cacao plantations, may be in association with *Erythrina poeppigiana* (f.e. Costa Rica); intercropping with f.e. sugarcane (depresses sugar production but this is compensated by the value of timber).

GROWTH AND YIELD: fast growing

Increment in height: 4 m during the first 4 years, decreasing later with age.

Increment in diam. : 1.5-2.0 cm/yr during first 10 years.

Volume increment : 10-20 m³/ha/yr

PESTS AND DISEASES:

Pests: Serious insect damage reported the Spanish elm lacewing bug *Monanthia monotropidia*.

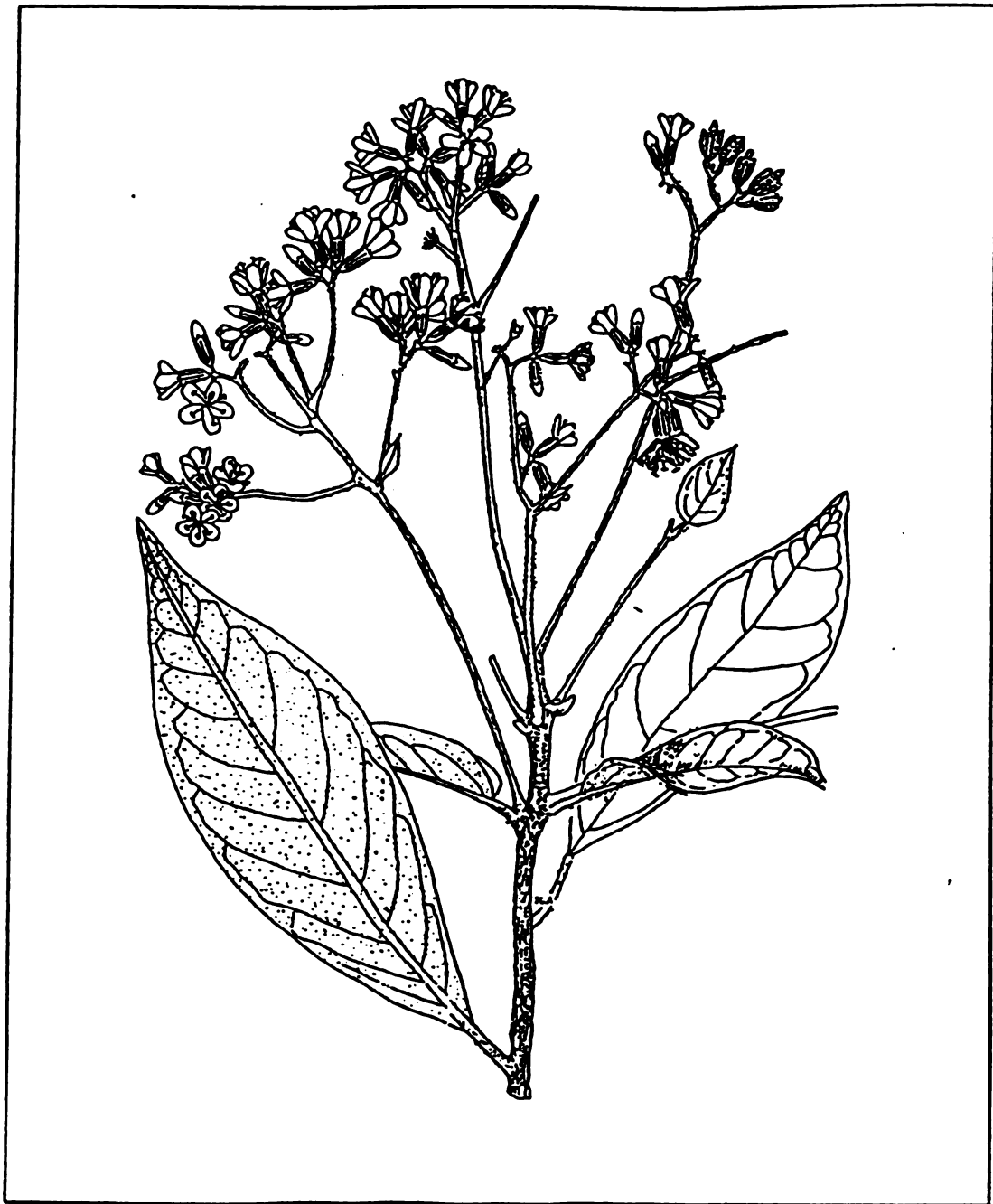


Figure 3 *CORDIA ALLIODORA* (from Little, 1964):
Shoot with leaves and flowers (x2/3).

In Columbian plantations the defoliator *Ramphidium pselaphialis* and the sucking insect *Dyctyla monotrophia* cause significant delays in tree growth.

Diseases: Susceptible to the canker-causing rust *Puccinia cordiae* (mainly less vigorous trees seem to be affected).

POTENTIAL PROBLEMS:

Insect susceptibility.

REMARKS:

When introduction of this species make allowance for provenances.

LITERATURE:

Beer, 1987a; Carlowitz, 1986; Lamprecht, 1986; Little, 1964; Maithani, 1987; Salas, de las, 1982; TFT, 1987; Webb, 1980.

Appendix 5

APPENDIX 5 CROWN PROJECTION

The crown projections in the trials given for the Gavilán and Laurel trees. The projection is measured in four directions from the trunk to the outside of the crown (m). Also the variance of between the measurements are given.

Site and species	Nr trees	North (m)		East (m)		South (m)		West (m)	
		Mean	σ	Mean	σ	Mean	σ	Mean	σ
Adrimaga-Gavilán	5	7.5	1.1	8.7	2.7	8.6	1.7	8.1	2.1
Santa Rosa-Gavilán	5	7.1	0.9	7.2	2.7	7.0	1.4	6.0	1.5
Average Gavilán	10	7.3	0.9	7.9	6.9	7.8	2.8	7.1	4.1
Adrimaga-Laurel	5	5.7	1.7	5.5	1.3	4.5	0.9	4.9	2.2
Africa-Laurel	5	4.9	1.2	6.1	2.6	6.0	1.0	6.9	1.6
Average Laurel	10	5.3	1.5	5.8	2.0	5.2	1.2	5.9	2.1

APPENDIX 6 GRASS PRODUCTION

The different grass productions per tree-site combination, expressed as a proportion of the values on the reference plots, in relation to the distance of the trunk of the trees. In the figures a-d the grass production is given for the whole transect. In the figures e-h the grass production of the north and south plots are combined.

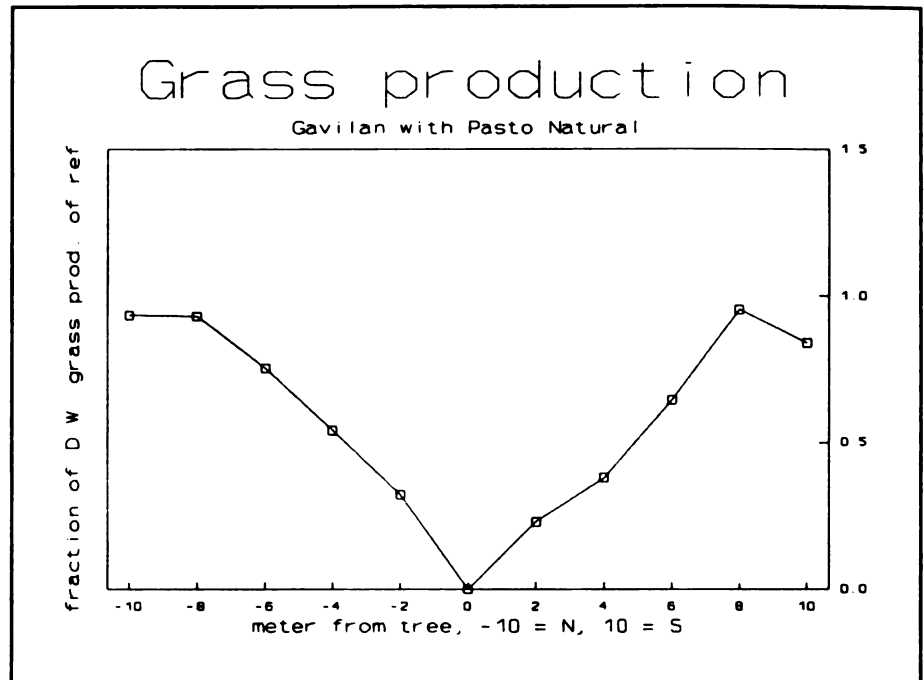


Figure a. Grass production, Pasto Natural under Gavilán.

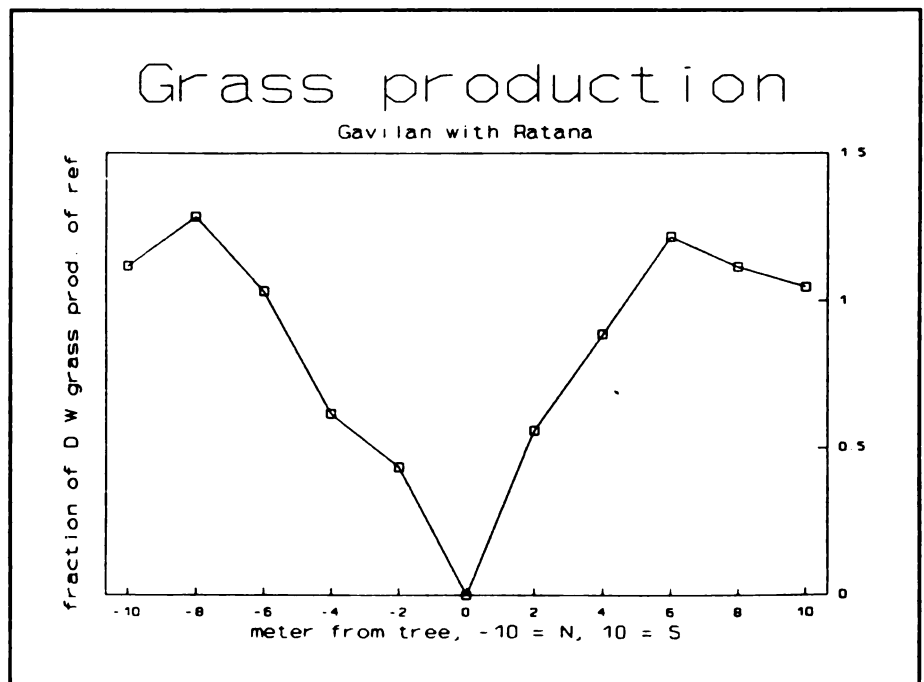


Figure b. Grass production, Ratana under Gavilán.

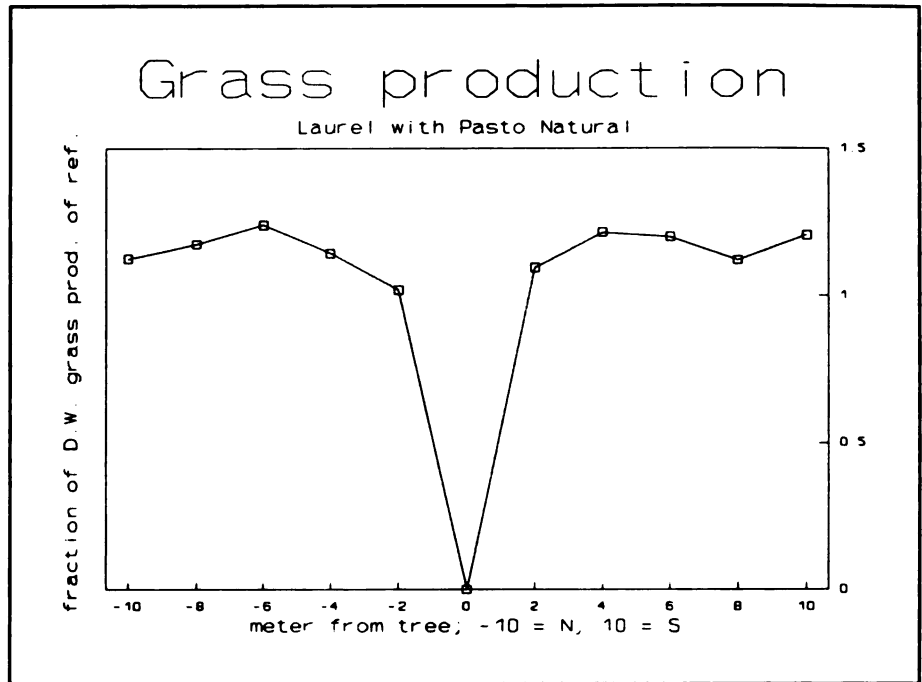


Figure c. Grass production, Pasto Natural under Laurel.



Figure d. Grass production, Ratana under Laurel.

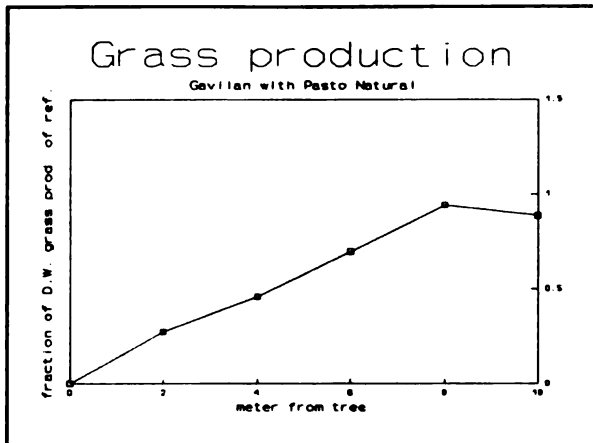


Figure e. Grass production, Pasto Natural under Gavilán, combined north-south results.

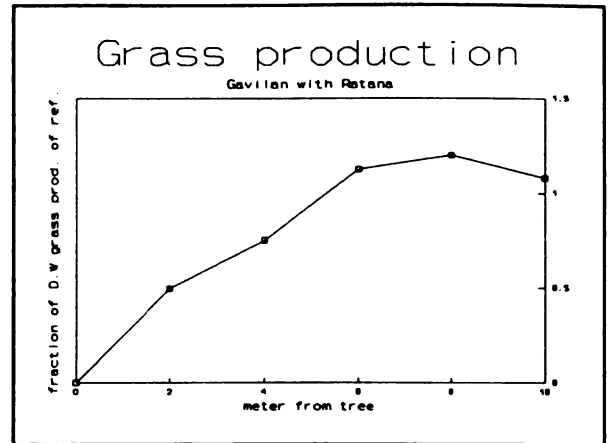


Figure f. Grass production, Ratana under Gavilán, combined north-south results.



Figure g. Grass production, Pasto Natural under Laurel, combined north-south results.



Figure h. Grass production, Ratana under Laurel, combined north-south results.

The grass production line from 0m. to 2m. and/or 0m. to -2m. is not the actually production line. The zero represents the trunk. At basal area of the trunk no grass production occurs.

Appendix 6

Table 1. Grass production, total transect, expressed as a proportion of the values on the reference plots in relation to the distance from the trunk.

Site and species	-10m.	-8m.	-6m.	-4m.	-2m.
Pasto Natural-Gavilán	0.93	0.93	0.75	0.54	0.32
Ratana-Gavilán	1.12	1.28	1.03	0.62	0.43
Pasto Natural-Laurel	1.12	1.18	1.24	1.14	1.02
Ratana-Laurel	1.02	1.09	1.01	0.96	1.09

C O N T I N U E D	0m.	2m.	4m.	6m.	8m.	10m.
	0.00	0.23	0.38	0.64	0.95	0.84
	0.00	0.56	0.89	1.22	1.11	1.05
	0.00	1.10	1.21	1.20	1.12	1.20
	0.00	0.87	1.04	0.99	1.01	1.06

Table 2. Grass production, combined north-south results, expressed as a proportion of the values on the reference plots in relation to the distance from the trunk.

Site and species	2m.	4m.	6m.	8m.	10m.
Pasto Natural-Gavilán	0.28	0.46	0.70	0.94	0.89
Ratana-Gavilán	0.50	0.75	1.12	1.20	1.08
Pasto Natural-Laurel	1.06	1.18	1.22	1.15	1.16
Ratana-Laurel	0.98	1.00	1.00	1.05	1.04

APPENDIX 7 GRASS COMPOSITION

<u>Dominantly</u>	<u>Rare</u>
Santa Rosa, Gavilán with Ratana: <i>Ischaenum ciliare</i> (Ratana)	<i>Cyperacea</i> <i>Homolepis aturensis</i> (Arozilla) <i>Paspalum conjugatum</i>
Africa, Laurel with Ratana: <i>Ischaenum ciliare</i> (Ratana)	<i>Braciaria ruziensis</i> (Congo, Mejorado) <i>Homolepis aturensis</i> (Arozilla) <i>Panicum laxum</i> <i>Paspalum conjugatum</i> <i>Paspalum fasciculatum</i> (Gamalote)
Adrimaga, Gavilán with Pasto Natural: <i>Homolepis aturensis</i> (Arozilla) <i>Panicum laxum</i> <i>Paspalum conjugatum</i>	<i>Desmodium sp.</i> <i>Digitaria sp. (sanguinalis)</i>
Adrimaga, Laurel with Pasto Natural: <i>Homolepis aturensis</i> (Arozilla) <i>Panicum laxum</i> <i>Paspalum conjugatum</i>	<i>Cyperacea</i> <i>Desmodium sp.</i> <i>Digitaria sp. (sanguinalis)</i>

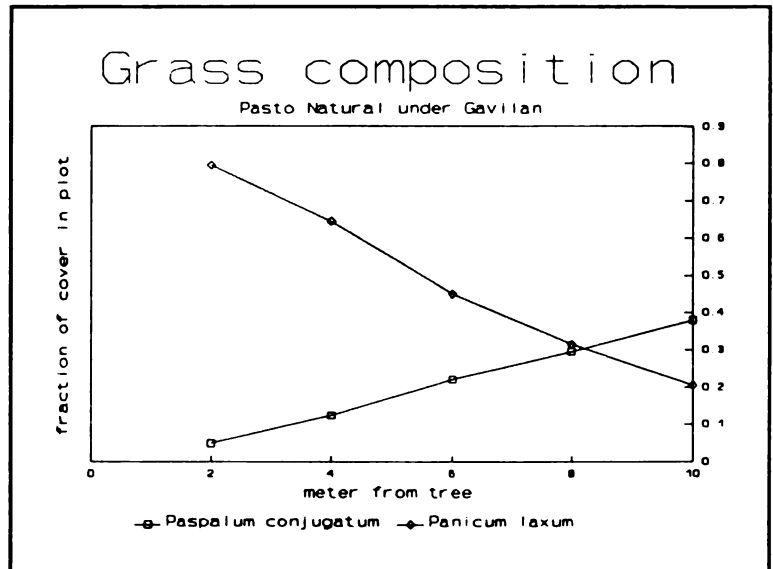


Figure a. Grass composition as a relation to the distance from the tree for two grass species, *Panicum laxum* and *Paspalum conjugatum*.

APPENDIX 8 LIGHT INTENSITY

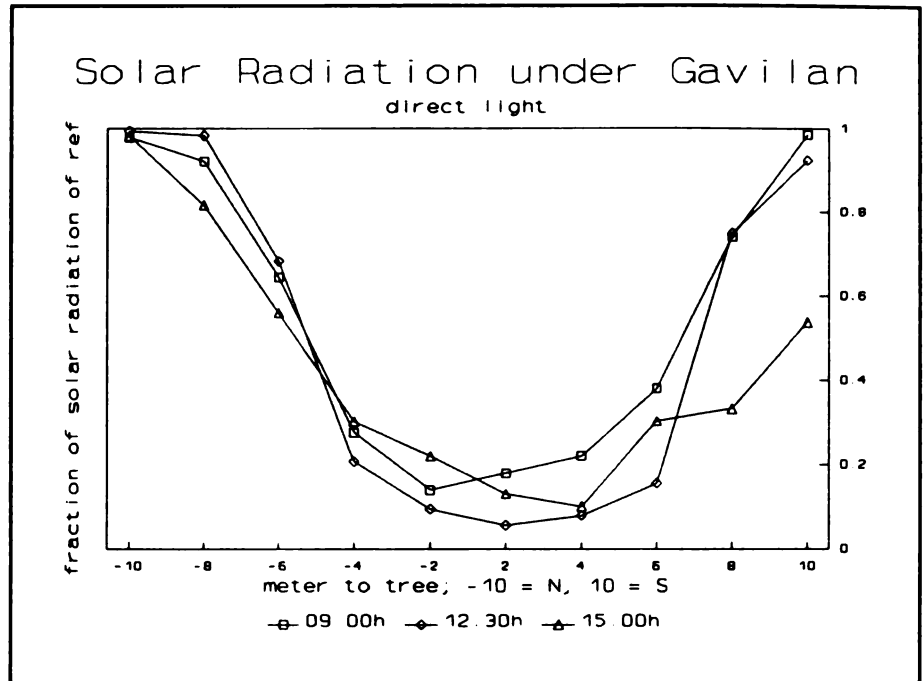


Figure a. Light intensity, direct light under Gavilán.

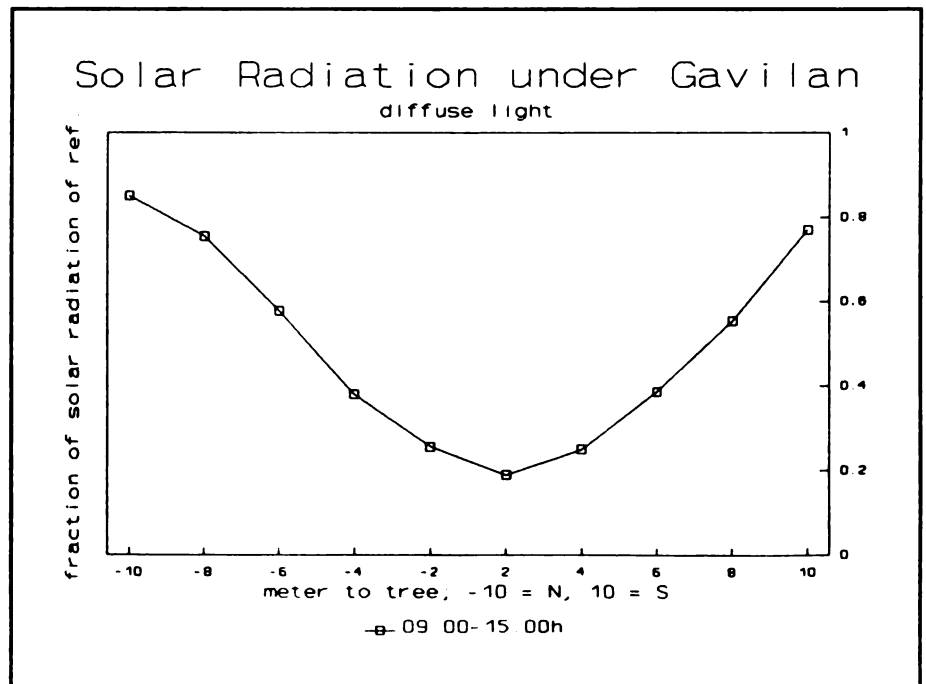


Figure b. Light intensity, diffuse light under Gavilán.

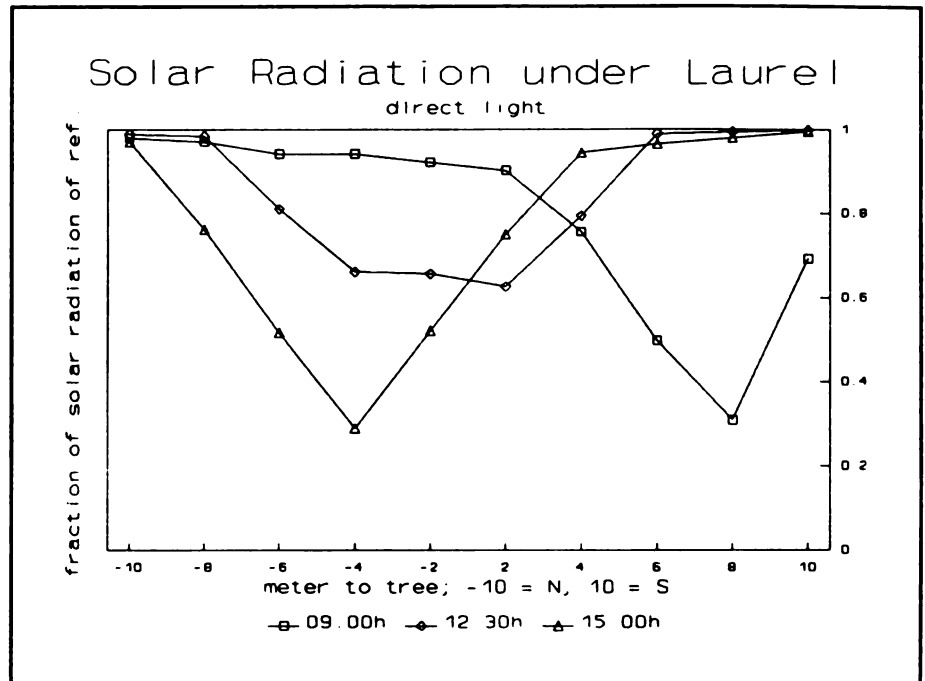


Figure c. Light intensity, direct light under Laurel.

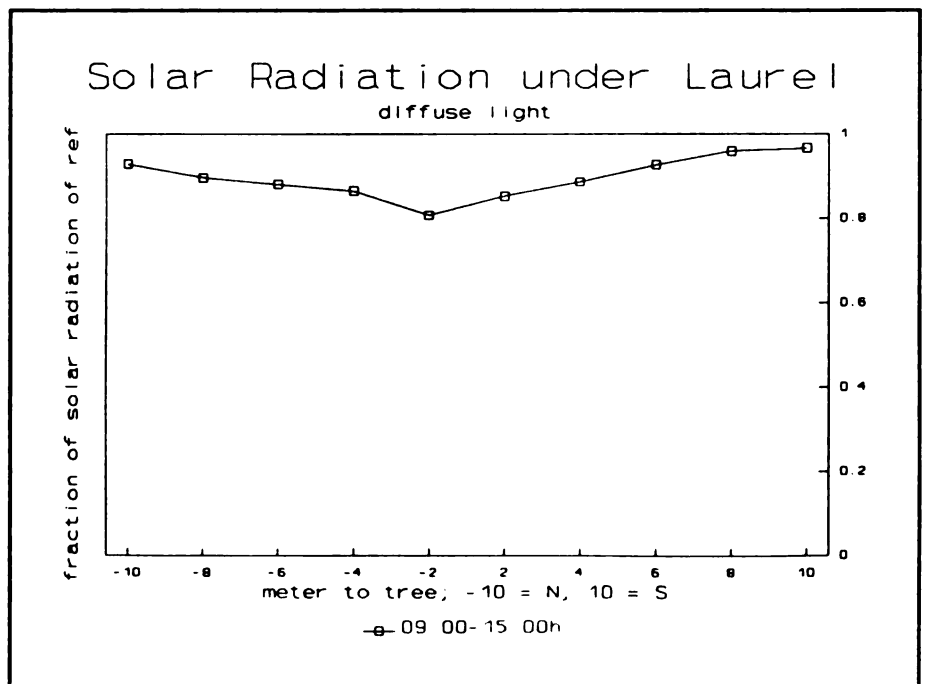


Figure d. Light intensity, diffuse light under Laurel.

APPENDIX 9 RELATION LIGHT INTENSITY-GRASS PRODUCTION

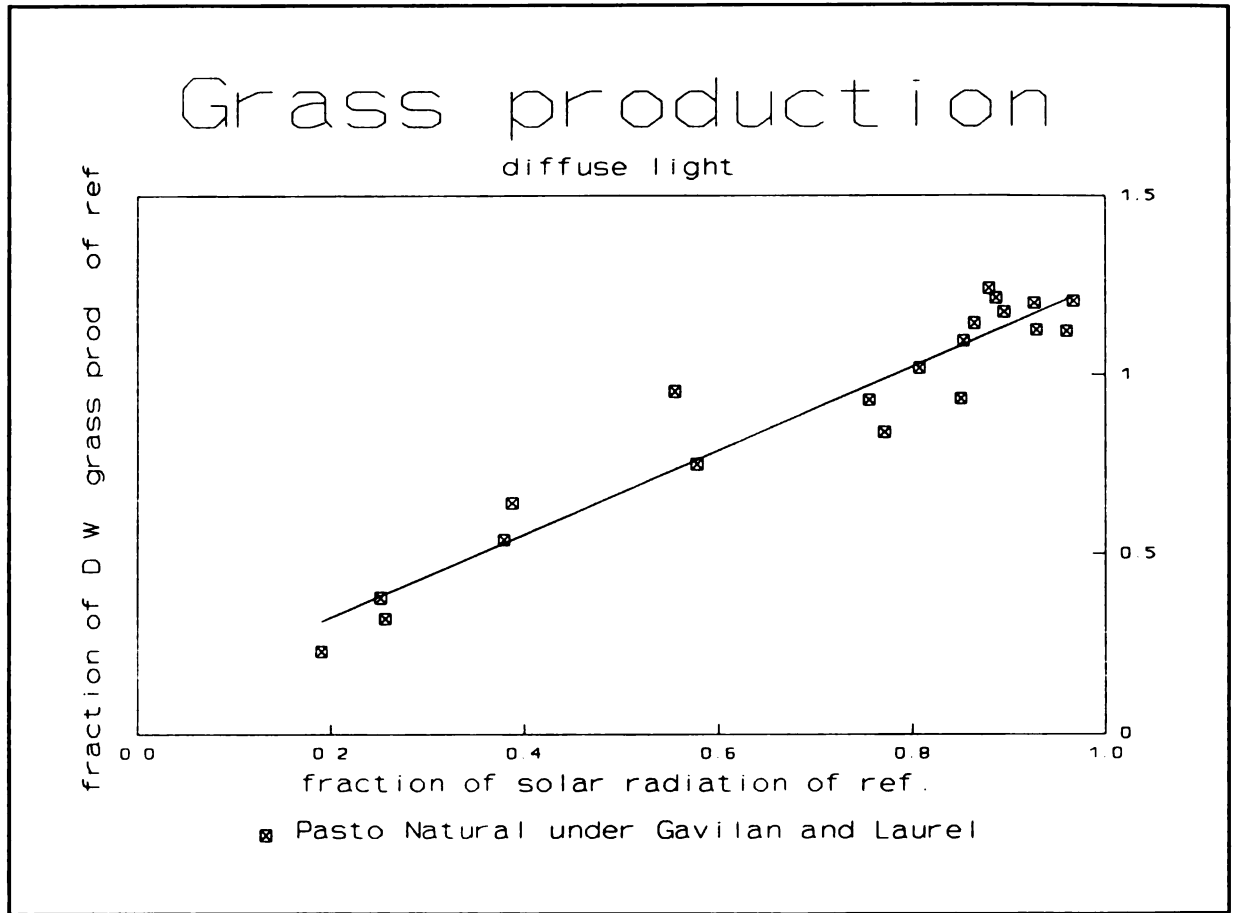


Figure a. The relation between light intensity and grass production.

A linear regression is made for the light-grass production relation with independent variable (x), % solar radiation of reference and dependent variable (y), % D.W. grass production of reference.

The linear regression equation is,

$$Y = 0.09 + 1.17 X$$

r^2	:	0.92
number of observations	:	20
degrees of freedom	:	18
standard error of Y	:	0.092
standard error of coef.	:	0.080

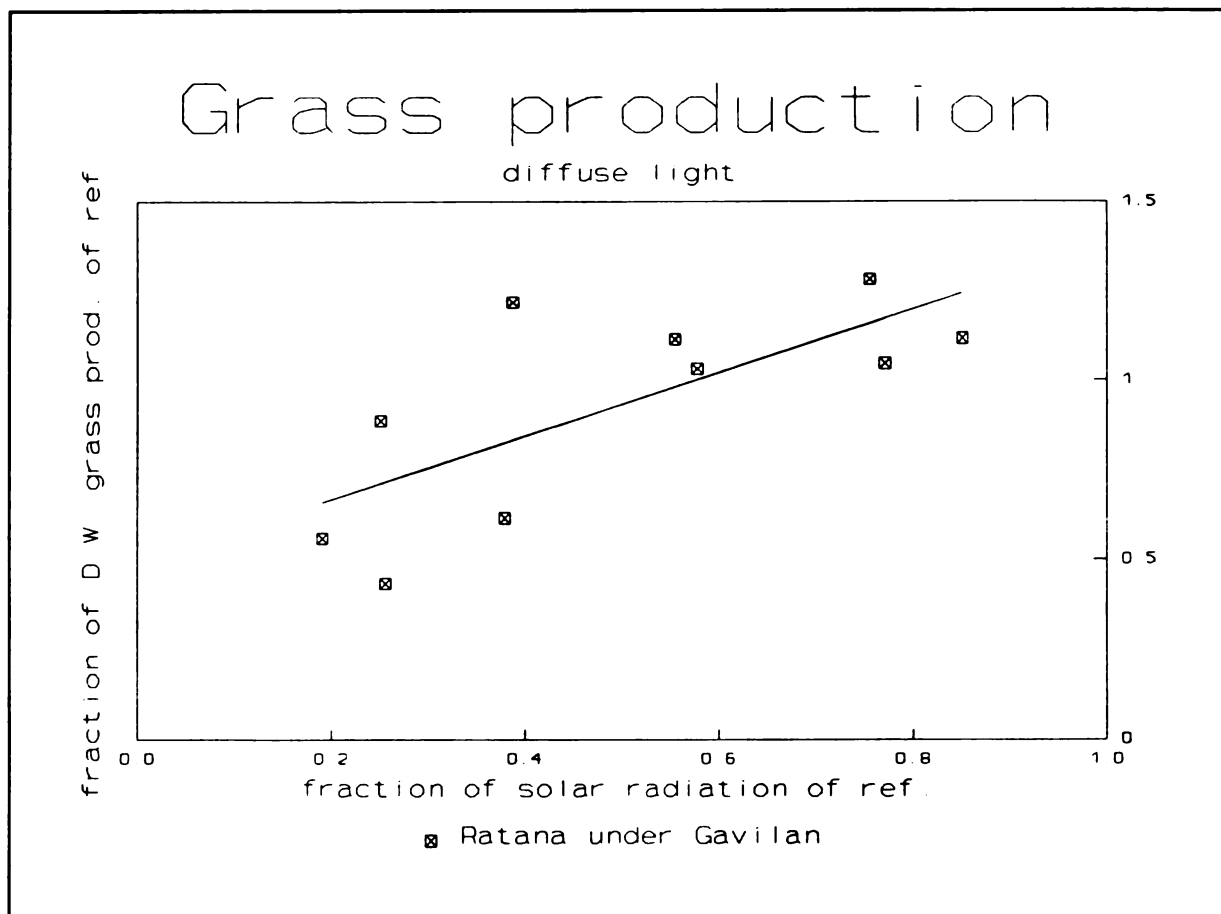


Figure b. The relation between light intensity and grass production.

The linear regression for the light-grass production relation for Ratana is less accurate compared to the one for Pasto Natural. This is due to the fact that hardly no data is available of the light distribution of Gavilán and Laurel of the two sites for Ratana. To get an impression a combination is made of the light intensity data of all four sites.

The linear regression equation is,

$$Y = 0.49 + 0.89 X$$

r^2 : 0.52
 number of observations : 10
 degrees of freedom : 8
 standard error of Y : 0.217
 standard error of coef. : 0.303