University of Alberta

TREES IN PASTURES IN HERRERA PROVINCE, PANAMA, WITH AN EMPHASIS ON SMALL-SCALE FARMERS

by ©

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A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree of Master of Science

in

PLANT SCIENCE

Department of Agricultural, Food and Nutritional Science

Edmonton, Alberta

SPRING 2004

Your file Votre référence
ISBN: 0-612-96515-5
Our file Notre référence
ISBN: 0-612-96515-5

Abstract

Deforestation in Latin America is mainly due to pasture creation. The present study used a farming systems research approach to investigate silvopastoral systems (use of trees in pastures) in Herrera province, Panama. Statistical analysis of agricultural census data revealed that Herrera is more agricultural than Panama as a whole. Women-headed households and small-scale farmers are less dependent on farm income than male-headed households and large-scale farmers. Pasture is more prevalent on titled land, with a greater percentage in improved grasses, than untitled land. Forest and fallow are less prevalent on titled land than untitled land. A survey of 45 small-scale pasture owners identified nine different tree uses. Native species tended to receive the highest multipurpose tree ratings. An on-farm experiment examining the impact of *Bursera simaruba* living fences on biophysical pasture properties found that soil Mn and percent litter cover were higher, and that soil pH (H_2O, 2:1) and percent herbaceous cover were lower at the base of living fences, than 6 m away. Trees provide a number of products and services in Herreran pastures, with Guácimo (*Guazuma ulmifolia*), Corotú (*Enterolobium cyclocarpum*) and Nance (*Byrsonima crassifolia*) deserving further research and development.

Dedication

Nat (1924 - present) and Edward Payne (1928 – 2003)

The best grandparents ever.

Acknowledgements

Thanks to all my friends, family, professors, and colleagues. You have made this adventure fun, possible, and educative.

Special thanks to:

Dean Spaner for being a truly unique advisor, writer, and friend.

Jane King for making pasture science interesting and understandable.

Deborah Davidson for helping me with, and reviewing the social science aspects of my thesis.

Jose Deago, Rolando Perez, and Carmen Gladames for being three excellent Panamanian botanists.

The Brazilero (Henrique Nascimento) for suggesting I study trees in pastures.

Zach Smith for being my gringo friend in Panama.

Mike Evans for writing references for me on very short notice.

MIDA, ANAM, IDIAP, STRI, PRORENA and Peace Corps for being understanding and supportive institutions in Panama.

National Controller for sharing census data and clarifying census concepts.

U of A Interlibrary Loans for being simply awesome.

CBIE/CIDA[11] for providing fieldwork funding.

OAS[12]**, NSERC**[13]**, U of A**[14]**, Alberta Learning**[15] **and Government of Alberta**[16] for supporting me during writing of this thesis.

La gente de Herrera for generously helping me along my way.

Herreran pasture owners for their patience with a crazy gringo.

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[11] Canadian International Development Agency (CIDA) Awards Program for Canadians administered by the Canadian Bureau for International Education (CBIE)

[12] Organization of American States Graduate Fellowship

[13] National Sciences and Engineering Research Council of Canada Postgraduate Scholarship (PGSA) upgraded to Canada Graduate Scholarship (CGS)

[14] Walter H Johns Graduate Fellowship

[15] Alberta Learning Graduate Student Scholarship

[16] Province of Alberta Graduate Scholarship

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List of Symbols

Object	Symbol
Ministry of Agriculture and Livestock Development / *Ministerio de Desarrollo Agropecuario*	MIDA
Panamanian Institute for Agricultural Investigation / *Instituto de Investigación Agropecuaria de Panama*	IDIAP
National Environmental Authority / *Autoridad Nacional del Ambiente*	ANAM
Tropical Agriculture Research and Training Centre / *Centro de Agronomia Tropical para Investigacion e Enseñaza*	CATIE
International Council for Research in Agroforestry	ICRAF
pH (H_2O, 2:1)	pH
pH ($CaCl_2$, 2:1)	Exchangeable pH
Productivity (metric tonnes per hectare)	T/ha
Hectares	Ha
Microgram per milliliter	µg/ml
Milliequivalents per 100 milliliters	Meq/100ml
Square meter	m^2
Square kilometer	km^2
Millimeter	mm
Centimeter	cm
Meter	m
Percent	%
Gross domestic product	GDP
United States Dollar	$US
Organic carbon	Organic C
Calcium	Ca
Phosphorous	P
Magnesium	Mg
Iron	Fe
Manganese	Mn
Copper	Cu
Zinc	Zn
Potassium	K

1.0 Trees in pastures in Panama: a literature review

1.1 Panamanian and Herreran biogeographical history and demographics

Panama is a small Central American country of 75 500 km^2 located between 7°12'07" and 9°38'46" N and 77°09'24" and 83°03'07" W (Comisión Nacional de Recursos Fitogenéticos de Panamá 1995) (Figure 1.1). The Panamanian isthmus bridges the gap between Costa Rica and Colombia and is famous for the Panama Canal (McCullough 1977). The population in 2001 was estimated at 2.9 million (World Bank 2002), with a population density of 38 inhabitants/km^2.

It is thought that Panama is geologically one of the newest parts of Central America (Coates 1997). The eastern part of the isthmus rose completely out of the sea only three million years ago (Coates 1997). The Azuero peninsula is an exotic terrane, which formed thousands of kilometres away from Panama before being deposited on the isthmus along the trailing edge of the subducted Caribbean Plate (Coates 1997). Panama's Herrera province is situated on this peninsula between 7°13'00" and 7°37'30" N and 80°4'30" and 80°22'30" W (Jaen 1962) and covers 2 300 km^2 (Figure 1.1). The population of Herrera province was estimated at 103 000 in 1998, with a population density of 44 inhabitants/km^2 (Contraloria 2000a).

Stone tools (the oldest Central American artefacts) dating to 9500 B.C. to 8500 B.C. have been found in Panama in the form of spear points (Cooke 1997). Piperno (1989) suggests that a rapid increase in Panama's population density 7000 years ago is evidence for the beginning of agriculture in Panama. Thus, slash and burn agriculture (a form of agroforestry) has been practiced in Panama since at least 5000 BC. Herrera's dry forest lifezone is thought to be the first place in Panama that Amerindians and Spaniards colonized (Holdridge 1967). The importance of dry ecological lifezones to agriculture is evidenced by the more pronounced removal of forest cover for agriculture in the drier ecological zones of the Brazilian Amazon (Laurance *et al.* 2002).

Panama is located in the tropics, geographically defined by the tropics of Capricorn (23° 27'00" S) and Cancer (23° 27'00" N). The tropics are characterized by diurnal changes in temperature that are greater than seasonal changes, and day lengths that vary little (constant 12.1 hours at the equator and day lengths ranging from 10.9 to 13.3 hours at 20° latitude) (Dennett 1984). Precipitation in Panama ranges from slightly under 1000 to 7000 mm annually (IGNTG 1988). Near the Caribbean >3000 mm falls annually while near the Pacific <2000 mm falls annually (Condit *et al.* 2002). Annual precipitation in Herrera province ranges from 900 to 2100 mm (IRHE 1998) while altitude varies from sea level to just under 1100 m (IGNTG 1988). Annual median temperature ranges from 14°C, atop Panama's highest mountain, to 27°C along its coasts (IGNTG 1988). Annual median temperatures in Herrera range from 25°C in its mountainous region to 27°C in its lowlands (IGNTG 1988).

The east shore of Herrera stretches along the Gulf of Panama, where flat plains near the coast give way to gentle hills and finally broken hilly lands (referred to locally as mountains) to the west. Soils in Herrera include alfisols in the flat dry lands and inceptisols and utilsols in the wetter hillier regions (Jaramillo 1986). Panama contains 12 of Holdridge's life zones[1] (IGNTG 1988) of which eight are found in Herrera province (IGNTG 1988). Panama has high levels of biodiversity with over 1 250 vertebrate species and 7 000 plant species, and 15% of Panama's flora is endemic (Polsky 1992).

Forty-three percent of Panama's population is rural (World Bank 2002). In 1995 the World Bank determined that 41% of Panama's population was living below the national poverty line. However, while 48% of the rural population was classified as poor, only 34% of the urban population was considered poor (Elton 1997). In 2001 the World Bank determined poverty had declined to 37% (World Bank 2002). Recent agricultural development in Panama has displaced small-scale farmers (Heckadon Moreno and McKay 1982). Small-scale farmers have been forced to migrate to agricultural frontiers such as Darien province or relocate to upland areas (Jones 1990). Two-thirds of Panamanian farmers do not have title to their land (Elton 1997). Rice (*Oryza sativa*) is the most important part of the Panamanian diet. Maize (*Zea mays*), manioc (*Manihot esculenta*), plantain (*Musa spp.*), pigeon pea (*Cajanus cajan*) and yams (*Dioscorea spp.*) are also subsistence staples (McKay 1990).

In 2000 and 2001 Panama's food imports totalled 348 and 296 million $US, respectively. This was significantly greater than 1991 food imports of 149 million $US (World Bank 2002). In 1991 agriculture accounted for 9% of Panama's Gross Domestic Product (GDP), while in 2000 it made up only 7% of GDP. In contrast, the service sector accounted for of 77% of the GDP (World Bank 2002). However, GDP does not adequately reflect the importance of agriculture in terms of rural employment, food security, and economic stability in many developing countries (Asian Productivity Organization 1995).

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[1] Holdridge's classification is commonly used in Central and South America. It uses mean annual temperature and precipitation and assumes temperature can be used to estimate potential evapotranspiration. These data are used to define humidity provinces and temperature zones. Each combination of humidity province and temperature zone is a life zone and is characterized by a particular vegetation type (Young 1987).

1.2 Cattle production in the neo-tropics and in Panama

Cattle were introduced to the New World during the Spanish conquest (Diamond 1997). In the early 1990s the tropics contained 64% of the world's cattle, 100% of its buffaloes, 51% of its sheep and 94% of its goats, but produced only 36% of the world's meat and 18% of its milk (FAO 1991). This underscores the low-input nature of livestock production in the tropics. Cattle ranchers in the tropics have generally increased production by increasing animal numbers rather than intensifying production to increase carcass weights (Delgado *et al.* 2001).

Myers (1981) posited a 'hamburger connection' between North American beef consumption and Central American cattle production. North American markets' demand for beef was thought to provide incentives for the rapid expansion of cattle ranching in Central America at the expense of tropical forest. This 'hamburger connection' was important during the limited but dynamic beef market of the 1960s and 1970s, but domestic demand and historical factors supporting cattle production were also important. In Costa Rica a case study revealed that "the politics of land appropriation over time, the changing uses of that land, and transformation of the labour process" explained why cattle ranching occupies nearly three-quarters of Costa Rica's productive land (Edelman 1992).

In Panama, approximately 97% of beef production was consumed locally between 1970-1989 (BNP 1990-91). Domestic consumption of milk and beef products has been growing much faster in developing countries than in developed countries. Delgado *et al.* (2001) reported that, from 1970 to the mid 1990s, beef consumption in developing countries grew nearly three times as much, and consumption of milk equivalents grew twice as much, as in developed countries. Projections for the 1996 to 2020 period indicate that annual growth in meat and milk consumption in developing countries will be 2.9%, compared to 0.7% and 0.6%, respectively, in developed countries (Delgado *et al.* 2001). Such growing markets provide economic opportunities for cattle ranchers in tropical developing nations.

Owning cattle in Central America is an important small-scale farmer activity. Escolán *et al.* (1998) reported that possession of livestock was the single most important factor differentiating levels of poverty in Honduras. Ruminant livestock is a highly mobile resource that permits market access for small-scale farmers even in remote areas (Peters 2001).

Panama's 2000 agricultural census enumerated 1.5 million head of cattle in Panama on 1.5 million ha of pasture. Herrera province had 138 000 head and 128 000 ha of these national totals (9% and 8% of the nation's total respectively) (Contraloria 2000b). These small percentages belie the importance of cattle ranching in Herrera. Herrera is one of only three

Panamanian provinces that have more head of cattle than inhabitants. Sixty-two percent[2] of Herreran farms own cattle compared to the nation's average of 49% (Contraloria 2000b). Herrera province has the second highest cattle density per square kilometre in Panama with 59 head/km^2 compared to the nation's 20 head/km^2 (Contraloria 2000b).

1.3 Deforestation, pastures and small-scale farmers in Panama

Forest cover has been reduced from 70% of Panama's landmass in 1947 to 44% in 1995 (Fischer and Vasseur 2000). Flores (1994) has mapped continual forest cover reduction in Panama from the 1950s onwards. This process has been exaggerated in Herrera. Forest cover in Herrera was 4% in 1998 (ANAM 1999), while pastures covered 51% of the landmass in 2000 (Contraloria 2000b). This is the lowest forest percent cover of all Panamanian provinces and the second highest pasture cover. Pastureland is not an indigenous vegetative type in Panama according to the Holdrige's life zone classification (IGNTG 1988).

Sixty-five percent of the deforestation in Latin America and the Caribbean in the 1980s has been attributed to cattle ranching (Nair *et al.* 1991). Deforestation in Panama has also been the result of cattle ranching (Heckadon Moreno 1985). In 1992 it was estimated that 70% of Panama's deforested land was in cattle pasture (Ledec 1992). Shifting or swidden agriculture is the mainstay of small-scale farmers in Panama and the rest of Central America (Fischer and Vasseur 2000). Shifting agriculture is the practice of clearing and burning small plots which are then cropped for a short period of time and subsequently left to fallow for many years (Greenland 1975). In Panama, small-scale farmers' swidden agricultural has been implicated in the deforestation of large tracts of land, which is often subsequently converted to pasture for large land owners (Jones 1990; Heckadon Moreno 1983, 1985). The province of Herrera has traditionally been considered a heartland of small-scale agriculture (Jaen-Suarez 1978).

Jazairy *et al.* (1992) reported that in 1988, that 429 000 of Panama's rural inhabitants were small-scale farmers. These farmers used 575 000 ha of arable and permanent cropland, or 9% of Panama's total (Jazairy *et al.* 1992). The authors used a 3 ha maximum and no minimum farm size to define small-scale farmers. Such a definition may not be appropriate for Panama, especially when pasture ownership is being considered. What constitutes a small land-holding in Latin America and the Caribbean may vary from <2 ha in Haiti to >50 ha in Brazil (Nair *et al.* 1991). Fischer (1998) reviewed five agroforestry projects in Panama and reported that small-

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[2] This percentage is calculated for farms of 3 ha or more: see chapter 2 for explanation.

scale farmers typically had less than 10 ha of land. Regardless of the size of small-scale farmers' pastures, and the deforestation required to produce them, trees are a common and important part of these pastures.

1.4 Agroforestry, silvopastoralism and Panama

Agroforestry – the use of woody species (trees, shrubs, palms, bamboos) on farms – has been considered an alternative to deforestation (Alcorn 1990), swidden agriculture (Fischer 1998), and intensive monocrop agriculture (Gholz 1987). It is also thought to be particularly appropriate for small-scale farmers (Sepulveda 1987; Winterbottom and Hazelwood 1987). Agroforestry permits diversification of agricultural production while preserving the natural resource base and the productive capacity of the land (Winterbottom and Hazelwood 1987). Accomplishing this objective may lead to an improvement in farmers' standard of living (Fischer 1998). Social forestry promotes the incorporation of trees into agricultural landscapes by individuals and rural communities, and thus represents an alternative to large-scale commercial tree planting (Gregersen *et al.* 1989). Fischer (1998) suggested that interest in agroforestry and social forestry is due to governments recognizing that they do not have the resources required to reforest at rates that satisfy the demand for tree products.

Agroforestry achieved a formal professional identity with the establishment of the International Council for Research in Agroforestry (ICRAF) in 1977 in Nairobi, Kenya (King 1989). The Tropical Agriculture Research and Training Centre (CATIE), located in Turrialba, Costa Rica has been active in the promotion of agroforestry in Latin America since 1976 (Budowski 1993). In 1980 CATIE initiated the Madaleña project to promote the planting of fuel wood in Central America, but quickly shifted its emphasis to trees having more than one use (multipurpose trees) with the initiation of its second phase in 1986 (Current and Scherr 1995). The Madaleña project ended in 1995, but the number of agroforestry projects in Panama increased throughout the 1990s (Fischer and Vasseur 2000).

Silvopastoral systems – the use of woody species in pastures – are a subset of agroforestry systems and may be important in pasture-rich Panama. Silvopastoralism has recently become a topic of interest in Central America (Dagang and Nair 2001, Casasola *et al.* 2001; Harvey and Haber 1999). Panamanian agroforestry research in the Canal Zone (Aguilar and Condit 2001; Hauff 1999) and elsewhere (Simmons *et al.* 2002) has not emphasized silvopastoralism. One exception is the International Development Research Centre's dairy and beef cattle feeding project, which introduced herbaceous protein banks in the 1980s (IDIAP

1986), which subsequently resulted in the introduction of *Leucaena leucocephala* protein banks by the Panamanian Institute for Agricultural Investigation (IDIAP) (Urriola 2002 *pers. comm.*).

Protein banks are high-density plantings of shrubs or trees that are usually leguminous and produce high protein foliage (Schlonvoigt and Ibrahim 2001). *Erythrina* is one example of a leguminous tree that has been studied for its use in protein banks (Ibrahim *et al.* 2000). Scientists suggest that unlike herbaceous vegetation, shrubs/trees' resistance to drought will permit the supplementation of cattle diets with high protein fodder during the dry season (Paterson *et al.* 1998). The production contribution of protein banks has been assessed favourably in terms of animal weight gain when compared with other feeding systems (Ibrahim *et al.* 2000). However, the introduction of new tree species and production systems for fodder will not be adopted if they do not conform to farmers' management practices, and if they do not address farmers' needs and socio-economic limitations (Bunch 1985; Shelton 2000). Protein banks are a relatively new agroforestry technology (Kapp 1999) and have had poor adoption rates among small-scale farmers in Kenya (Paterson *et al.* 1998). Existing farming systems must be assessed before new farming technologies are introduced.

1.5 Farming systems research and participatory techniques

Farming systems research and extension (FSRE) is a research approach which is thought to be appropriate for the characterization, development, and promotion of agroforestry systems in tropical developing countries (Gold and Tombaugh 1987). The key components of this methodology are: 1) multidisciplinary diagnosis of farmers' practices and problems, 2) laboratory and on-station research, 3) on-farm biophysical research, 4) socio-economic research and evaluation of on-farm trials and the farming community, 5) rapid dissemination and diffusion of results (Stroup *et al.* 1993). Although the effectiveness of FSRE was questioned in the late 1980s (Herdt 1987; Fielding 1988), it has remained a highly successful and appropriate approach for working with small-scale farmers when properly applied (Tripp 1991).

A review of farming systems research and extension in the tropics reported that multidisciplinary understanding of existing farming practices and systems was of utmost importance, and suggested that multidisciplinary work might be best carried out by individuals rather than research teams (Simmonds 1986). Multipurpose tree research in agroforestry has used multidisciplinary techniques much like those of farming systems research and extension (Franzel *et al.* 1995).

Secure land tenure has an important positive impact on tree planting (Raintree 1987; White and Runge 1994; Unruh 1995; Walters *et al.* 1999). Simmons *et al.* (2002) call secure tenure "the most widely cited essential ingredient for the success of any type of conservation effort" and they reported that tree planting in Brazil and Panama is more prevalent on titled land.

1.6 Agricultural censuses and demographics of importance

Agricultural censuses are often required by law in many countries, and provide periodic baseline data about agricultural activities within nations and their regions (FAO 1978). This information may be used to improve public policy or regulation in the agricultural sector (Clark 1982). Ahn *et al.* (2002) noted the importance of agricultural census data for understanding the effects of land use on people and the environment.

Gender is an important theme in development and agriculture (Boserup 1970), but women's roles are not the same in all regions (ESCWA 2001). In Latin America, women farm plots with their male counterparts (Quisumbing *et al.* 1995) and their contributions have traditionally been underestimated because women are mainly engaged in subsistence farming (FAO 1998). Levels of non-farm employment differ with gender. In 1998 it was estimated that 47% of male rural employment and 93% of female rural employment in Panama was non-farm (Lanjouw and Lanjouw 2001). Off-farm work (an opportunity cost) may make adoption of labour-intensive agroforestry systems such as alley-cropping[3] difficult (Rao *et al.* 1990).

In parts of Latin America, pasture creation has been a method of land acquisition (Hetch and Cockburn 1989). In Panama, (until 1994) the agrarian code of 1962 encouraged deforestation as a precondition to obtaining possession rights or legal title to land (Joly 1989). Women often do not have the same access to titled land as men (Quisumbing 1995).

1.7 Multipurpose trees and Panama

Multipurpose tree species – trees used for more than one end product, for example mango (*Mangifera indica*, fruit, shade, fodder, medicine) – are considered an important part of agroforestry systems in Panama (Aguilar and Condit 2001; Hauff 1999; Fischer and Vasseur 2000) and silvopastoral systems in general (Rai *et al.* 2001; Cajas-Giron and Sinclair 2001). Multipurpose trees are considered particularly appropriate for small-scale farmers (Hedge and

[3] Alley-cropping is the sowing of crops inbetween row-planted trees or shrubs which are used to provide mulch for the cropped area.

Daniel 1992; Winrock International 1988). Multipurpose trees have also been intensively studied for their potential as fodder (Gutteridge and Shelton 1994), making them prime candidates for protein bank technology. Unfortunately, multipurpose tree species are often largely unknown to science (Huxley 2001). Condit *et al.* (1993) suggested that limited use of native species in Panama is due to deficiencies in silvicultural information. However, traditional agroforestry systems are existing sources of silvicultural information.

Researchers investigating multipurpose trees have developed interview techniques involving the evaluation of tree species by farmers through ranking exercises (Franzel *et al.* 1996; MacDicken and Mehl 1990). Some of these techniques have acknowledged that male and female perspectives differ (Franzel *et al.* 1996). Women in Africa have different tree species preferences compared to men, and some trees have gender specific uses (Just and Murray 1996). Prioritizing multipurpose trees is important because in agroforestry there are always more research questions than research resources (Wood and Burley 1991). Despite the development of these rating techniques, Harvey and Haber (1999) claimed that there have been no formal studies of why trees are retained in pastures.

1.8 Living fences and chemical soil fertility

Trees are known to affect soil chemical properties and the yield of associated crops (Rao *et al.* 1998). Isolated parkland trees and boundary plantings have been found generally to increase soil N, P, Organic C, and pH (Rao *et al.* 1998). Effects on soil are known to vary with tree species (Rao *et al.* 1998). However, in the case of isolated trees it is difficult to separate the effects of better tree recruitment in islands of high fertility from tree modification of soil properties (Geiger *et al.* 1994). Fisher (1995) criticizes agroforestry research of this type as lacking true controls because initial soil fertility is not assessed. Improved tree fallows, in which farmers enrich natural vegetation regeneration by planting trees, are established regardless of prior soil fertility. Improved tree fallows are thought generally to increase organic C, extractable P, N, and other exchangeable cations, and variably affect pH compared to natural tree or grass fallows (Rao *et al.* 1998).

Using trees to make living fences is a common agroforestry practice in Latin America (Budowski 1993). Living fences are row-planted trees (usually vegetatively propagated) to which barbed wire is attached (Budowski 1987). A study of a small farming community in the Panama Canal Zone reported that thirteen different species were used in living fences (Aguilar and Condit 2001). In Costa Rica, Budowski (1987) identified ninety different species used in living fences.

Living fences (a form of boundary planting) are intentionally planted but generally have not been studied for their effects on soil characteristics. This may be because living fences' impact on soil fertility is not considered relevant (Young 1991), or the area affected by boundary plantings is considered minimal (Rao *et al.* 1998). However, small farms have a greater proportion of their pastures affected by virtue of having a larger perimeter to surface area ratio. Boundary plantings are known to generally reduce the yield of associated crops (Rao *et al.* 1998).

Bursera simaruba (a deciduous tree of the Burseracea family) (Gentry 1996) is a common tree species in Central American living fences (Budowski 1987). *B. simaruba*'s deciduous nature implies dry season leaf drop which provides substantial seasonal litter inputs. Given deciduous plants usually translocate nutrients out of their foliage before leaf fall (Bernhard-Reversat 1987), chemical soil fertility improvement in associated areas may not be pronounced. However, some nutrients such as iron and calcium are not very mobile and the mobility of zinc, manganese, and copper is intermediate in plants (Salisbury and Ross 1992). This implies that some nutrients are not translocated and mineral enrichment through litter may occur. *B. simaruba* does not biologically fix nitrogen, which is one of the principal ways in which trees are thought to improve soil fertility (Rao *et al.* 1998).

The impact of non-nitrogen-fixing trees on soil fertility has also been evaluated in Africa (Kater *et al.* 1992; Tomlinson *et al.* 1995) and Latin America (Tornquist *et al.* 1999). Tomlinson *et al.* (1995) found soil total N and available K was higher closer to *Parkia biglobosa* trees than in cultivated fields. However, pH, organic matter and P were not significantly affected. Kater *et al.* (1992) found higher organic C, Mg, and K under trees but no significant differences in pH, N, available P, and Ca. Tornquist *et al.* (1999) reported higher pH in pastures compared to adjacent five-year-old tropical hardwood agroforestry systems in Costa Rica. They found few differences in Ca, Mg, K, and Na, and no differences in organic C (Tornquist *et al.* 1999). None of these studies involved living fences.

1.9 Statistical considerations for on-farm experiments

On-farm research often requires statistical approaches different from classical statistical designs (Riley and Alexander 1997). Past analysis of on-farm soil fertility has tended not to use mixed model analyses (see Pandey *et al.* 2000; Tomlinson *et al.* 1995). Nor have rejective tests been employed when examining a suite of soil properties (see Tornquist *et al.* 1999; Fisher 1995). This makes the detection of statistically significant differences more probable. When a suite of ten variables is analyzed at α=0.05, a significant difference is expected to be detected for at least one variable 40% of the time (Rice 1989). Biological significance is as important as statistical significance, however only a few studies have conducted ex-situ bioassays with tree-affected soils (Jackson and Ash 2001; Jonsson *et al.* 1996). More common in-situ yield trials (Weltzin and Coughenour 1990; Tiedemann and Klemmedson 1977) may confound the soil effects with other tree effects (shading, alleophathy, and moisture competition).

1.10 Development of thesis research

In 2002, I visited Panama with the intention of studying the potential of *Cratylia argentea* protein banks under-sown with different pasture grasses in Herrera province. It quickly became apparent that pasture owners were not using protein banks. *Cratylia argentea* plots had been established by IDIAP in El Ejido, Herrera and had generally been neglected. Little research had been done on existing silvopastoral systems in the region and recently published 2000 agricultural census data had not been analyzed in order to guide farming systems research and extension.

In light of this situation I interviewed 53 pasture owners during the months of May through August in order to describe existing silvopastoral systems, and negotiated with the National Controller for access to published and unpublished 2000 agricultural census data. In my travels it became apparent that *Bursera simaruba* was used in living fences and that little was known about their impact on soil fertility. In 2003 I returned to Panama and conducted an experiment on how *Bursera simaruba* living fences impact soil chemical fertility during the months of January through May and analyzed agricultural census data in the months of June through August.

Thus, the objectives of this thesis evolved out of my initial and subsequent observations of small-scale pastures in Herrera, Panama. The research conducted represents an attempt to do work, which may be of use to resource-poor farmers in Herrera province and other regions of the tropics with similar biophysical and socio-economic characteristics.

1.11 Thesis objectives

Agricultural census

1) Describe Panamanian agriculture in the year 2000 using census data and compare Herreran agriculture to agriculture in Panama as a whole.

Multipurpose trees

1) Describe the use of trees in Herreran pastures and their multipurpose nature, considering the effects of ecozone, informant gender, and different types of uses.
2) Investigate the current status of protein banks in Herreran silvopastoral systems.
3) Prioritize multipurpose tree species in Herrera for further research.

Living fences and soil fertility

1) Employ an on-farm study to quantify the impact of *Bursera simaruba* living fences on pasture soil chemical properties and vegetation characteristics, and examine associations within and between soil chemical properties and vegetation characteristics in El Cedro, Los Pozos.

1.12 Thesis hypotheses

The underlying hypotheses of this thesis were:

Agricultural census

1) Herrera province is more agricultural than Panama as a whole.
2) Female-headed households are less dependent on farm income than male-headed households.
3) Smaller farmers do not depend as much on farm income as do larger farmers.
4) Titled land is altered for agriculture more than untitled land, resulting in titled land having a smaller percentage of its surface area in fallow and forest and a greater percentage in pasture.
5) Improved pasture grasses cover a greater percentage of titled pastureland than untitled pastureland.

Multipurpose species

1) Multipurpose species are favoured for retention in pastures.
2) Different uses for trees in pastures differ in popularity.

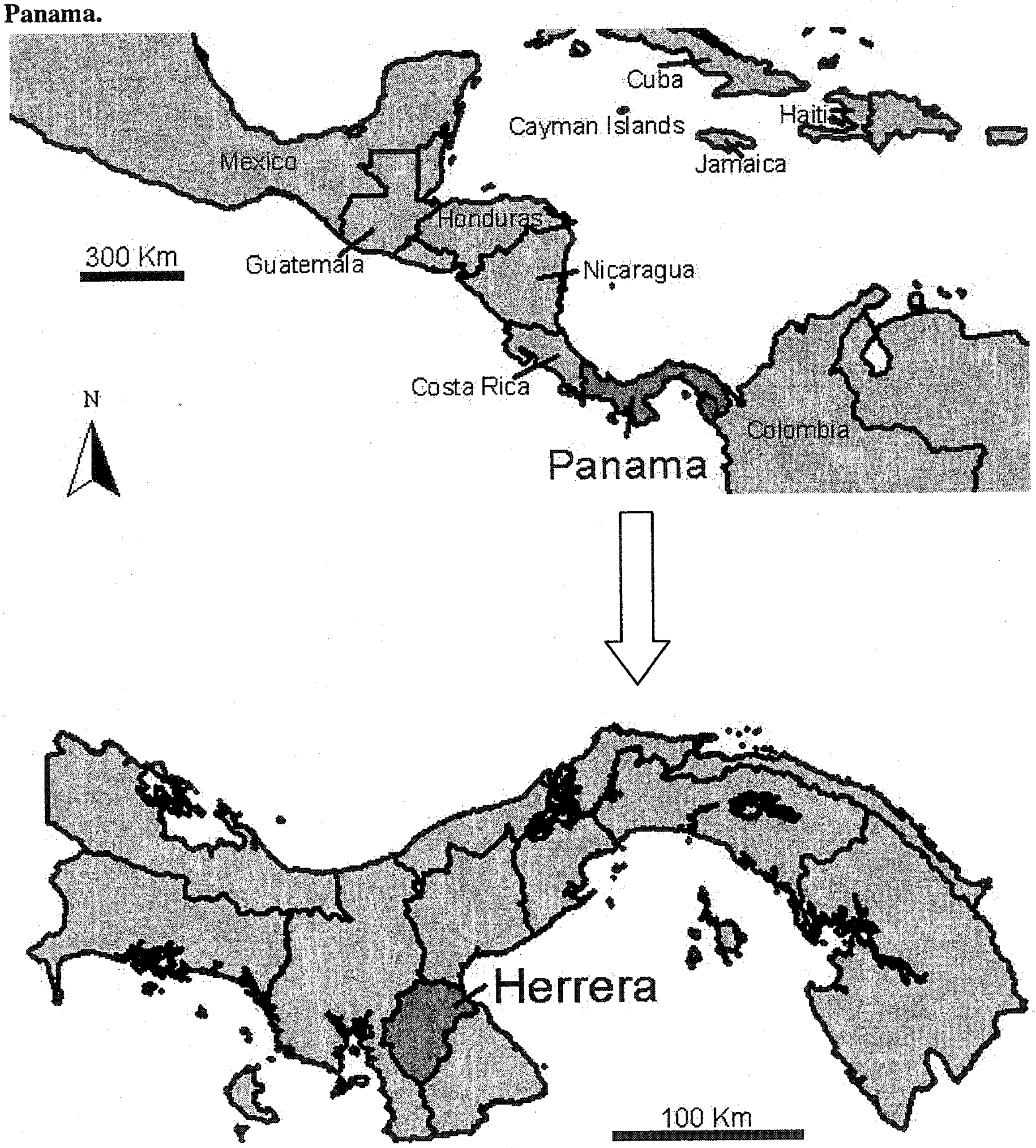
3) Differences in reported species richness are detectable on the basis of informant gender and type of use.
4) Protein banks are not a popular technology because of the social and economic context of Herreran cattle ranching.
5) There is heavy reliance on only a few species to provide specific products and services.
6) Native tree species play an important role in Herreran silvopastoral systems.

Living fences and soil chemical properties

1) *Bursera simaruba* living fences negatively affect grass cover and soil pH, and this effect will be associated with leaf litter.
2) Many of the soil chemical properties affected by *Bursera simaruba* living fences will not differ in magnitude sufficiently to be biologically significant.

1.13 Tables and figures

Figure 1.1 Map of research area in relation to Central America and the Republic of Panama.



Source: Central American Image, ESRI (1999); Panama Image, EoN Systems (2002).

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2.0 An examination of Panamanian agriculture employing an analysis of 2000 agricultural census data, with special emphasis on Herrera province.

2.1 Abstract

Census data may be helpful in understanding a region's agricultural sector and thereby improve public policy and regulation. The present study empirically assessed the importance of agriculture in both the Republic of Panama and Panama's Herrera province using published and unpublished 2000 agricultural census data. A minimum farm size of 3 ha was selected in order to focus the analysis on rural subsistence and commercial farming activities. Herrera is noticeably more agrarian than the Republic of Panama. Female-headed households and farmers with less land are less dependent on farm income than male-headed households and larger-scale farmers. Pasture is more prevalent on titled land compared to untitled land, while fallowed and forested land is less prevalent. Cattle and pastures are very prevalent in Herrera, and improved grasses cover a greater percentage of titled pastureland compared to untitled pastureland. Recommendations arising from this study are that: 1) the Ministry of Agriculture and Livestock Development use farm numbers and area to guide personnel placement in a given region; 2) non-farm employment of small-scale farmers and women be considered an important rural subsistence strategy which may make it difficult to adopt agroforestry technologies; and 3) the political and policy context of agriculture be reshaped so titling agricultural lands leads to sustainable use and increased forest cover on agricultural land.

2.2 Introduction

Agricultural censuses are required by law in many countries and provide periodic baseline data about agricultural activities within nations and their regions (FAO 1978). This information can be used to improve agricultural sector public policy and regulation (Clark 1982). Developing nations' agricultural sector may contribute little to Gross Domestic Product (GDP) but is important because agriculture is often the largest source of rural employment, food security and economic stability in developing countries (Asian Productivity Organization 1995). Ahn *et al.* (2002) indicate that agricultural census data is important for understanding the effects of land use on people and the environment.

Boserup (1970) made clear the importance of women in development and agriculture. Women are thought to grow more than 50% of world's food (FAO 1995). However, women's roles are not the same in all regions (ESCWA 2001). In Latin America, women farm plots with their male counterparts (Quisumbing *et al.* 1995), and their contributions have traditionally been underestimated because women are mainly engaged in subsistence farming (FAO 1998). Latin American women have been perceived as primarily responsible for household activities (Hamilton 2000). Women often play a key role in food security (FAO 1998) through both farm production and non-farm work (Quisumbing *et al.* 1995).

Non-farm employment is an increasingly important part of rural economies (Lanjouw and Lanjouw 2001). Women's non-farm work is often poorly remunerated but does offer a means of economic security (Lanjouw and Lanjouw 2001). It is also important because, in Latin America, women are culturally excluded from some types of farm labour for example, clearing forest and weeding pastures (personal observation). Non-farm employment can be so important to women that agricultural activities play a secondary role in income generation (Knaster 1976). Female-headed households in Latin America are among the poorest social groups in rural society (FAO 1998). Lack of secure tenure is an impediment to women's food security goals (Quisumbing *et al.* 1995).

Agrarian reform has been pursued throughout Latin America but has been of variable success (Lastarria-Cornhiel and Melmed-Sanjak 1999). Women in particular have been excluded from these land reform programs (Hamilton 2000). In most Latin American countries skewed land tenure structure exists especially in Central America where land reform has had a limited impact (Shearer *et al.* 1991). Generally, land tenure in Latin America has been based on private ownership with heavy land concentration leaving most farmers with only small plots (Lastarria-Cornhiel and Melmed-Sanjak 1999). Titling land legalizes private ownership. Titled land is distinguished from untitled land in Panama through its registration with the Property Registry (Contraloria 2001). While all agricultural land in developed nations such as Canada are either owned or leased (Statistics Canada 2002), many Panamanian farmers do not have title to their land (Elton 1997). Titled land gives farmers access to credit (Maxwell and Wiebe 1998) and provides an incentive to improve land because use of improvements is secure (Shearer *et al.* 1991). Secure land tenure is viewed as having an important positive impact on tree planting (Raintree 1987; White and Runge1994; Unruh 1995; Walters *et al.* 1999). Simmons *et al.* (2002) call secure tenure 'the most widely cited essential ingredient for the success of any type of conservation effort' in any part of the world. However, tree planting may compete with other land uses such as agriculture (Simmons *et al.* 2002).

Pastures and cattle ranching became major components of Central American agricultural systems in the late 1960s through the 1970s (Myers 1981). Pasture creation has been encouraged through tax (Myers 1981) and credit (Ledec 1992) incentives for cattle ranching, and by the low costs of expropriating large areas of land through cattle ranching (Hetch and Cockburn 1989). Improving tropical pastures with leguminous forages has been largely limited to Australia (Mannetje 1997). This partly explains the low-carcass weights achieved in most tropical countries (Delgado *et al.* 2001). Grass species adapted to poor soil conditions such as the *Brachiaria* species have been widely used in pasture improvement in tropical America (Pizarro *et al.* 1996). However, lack of secure land tenure decreases the willingness of farmers to improve pastures (Mannetje 1997).

The objective of this study was to describe Panamanian agriculture in the year 2000 using census data, and compare Herreran agriculture to agriculture in Panama as a whole. This is necessary because tabular census data are not easily used in policy making or research. Comparing Herrera with the Republic of Panama reveals how Herrera (a traditionally agricultural province) differs from the nation as a whole. This information is valuable when planning and conducting research in Herrera. Analysis of census data looking for effects across all provinces provides more weight to findings than the normally used national totals. If these data are not analyzed, they cannot inform policy and the validity of census expenditures is questionable.

2.3 Materials and methods

2.3.1 Study area

Panama is located between 7°12'07" and 9°38'46" N and 77°09'24" and 83°03'07" W (Comisión Nacional de Recursos Fitogenéticos de Panamá 1995) and is Central America's isthmus, joining Costa Rica to Colombia. Panama has a surface area of roughly 75 500 km^2. Its 2001 estimated population was 2.9 million (World Bank 2002) with a population density of 38 inhabitants/km^2.

Panama is divided into eight provinces. Herrera province is located between 7°13'00" and 7°37'30" N and 80°4'30" and 80°22'30" W (Jaen 1962) with a surface area of 2 300 km^2, a 1998 estimated population of 103 000 people and a population density of 44 inhabitants/km^2 (Contraloria 2000a). Herrera province is divided into seven districts (Figure 2.1). Panama has 12 life zones according to Holdridge's classification of which Herrera contains 7 (IGNTG 1988) (Table 2.1). Annual precipitation in Panama ranges from slightly under 1000 to 7000 mm annually (IGNTG 1988). In general, near the Caribbean >3000 mm falls annually while near the Pacific <2000 mm falls (Condit *et al.* 2002). Annual precipitation in Herrera ranges from 900 mm to 2100 mm (IRHE 1998).

Annual median temperature ranges from 14°C atop Panama's highest mountain to 27°C along its coasts (IGNTG 1988). Herrera has annual median temperatures of 25°C in its mountainous region and 27°C in its lowlands (IGNTG 1988). Panama contains entisols, inceptisols, molisols, alfisols, andisols, vertisols and ultisols with ultisols and inceptisols dominating the landscape (Jaramillo 1986). In 2001, Panamanian agriculture contributed 7% to GDP, while the service sector contributed 77% (World Bank 2002).

2.3.2 Study data

Every ten years the Republic of Panama's National Controller has a legal obligation to conduct an agricultural census (Contraloria 2000b). It is taken through the process of enumeration and every Panamanian having an agricultural plot is interviewed. Interviews are conducted directly with the producer, family member of the producer, or the farm administrator (Contraloria 2001). Local people are employed to administer the census in an attempt to reduce false responses (Perez-Lopez 2003 *pers. comm.*). However, the census notes that the "traditional lack of trust that producers have" is a major limitation to accurate data collection (Contraloria 2000b *author translation*). The census does, however, give a general idea of the current state of agriculture in Panama, despite false responses.

The census collects data for all 'agricultural exploitations'. An agricultural exploitation is "all land used entirely or partially for agricultural and forestry activities by a producer and household members." (Contraloria 2001, *author translation*). Hereafter the term farm is used instead of agricultural exploitation. If land is worked separately by another household member this is considered a separate farm. The agricultural producer is defined as the civil or legal person who makes the principle decisions regarding the operation of the farm (Contraloria 2001). Unpublished data and published data for the 2000 agricultural census was obtained from the National Controller and is used throughout this chapter.

2.3.3 Methods

Metrics such as percent cover and productivity were calculated using the census data. The structure of the data was explored based on the provinces of the Republic of Panama and districts of Herrera province. Herrera province was compared to the Republic of Panama, and Herreran districts were compared to Herrera province. The Republic of Panama is hereafter referred to as Panama.

The Ngöbe Buglé, Kuna, and Emberá Comarcas[4] are not considered in provincial comparisons because the data gathered for these areas are of questionable quality (personal observation). As such, national totals do not include these areas. Rounding was used to make numbers more intelligible. The census considered hundreds of variables but the present study focused on the areas of: 1) agricultural households, lands, and farm size; 2) dependence on agriculture by male and female headed households; 3) effect of land tenure on land use; and 4) importance of cattle and pastureland.

2.3.4 Statistical analysis

Graphs generated by Sigma Plot 2000 (SigmaPlot 2000) were used to visually assess differences between categories (provinces, titled and untitled lands, male and female headed households). Cluster analysis using PC-ORD (McCune and Mefford 1999) was employed to describe the relationships between titled and untitled lands in each province on the basis of percent land cover for different land uses. The cluster analysis employed Ward's Method with a Euclidian distance measure (McCune and Grace 2002). Correlations were performed to assess the association between land use in Herrera and land use in Panama. Variables having a non-normal distribution were analyzed using Spearman's rank correlation (Spearman 1904). The assumption of normality was tested using the Shapiro-Wilk test (Shapiro and Wilk 1965). An α of 0.05 was used to evaluate the significance of all tests.

2.4 Results and discussion

2.4.1 Agricultural households, lands, and farm size

It has been estimated that Panamanian agriculture in 2000 contributed only 7% to GDP (World Bank 2002). Despite this limited contribution to the GDP, the 2000 agricultural census recorded over 237 000 farms belonging to 232 000 households and supporting just over 1 million people, or $\approx$ 33% of Panama's population. Unfortunately, the agricultural census does not separate small hobby gardens and urban agriculture from more extensive operations. Because the present study was more interested in rural subsistence and commercial agriculture, a minimum farm size was set at 3 ha. A 3 ha cut off was chosen for the present study because field

[4] Comarcas are territories belonging to Panamanian indigenous groups and serve as administrative units that are self-governed in coordination with the Panamanian government.

observations suggest this is the minimum amount of land that a true farming household will possess.

When a 3 ha minimum farm size is employed, Panama has only 74 000 farms belonging to 71 000 households, supporting 321 000 inhabitants or approximately 11% of Panama's populace. Females only head 6 000 (9%) of these households. Jaizary *et al.* (1992) reported that in 1988 21% of Panama's rural households were female-headed. Thus, female-headed households seem not favour agriculture as an economic activity. In contrast, Herrera has 7 000 farms belonging to 6 000 households, supporting 31 000 people or 30% of its population, compared to 11% of the nation's population. Females only head 400 (7%) of these households. While some male-headed households in Herrera manage farms of more than 2 500 ha in size, female-headed households do not manage farms over 500 ha in size. Thus, female-headed households engaged in agriculture are not common and may be more marginalized than male-headed households. Vulnerability of female-headed households is a global concern and negatively impacts food security (Quisumbing *et al.* 1995).

Some studies have not attempted to remove hobby farms from the census data before analysis. Jazairy *et al.* (1992) used a 3 ha maximum size to define small-scale farmers in Panama and thereby determined that Panama had 429 thousand small-scale farmers in 1988. This number is clearly different from the above census determinations. Jazairy *et al.* (1992) do not discuss the urban or hobby nature of such farms. Nor do they mention that the definition of small-scale may vary from country to country. In Latin America and the Caribbean, for example, small-scale farms in Haiti may be <2 ha whereas in Brazil small-scale farms may be >50 ha (Nair *et al.* 1991). Elton (1997) used Panamanian agricultural census data to determine that agricultural land distribution in Panama was among the most inequitable in Latin America. Like Jazairy *et al.* (1992), Elton (1997) considered the large number of 'farms' under 0.5 ha to be true farms rather than hobby gardens or urban agriculture. All discussion of agricultural statistics from this point on is for farms of 3 ha or more, unless otherwise indicated.

Farms cover 184 000 ha or 79% of Herrera's 234 000 ha surface. This is one of the highest percentages among Panamanian provinces and far surpasses the national total of 37% (Table 2.2). As such, while Herrera makes up only 3% of Panama's landmass (data not shown) it contains 7% of its agricultural lands (Table 2.2). These lands are not distributed evenly among Herrera's seven districts (Table 2.3). Pesé has almost all its territory dedicated to agricultural activities (99%), whereas Chitré, a small district housing the provincial capital has less of its land dedicated to agricultural use (67%) (Table 2.3). Ocú is the district with the most agricultural land

(51 000 ha or 27% of Herrera's agricultural land) but being a larger district, this amounts to only 82% of its surface area (Table 2.3).

Panama's history partly explains the prevalence of agricultural lands in Herrera. Herrera is considered to be one of the first areas inhabited in Panama because of the presence of dry forest lifezones in its lowlands. Holdridge (1967) suggested that dry lifezones are well adapted for agricultural use. Even today dry ecological zones in the Amazon are deforested at faster rates than wetter ecological zones (Laurance 2002). The established agricultural nature of Herrera province contrasts with the small percentage of provincial land under agriculture in Darién (14%) and Bocas del Toro (11%) (Table 2.2). Darién and Bocas del Toro are considered to be Panama's agricultural frontiers (Elton 1997) and until recently poor road access has hindered agricultural development in these regions.

2.4.2 Dependence on agriculture

Of the 71 000 Panamanian households involved in agriculture only 28 000 (39%) report being completely dependent on farm income. When these completely dependent households are pooled with households who report making most of their income from farming, the number of households dependent on farming in Panama grows to 32 000 (46%). Thus, the majority of 'farming' households (54%) are not dependent on farm income. Dependence differs on the basis of whether households are female or male-headed.

Only 25% of female-headed agricultural households are solely dependent on farm income and 6% are mostly dependent on farm income (data not shown). Thus, 31% of female-headed households are dependent on farm income. This contrasts with the 47% of male-headed households that are similarly, dependent. Of this 47%, 40% are solely dependent on farm income and 7% are mostly dependent on farm income. These low levels of dependence indicate the importance of off-farm agricultural and non-agricultural income, especially in the case of female-headed households. Lanjouw and Lanjouw (2001) noted the importance of non-farm income in rural areas and reported that rural Panamanian men and women obtained 47% and 93% of their employment from non-farm sources, respectively, in 1998. These differences in employment on the basis of gender agree with the results of the present study regarding dependence on farm income.

The proportion of households solely or mainly dependent on farm income is lowest for the smallest farm size classes (Figure 2.2). The largest farm size classes also have a lower proportion of households that are solely or mainly dependent on farm income (Figure 2.2).

Smaller farmers may be diversifying their income because their land base cannot support household needs.

In Herrera 2 900 (47%) farming households are solely dependent on farm income while 500 (5%) are mainly dependent on farm income (data not shown). The proportion of households dependent on their farms in Herrera is comparable or higher than in Panama for most size classes. This is especially noticeable in midrange size classes (Figure 2.2). Thus, dependence on farm income is greater in Herrera (52%) than in Panama (46%). The national trend for female and male-headed households remains the same in Herrera. There are, however, higher levels of male-headed household dependence on farming. While 49% of male-headed households are solely dependent and 7% are mainly dependent on farm income, these numbers are 24% and 5% respectively for female-headed households.

Greater dependence on farm generated income may indicate that Herreran farmers have higher quality land or have developed techniques that allow them to live off their land more effectively than elsewhere in Panama. However, lower or comparable productivity in Herrera for important staple crops like rice (*Oryza sativa*), corn (*Zea mays*), and cassava (*Manihot esculenta*) (Table 2.4) suggests otherwise. This may indicate that non-farm economic alternatives are lacking in Herrera, thereby forcing people to live off of their land. Low levels of dependence on farm income in Panama suggest off-farm work is important, which makes it difficult to adopt labor-intensive agroforestry technologies. Rao *et al.* (1998) have noted this with regards to alley-cropping[5] and its poor adoption, due to opportunity costs.

2.4.3 Effect of tenure and farm size on land use

Eight different land use types are used to characterize agricultural land in the 2000 census. These are: 1) annual crops, 2) permanent crops, 3) fallow, 4) traditional grasses, 5) improved grasses, 6) natural grasses, 7) forest and 8) other. For the purpose of general description, the crops and grass categories have been collapsed into crop and pasture categories, respectively. The percentage of agricultural land under each use type gives some insight into the importance of different land uses. Land tenure status is known to affect land use (FAO 2002).

[5] Alley-cropping is the sowing of crops inbetween row-planted trees or shrubs which are used to provide mulch for the cropped area.

The percentage of agricultural land that is untitled varies from province to province and ranges from 46% in Chiriquí to 90% in Darién with a national total of 64%[6] (Contraloria 2000b). Titled land is legally owned and is registered with the Property Registry (Contraloria 2001). Untitled land is generally state land occupied with or without use rights (Contraloria 2001). In the present study percent cover of different land use types was calculated within titled and untitled land categories. Rented land was not included in the analysis because title status of rented land was not available. Rented land makes up only 7% of all agricultural lands.

The cluster dendrogram (Figure 2.3) generated by considering percent cover of different land uses on titled and untitled provincial agricultural land is made up of two clusters (solid bars) when cut at a distance of 3.9×10^3 (dashed bar). Units (titled and untitled provincial agricultural land) of the same title status dominate clusters. Thus, the proportions of titled and untitled land dedicated to different land uses (permanent crops, annual crops, fallow, forest, improved grass, traditional grass, native grass, other) is generally similar on the basis of land's title status, irrespective of the province the land is in. Where units of different title status cluster closely they come from the same province. Thus, the dominant relationship based on title status can be obscured by province membership. Lands in the same geographic area (province) likely share biophysical resources, infrastructure, and history that shape land use, irrespective of title status.

Titled agricultural land in both Panama (Figure 2.4) and Herrera (Figure 2.4) has a greater percentage of its surface area dedicated to pasture (68% and 76%) and a smaller percentage of its surface area dedicated to forest (10% and 5%) and fallow (7% and 4%) than does untitled agricultural land (Panama: 45%, 19%, 18%; Herrera: 55%, 10%, 17%, pasture, forest and fallow, respectively). Forests are defined as five year or older secondary growth (Contraloria 2001). The relative magnitudes of land use percent cover on titled and untitled lands are similar for both Panama and Herrera, as indicated by large positive correlation coefficients for uses of untitled ($r = 0.96$, $p = 0.01$) and titled ($r = 0.9$, $p = 0.04$) land. However, the absolute magnitudes of these uses do differ (Table 2.5).

Herrera has a noticeably smaller percentage of land dedicated to forest and other uses on both titled and untitled lands than in Panama (Figure 2.4). Herrera also has a noticeably higher percentage of land dedicated to pasture than does Panama on both titled and untitled land (Figure 2.4). Forest covers a smaller percentage of titled agricultural land compared to untitled agricultural lands in all provinces except for Darién (Figure 2.5). Conversely, pasture covers a larger percentage of titled agricultural land compared to untitled agricultural lands in all

[6] These percentages are calculated using all farms not just those of 3 ha and more. Thus, they are slight overestimates.

provinces (Figure 2.5). It can be assumed that pastures were previously forested because rangeland does not naturally occur in Panama according to Holdridge's life zone classification (IGNTG 1988).

The tendency for titled land to have less of its area forested and more of its area dedicated to pasture is the result of many processes. Firstly, land in Latin America has generally been more easily titled if use of the land can be proven (Ledec 1992), which has typically been achieved by removing forest cover (Hetch and Cockburn 1989). In Panama, (until 1994) the agrarian code of 1962 encouraged deforestation as a precondition to obtaining possession rights or legal title to land (Joly1989). Secondly, extensive pastures are one of the easiest ways for wealthy speculators to lay claim to large tracts of land (Hetch and Cockburn 1989). Thirdly, economic markets (Myers 1981), tax incentives (Myers 1981), and subsidized credit (Ledec 1992) have favoured investment in cattle ranching. Farmers with titled land have most easily accessed these incentives, thereby encouraging deforestation for pasture creation on titled land. Lastly, 24% of Panama's surface area has protected area status (Fischer and Vasseur 2000). These protected areas by nature have more forest, but titling of farmland is not permitted.

The findings of the present study contrast with Simmons *et al.*'s (2002) finding that trees are 15.4 times more likely to be planted on titled land in Brazil and Panama compared to untitled land. These findings are not mutually exclusive. Tree planting may be greater on titled land but may be out-paced by forest conversion to pasture. The situation described by the present census data suggests that titling land has resulted in the reduction of forest cover.

Titled agricultural lands have a smaller percentage of their area dedicated to fallows in all provinces except Bocas del Toro (Figure 2.6). This is in agreement with development theory, which suggests that titled land will be worked more intensively than untitled land (Shearer *et al.* 1991). However, untitled land in all provinces except Bocas del Toro has a greater proportion of its area dedicated to crops (permanent and annual) (data not shown). Thus, use of titled land has mainly been intensified through pasture creation, perhaps the result of past incentives for cattle ranching. On untitled land, as average farm size increases so does the percentage of land under forest in both Herrera and Panama (Table 2.6). In contrast, on titled land the percentage of land covered by forest marginally decreases with increasing average farm size in Herrera while in Panama it inconsistently and weakly increases. (Table 2.6). Large agribusiness and extensive cattle ranching on titled land may have reduced forest cover on titled land regardless of farm size, whereas subsistence agriculture on untitled land has not encouraged deforestation because land development beyond subsistence needs is not prevalent or needed. Sepulveda (1987) observed a similar phenomenon of increasing forest cover with increasing farm size in Honduras (1974 census data), but did not consider the effect of title status.

2.4.4 Cattle and pastures

In Panama 49% of farms have cattle whereas in Herrera 62% of farms have cattle. Panama has a national cattle herd of 1 500 000 animals distributed over 36 000 farms. Herrera has 138 000 head of cattle distributed over 4000 farms (9% and 11% of Panama's totals, respectively). Farms with cattle and cattle numbers are distributed unevenly among Herrera's seven districts (Figure 2.7). Ocú has the largest number of cattle (34 000 head) and cattle-owning farms (1200) in Herrera.

The percentage of the total herds in Herrera and Panama, which are calves, cows, bulls, feeder bulls, draft bulls, heifers, and yearling bulls, are similar. Draft bulls are so uncommon they make up less than 0.5% of total cattle, reflecting the lack of animal traction in Panama. Cows are the dominant class of cattle, making up 38% and 39% of cattle herds in Panama and Herrera, respectively. Calves, yearling bulls, and heifers make up similar percentages of the herds. In Herrera they make up 20%, 18%, and 21% of the cattle herd respectively, while in Panama they represent 17%, 21%, and 18% of cattle respectively.

Almost all districts in Herrera have cattle numbers distributed among the cattle classes in a similar manner. The noticeable exceptions are Los Pozos and Santa María. In Los Pozos, 44% of cattle are feeder bulls (data not shown). This prominence of feeder bulls in Los Pozos suggests that this district's pastures are being used to fatten cattle for slaughter. In contrast, in Santa María only 3% of cattle are feeder bulls and 44% of cattle are cows. This may be because the milk industry is more established in Santa María.

Pasture grasses are classified into three types: improved, traditional, and natural. Improved grasses are defined as highly productive exotic grass species such as *Brachiaria* species and *Digitaria swazilandensis* (Contraloria 2001). Traditional pasture grasses are grass species which are sown but not 'improved'. These include faragua grass (*Hyparrhenia rufa*) and ratana grass (*Ischaemum ciliare*) (Contraloria 2001). Natural pasture grasses are not intentionally sown and are thus a number of unnamed native species (Contraloria 2001). In Panama and Hererra, improved pastures cover 240 000 and 22 000 ha, respectively. This represents a small area, compared to the pasture sown to traditional and native grass species which cover 990 000 and 290 000 ha, respectively, in Panama and 85 000 and 51 000 ha, respectively, in Herrera.

When coverage is considered in terms of land tenure, a slightly different pattern emerges. Compared to Panama, Herrera has a smaller percentage of its pastures sown to improved grasses on both titled and untitled lands (Table 2.7). However, the percentage of titled pasture in both Panama and Herrera, which is improved, is much greater than the percentage of untitled pasture, which is improved (Table 2.7). This suggests that pasture owners with titled land have had both the means and will to improve their pastures. Theoretically, titled lands are more likely to receive improvement because the improvement is secure (Shearer *et al.* 1991). Mannetje (1997) reported that lack of title was a major impediment to pastureland improvement in the tropics. Farmers with the means to title land are also more likely to have the means to improve their land (Maxwell and Wiebe 1998). Titled land can also be used to access credit for land improvement (Maxwell and Wiebe 1998). Seed costs for establishing 1 ha of improved pastureland are approximately $50 US (personal observation), a large investment for resource-poor farmers.

Traditional grasses cover a smaller percentage of titled than untitled land, while natural grasses cover a slightly larger percentage (Table 2.7). Thus, improvement of titled pastureland with traditional grasses is not as prevalent as improvement of untitled pastureland with these grasses. The greater prevalence of natural grasses (unimproved pasture) on titled pastureland compared to untitled pastureland may be the result of land expropriation through cattle ranching with no concern for pasture productivity.

2.5 Conclusions

Despite contributing a small percentage to Panama's GDP, agriculture touches the lives of many Panamanians, especially in Herrera province. Herrera has a large amount of its landmass dedicated to agriculture. Household dependence on farm income generally increases with increasing farm size. In Herrera a higher proportion of households are dependent on farm income for most farm sizes, compared to Panama as a whole. A smaller proportion of female-headed households are dependent on farm income than male-headed households. This dependence suggests that female-headed households and smaller-scale farmers may find it difficult to adopt labour-intensive agroforestry technologies. However, there are substantially fewer female-headed farming households than male-headed ones.

Cluster analysis suggested that title status is important in determining land use, with untitled lands clustering closely. Titled land has a greater percentage of its area in pasture and a smaller percentage of its area in forest and fallow than does untitled land. This situation is similar in all provinces, with the exception of forest cover in Darién. Pasture for cattle is the principal use of agricultural lands. Owning cattle is more prevalent in Herrera than it is in Panama. While draft bulls are unimportant, other classes of cattle make significant contributions to herds in both Panama and Herrera. Districts within the province of Herrera with more feeder bulls are likely important for raising cattle for slaughter, while districts with more cows are likely more oriented towards milk production. Improved grasses are more prevalent in Panama than Herrera but cover a greater percentage of titled pastureland than untitled pastureland in both Panama and Herrera.

2.6 Recommendations

In Herrera the number of farms, quantity of agricultural land, and percent of district land in agricultural use should be used to guide assignment of human resources to Ministry of Agricultural and Livestock Development district offices. This would result in more personnel being assigned to districts like Ocú. The importance of non-farm employment of small-scale farmers and particularly female-headed households needs to be incorporated into rural extension activities. Levels of non-farm employment estimated from household dependence on farm income should be used to assess the opportunity costs of adopting agroforestry technologies. The political and policy context of agriculture must be attended to if titling agricultural lands is to lead to sustainable land use. Specifically, tree planting will not keep pace with deforestation for pasture creation if policies continue to favour providing title for deforested lands and promoting cattle ranching through credit and tax incentives.

2.7 Tables and figures

Table 2.1 Holdridge defined life zones[7] in Panama and Herrera.

Life zone	Place of Representation
Tropical moist forest	Panama excluding Herrera
Montane wet forest	Panama excluding Herrera
Lower montane moist forest	Panama excluding Herrera
Montane rainforest	Panama excluding Herrera
Lower montane rainforest	Panama excluding Herrera
Premontane rainforest	Panama and Herrera
Tropical wet forest	Panama and Herrera
Premontane wet forest	Panama and Herrera
Lower montane wet forest	Panama and Herrera
Premontane moist forest	Panama and Herrera
Tropical dry forest	Panama and Herrera
Premontane dry forest	Panama and Herrera

Table 2.2 Distribution of agricultural land (ha) in Panama by province, expressed as percent of national and provincial total surface area in 2000*.

Province	Agricultural Land (Ha)	Percentage of Panama's Agricultural Lands (%)	Percentage of Provincial Land (%)
Bocas del Toro	96000	3	11
Cocle	238000	9	48
Colón	166000	6	34
Chiriquí	412000	15	48
Darién	231000	8	14
Herrera	184000	7	79
Los Santos	302000	11	79
Panamá	474000	17	40
Veraguas	588000	21	52
Total	**2696000**	**100**	**36**

*Data obtained from unpublished and published agricultural census data sources provided by the National Controller of Panama.

[7] Holdridge's classification is commonly used in Central and South America. It uses mean annual temperature and precipitation and assumes temperature can be used to estimate potential evapotranspiration. These data are used to define humidity provinces and temperature zones. Each combination of humidity province and temperature zone is a life zone and is characterized by a particular vegetation type (Young 1987).

Table 2.3 Distribution of agricultural land (ha) in Herrera by district expressed as percent of provincial and district total surface area in 2000*.

District	Agricultural Land (Ha)	Percentage of Herrera's Agricultural Lands (%)	Percentage of District Land (%)
Ocú	51000	27	82
Los Pozos	33000	17	87
Las Minas	31000	16	70
Parita	28000	15	78
Pesé	28000	15	99
Santa María	12000	7	79
Chitré	6000	3	67
Total	**184000**	**100**	**79**

*Data obtained from unpublished and published agricultural census data sources provided by the National Controller of Panama.

Table 2.4 Productivity of various crops in the Republic of Panama and Herrera in 2000*.

Crop	Productivity (t/ha)		Herrera as % of Panama
	Republic of Panama	Herrera	
Corn	1.2	1.4	110
Cassava	4.1	3.8	92
Rice	2.3	1.6	68
Pigeon Pea	0.46	0.98	213
Yam	5.8	14	248
Sugar Cane	62	54	86
Taro Root	2.4	2.6	108

*Data obtained from unpublished and published agricultural census data sources provided by the National Controller of Panama.

Table 2.5 Landuses as percent of titled and untitled lands in the Republic of Panama and Herrera Province in 2000*.

Land use	Titled Land		Untitled Land	
	Panama (%)	Herrera (%)	Panama (%)	Herrera (%)
Crops	12	13	13	17
Pasture	68	76	45	55
Fallow	7	5	18	17
Forest	10	4	19	10
Other	4	2	5	2

*Data obtained from unpublished and published agricultural census data sources provided by the National Controller of Panama.

Table 2.6 Average farm size and percentage of titled and untitled land under forest for ten farm size classes in the Republic of Panama and Herrera in 2000*.

	Herrera				Panama			
	Titled		Untitled		Titled		Untitled	
Farm Size Class (Ha)	Average Farm Size (Ha)	Percentage of Land Under Forest (%)	Average Farm Size (Ha)	Percentage of Land Under Forest (%)	Average Farm Size (Ha)	Percentage of Land Under Forest (%)	Average Farm Size (Ha)	Percentage of Land Under Forest (%)
3.00 - 3.99	3	3	3	4	3	7	3	6
4.00 - 4.99	4	4	4	3	4	7	4	7
5.00 - 9.99	7	5	6	6	7	8	6	8
10.00 - 19.99	13	5	13	5	13	8	13	11
20.00 - 49.99	30	4	28	8	30	8	29	14
50.00 - 99.99	68	3	62	12	67	8	63	20
100.00 - 199.99	135	7	121	15	132	9	122	22
200.00 - 499.99	274	3	272	32	290	10	246	28
500.00 - 999.99	694	2	-	-	674	8	597	38
1000.00 - 2499.99	1282	3	-	-	1351	12	1278	41
2500.00 and more	3971	1	-	-	3339	21	49300	38

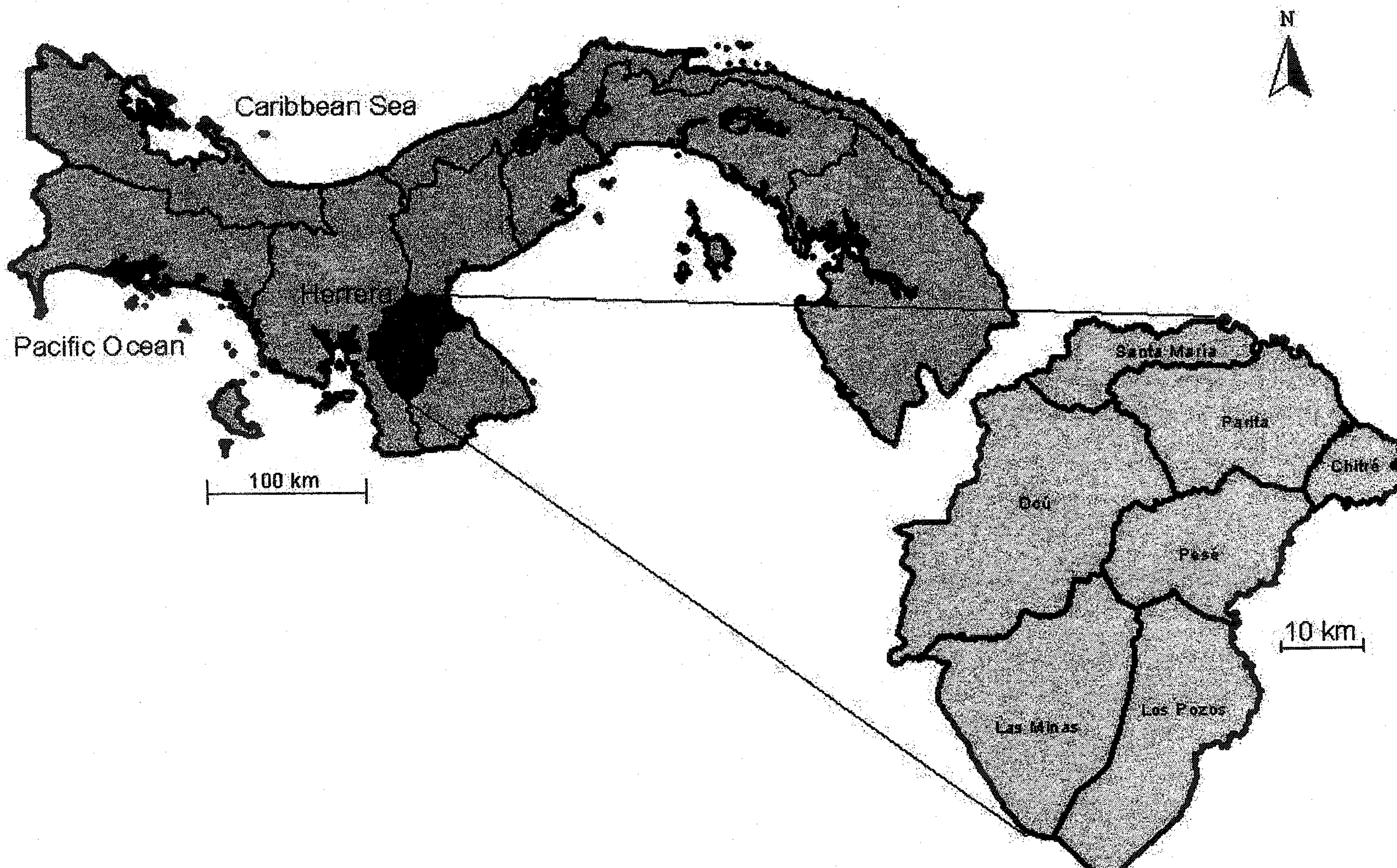
*Data obtained from unpublished and published agricultural census data sources provided by the National Controller of Panama.

Table 2.7 Percentage of titled and untitled pastureland under different types of pasture grasses in Herrera and the Republic of Panama in 2000*.

	Herrera		Panama	
Pasture Type	**% of Titled Pasture**	**% of Untitled Pasture**	**% of Titled Pasture**	**% of Untitled Pasture**
Improved	16	4	23	8
Natural	24	15	21	18
Traditional	60	81	56	74

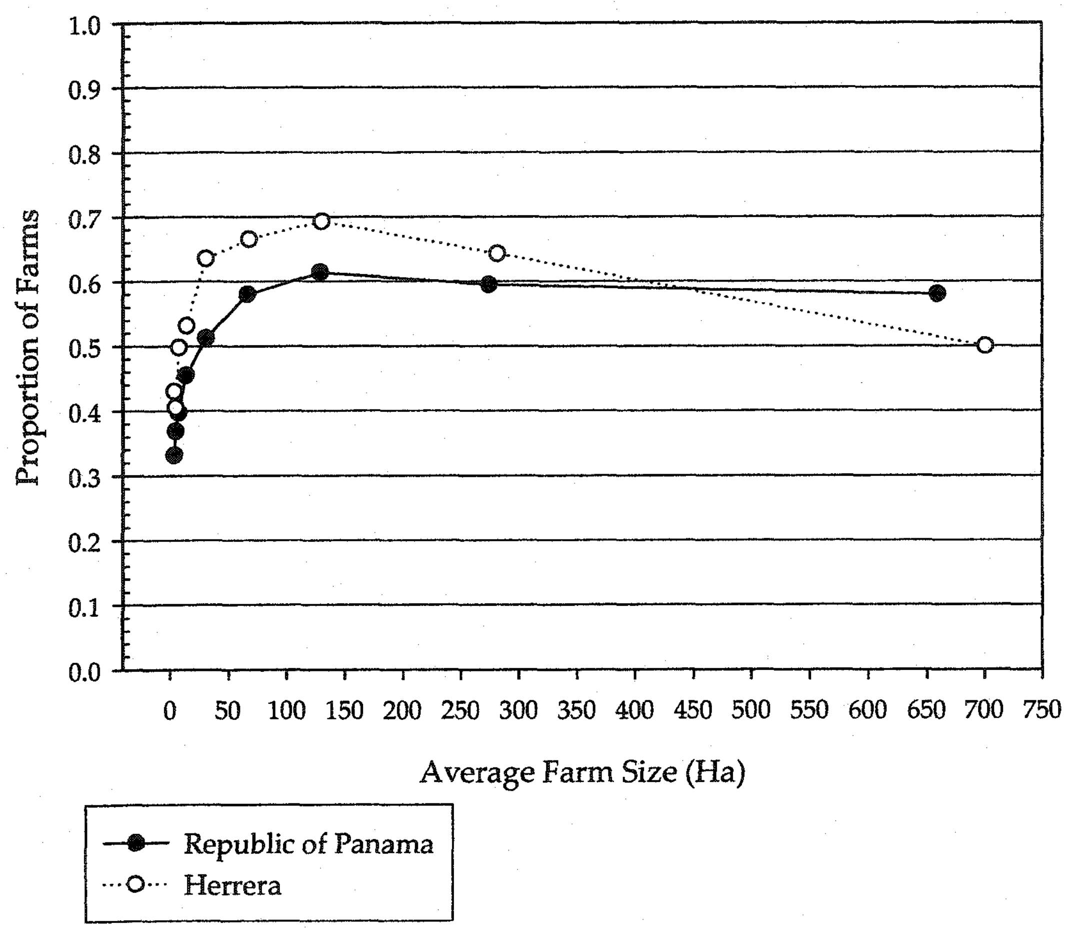
*Data obtained from unpublished and published agricultural census data sources provided by the National Controller of Panama.

Figure 2.1 Map of Panama and the districts of Herrera province.



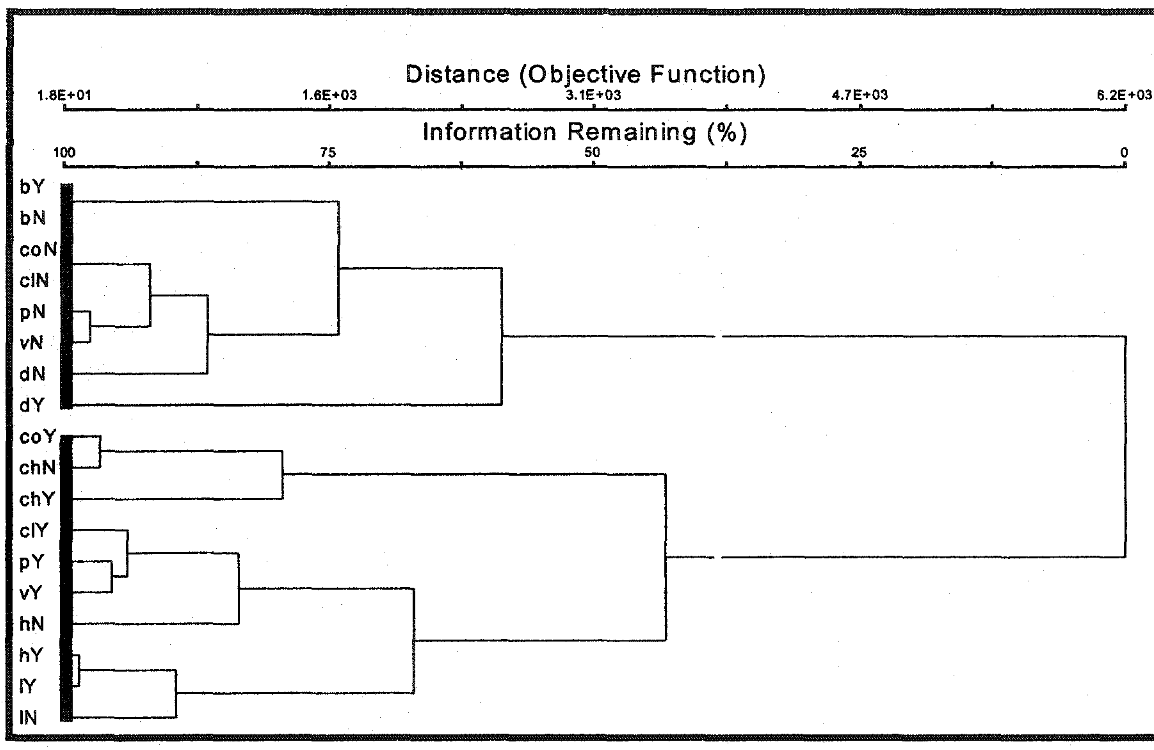
Source: EoN Systems (2002).

Figure 2.2 Proportion of farms that are dependent on farm income by average farm size* for 10 size classes in the Republic of Panama and Herrera province in 2000.**



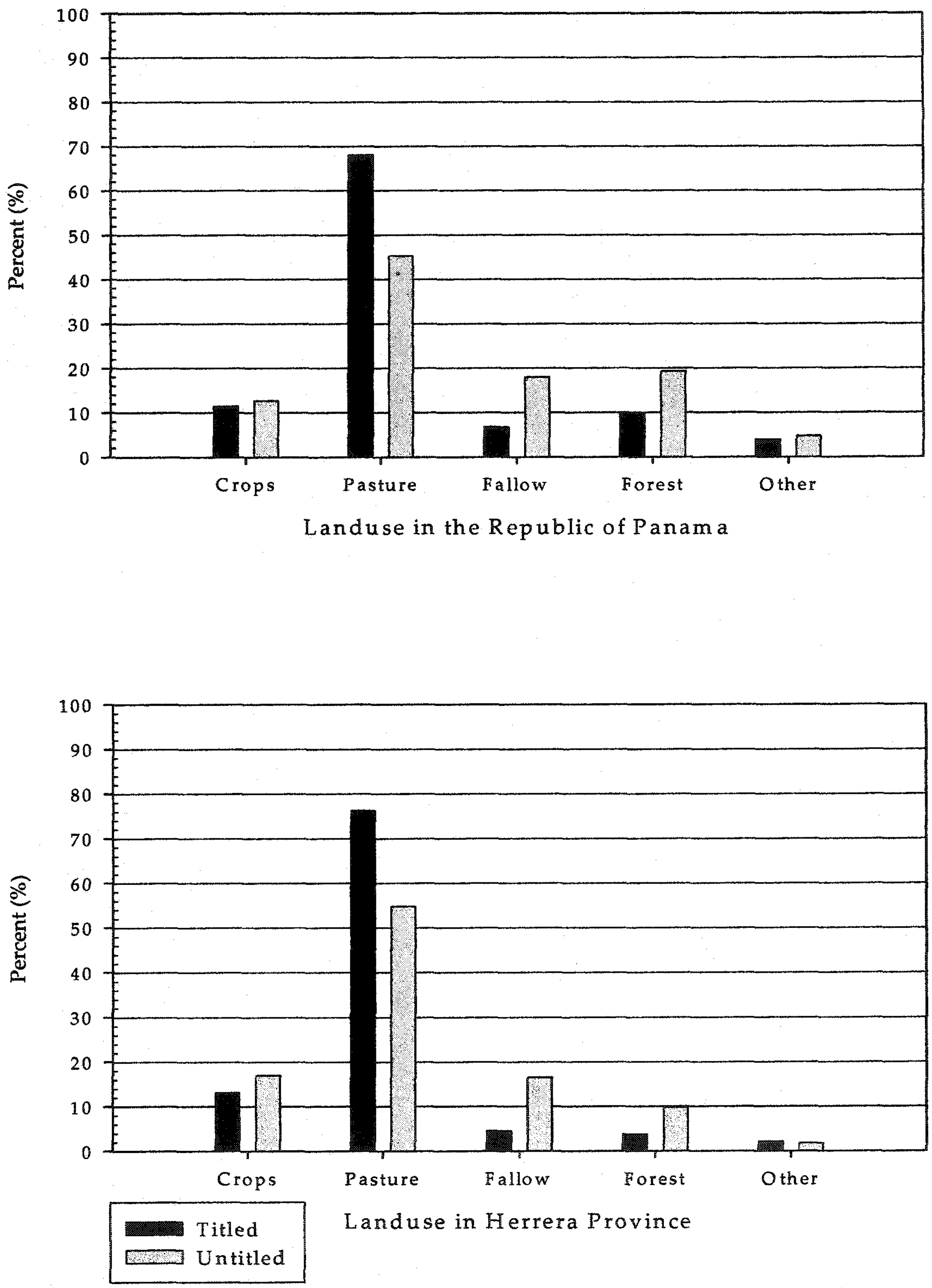
*Each data point is average farm size in ha for a National Controller defined farm size class (3 - 3.99, 4 - 4.99, 5 - 9.99, 10 - 19.99, 20 - 49.99, 50 - 99.99, 100 - 199.99, 200 - 499.99, 500 - 999.99, 1000 - 2499.99).
**Data obtained from unpublished and published agricultural census data sources provided by the National Controller of Panama.

Figure 2.3 Cluster* dendrogram based on land use percent cover (annual crops, permanent crops, forest, fallow, improved, traditional, and native grasses, and other) of titled and untitled agricultural lands in the provinces of the Republic of Panama in 2000***.**



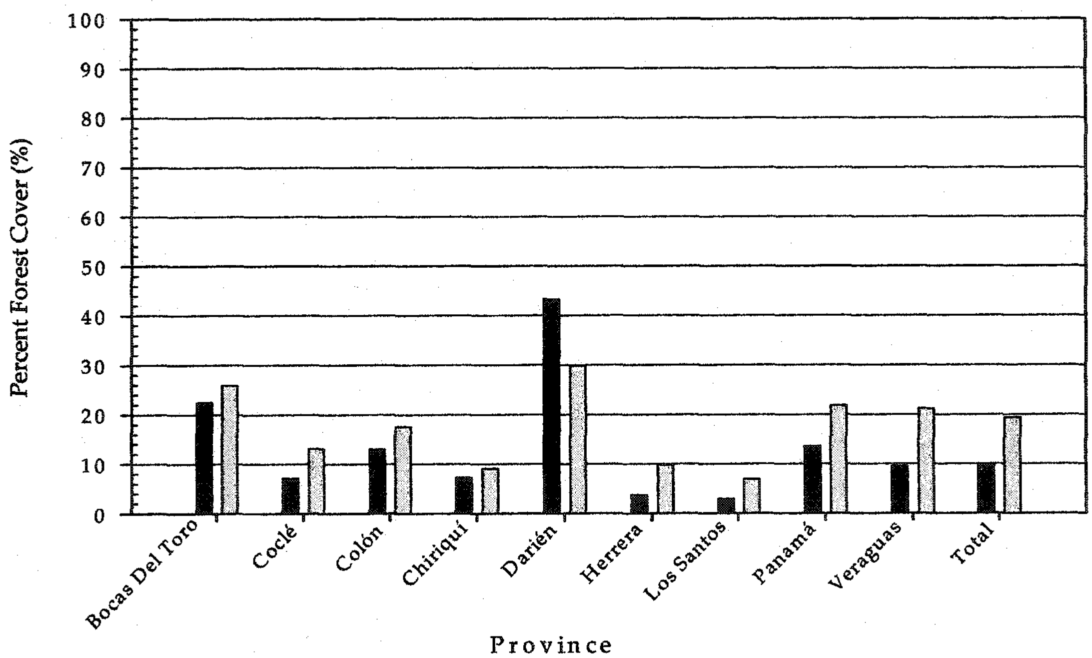
*Cluster analysis employed Ward's Method with a Euclidian distance measure (McCune and Grace 2002).
**Title status: Untitled (N), Titled (Y). Province membership: b = Bocas del Toro, co = Colon, cl = Cocle, ch = Chiriquí, d = Darién, h = Herrera, l = Los Santos, p = Panama, v = Veraguas.
***Data obtained from unpublished, published and to be published agricultural census data sources provided by the National Controller of Panama.

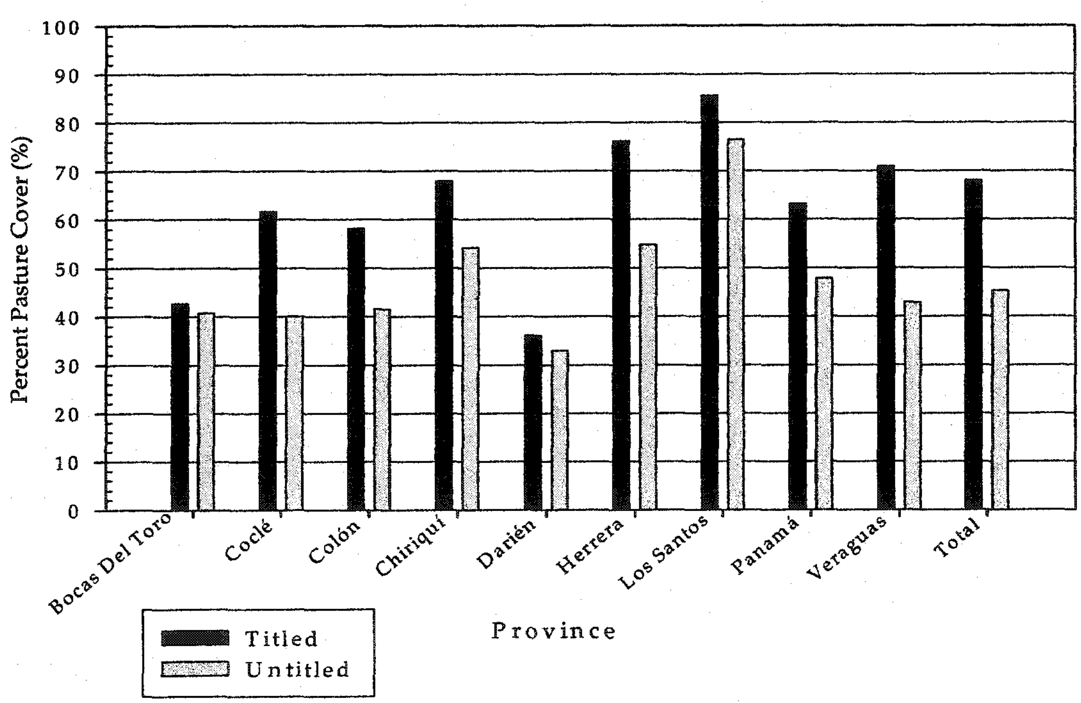
Figure 2.4 Percentage of titled and untitled agricultural land dedicated to various landuses in the Republic of Panama and Herrera province in 2000*.



*Data obtained from unpublished, published and to be published agricultural census data sources provided by the National Controller of Panama.

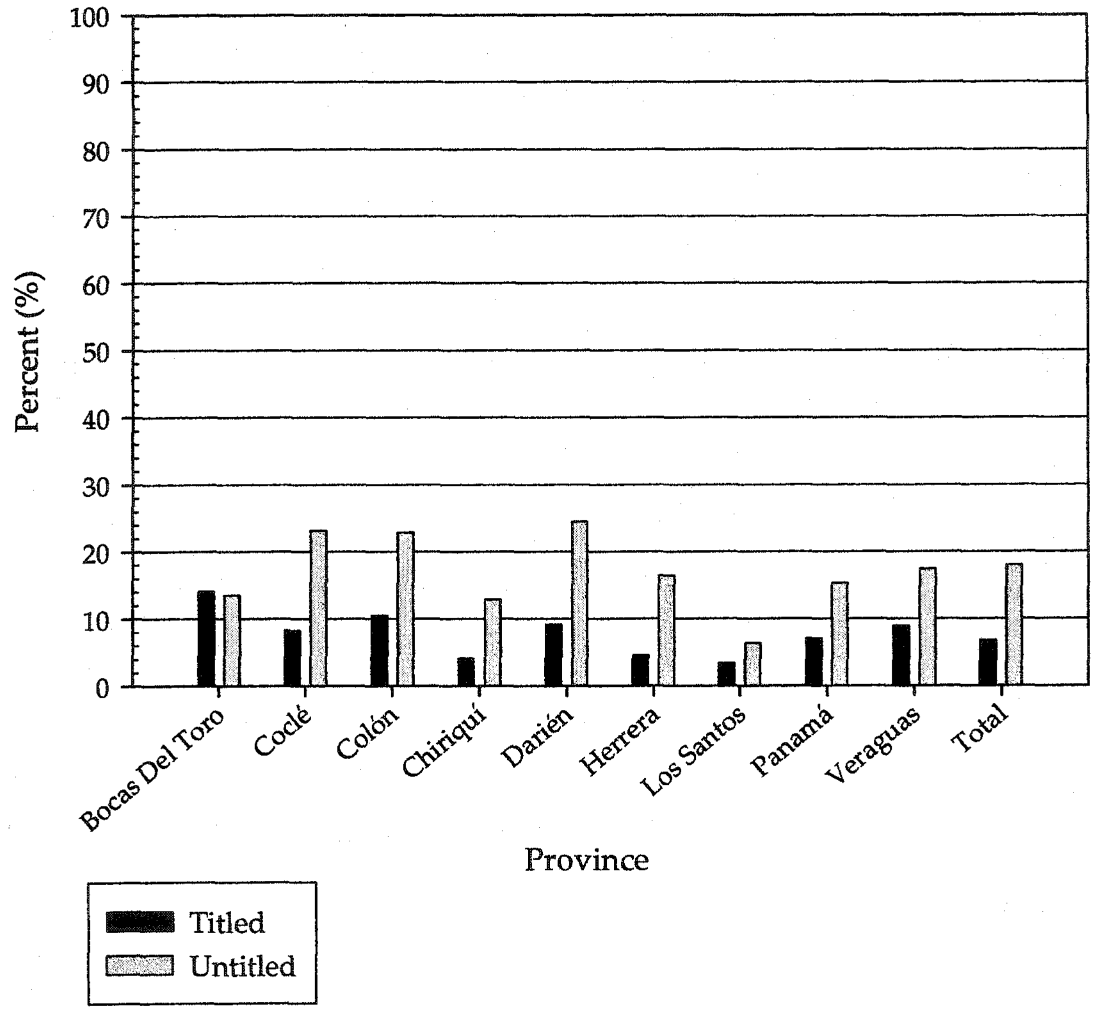
Figure 2.5 Percentage of agricultural land under forest and pasture on titled and untitled land in the Republic of Panama and its provinces in 2000*.





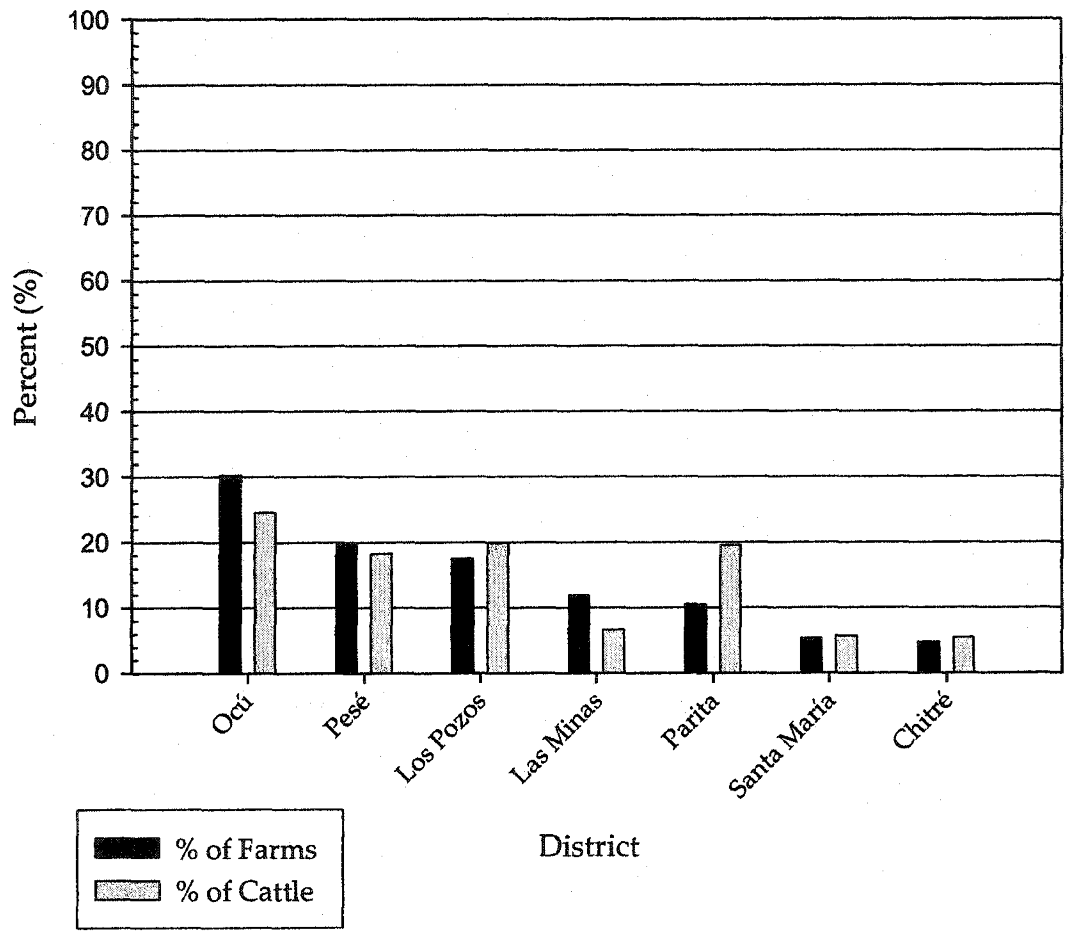
*Data obtained from unpublished, published and to be published agricultural census data sources provided by the National Controller of Panama.

Figure 2.6 Percentage of agricultural land under fallow on titled and untitled land in the Republic of Panama and its provinces in 2000*.



*Data obtained from unpublished, published and to be published agricultural census data sources provided by the National Controller of Panama.

Figure 2.7 Percentage of Herreran cattle and cattle owning farms contained within each district in 2000*, **.



*Data obtained from unpublished, published and to be published agricultural census data sources provided by the National Controller of Panama.
** District percent covers sum to 100%.

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3.0 A survey of small-scale farmers using trees in pastures in Herrera province, Panama.

3.1 Abstract

Herrera province in Panama has suffered massive deforestation due to cattle ranching. Scientific knowledge of tree species use in Herreran pastures is limited and baseline information is necessary for the development of viable silvopastoral systems. The present study employed a survey to describe the current use of trees in Herreran pastures. The Ministry of Agricultural and Livestock Development (MIDA) and the Peace Corps identified eight informants who were interviewed in order to develop a semi-structured interview. The developed survey was then administered to 45 randomly selected small-scale Herreran pasture owners, with stratification by informant gender and farm ecozone. Nine different tree uses were identified. There were differences in the popularity and perceived species richness of these use categories. Sørenson's similarity index indicated that percent similarity between use categories ranged from 0 – 51%. Abundance-diversity curves for use categories were steep with only a few dominant species. Native species tended to receive the highest multipurpose tree priority ratings. Protein banks were not used and are likely inappropriate for most small-scale farmers. However, fodder trees were often retained in pastures and agricultural by-products (stover, immature fruits) were commonly used as feed supplements. Trees provide a number of products and services in Herreran pastures and require further research, with special attention to native species.

3.2 Introduction

Multipurpose trees are woody perennials, grown to provide more than one main product or service to farmers (Huxley 1985). This contrasts with the single product crop approaches that have been adopted by forestry, horticultural and agricultural sciences over the last century (Huxley 2001). Research into multipurpose trees first became noticeable in the late 1970s (Bene *et al.* 1977; King 1979). Multipurpose trees are viewed as particularly appropriate for small-scale farmers (Hedge and Daniel 1992; Winrock International 1988) and are present in silvopastoral systems (Rai *et al.* 2001; Cajas-Giron and Sinclair 2001). Little is known to science about many multipurpose trees, and more research into their management and physiology is needed (Huxley 2001).

Herrera province in Panama is thought to have one of the longest histories of human habitation in Panama (Holdridge 1967). It is said to be Panama's heartland of small-scale farming and has a great deal of cattle ranching (Jaen-Suarez 1978). Approximately 68% of Herrera's agricultural land is under pasture (Contraloria 2000b) and pasture burning is a common practice in the area (Carrasquillas 1984). Herrera's vegetation is diverse and contains seven of the twelve Holdridge life zones found in Panama (IGNTG 1988). However, few botanical collection expeditions have been to this region (Galdames *pers. comm.* 2003).

Pastures cover ≈ 50% of Herrera's landmass (Contraloria 2000b), but little research into pasture trees has been conducted. Holdridge's (1970) dendrological manual for 1000 Panamanian tree species provides botanical descriptions and lists uses for trees found in Herreran pastures, but pasture trees were not the focus of Holdridge's monograph. Central America's Madaleña project (Cannon and Galloway 1995) provided recommendations for living fence species (Madaleña 3 1993). While the National Environmental Authority (ANAM) in Herrera possesses these documents, it is not clear if they are being used. In contrast to the lack of attention Herrera has received, studies of traditional silvopastoral systems have recently been conducted in other regions of Central America (Dagang and Nair 2001, Casasola *et al.* 2001; Harvey and Haber 1999).

Descriptive agroforestry case studies in the Canal Zone of Panama have emphasized the importance of multipurpose trees (Aguilar and Condit 2001; Hauff 1999) and a review of agroforestry projects in Panama recognized the popularity of multipurpose timber species (Simmons *et al.* 2002). Fischer (1998) cited a 1991 project carried out by ANAM, which documented agroforestry and silvopastoral systems in Herrera, but generally there has been little agroforestry and multipurpose tree research specific to Herrera.

Gender has been shown to affect species preference (Franzel *et al.* 1996). In Africa, some trees have gender specific uses (Just and Murray 1996). Agricultural spaces may also be gender specific (Garrett and Espinosa 1988). In Latin America, women are reported to make significant labour and management contributions to home gardens (Marsh and Hernandez 1996; Orcherton and Somarriba 1996). Ngöbe women in Panama are thought to highly value home gardens while Ngöbe men place greater value on field crops (Samaniego and Lok 1998).

Fodder is considered an important product from multipurpose trees (Gutteridge and Shelton 1994). Although fodder trees have a long history in animal husbandry (Robinson 1985), protein banks are a relatively new idea (Kapp 1999). Protein banks are high-density plantings of shrubs or trees that are usually leguminous and produce high protein foliage (Schlonvoigt and Ibrahim 2001). Scientists suggest that, unlike herbaceous vegetation, shrubs/trees resistance to drought will permit the supplementation of cattle diets with high protein fodder during the dry season (Paterson *et al.* 1998). In Herrera, leguminous tree protein banks were introduced in the

1980s as part of a dairy and beef cattle feeding project (Urriola 2002 *pers. comm.*). This system is a production-oriented technology (Murgueitio 2001) and economic analysis of protein banks has been done (Holmann and Ibrahim 2001). Adoption of leguminous forage technologies in the tropics has generally been poor (Sumberg 2002) and protein banks have been no exception (Paterson *et al.* 1998). Still, researchers are optimistic about the potential of protein banks and feel more research would be productive (Schlonvoigt and Ibrahim 2001).

In agroforestry there are always more research questions than available research resources (Wood and Burley 1991). The International Centre for Research in Agroforestry's mid-term plan in the 1990s only allowed for the genetic improvement of 5 multipurpose trees per ecozone (ICRAF 1993). Prioritization of multipurpose tree species for research and genetic improvement is necessary if limited resources are to be used efficiently. Domestication of agroforestry trees in Southeast Asia has emphasized prioritization of multipurpose species (Roshetko and Evans 1997). Some prioritization methodologies rely on expert-defined needs and ecozone adaptability, and the use of pre-existing databases (von Carlowitz 1989) with farmer participation occasionally being encouraged at the evaluation stage (Wood and Burley 1991). Other schemes have directly incorporated farmers into their prioritization methodologies by allowing farmers to rank tree products and services (von Carlowitz 1984), and occasionally tree species (Franzel *et al.* 1996). Farmer gender (Wiersum 1989; Franzel *et al.* 1995) and ecozone (Huxley 2001) are important considerations when studying multipurpose trees because they can affect the appropriateness of a given species for a particular region and clientele.

A review of farming systems research and extension in the tropics reported that multidisciplinary diagnosis of practices and problems was of utmost importance when designing technologies for farmers (Simmonds 1986). Surveys are a practical and efficient way of obtaining baseline information (Bernard 2002) so that researcher-designed systems can be informed by farmers' views and thus improve the chance of farmer adoption.

This study aimed to conduct a survey of small-scale pasture owners in order to:

1) Describe the use of trees in Herreran pastures and their multipurpose nature, considering the effects of use category, ecozone, and informant gender on perceived tree species richness.
2) Prioritize multipurpose species in Herrera for further research.
3) Investigate the current status of protein banks in Herreran silvopastoral systems.

3.3 Materials and methods

3.3.1 Study Area

Herrera is considered to be in one of the first regions of Panama inhabited by humans and settled by Spaniards (Holdridge 1967). It has a large number of small-scale farms and a great deal of cattle ranching (Jaen-Suarez 1978). Of Herrera's 190 000 ha of agricultural land, 129 000 ha (68%) is in pasture, with traditional pasture species covering 85 000 ha (Contraloria 2000b). *Hyparrhenia rufa* is one of the most common traditional species, and pasture burning is a common practice in the area (Carrasquillas 1984). Seven of Holdridge's (1967) life zones – premontane rainforest, tropical wet forest, premontane wet forest, lower montane wet forest, premontane moist forest, tropical dry forest and premontane dry forest - are present within Herrera (IGNTG 1988).

Ministry of Agricultural and Livestock Development officials perceive Herrera as being divided into three ecozones: lowland, transition, and mountainous (Moreno *pers. comm.* 2003). Weather stations in La Villa de Los Santos and La Pitaloza define the precipitation range of Herrera province. La Villa de Los Santos and La Pitaloza received annual precipitation of 980 mm and 2100 mm, respectively, between 1983 and 1997 (IRHE 1998). There is a pronounced dry season during the months of December to April and a bimodal rainy season between May and November (Figure 3.1). Annual mean temperature at La Villa de Los Santos is 27.5°C and varies little throughout the year (Alvarado and Farbridge 1986). No temperature data are available for La Pitaloza.

3.3.2 Methods

The study employed in-home interviews and pasture visits with male and female heads of pasture-owning[8] households. Female household heads were the wives of male household heads except in two instances where they were the sole household head. Initially, the Ministry of Agricultural and Livestock Development and Peace Corps personnel identified eight informants who were thereafter interviewed using an unstructured format. A semi-structured format was developed on the basis of these interviews and pre-tested with an informant selected by

[8] Ownership was considered in terms of social rather than legal recognition of possession. That is, a pasture may be on untitled land but locally the pasture is considered to be owned and managed by a particular farmer.

convenience. Semi-structured interviews (Appendix 6.1) were then conducted with 45 small-scale pasture owners in the province of Herrera. A study of multipurpose trees in Africa interviewed 94 farmers in three countries (Franzel *et al.* 1996). Cajas-Giron and Sinclair (2001) interviewed 54 farmers to characterize silvopastoral systems in Colombia. Pasture owners were selected using stratified random sampling (Bernard 2002), within the bounds of convenience. Stratification was on the basis of farm ecozone and informant gender (Appendix 6.2). Small-scale was defined as owning ≤20 ha of pasture, excluding other agricultural holdings.

The number of small-scale cattle ranches in each district was determined using year 2000 unpublished agricultural census data (Contraloria 2000c; Chapter 2). The number of interviews in each district was then weighted to reflect the proportion of provincial cattle ranches it contained. This number was then slightly adjusted so that interviews were stratified by Ministry of Agriculture Development ecological zones (lowland, transition, and mountainous). Towns within each district containing more than 20 households involved in agriculture, and accessible by public transport (4x4 trucks), were identified using year 2000 household census data (Contraloria 2000a). Towns were then randomly selected so that the required interview number could be obtained for each ecozone, with a maximum of two interviews per town.

Selected towns were visited and informants selected on the basis of convenience, that is: available and willing to participate. In each town an attempt was made to stratify on the basis of gender, however, equal representation was not possible because pastures are a gendered male agricultural space and willing female informants were difficult to find. If no informants were willing or available in a given town, the next nearest town was visited until two interviews had been conducted.

Interviews took from 40 minutes to just over an hour to administer and consisted of four general categories of questions: 1) pasture owner information (age, off-farm work, etc.); 2) animal information (quantity, type, etc.); 3) pasture information (quantity, age, management, etc.); and 4) tree information (species, uses, preference, etc.). Responses were recorded in a notebook during each interview and extra notes made after the interview, when necessary. It was assumed that home interviews would force farmers to recall tree species and their uses solely on the basis of memory. Remembered species and uses were thought to be those of greatest agronomic interest to farmers. Thus, home interviews were expected to identify fewer species and uses than pasture visits that provided visual cueing. Cajas-Giron and Sinclair (2001) used similar interview techniques to characterize silvopastoral systems and examine how farmers use and perceive trees in Colombia. When possible, pastures were visited and notes taken about the presence and absence of species. In two cases 100% and 50% samples of living fence species were taken. All species along 100% and 50% of the fences' length were identified beginning from a randomly selected cardinal point. The interviews and pasture visits were conducted between May and August 2002.

When a species could not be identified in the field or during an interview, a leaf sample was taken (if possible) and identified at the University of Panama's and/or the Smithsonian Tropical Research Institute's herbaria. If positive identification of a tree during an interview could not be reached on the basis of physical descriptors, and no botanical sample could be obtained, it was not included in analyses.

Prior to conducting research the Human Research Ethics Board of the Faculty of Agriculture, Forestry, and Home Economics at the University of Alberta, reviewed and approved this study (Appendix 6.3). An information sheet and a signed consent form were used in the study to ensure that informants' rights were respected (Appendix 6.4 and 6.5).

3.3.3 Statistical Analysis

Semi-structured interviews allowed informants to guide the interview and, in some cases, this resulted in not all questions being answered. For descriptive statistics, response rates of less than 100% are indicated. For inferential statistics, unanswered questions were treated as missing data. Spearman rank correlation (Spearman 1904) was used to analyze non-normal associations between variables. The effect of different tree uses on species richness was evaluated using a parametric two-way analysis of variance with informant as block, and the result was substantiated using rank transformation (Conover and Iman 1976) for the same analysis. Tukey's test (Zar 1999) was used to perform multiple comparisons between treatment means.

The effect of informant gender and farm ecozone on species richness for each tree use category was assessed using the Mann-Whitney non-parametric t-test (Zar 1999) and the Kruskal-Wallis non-parametric one-way analysis of variance (Kruskal and Wallis 1952), respectively. An α-level of 0.05 was used for all tests. The interaction of informant gender and ecozone was not assessed using the multifactor extension of the Kruskal-Wallis test proposed by Scheirer *et al.* (1976) because Toothaker and Chang (1980) found that it is not reliable. Abundance-diversity curves (Zarin *et al.* 1999) and Sørenson's similarity index (Zarin *et al.* 1999) were used to compare species diversity and similarity between different tree uses, respectively.

3.3.4 Rating Multipurpose Species

Upon completion of the interviews, it was evident that pasture owners often perceived all products and services as being of similar importance. As such, prioritization of tree species could not be based on conventional ranking methodologies. Pairwise ranking (Fielding *et al.* 1998) is an alternative and has been used in agricultural on-farm trials (Pimbert 1991). In the present study pairwise ranking would have been too time consuming given the large number of tree uses and species involved. I opted for an alternative prioritization scheme developed on the basis of species use plurality, spread of use, and indications of superiority.

Use plurality can be present at the level of the community or the level of an individual user. At one extreme a tree species may be used by nine different pasture owners for nine different uses while at the other extreme one pasture owner may use a tree species for nine different purposes. "Total number of uses" reported for a species by all informants captures use plurality at the community level, while "mean number of uses" for a species adjusts for use plurality at the user level. Unfortunately, a species mentioned for a large number of uses by only a few farmers will score high for both parameters. This is tempered by the "spread of use" parameter. Spread of use is reflected by the percentage of informants reporting use of a species. Finally, within a given use category, informants may be able to identify species that are superior/preferred for a particular use. "Species preference" within each use category was ranked and points assigned for placement (10 points 1st place, 8 points 2nd place, 6 points 3rd place, 2 points all other places). Species for which preference was never indicated were not ranked and did not receive points. Points were then summed for each species across all use categories and species ranked on the basis of total points.

An overall rating was assigned by summing the ranks for each parameter and dividing by the number of parameters. A particularly important parameter can be assigned extra weight by allowing it to contribute to the overall rating more than once. Spread of use was considered very important because it indicates the potential for widespread adoption. Species rank for this parameter was given double weight when calculating overall rating. Species mentioned by only one pasture owner and having only one reported use were not considered. However, species reported by more than one informant and having only one reported use were considered. Rating was carried out for Herrera province as a whole rather than for its respective ecozones because MIDA and the Panamanian Institute for Agricultural Investigation (IDIAP) desire general provincial recommendations. Rating systems outlined by Franzel *et al.* (1996) used to set priorities for multipurpose tree improvement were the impetus for the above rating system.

3.4 Results and discussion

3.4.1 General

Forty-five interviews were obtained from 51 approached pasture owners, resulting in a response rate of 88%. Despite efforts to make selection of informants as random as possible, selection was not random. This is reflected in the high percentage of informants (16%) that owned stores. Small kiosk stores are common in rural Herrera, but storeowners were also more likely to be captured in the study because they were available during the day and accustomed to conversing. These kiosks also generate cash flow that can be invested in cattle, so kiosk owners often had cattle and pastureland (personal observation).

3.4.2 Tree uses

Unstructured interviews identified eight distinct use categories for which trees were maintained in pastures: 1) shade for animals, 2) shade for water, 3) fodder for animals, 4) living fence stakes, 5) fruit, 6) construction wood, 7) firewood, and 8) medicinal products. A ninth category – posts – was added after five semi-structured interviews because it became apparent that users distinguish between living and dead fence posts, and different tree species populate each of these use categories. For three categories (medicinal products, shade for water, and posts), responses were obtained from less than 100% of informants (41, 41, and 34 respondents, respectively).

The number of users reporting maintenance of tree species in their pastures for particular use categories differed substantially between use categories. Whereas only 17% of pasture owners reported retention of trees for medicinal products, 100% of pasture owners reported retaining trees for shade for animals and living fence stakes (Figure 3.2). The proportion of pasture owners reporting use was not the same for all use categories ($p < 0.001$) according to Cochran's Q test (Cochran 1950). With the exception of shade for water, shade for animals, and living fences all of the use categories are extractive, although fruit and fodder uses are low intensity extraction and not likely to affect tree health (Hetch and Cockburn 1989).

3.4.3 Tree species richness

Hubbell (2001) defined species richness as "the total number of species in a defined space at a given time". A total of 82 different species in pastures were reported as used by small-scale pasture owners in Herrera (Appendix 6.6). However, pasture visits on 36% of the farms revealed that far more species were present than actually mentioned. In some cases this was the result of the cultural construction and perception of use categories. For instance palma real (*Attalea butyracea*) is a common pasture species and used for roof thatch in house construction, but only one informant reported palma real as being used as construction wood because thatch is not considered wood. This situation might be rectified by adding a use category for thatch, by changing wood for construction to materials for construction, or by having species-specific questions for such exceptions.

Most tree species not mentioned in a home interview, but present in a pasture, were not used by the pasture owner despite having known uses. Thus, a survey based on a pasture visit in which uses are elicited for all of the trees present in the pasture will yield different results compared to a survey that asks which trees are retained in pastures for specific purposes. For instance, Harvey and Haber's (1999) survey found farmers reported 19 reasons for having remnant trees in pastures, including aesthetics, oxygen production, and fruit for birds.

The number of species retained per farm ranged from 6 to 25, with an average of 13. Herreran silvopastoral systems do not appear to be species rich on the basis of used species. However, this does not mean that pasture owners' needs are satisfied by only a few retained tree species per pasture. Aguilar and Condit (2001) suggested that secondary and primary forests are needed to meet farmers' demand for woody species products. Furthermore, Herreran silvopastoral systems are far richer when species without reported uses are considered. For instance a 100% and 50% sample of trees in two living fences on two farms in the district of Parita found 28 and 40 different species, respectively (Appendix 6.7). Pasture owners had reported only 6 living fence species in both cases. The reported species were generally the most abundant species in the surveys.

Some use categories are more species rich than others. The medicinal use category contained only 8 species, whereas the shade for animals use category contained 29 species (Figure 3.3). Use category species richness was not associated with the number of pasture owners reporting tree retention ($r = 0.5$, $p = 0.18$). This suggests that use categories may be species rich, irrespective of whether tree retention for that particular purpose is popular or not.

Species richness within a given use category can be considered in two different ways: in terms of all pasture owners, or only in terms of pasture owners reporting use.

When all informants were considered, the medicinal category had lower species richness than all other use categories except fodder (Table 3.1). Fodder had lower species richness than all other use categories except water shade and posts. Wood, posts, and water shade categories had lower species richness than the living fence use category (Table 3.1).

When only users were considered, the fodder use category had lower species diversity than living fence, firewood and fruit use categories. Water shade, animal shade, wood, posts, and medicinal categories all had less species richness than the living fence category (Table 3.1). Thus, medicinal species richness was not different from most other use categories, whereas it was the lowest when all informants were considered. This is because, while the vast majority of pasture owners did not report retaining trees for medicinal purposes, those that did named some species. This and the small sample size resulted in no differences detected between medicinal uses and most other use categories, even though medicinal uses had the lowest mean species richness.

Mean species richness tended to be low for all use categories: ranging from 2 to 4 when only users were considered and 0.3 to 4 when all pasture owners were considered (Table 3.1). This suggests that in order to meet any given need, Herreran pasture owners do not purposefully retain many tree species. Aguilar and Condit (2001) suggested that most woody species products in a Hispanic community in the Canal Zone were obtained from forest, and not from pastures. In the present study, differences were detected between use categories for both considerations of species richness.

Differences in species richness were tested for each use category on the basis of informant gender and pasture ecozone membership. No differences were found on the basis of ecozone (data not shown). When all pasture owners were considered, informant gender affected reported fruit tree species richness with female informants mentioning more species (Table 3.2). When only users were considered, the effect of informant gender remained for fruit trees and an effect was detected for fodder trees, with men mentioning more species than women (Table 3.2).

Lack of an ecozone effect may indicate that although the species used for a given use category may change between ecozones, the average number of species retained for a particular use does not. Alternatively, the three ecozones defined in this study may not have been appropriate for detecting differences. An approach using Holdridge's life zone classification for Herrera may be more appropriate for detecting differences, but the present study was not designed with this classification in mind. Gender effects may indicate that women have a greater interest in fruit trees in pastures, while men have a greater interest in fodder trees. Fischer (1998) and Wiersum (1989) have reported women's preference for fruit trees. There are no gender effects for most use categories in the present study. This may indicate that men and women have similar interests in pasture trees. It also indicates that women are sufficiently knowledgeable of pasture tree species to name numbers of species comparable to those mentioned by males, despite pastures being male-gendered spaces. Franzel *et al.* (1995) found women in Burundi had similar interests in tree species, except for women's preference for *Markhamia lutea* because of its medicinal uses.

3.4.5 Abundance-diversity curves

Abundance-diversity curves rank species by their abundance, with the most abundant species receiving the lowest ranks (Zarin *et al.* 1999). Relative species abundance (percent of total abundance represented by a given species) is then plotted against the ranks of the species to graphically represent diversity (Zarin *et al.* 1999). Relative species abundance is a measure of how rare or common species are, and is log-transformed in some cases (Hubbell 2001). With the exception of the medicinal use category, for which a small number of species were mentioned, use categories have only a few dominant species (very large relative abundance) and a large number of rare species (small relative abundance) (Figure 3.4). Only a few species are commonly mentioned, meaning most are mentioned rarely. This suggests a reliance or preference for only a few species within each use category. Some use categories (fodder, wood, firewood, water shade) have very steep abundance-diversity curves, suggesting greater reliance on or preference for a few species. Animal shade, posts, living fence, and fruit use groups also have steep abundance-diversity curves, compared to the medicinal use group, but their curves are less steep than the previously mentioned groups. This general lack of evenness indicates that only a few tree species tend to be retained for a given use although many other tree species are mentioned at low frequencies.

Considering tree species with a relative abundance ≥ 10% in a given use category (Table 3.3) focuses attention on tree species that make a recognizable contribution to use categories. Such species may be of particular interest when designing silvopastoral systems with specific uses in mind. Only 16 species of the 82 mentioned in the survey meet this criterion. Three of these species are from the medicinal use category, which is not a popular reason for retaining trees in pastures in Herrera. Five species are mentioned for more than one use category, indicating that their importance is not limited to a single use. These five species are not only multipurpose in nature but are popular within the use categories they belong to.

3.4.6 Similarity

Sørenson's similarity index is recommended for the comparison of species in different agricultural field types (Zarin *et al.* 1999). Agroforestry research has used similarity indices to compare species used in home gardens from different villages (Wezel and Bender 2003) and similarity between forest gardens, forest fallows, and primary forest (Kaya *et al.* 2002). In the present study use categories, on average, shared 25 ± 5% similarity with other use categories, and percent similarity ranged between 0 and 51% (Table 3.4). The maximum level of similarity (51%) is close to the maximum of 50% similarity found between forest gardens in Indonesia (Kaya *et al.* 2002). Fruit and medicinal uses tend not to share many species with other use categories, with percent similarities ranging from 5 – 24% and 0 – 13%, respectively (Table 3.4). Firewood, shade for animals and shade for water categories have higher percent similarities with other categories (6 – 51%, 5 – 50%, and 5 – 50%, respectively) (Table 3.4).

In the case of firewood this may reflect the notion that any tree species is useable once dry. The relatively low similarity between shade for water and wood for construction categories (22%) suggests that deforestation[9] of riparian areas in pastures may be for reasons other than wood extraction. However, high similarity with firewood and post categories offers a potential explanation for riparian deforestation in pastures. Living fences also have a high percent similarity with the water shade category (30%), but this is unlikely to impact riparian areas in pastures because most living stakes are obtained from existing fences (personal observation). Water shade, animal shade, and fodder use categories all have high percent similarities with each other (32 – 43%). This raises the question of whether riparian areas in pastures might be effectively managed for fodder and shade and thus encourage afforestation, or prevent deforestation prevention of pasture riparian areas.

3.5 Multipurpose nature

There was a positive association between the number of pasture owners reporting use of a given species and both the total number ($r = 0.73$, $p < 0.0001$) and mean number ($r = 0.58$, p

[9] Deforestation of riparian areas in pastures may occur for reasons other than extractive use of woody species. For instance, pasture creation can drive the deforestation of riparian areas.

<0.0001) of uses reported for a species. The association between total number of uses and number of pasture owners reporting use may be explained by a species with more total uses having a greater chance of being mentioned by pasture owners. The association between mean number of uses (the average number of uses per species per pasture owner) and total number of users may indicate that multipurpose trees are slightly favoured for retention within pastures.

Thirty-six of the 82 species reported in the present study had only one reported use, 20 had two uses, 10 had three uses and 16 had between four and seven uses. Thus, 44% of the species have only one use, which seems to indicate that multipurpose trees are not very important in pasturelands. However, 18 of these single-use trees are reported by only one pasture owner. This may be because species are dispersal limited. Given that 100% of pasture owners reported retention of trees by managing natural regeneration, whereas only 49% reported planting trees in their pastures (and then only sporadically), dispersal limitations on species are likely. Simmons *et al.* 2002 also found that close to 50% of 95 surveyed households in the Darién region of Panama reported tree-planting activities, albeit in plantations instead of pastures.

Low rates of tree planting and reliance on natural regeneration, for which dispersal limitations are probable (Muller-Landau *et al.* 2002), make spatial constraint of pasture species in Herrera likely. Condit *et al.* (2002) reported that dispersal limitations in Panama result in forest plots 50 km apart only sharing 1 to 15% of their species. Thus, the species populating a given use category may be very specific to a geographic location. Alternatively, species may be specific to informant interest in using and/or reporting certain trees.

3.5.1 Multipurpose index

The overall rating for the top 25 rated species ranged from 2 – 31 with decreases occurring gradually rather than at a noticeable breakpoint (Table 3.5). Ranks for the different parameters ranged from 1 – 56 (Table 3.5) indicating that poor ranking in any one category did not exclude species from receiving an overall high rating. Of the top 25 rated species only 12% are exotic species (*Mangifera indica* (Mango), *Tectona grandis* (Teca), *Swietenia macrophylla* (Caoba)), indicating the importance of native species in Herreran silvopastoral systems. Rating was done for Herrera as a whole because this is the recommendation domain IDIAP and MIDA were interested in.

3.5.2 Single purpose trees

Trees that have only one use but are mentioned by a large number of users are of particular interest. Genetic improvement of these species for pastures is likely to benefit users and will not compete with other uses (Huxley 2001). Only two species in pastures were mentioned by more than 25% of users for a single use category. These were *Bursera tomentosa* for living fences (21 informants) and *Swietenia macrophylla* for wood (12 informants). Because of the high number of users, and expressed preference for these species, they appear in the top 25 species of the multipurpose species index despite being single purpose pasture trees. Species with only one use make up only 13% of the species reported by 25% or more of users (Table 3.6).

Of the multipurpose species reported by 25% or more of users, nance (*Byrsonima crassifolia*) is the most used and the most multipurpose in Herrera province. Eighty-nine percent of informants reported its use. Overall it was mentioned for 8 use categories and had an average number of uses of 2.2. Such a species, while quite valuable, may be difficult to 'improve' genetically because selection for characteristics pertinent for one use category may select against useful characteristics for another (Huxley 2001). However, given the low average number of uses per species per farm, it may be possible to develop 'improved' varieties that are well suited for one or a few uses, and still meet pasture owners' needs. Any attempt at genetic improvement, even for protein banks, will face the obstacle of pasture owners' preference for managing natural regeneration to recruit trees for pastures rather than planting trees.

3.6 Protein banks

No single purpose tree identified in the present study was used for fodder. However, scientists are hopeful that leguminous trees/shrubs may serve as single purpose trees in the form of protein banks (Dagang and Nair 2001). The International Development and Research Council (IDRC) of Canada attempted to introduce herbaceous protein banks into Los Santos in the 1980s (IDIAP 1986) and IDIAP subsequently attempted to introduce *Leucaena leucocephala* protein banks (Urriola 2002 *pers. comm.*). Only one rancher seems to have retained the *Leucaena leucocephala* technology in the provinces of Herrera and Los Santos (personal observation). Ironically, he indiscriminately grazes his *Leucaena* protein bank during the rainy season and allows it to rest during the dry season. Scientists have promoted this technology for dry season feeding, with cut and carry systems preferred over grazing (Paterson *et al.* 1987). Many other ranchers in the area are aware of this rancher and his adoption of this technology, yet have not adopted it (personal observation). None of the 43 informants questioned managed protein banks, however one had tried to establish a protein bank and two others expressed interest. Informants cited a number of reasons for not having protein banks.

Six pasture owners cited not enough space, another six cited poor palatability as a problem, four felt lack of education was the limiting factor, and two suggested the cost of establishment would be too great. Fischer (1998) found that small-scale farmers in Panama lacked space to establish agroforestry plots. Small-scale pasture owners may face the same constraint. The poor palatability of tropical fodder has also been recognized as a limitation to its intensive use (Lowry 1990). Grist *et al.* (1999) found that the cost of establishing a fodder legume as an alley-crop was not recouped until 4 years after establishment. Such an investment is difficult for small-scale farmers to make (Winterbottom and Hazelwood 1987). These technical limitations aside, the reason most informants cited for not having a protein bank was already having sufficient forage. Interestingly, all of the eleven pasture owners reporting sufficient forage also reported that their cattle lost weight (in some cases severely) during the dry season. Thus, these pasture owners are the very ones protein bank technology is supposed to aid and yet they claim no need for them.

In some cases pastures are rented out, so demand for forage is seasonal. Thus forage is considered sufficient even if annual pasture productivity is low. Furthermore, pasture-owners who rent out their pastures may face the additional constraint of renters traditionally seeking grassland for their cattle rather than protein banks, which are a new concept. However, pastures with scrub brush are rented during the summer months and may be a traditional protein bank (personal observation; Appendix 6.8).

Of the 43 pasture owners asked about renting, 14 indicated that they rented their pasture to other pasture owners and 19 indicated that they rented pasture from other pasture owners. Thus, 78% of questioned pasture owners are engaged in some sort of rental arrangement. One pasture owner who had stopped renting the previous year was presently sowing improved pasture grasses. He noted that when you rent pasture, it is impossible to improve it. Conversely, if it is possible to rent cheap pasture, there is no need to improve existing pastures.

In cases where pasture owners have cattle, 41% reported owning cattle for unexpected expenses, as a bank account, or out of tradition. This may explain why weight loss is observed annually and yet forage is felt to be sufficient. As such, technology that improves productivity does not always suit such pasture owners' objectives. Similar scenarios have been reported for African pastoralists where the number of animals kept, rather than their condition, is the most important consideration (Tapson 1991). During the dry season, Herrera's small-scale pasture owners may be more concerned with cattle survivorship than weight gain. Ironically, protein banks have been shown to increase calf mortality (Campbell *et al.* 1996). However, some cattle owners reported owning cattle for production and also claimed to have sufficient forage, despite dry season weight loss. This is more difficult to explain, but may be related to how cattle are bought and sold in Herrera province, and how cattle feed is supplemented in the dry season.

Cattle tend to be purchased by visual inspection rather than by weight and meat quality (personal observation). Thus, some weight loss is tolerable and economic analysis of protein banks based on input and output prices (Holmann and Ibrahim 2001) is questionable. Dry season supplementation with non-fodder resources may also explain why protein banks are not in demand. Seventy-one percent of 41 pasture owners reported supplementing their cattle's diet during the dry season. A total of 14 different supplements were mentioned, but only use of sugar cane waste, maize stover, salt, concentrate, and cane molasses was mentioned often (22, 16, 13, 8, and 8 users, respectively). Users sum to more than the total number of informants because informants often mentioned more than one supplement. The number of supplements reported by pasture owners ranged from 1 to 7 with an average of 3 supplements being administered. Other studies have also found that agricultural by-products are important feed supplements in developing countries (Devendra 1988).

The two informants reporting interest in protein bank technology, and the rancher previously owning a protein bank, are all well educated and have highly capitalized dairy operations close to large city centres. Promotion of protein bank technology could focus on ranchers of similar demographics. Generally, protein banks do not seem to be appropriate for small-scale farmers given their current management practices and economic goals. Specifically, cattle survivorship is likely more important than cattle productivity (weight gain).

3.7 Fodder species

Even though most interviewed pasture owners do not have protein banks, fodder trees are an important pasture resource. Sixty-two percent of pasture owners reported retaining a total of 18 tree species for fodder, and 98% of pasture owners were aware that their cattle consumed fodder. Apart from purposefully retained fodder species, 14 other fodder species were identified as being consumed by cattle (Table 3.7). Only 8 of these 32 fodder species were leguminous but all leguminous species were purposefully retained, suggesting farmers recognize the value of leguminous fodder. Many of these fodder species were valued for their fruit, which drops during the dry season, rather than for their foliage. Some pasture owners also reported that hungry cattle eat all manner of fodder, even physiologically inefficient species such as mango and cashew leaves. Studies of mango leaves have shown their crude protein content to be less than 5% (Reddy 1990).

Of the 18 species retained for fodder in pastures, only two (*Enterolobium cyclocarpum* and *Guazuma ulmifolia*) were reported by an appreciable number of pasture owners (7 and 24 users, respectively). The average number of fodder species used by pasture owners was 1.9 with 12 pasture owners reporting only one species. This indicates that any given pasture owner relies heavily on a few fodder species for supplementation, although other tree species are being exploited by cattle, with or without pasture owners knowledge. A study of long-chain fatty acids in cattle feces in Colombia found that approximately half the cattle's diet was shrub fodder (Cajas-Giron *et al.* 2001).

3.8 Living fence protein banks

A modification of the protein bank concept is to use living fences to provide fodder. The notion here is that a periodically pruned living fence made up of leguminous tree species can provide fodder for animals (Romero *et al.* 1993). However this technique may be in direct conflict with pasture owners' current uses for living fences. In the present survey, 83% of 35 informants pruned their fences in order to obtain stakes. These stakes are used to repair and expand existing living fences. Stakes are roughly two meters in length, and larger diameter stakes are considered more valuable (personal observation). Thus harvesting of stakes may be in direct conflict with the management of a living fence for fodder because periodic pruning does not permit the development of appropriately sized stakes. Nevertheless, many pasture owners recognized the value of living fence foliage as fodder, with 63% of 30 informants reporting feeding fence prunings to their cattle.

3.9 Conclusions

Trees are retained in Herreran pastures for many reasons. Medicinal use is the least popular. Species richness is low for all categories but there are differences between categories. Living fence, firewood, and fruit uses had the highest species richness, while medicinal uses had the lowest. There are more tree species in pastures than are reported during interviews. These unreported species have known uses, but they tended not to be directly used by the pasture owner questioned. Species richness did not differ for ecozone, either because this is so, or because ecozones were not adequately defined.

Women mentioned more fruit species while men mentioned more fodder species. This may reflect greater interest in, or knowledge of, species for these uses on the basis of gender. Sørenson's similarity index indicated that use categories have percent similarities ranging from 0 to 51%. Most use categories' diversity was uneven, with only a few species being dominant in each category. Multipurpose tree species were slightly favoured for retention in pastures.

Prioritization of tree species on the basis of preference, spread of use, and plurality of use identified mainly native species as having top priority ratings: Nance – (*Byrsonima crassifolia*), Guácimo (*Guazuma ulmifolia*), Laurel (*Cordia alliodora*), Cedro Amargo (*Cederla ordonata*), Espave (*Anacardium excelsum*), Carate (*Bursera simaruba*), Corotú (*Enterolobium cyclocarpum*), Macano (*Diphysa robinioides*). Mango (*Mangifera indica*) was one of the few exotic species that received a high priority rating. Caoba (*Swietenia macrophylla*) and Caratillo (*Bursera tomentosa*) distinguished themselves as popular single purpose species for construction wood and living fences, respectively.

Protein banks, despite having been introduced to the region in the 1980s, (IDIAP 1986) were not prevalent and appear not to complement small-scale pasture owners' reasons for owning cattle. There are a number of management and economic constraints that currently make protein bank technology inappropriate for most small-scale farmers. Specifically, cattle survivorship is likely more important than cattle productivity (weight gain). However, trees were retained in pastures for fodder, and supplementation of cattle feed with agricultural residues was prevalent. Capital-intensive milk producers seemed most interested in protein banks. Living fences are unlikely to be used for fodder because this conflicts with their current management for living fence replacement stakes.

3.10 Recommendations

There is need to study existing pasture tree species richness and compare it to species richness reported for use categories. Nance (*Byrsonima crassifolia*) deserves research attention because it is a popular and often preferred multipurpose pasture tree in the province of Herrera. More consideration needs to be given to native species in Herreran silvopastoral systems. Research into protein bank technology should focus on small-scale capital-intensive milk producers. Fodder tree research should focus on the management of isolated trees to increase the production and quality of fallen fruit during the dry season. Genetic selection and fertilization of isolated pasture trees for increased fodder productivity and quality are potential lines of research. Guácimo (*Guazuma ulmifolia*) and Corotú (*Enterolobium cyclocarpum*) are popular fodder species that merit such research. Riparian areas in pastures should be considered for fodder and shade species, in order to encourage the maintenance of tree cover in these areas.

3.11 Tables and figures

Table 3.1 Mean species richness (± 95% confidence interval) for pasture owner identified use categories in a survey of 45 pasture owners in Herrera province, Panama.

	All Pasture Owners			Only Users		
Use Category	DF[1]	Mean ± 95% CI[2]	Test CI[3]	DF	Mean ± 95% CI	Test CI
Living Fence	45	3.5 ± 0.4 a	0.4	45	3.5 ± 0.4 a	0.4
Firewood	45	2.7 ± 0.6 ab	0.4	38	3.2 ± 0.5 ab	0.4
Fruit	45	2.7 ± 0.6 ab	0.4	39	3.1 ± 0.7 ab	0.4
Animal Shade	45	2.5 ± 0.3 ab	0.4	45	2.5 ± 0.3 bc	0.4
Wood	45	2.1 ± 0.4 b	0.4	40	2.4 ± 0.4 bc	0.4
Water Shade	43	1.8 ± 0.5 bd	0.4	32	2.4 ± 0.4 bc	0.5
Posts	36	2.0 ± 0.5 bd	0.5	33	2.2 ± 0.5 bc	0.5
Fodder	45	1.2 ± 0.4 cd	0.4	28	1.9 ± 0.4 c	0.5
Medicinal	41	0.3 ± 0.2 d	0.4	7	1.7 ± 0.7 bc	1.0

[1]Degrees of freedom.
[2]95% confidence interval of the mean.
[3]95% confidence interval of the test.
Numbers followed by different letters are significantly different from each other for an $\alpha = 0.05$ according to a pairwise test (SAS Institute Inc. 1999) for multiple comparisons after conducting a parametric two-way analysis of variance substantiated by rank transformation (Conover and Iman 1976).

Table 3.2 Mean species richness (± 95% confidence interval) for pasture owner identified use categories by gender in a survey of 45 pasture owners in Herrera province, Panama.

Use Category	All Pasture Owners				Only Users			
	DF[1]	Male	Female	Difference	DF	Male	Female	Difference
Living Fence	31,14	3.6 ± 0.5	3.3 ± 0.7	ns	31,14	3.6 ± 0.5	3.3 ± 0.7	ns
Firewood	31,14	2.7 ± 0.7	2.6 ± 1.0	ns	13,25	3.4 ± 0.7	2.8 ± 0.9	ns
Fruit	31,14	2.0 ± 0.7	4.1 ± 1.0	2.1 ± 1.3*	14,25	2.5 ± 0.8	4.1 ± 1.0	1.6 ± 1.3*
Animal Shade	31,14	2.5 ± 0.4	2.6 ± 0.5	ns	31,14	2.5 ± 0.4	2.6 ± 0.5	ns
Wood	31,14	2.0 ± 0.5	2.4 ± 0.7	ns	27,13	2.3 ± 0.5	2.6 ± 0.6	ns
Water Shade	29,14	1.8 ± 0.5	1.6 ± 0.8	ns	21,11	2.5 ± 0.5	2.1 ± 0.7	ns
Posts	27,9	2.2 ± 0.5	1.6 ± 0.9	ns	25,8	2.4 ± 0.5	1.8 ± 0.9	ns
Fodder	31,14	1.4 ± 0.5	0.8 ± 0.7	ns	20,8	2.2 ± 0.5	1.4 ± 0.8	ns
Medicinal	27,14	0.1 ± 0.3	0.6 ± 0.4	ns	4,3	1.3 ± 1	2.0 ± 0.9	0.8 ± 0.9*

[1]Degrees of freedom (male, female).
* Indicates significance at $\alpha = 0.05$ as determined by the Mann-Whitney non-parametric t-test (Zar 1999). Means and confidence intervals were calculated using least square means in a general linear model (SAS Institute Inc. 1999).
Note: Variability of test is based on the spread of the sum of the ranks and is not shown.

Table 3.3 Tree species mentioned most often (≥ 10% relative abundance) for pasture owner identified use categories in a survey of 45 pasture owners in Herrera province, Panama.

Species	Relative Abundance (%)	Use Category(ies)
Nance – *Byrsonima crassifolia*	28, 16, 15	FR, AS, P
Guácimo – *Guazuma ulmifolia*	12, 46, 14	FR, F, AS
Laurel – *Cordia alliodora*	10, 11, 21	FR, W, P
Cedro Amargo – *Cederla ordonata*	27, 11	W, P
Corotú – *Enterolobium cyclocarpum*	13	F
Eucalipto – *Eucalyptus globulus*	17	M
Guanábana – *Annona muricata*	17	M
Pazmo – *Siparuna sp.*	17	M
Mango – *Mangifera indica*	15, 24	AS, FRU
Marañon – *Anacardium occidentale*	10	FRU
Guava – *Inga vera*	12	WS
Espave – *Anacardium excelsum*	32	WS
Macano – *Diphysa robinioides*	16	P
Carate – *Bursera simaruba*	23	LF
Caratillo – *Bursera tomentosa*	13	LF
Balo – *Gliricidia sepium*	15	LF

M= Medicinal, F= Fodder, WS= Water Shade, FR= Firewood, W= Wood, FR= Fruit, P= Posts, LF= Living Fence Stakes, AS= Animal Shade.

Table 3.4 Sørenson's similarity index for comparison of pasture owner identified use categories in a survey of 45 pasture owners in Herrera province, Panama.

	Firewood	Fruit	Living Fence	Medicinal	Animal Shade	Water Shade	Posts	Wood
Fodder	35	24	37	0	43	32	29	30
Firewood		16	33	6	49	50	51	44
Fruit			14	13	12	5	17	13
Living Fence				0	41	30	19	29
Medicinal					5	7	0	7
Animal Shade						37	50	43
Water Shade							33	22
Posts								38

Note: All values are percent similarity as calculated by Sørenson's Similarity Index, which is the number of species two categories have in common divided by the sum of the total number of species in each category.

Table 3.5 Ranking of multipurpose tree species' attributes and overall rating for 25 tree species in Herrera province, Panama[7].

Species	Preference Rank	Total Uses Rank	Average Uses Rank	Users Rank	Overall Rating
Nance – *Byrsonima crassifolia*	4	1	1	1	2
Guácimo – *Guazuma ulmifolia*	1	3	5	3	3
Mango – *Mangifera indica*	4	3	6	4	4
Laurel – *Cordia alliodora*	5	3	4	7	5
Cedro Amargo – *Cederla ordonata*	2	8	17	5	7
Espave – *Anacardium excelsum*	7	8	13	6	8
Carate – *Bursera simaruba*	13	8	27	2	10
Corotú – *Enterolobium cyclocarpum*	10	8	7	15	11
Macano – *Diphysa robinioides*	10	14	18	13	13
Lazo – *Matayba sp.*	13	14	11	19	15
Balo – *Gliricidia sepium*	7	22	33	8	15
Higo – *Ficus sp.*	10	14	20	19	16
Jarino – *Andire inermis*	10	22	15	21	17
Marañón – *Anacardium occidentale*	43	8	15	11	18
Ciruela – *Spondias purpurea*	43	8	29	13	21
Canillo – *Miconia argentea*	43	8	15	21	21
Coquillo – *Jatropha curcas*	43	22	28	10	22
Teca – *Tectona grandis*	43	14	21	24	25
Guabito – *Inga sp.*	20	37	19	26	25
Caratillo – *Bursera tomentosa*	16	56	50	9	28
Guava – *Inga vera*	43	22	32	22	28
Aguacate – *Persea americana*	43	37	30	17	28
Jobo – *Spondias mombin*	43	22	31	24	28
Caoba – *Swietenia macrophylla*	13	56	50	15	30
Palo Santo – *Erythrina poeppigiana*	43	22	24	34	31

All values have been rounded to zero decimal places.

[7]Ranks are assigned total number of uses, average number of uses, and number of users across all use categories. Rank for preference is assigned by ranking species based on the number of users reporting preference within each use category, averaging preference ranks across all categories and ranking the resulting average ranks. Overall rating is an average of the above-mentioned ranks in which rank for users is weighted twice.

Table 3.6 Average number of uses, total number of uses and use category membership of the 20 most reported tree species in pastures in Herrera.

Species	Users	Average Uses	Total Uses	F	FR	FRU	LF	M	AS	P	WS	W
Nance – *Byrsonima crassifolia*	40	2.2	8	1	1	1	1		1	1	1	1
Carate – *Bursera simaruba*	37	1.2	5	1	1		1		1	1		
Guácimo – *Guazuma ulmifolia*	33	1.9	6	1	1				1	1	1	1
Mango – *Mangifera indica*	30	1.9	6	1	1	1			1		1	1
Cedro Amargo – *Cederla ordonata*	27	1.4	5				1		1	1	1	1
Espave – *Anacardium excelsum*	25	1.5	5	1	1				1	1	1	1
Laurel – *Cordia alliodora*	24	2.0	6		1		1		1	1	1	1
Balo – *Gliricidia sepium*	23	1.1	3	1			1			1		
Caratillo – *Bursera tomentosa*	21	1.0	1				1					
Coquillo – *Jatropha curcas*	20	1.2	3				1	1	1			
Marañon – *Anacardium occidentale*	18	1.4	5	1	1	1	1		1			
Ciruela – *Spondias purpurea*	16	1.2	5		1	1	1		1			1
Macano – *Diphysa robinioides*	16	1.4	4		1		1			1		1
Caoba – *Swietenia macrophylla*	12	1.0	1									1
Corotú – *Enterolobium cyclocarpum*	12	1.8	5	1	1				1		1	1

M= Medicinal, F= Fodder, WS= Water Shade, FR= Firewood, W= Wood, FR= Fruit, P= Posts, LF= Living Fence Stakes, AS= Animal Shade.

Table 3.7 Fodder species mentioned by small-scale pasture owners as being purposefully retained in pastures or observed being consumed by cattle in Herrera province, Panama.

Common Name	Scientific Name	Leguminous	Principle Fodder
Purposefully Retained			
Balo	*Gliricidia sepium*	Y	L
Bobo	*Erythrina fusca*	Y	L
Carate	*Bursera simaruba*	N	L
Corotú	*Enterolobium cyclocarpum*	Y	F
Espave	*Anacardium excelsum*	N	F
Guácimo	*Guazuma ulmifolia*	N	F
Guachapalí	*Samanea saman*	Y	F
Guava	*Inga vera*	Y	F
Higo	*Ficus sp.*	N	F
Jobo	*Spondias mombin*	N	F
Leucaena	*Leucaena leucocephala*	Y	L
Mango	*Mangifera indica*	N	F
Marañon	*Anacardium occidentale*	N	F
Nance	*Byrsonima crassifolia*	N	F
Palma Real	*Attalea butyracea*	N	F
Palo Santo	*Erythrina poeppigiana*	Y	L
Pito	*Erythrina costaricensis*	Y	L
Palma Pacora	*Acrocomia aculeata*	N	F
Observed Consuming			
Papo	*Hibiscus rosa-sinensis*	N	L
Caratillo	*Bursera tomentosa*	N	L
Caimito	*Chrysophyllum cainito*	N	F
Sapote	*Licania platypus*	N	F
Guayaba	*Psidium guinensis*	N	F
Ciruela	*Spondias purpurea*	N	F
Cañaza	*Bambusa sp.*	N	L
Lazo	*Matayba sp.*	N	L
Caoba	*Swietenia macrophylla*	N	L
Bamboo	*Bambusa sp.*	N	L
Tamarindo	*Tamarindus indica*	N	F
Aguacate	*Persea americana*	N	F
Laurel	*Cordia alliodora*	N	L
Naranja	*Citrus sinensis*	N	F

Leguminous Y = Yes, N = No. Fodder Type L = Leaf, F = Fruit.

Figure 3.1 Average monthly and annual rainfall in La Villa Los Santos and La Pitaloza (1983-1997 Instituto de Recursos Hidraulicos y Electrificacion Data).

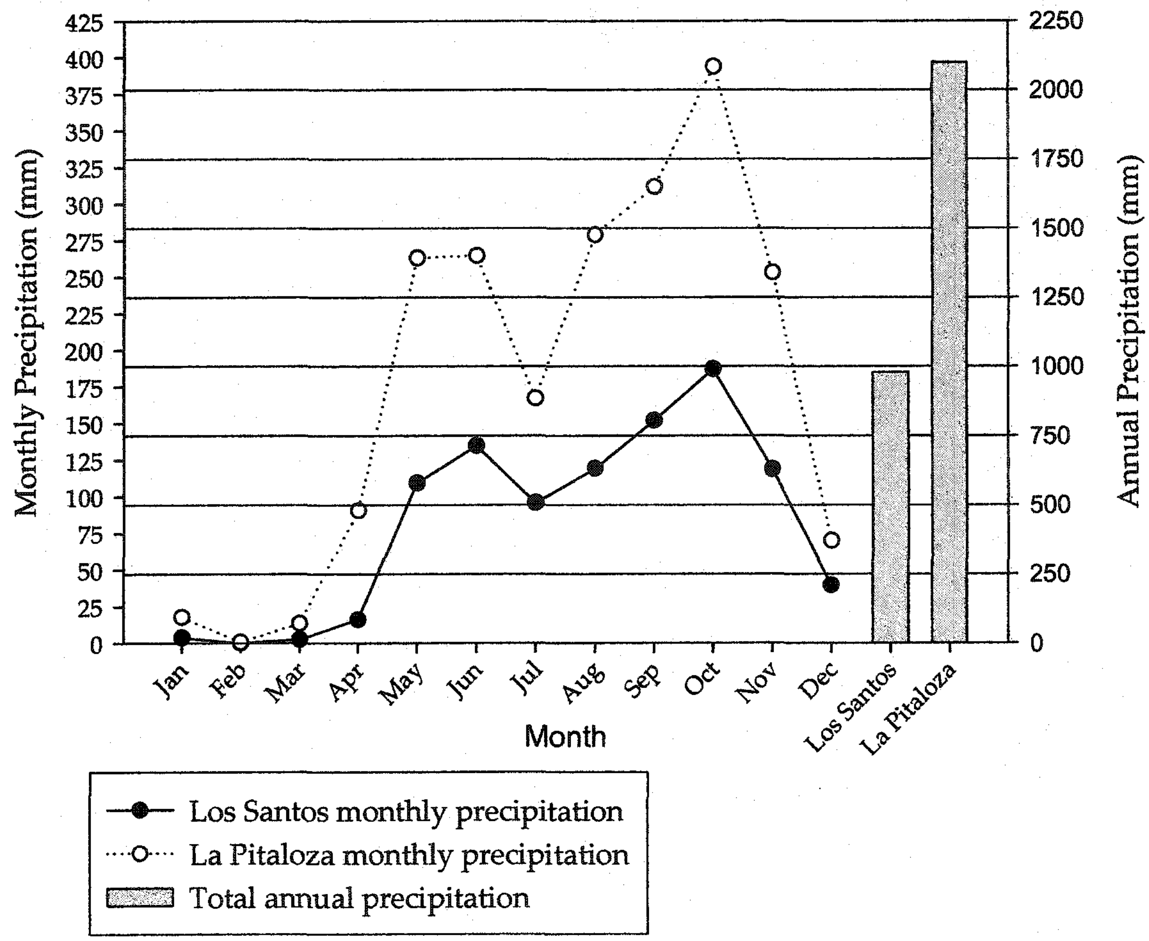
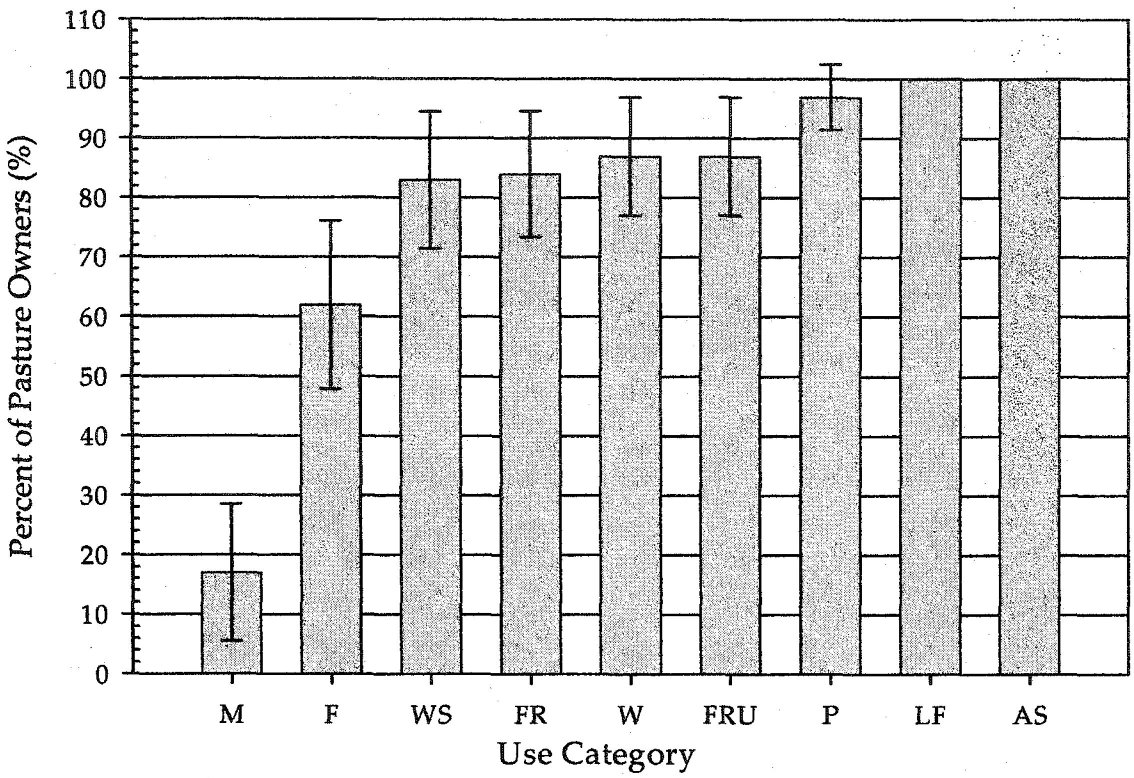
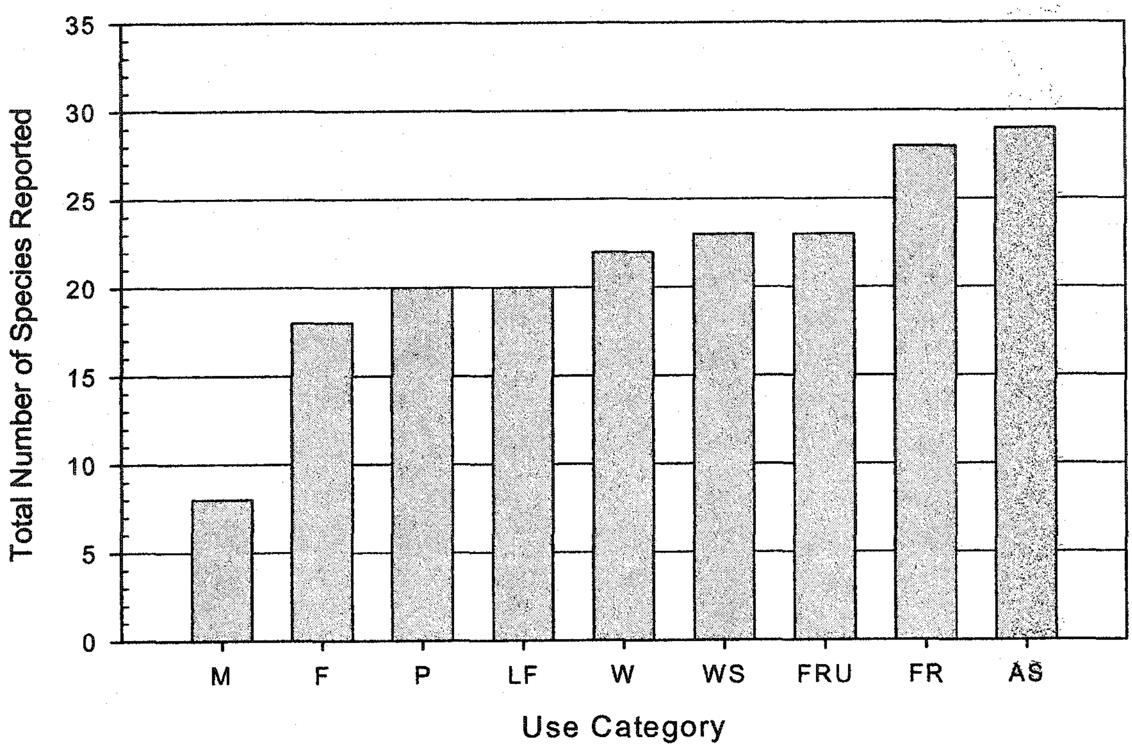


Figure 3.2 Percentage (± 95% confidence interval) of pasture owners reporting retention of trees for nine different use categories in a survey of 45 small-scale pasture owners in Herrera, Panama.



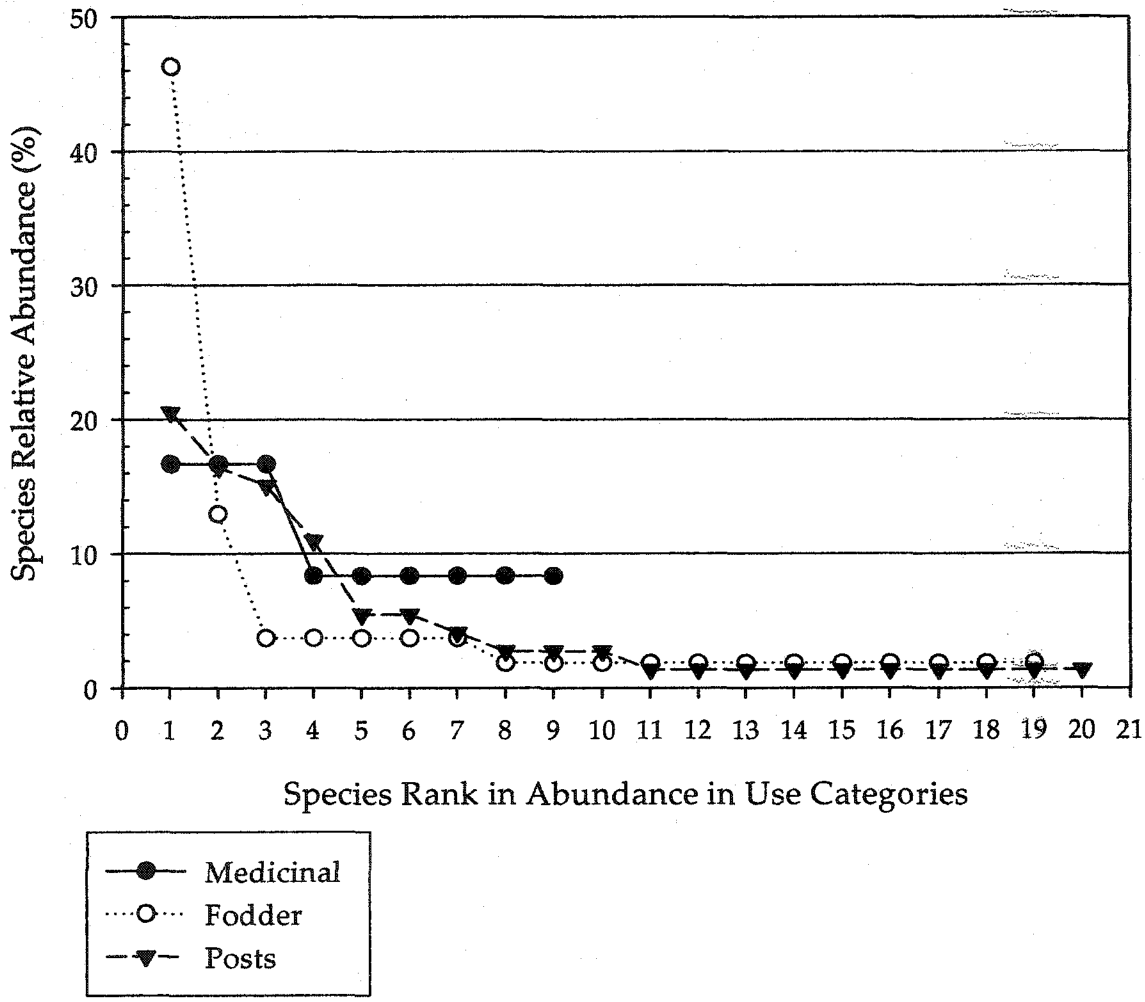
M= Medicinal, F= Fodder, WS= Water Shade, FR= Firewood, W= Wood, FR= Fruit, P= Posts, LF= Living Fence Stakes, AS= Animal Shade.

Figure 3.3 Total number of tree species reported by 45 small-scale pasture owners for nine different use categories in Herrera, Panama.



M= Medicinal, F= Fodder, WS= Water Shade, FR= Firewood, W= Wood, FR= Fruit, P= Posts, LF= Living Fence Stakes, AS= Animal Shade.

Figure 3.4 Abundance-diversity curves for fodder, post, and medicinal use categories as representative of highly, moderately, and not uneven species diversity in pasture owner identified use categories in Herrera, Panama.



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4.0 The effects of established *Bursera simaruba* living fences on pasture vegetation and chemical soil properties in the tropical moist forest life zone of Herrera, Panama, following dry season leaf drop.

4.1 Abstract

Living fences are an important component of Latin American silvopastoral systems and are often regarded as agroforestry systems unto themselves. Little work has been done on their impact on soil fertility. The present study examined the impact of *Bursera simaruba* living fences on pasture vegetation and chemical soil fertility during the dry season, after leaf drop, in the tropical moist forest life zone of Herrera province, Panama. Soil and vegetation samples were collected from farmer established and managed pastures at two distances from living fences. Manganese and percent litter cover was 51 ± 27 µg/ml and 30 ± 9 percentage units higher at the base of the living fences, respectively. pH (H_2O, 2:1) and percent herbaceous cover were 0.2 ± 0.2 pH units and 34 ± 13 percentage units lower at the base of the living fence, respectively. Percent litter cover was negatively associated with percent herbaceous cover and pH (H_2O, 2:1). Calcium was negatively associated with Fe. Zinc was positively associated with copper and manganese. A farm × treatment interaction, in which organic C was higher at the base of the fence in all but one case, was explained by past pasture cropping with maize. Nutrient concentrations at the base and away from the fences tended not to be biologically different. *Bursera simaruba* living fences do not seem to have a profound impact on soil fertility but they do impact litter and herbaceous cover.

4.2 Introduction

Agroforestry – the use of woody species (trees, shrubs, palms, bamboos) on farms – has received increasing attention in the tropics since the 1970s (King 1989). There is a long history of agroforestry in the tropics and it is thought to be particularly appropriate in areas where more conventional annual monocrops have not been successful (Hetch and Cockburn 1989; Gholz 1987). Silvopastoral agroforestry systems – the use of woody species in pastures – have recently become popular in Latin America (Cajas-Giron and Sinclair 2001; Dagang and Nair 2001, Casasola *et al.* 2001). Deforestation in the tropics has received worldwide attention (Hetch and Cockburn 1989), and in Latin American countries cattle ranching and pasture creation is often associated with deforestation (Szott *et al.* 2000; Nair *et al.* 1991).

In Panama, Ledec (1992) estimated that over 70% of deforested lands were in cattle pasture. Pastures, even if situated on previously deforested land, contain isolated trees (Harvey and Haber 1999) and forest fragments (Guindon 1996). Living fences, or boundary plantings, are also an important part of pastures in Latin America (Budowski 1987). The interaction between woody and non-woody components of agroforestry systems has received increasing attention in the last decade (Rao *et al.* 1998).

Rao *et al.* (1998) reported that soil fertility as affected by trees is a major component of agroforestry's impact on crop yield. They divided this effect into soil chemical, biological, and physical components. In their review, Rao *et al.* (1998) found that hedgerows in alley-cropping[10] generally increase soil fertility except on acid infertile soils and in semi-arid regions. Specifically, soil organic C, N, and available P increase, although the magnitude of the increase is species dependent (Rao *et al.* 1998). Under both boundary plantings and isolated trees, organic matter, extractable P, N, and pH tend to be greater, but in the case of isolated trees this may in part be due to tree establishment in islands of inherently higher soil fertility (Geiger *et al.* 1998). Fisher (1995) has criticized tree-soil fertility experiments as lacking true controls and has shown that different conclusions are reached if original soil fertility is not known. Boundary plantings generally reduce crop yield (Rao *et al.* 1998). Improved tree fallows, in which farmers enrich natural vegetation regeneration by planning trees, variably affect pH, and increase organic C, extractable P, N, and other exchangeable cations compared to fallows of solely natural vegetation regeneration (Rao *et al.* 1998). Past studies examining isolated trees have used transect methodologies (Tomlinson *et al.* 1995; Weltzin and Coughenour 1990).

Research has concentrated on leguminous tree species because of their ability to biologically fix nitrogen (Nygren *et al.* 2000), but the impact of non-nitrogen fixing trees on soil fertility has also been evaluated in Africa (Kater *et al.* 1992; Tomlinson *et al.*, 1995) and Latin America (Tornquist *et al.* 1999). Tomlinson *et al.* (1995) found soil total N and available K was higher closer to *Parkia biglobosa* than in cultivated fields. However, pH, organic matter and P were not significantly affected. Kater *et al.* (1992) found higher organic C, Mg, and K under trees but no significant differences in pH, N, available P, and Ca. Tornquist *et al.* (1999) reported higher pH in pastures compared to individual adjacent five-year-old tropical hardwood agroforestry systems in Costa Rica. They found few differences in Ca, Mg, K, and Na, and no differences in organic C (Tornquist *et al.* 1999). None of these studies involved living fences.

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[10] Alley-cropping is the sowing of crops inbetween row-planted trees or shrubs which are used to provide mulch for the cropped area.

Living fences have been studied in terms of their ability to produce fodder (Romero *et al.* 1993), but little research has been done on their inherent impact on soil chemical properties. Some researchers have considered living fences' impact on fertility irrelevant (Young 1991), or the affected area to be minimal (Rao *et al.* 1998). However, the area of their potential influence may be significant in small pastures. This is because the perimeter-to-area ratio for such pastures is high. Living fences usually consist of vegetatively propagated stakes to which barbed wire is attached (Budowski 1993). They are pruned, and litter and pruning trash are often left to decompose a short distance from the trees (personal observation; Appendix 6.9). Because living fences are propagated and maintained by humans to demarcate boundaries, their impact on soil is less likely to be confounded by areas of higher fertility soil favouring tree establishment, as is potentially the case with naturally regenerating isolated trees (Geiger *et al.* 1994).

Studies on experimental stations can obtain effective replication by using classical experimental designs such as the randomized complete block (Steel *et al.* 1997). However, such studies have the disadvantage of not always being representative of farming communities where scientists do not design and manage the systems. On-farm studies within farming communities must deal with highly variable systems, while respecting time and monetary constraints. Furthermore, they may require experimental designs and analyses that differ from more classical approaches (Ver Hoef and Cressie 1993).

Bursera simaruba is a deciduous tree of the Burseracea family (Gentry 1996), which is commonly found in living fences in the American tropics (Budowski 1987). It is very prevalent in the living fences of the El Cedro judicial district in Herrera province, Panama. All pastures in the area have this species present in their fences with some fences almost exclusively made up of *Bursera simaruba* (personal observation, Appendix 6.10). Dry season leaf drop adds litter to the soil and signals the beginning of fence pruning.

The objectives of the present study were to: 1) quantify the impact of *Bursera simaruba* in El Cedro pastures on soil chemical properties and vegetation characteristics, and 2) examine associations within and between soil chemical properties and vegetation characteristics.

4.3 Materials and methods

4.3.1 Study area

The study was conducted in Panama in the judicial district of El Cedro belonging to the district of Los Pozos in Herrera province (Figure 4.1). This area is located in Holdrige's (1967) tropical moist forest life zone (IGNTG. 1988). Herrera has a large number of small-scale farms and a great deal of cattle ranching (Jaen-Suarez 1978). Of Herrera's 190 000 ha of agricultural land, 129 000 or 68% are in pasture, with traditional pasture species covering 85 000 ha (Controlaria 2000; Chapter 2). *Hyparrhenia rufa* is one of the most common of these traditional species, and pasture burning is a traditional practice in the area (Carrasquillas 1984). In Los Pozos district, 61% of farms of 3 ha or more area have cattle and there are 27 500 head of cattle, representing 20% province's total herd (Controlaria 2000).

The judicial district of El Cedro does not have a rain station, however it lies between the rain stations of Los Pozos and La Pitaloza, which respectively received average annual precipitation of 1600 mm and 2100 mm for the period 1983-1997 (IRHE 1998). There is a dry season during the months of December to April and a bimodal rainy season between May and November (Figure 4.2). Annual median temperature is 26°C (INGTG 1988).

4.3.2 Methods

Four towns – El Cedro, Marañón, Tierras Blancas, and Pedrenal – in El Cedro were randomly selected and a convenience survey of pasture owners in these towns was used to identify four pastures – one from each town – with similar characteristics. These characteristics included age of fence, primary fence species, fence form, original sown pasture species, burning regime, fertilizer regime, cropping regime, soil order and stocking rate (Table 4.1). Farms were selected based on these criteria in an attempt to reduce variability, as on-farm experiments often have the drawback of treatment effects (signal) being swamped by natural variability (noise) (Ver Hoef and Cressie 1993). This large noise to signal ratio may be dealt with by increasing sample size (Ver Hoef and Cressie 1993) but in the present study I was unable to increase sample size. A smaller number of farms was sampled because travel to the area was difficult, participating pasture owners deserved personal attention, and all pastures needed to be sampled quickly in order to avoid potentially confounding rainstorm and grazing effects.

On each farm three sections of living fence of 10m in length were randomly selected, subject to the constraints of: 1) uniform species composition; 2) isolation from other pasture trees, human trails, corrals, pasture gates, hydrologically active areas; 3) no excessive slope, erosion, fence curvature and; 4) at least 20m away from all other selected fence sections. The number of trees and diameter at breast height (1.3m above ground) of each tree was recorded in each 10m section of fence. Each fence section was sampled 2m, 4m, 6m, and 8m along the fence line, employing a transect. Quadrats (0.25m^2) placed 0.2m and 6.2m away from the fence were sampled for type of ground cover, and animal activity. These distances represent beside the trunk and beyond the canopy positions, respectively. Ground cover included the categories of herbaceous cover, woody cover, litter cover, and bare ground cover. Cover was visually estimated in 1% intervals using $25cm^2$ subdivisions within the quadrat (Bonham 1989). Litter cover was tree leaf litter. Herbaceous cover was both senesced and living grass and forb vegetation. All cover categories were estimated in a single layer and considered to lie directly over the soil surface. Animal activity was assessed using a five-point scale on the basis of feces and trampling intensity.

Soil samples (15cm depth) were taken from the centre of each quadrat following vegetation data collection using an Eijkelkamp auger (1.25 m length with 7 cm blade diameter). Samples were bulked by distance from fence and fence section on each farm, for a total of 24 bulked samples from the four farms. Soils were air dried and large root and rock material was removed. The soil samples were then ground with a Standard Model No.3 Wiley Mill, passed through a 2mm screen again removing any root and rock material, and finally thoroughly mixed by hand. Samples were analyzed for pH (H_2O, 2:1), exchangeable pH ($CaCl_2$, 2:1), P and K (Melich I Extraction (SCSB 1983), employing Milton Roy Spectronic 501 and Corning Flame Photometer 410C analysis equipment, respectively), Cu, Fe, Zn, Mn (Melich I Extraction, employing Perkin Elmer atomic absorption spectrometer 3100 analysis equipment), Ca, Mg (KCl extraction, employing Perkin Elmer atomic absorption spectrometer 3100 analysis equipment) and organic C content (Walkley Black procedure (Walkley and Black 1934)). All analyzes were conducted at the Panamanian Institute for Agricultural Investigation (IDIAP) soils laboratory in Divisa, Herrera. Inorganic N was not analyzed because leaching of N in pastures in high rainfall environments is pronounced (Boddey *et al.* 1996). Thus, IDIAP soil laboratories consider inorganic N to be negligible for agricultural purposes and do not normally conduct N analyzes (Villareal 2002).

4.3.3 Statistical analysis

Initially, the data were analyzed using PC-ORD (McCune and Mefford 1999) to perform a cluster analysis in order to describe the general nature of the data using all soil characteristics. The cluster analysis employed Ward's Method with a Euclidian distance measure after relativation of the data by adjusting to the standard deviate (McCune and Grace 2002). Hierarchical clusters were generated for each farm and for all farms together, to describe how each of the 24 sites were related to each other in terms of all measured soil properties. These relationships were then considered in terms of site membership to treatment, farm, and location categories. Statistical computer software (SAS Institute Inc. 1999) was used to perform mixed model analyses. In mixed model analysis with farm effects, sites within farms and farms are considered random factors, and treatment is considered fixed (Zar 1999; Potvin 1993, Littel *et al.* 1996). A paired t-test (Zar 1999), an analysis of variance with fixed effects (Zar 1999), and a rank transformed analysis of variance (Iman 1974) were also performed on the data for the purpose of comparison.

Correlation analyses were conducted between all soil and pasture variables. Variables having a non-normal distribution were analyzed using Spearman's rank correlation (Spearman 1904). Variables meeting the assumption of normality were analyzed by calculating Pearson's product-moment correlation coefficients (Zar 1999). The assumption of normality was evaluated using the Shapiro-Wilk test (Shapiro and Wilk 1965) with an α of 0.05. Statistically significant associations in which the two assessed variables were both significantly correlated with a third variable were analyzed using a partial correlation, where the third variable was held constant (SAS Institute Inc. 1999).

All p-values were thereafter subjected to a sequential rejective Bonferonni test (Holm 1979) – hereafter referred to as Holm's test – before determining significance. A conservative rejective test was used because the suite of soil and pasture variables analyzed in this study do not represent independent apriori hypotheses. Under such circumstances it is expected that for every ten variables analyzed a significant difference (α=0.05) will be detected for at least one variable 40% of the time (Rice 1989). Many rejective tests are available (Westafall *et al.* 1999) but Holm's test was employed because it uses the well understood Bonferonni adjustment in a stepwise manner. Holm's test was not applied to the results of partial correlations because they were specifically planned tests.

For Holm's test the smallest p-value is multiplied by the total number of tests performed and the third smallest p-value is multiplied by the total number of tests performed less two. Holm (1979) envisioned dividing the alpha value instead of multiplying the p-value, but the latter method has been favoured in more recent publications (Ræbild *et al.* 2002) and in SAS software (Westafall *et al.* 1999). Rice (1989) notes that it would be inappropriate to apply this test indiscriminately to all analyzes in a monograph. Therefore, in the present study the analyzes were broken into three categories to which Holm's test was applied: 1) Mixed model analysis of soil properties – 11 tests, 2) mixed model analysis of pasture properties – 6 tests, 3) Correlations of soil and pasture variables – 136 tests.

Prior to each analysis, the assumptions of analysis of variance were tested where possible. The assumptions were tested for each farm by treatment combination as is required in factorial experiments (Zar 1999). Serial independence of soil property means could not be tested because the laboratory did not record the order in which samples were analyzed. Homogeneity of variance was evaluated using Levene's test (Levene 1960). Normality of the residuals was assessed using the Shapiro-Wilk test (1965). Violations of normality were observed. However, the present study relied on the robustness of parametric techniques (Zar 1999) because of the desire to use a maximum likelihood approach in mixed models.

Mixed model analyses using the Proc Mixed statement in SAS (Littel *et al.* 1996) uses a maximum likelihood approach (McLean *et al.* 1991) as opposed to the more traditionally used least-squares approach for analyzing variance. A general Satterthwaite approximation (Satterthwaite 1946) was used to determine the denominator degrees of freedom because, when no significant interaction effect is detected, the mean square of the interaction and error terms are estimates of the same population variance (Zar 1999). An α-level of 0.05 was used to determine the significance of all tests.

4.3.4 Assessing biological significance

The biological significance of treatment differences can be evaluated by comparing treatment means and 95% confidence intervals with biologically significant intervals. Soil yield potential based on physical and chemical properties is used in agriculture as a biologically important parameter to guide fertilizer application rates (Donohue *et al.* 1994). Five situations of interest exist with regards to biological significance, statistical significance and power.

1) A statistically significant difference is found where treatment means and their 95% confidence intervals lie within a single biological category. That is, the study has detected statistical differences that are not biologically significant.
2) A non-significant difference is observed where treatment means and their 95% confidence intervals lie within a single biological category. That is, the treatments are neither statistically or biologically significant.
3) A statistically significant difference is found where treatment means and their 95% confidence intervals come from different biologically significant categories. That is, the difference detected is both statistically and biologically significant.

4) A statistically significant difference is found where treatment means and their 95% confidence intervals cross over biologically significant categories. That is, the difference detected is statistically significant and may be biologically significant.
5) A non-significant difference is observed where treatment means and their 95% confidence intervals cross over biologically significant categories. That is, the difference detected is not statistically significant but may be biologically significant.

In the first, second and third cases, no power analysis is required. This is because either 1) results are statistically significant or 2) statistically insignificant results are not biologically significant. Thus, increased power will only lead to the detection of biologically unimportant differences. In cases four and five, power analysis is worthwhile. In case five, this is to determine whether sample size can be increased to effectively reduce the chance of a type II error. In case four, power analysis can determine if confidence intervals can be reduced in order to better assess biological significance.

4.4 Results and discussion

4.4.1 Cluster Analysis

When the cluster dendrogram is cut at a distance of 1.4×10^2 (dashed bar), four clusters are apparent (solid bars) (Figure 4.3). Sample sites belonging to the same treatment dominate clusters. In cases where sample sites from different treatments lie close together they come from the same farm. Thus sample sites are related on the basis of treatment, however, this relationship can be obscured by farm membership. When cluster dendrograms are generated for individual farms, farm membership is removed from consideration (data not shown), and sample sites belonging to the same treatment again dominate clusters. This indicates that similarity on the basis of treatment holds true across farms. On farms where samples from different treatments lie close together, they come from the same sample fence. Thus, sample fence can obscure the relationship of sample sites based on treatment. Obscuring of relationships on the basis of farm, or sample fence, reflects the inherent 'noise' of natural systems that makes it difficult to detect treatment effects (Ver Hoef and Cressie, 1993).

4.4.2 Treatment means and effects

Soil characteristics' coefficients of variation (CV) ranged from 2 to 58% (Table 4.2). While pH and exchangeable pH had low CV values (ranging from 2 to 6%), all other soil characteristics had CVs of 16% or more (Table 4.2). Exchangeable pH was lower than pH, which is consistent with worldwide data for rainforest soils in the humid tropics (Schulte and Ruhiyat 1998). Mean pH, exchangeable pH, K, Mg, and Ca were numerically lower at the base of the living fence than 6m away (Table 4.2). Mean P, organic C, Fe, Zn, Cu, and Mn were numerically higher at the base of the living fence. However, treatment differences were only significant for Mn following the application of Holm's test (Table 4.2). Mn was 50.9 ± 29 μg/ml higher at the base of the fence (0.2m) than away from the fence (6.2m). Micronutrients have not been frequently analyzed when considering tree impacts on soil fertility. Onim *et al.* (1990) reported that leucaena (*Leucaena leucocephala*), sesbania (*Sesbania sesban*) and pigeon pea (*Cajanus cajan*) leaf litter applied as green manure had no significant effect on Mn. However, that study only applied leaf litter to the soil and so tree root effects were not present. Lack of differences between soil nutrients at the base and 6m away from the base of living fences may be because deciduous plants translocate nutrients out of their foliage before leaf fall (Bernhard-Reversat 1987). However, the low mobility of iron and calcium and the intermediate mobility of zinc, manganese, and copper in plant tissues (Salisbury and Ross 1992) make some mineral input to soil from litter probable.

Farms differed for total mean organic C, Zn, and Mn following the application of Holm's test (p=0.0012; p=0.0066; p=0.008, respectively). Multiple comparisons and confidence intervals were not calculated as it is inappropriate to do so for a random effect in a mixed model (Zar 1999). Still, significant farm effects indicate that the selection criteria (Table 4.1) used to select farms did not eliminate farm variability from the model. Farm × treatment interaction effects are also considered random, so these means are not given.

Coefficients of variation for pasture variables ranged from 12 to 145% (Table 4.2). There was 30% more litter cover and 34% less herbaceous cover at the base of the fence (0.2m), than away from the fence (6.2m). Generally, boundary plantings negatively impact associated vegetation (Rao *et al.* 1998), which supports the observed reduction in herbaceous cover in this study.

The above results were obtained from mixed model analyses employing a general Satterthwaite approximation and applying Holm's test to resultant p-values. It is useful to consider this study's results without using a rejective test because many studies of tree-soil interactions do not employ a rejective test (Sanborn (2001) is an exception). When Holm's test is not applied, pH and exchangeable pH treatment effects are significant. The mean difference in pH of 0.2 units is within the range of 0.2 – 0.3 that Binkley and Giardina (1998) found that tree species vary in their impact on soil.

4.4.3 Comparison with other analytical procedures

Researchers have used t-tests to examine the effects of trees on soil and vegetation (Kater *et al.* 1992; Tornquist *et al.* 1999). Paired sampling designs have been used to analyze how isolated trees affect pasture vegetation (Esquivel and Calle 2001) and are amenable to paired t-test analyses. The present study used a similar paired design. Paired t-tests yield results similar to those reported above with two exceptions: 1) a significant percent bare ground cover treatment effect was detected before applying Holm's test and 2) the percent herbaceous cover effect was not significant after applying Holm's test (p=0.076). However, paired t-tests cannot test farm and farm × treatment interaction effects.

Most studies examining soil properties as affected by trees on farms, or at different locations, have not employed mixed model analyses (see Pandey *et al.* 2000; Tomlinson *et al.* 1995). If the data of this study were analyzed by treating all factors as fixed (in a general linear model), Zn and organic C content also exhibit significant treatment effects after employing Holm's test. Farm × treatment interaction effects are also analyzed and organic C, pH and Zn farm × treatment interaction effects are significant. The interaction effects (Figure 4.4) merit discussion, as they are meaningful in terms of farm characteristics.

In two of the three cases where an interaction was detected, treatment means for farm #4 (open triangle) exhibited crossover interactions (organic C (Figure 4.4) and pH (data not shown)) while in the third case farm #4 is the only farm to show significant treatment differences for Zn (Figure 4.4). When the pasture owner of farm #4 was consulted about these differences, it became apparent that the pasture had been cropped with maize the previous year, despite its inclusion in the study on the basis of no farmer-reported cropping. This may explain the dynamic observed with regards to organic C and pH. Crop residues away from the fence may increase organic C (Smith *et al.* 1993) and pH (Paul *et al.* 2001). It is not apparent why cropping would increase Zn concentrations near the fence. The significant farm × treatment interaction, in which organic C is higher at the base of the living fence on three of the four farms agrees with existing literature which suggests trees increase organic C (Rao *et al.* 1998). The magnitude of the average difference between organic C contents for treatments (0.7 percentage points) in the present study is similar to results reported in other studies (Hailu *et al.* 2000; Jackson and Ash 1998).

The disadvantage of treating farm as a fixed factor is that any inferences made about the treatment effects cannot be extended beyond the farms or locations considered in the study (Potvin 1993). Tornquist *et al.* (1999) employed a mixed model analysis of variance and no rejective test and found, as did the present study, higher pH (H_2O, 2:1) in pastures and few other significant differences in base cations. However, when Tornquist *et al.* (1999) pooled their data and used a t-test they found higher extractable P under agroforestry systems, which was not detected in the present study.

The nonparametric rank transformation analysis of variance (Iman 1974; Zar 1999) can be used to substantiate the findings of parametric techniques. Results of the rank transformation approach detected a significant Mn treatment effect before and after Holm's test, and a significant pH treatment effect before but not after Holm's test. This approach did not detect an exchangeable pH treatment effect before applying Holm's test. Farm or farm × treatment interaction effects were not present. This reinforces the previously discussed finding of treatment differences for Mn and pH. Litter and herbaceous cover outcomes did not require validation using non-parametric techniques because the samples of these variables did not violate analysis of variance assumptions.

Rao *et al.*'s (1998) review of how trees affect tropical soil suggested that soil organic C, and phosphorous under tree canopies should be greater than in open areas, and that soil pH should be greater than or equal to soil pH in open areas. However, in pastures where trees are recruited through natural regeneration (rather than planting) it is possible that trees are establishing on sites of higher soil fertility (Geiger *et al.* 1994). Thus, it is difficult to determine whether trees are improving soil fertility or merely indicating areas of inherently higher soil fertility (Rao *et al.* 1998). Boundary plantings such as living fences do not suffer as much from this confounding effect because trees have been planted rather than naturally recruited. The location of tree fallows is also determined by farmers' decisions. Thus, it may be more reasonable to compare the effects of boundary plantings with those of tree fallows. While some fallows have been observed to increase pH (Drechsel *et al.* 1991; Onim *et al.* 1990), others have reported to decrease it (Drechsel *et al.* 1991; Jonsson *et al.* 1996). Other studies have reported that extractable P and organic matter are increased under fallowed land (Rao *et al.* 1998). The findings of the present study are in agreement with these observations with the exception of increases in extractable P.

4.4.4 Biological significance and power analysis

Most of the soil variables measured in this study did not differ on the basis of distance from the fence. However, the study was small, consisting of only a few farms and a small number of samples per farm. Other on-farm studies [Tornquist *et al.* (1999) and Pandey *et al.* (2000)] used 9 and 10 farms respectively. Littel *et al.* (1996) suggest that 21 farms is a more realistic number when conducting on-farm trials on large-scale farms in the United States. As such, the present study's experimental power may be low. That is, there is a high probability of committing a type II error and accepting the null hypothesis of no difference between treatment means even if a significant difference does exist. Power analysis can suggest how large a sample is required in order to achieve a desired level of power (Zar 1999). Castelloe (2000) points out that power analysis involving random factors is best done through simulation, which is an area of ongoing research and falls outside of the scope of the present research.

It may, however, be possible to determine when power analysis is necessary based on the concept of biological significance. Researchers aim to detect biologically meaningful differences and not just statistically significant differences. Buresh and Tian (1998) reported that many studies have not given attention to how crop production is affected by tree-induced soil changes. Not investigating biological significance is problematic when large sample sizes permit the detection of very small statistically significant differences. A study of tree effects on soil in Nigeria involving 300 samples (Isichel and Muoghalu 1992) is a case in point. Isichel and Muoghalu (1992) found that all soil fertility properties, except soil mechanical properties and C:N ratios, were higher under trees than in open savannas, and some of the differences detected were as small as 0.03 meq/100g. Some studies have conducted ex-situ bioassays to assess the impacts of trees on soil in terms of potential plant yield (Jackson and Ash 2001; Jonsson *et al.* 1996). However, most studies evaluate biological significance in-situ (Kessler 1992; Weltzin and Coughenour 1990; Tiedemann and Klemmedson 1977). Thus, it is not known whether impacts on vegetation are due to direct tree effects on soil or other indirect environmental alterations by trees.

Biologically significant categories used by IDIAP for soil nutrients (Table 4.3) were used to assess the biological significance of treatments on the basis of a least-square means ± 95% confidence interval. Based on these analyses it was found that: 1) the statistically significant treatment effect for Mn was not biologically significant, 2) the treatment effects for organic C, Fe, Ca, Mg, and P were neither statistically nor biologically significant and 3) although the treatment effects for pH, exchangeable pH, Cu, Zn, K were not statistically significant after Holm's test they are potentially biologically significant (Table 4.4). For this last category of variables it would be advisable to pursue power analysis using simulation.

4.4.5 Correlations

Correlations of the soil and vegetation variables fall into three categories: 1) pasture to pasture variable correlations; 2) soil to soil variable correlations; and 3) pasture to soil variable correlations. All soil to soil variable correlations were conducted while holding pH constant because pH is known to affect nutrient availability (Brady and Weil 1996). There were a total of 25 significant correlation coefficients but only a few were ≥0.7 (Table 4.5).

Within the category of soil to soil variable correlations, zinc was positively associated with copper, iron was negatively associated with calcium, and manganese was positively associated with zinc (Table 4.5). When both pH and copper were held constant, manganese's association to zinc became weaker although it remained significant. For pasture to pasture variable correlations, percent litter cover was strongly negatively associated with percent herbaceous cover (Table 4.5). Herbaceous cover is often correlated with herbaceous biomass (Rottgermann *et al.* 2000) so reductions in percent herbaceous cover may indicate a reduction in pasture herbaceous biomass. For pasture to soil variable correlations percent litter cover was negatively associated with pH. When percent herbaceous cover was held constant, this association became weaker (Table 4.5).

Correlations do not infer causation (Zar 1999), but established soil-tree-vegetation relationships agree with the results of the present study. Decomposition of leaf litter releases organic acids, which acidify soils (Onim *et al.* 1990). An established litter layer can suppress emergence of perennial herbaceous species (Goldberg and Werner 1983) and is thought to be a mechanical factor that can retard growth by damaging and/or killing plants (Benitez-Malvido and Kossmann-Ferraz 1999). Tornquist *et al.* (1999) speculated that reductions in pH under agroforestry systems compared to pastures might be associated with litter production. Acidic soil conditions can slow litter decomposition (Hopkins *et al.* 1990) but in the present study litter accumulation was due to dry season conditions (personal observation).

4.5 Conclusions

Implementation of Holm's test, while sound statistical methodology (Rice 1989), rejects findings that are explicable in terms of farm characteristics and current theory regarding tree soil relationships. When employing Holm's test in the present study, Mn was higher at the fence base but not biologically different from Mn 6 m away. Without Holm's test, exchangeable pH and pH were lower at the fence base and may be biologically different from pH 6 m away. However, the exchangeable pH result was not substantiated with non-parametric techniques. Crossover interactions for organic C and pH involving farm #4 appear to be related to past cropping of the pasture. However, differences in organic C were not biologically significant. Differences in Fe, Ca, Mg, and P were neither statistically nor biologically significant. However, non-significant differences in Cu, Zn, and K may be biologically significant, and power analysis using simulation is advisable for these variables. Given the results of the present study, with the exception of pH, there is no evidence of biologically significant impacts on soil properties by *Bursera simaruba* living fences during the dry season in the tropical moist forest life zone of Herrera, Panama. Independent of living fence findings, soil Zn was positively associated with Cu and Mn, while soil Ca was negatively associated with Fe.

There was a strong negative association between percent litter cover and percent herbaceous cover (a correlate of herbaceous biomass). This suggests that *Bursera simaruba* leaf litter may have a negative impact on herbaceous cover (biomass) in the dry season. Non-significant correlations between pH and herbaceous cover, while holding litter cover constant, suggests this impact is not due to pH. However, pH is negatively associated with litter cover, even when holding herbaceous cover constant, suggesting that leaf litter may reduce soil pH. *Bursera simaruba* living fences do not have biologically important impacts on most soil properties, however, their impact on pH is negatively associated with litter fall, and litter fall also appears to negatively affects herbaceous cover.

4.6 Tables and figures

Table 4.1 Characteristics used to select pasture study sites in El Cedro, Los Pozos, Herrera, Panama.

Characteristic	Value
Pasture Age	25 – 30 years
Original Pasture Species	*Hyparrhenia rufa*
Fence Species	*Bursera simaruba*
Fence Age	25 – 30 years
Fence Form	Linear
Burning Regime	Every couple years
Stocking Rate	1 – 2 animals^{-1}ha^{-1}year^{-1}
Last Grazed	30 days prior
Cropping Regime	No cropping last 10 years
Fertilizer Regime	No fertilization
Soil Order	Ultisol

Table 4.2 Summary of treatment effects on pasture and soil properties for four farms in the tropical moist forest life zone of Herrera, Panama, in the dry season of 2003.

			CV		Treatment Mean ± CI[6]					Difference Between Treatment Means ± CI[5]
Variable	Units	DDF[1]	6.2m	0.2m	6.2m	0.2m	Test CI[2]	P-value[3]	Adjusted P-value[4]	
Soil Properties										
Mn	μg/ml	19	36	32	113 ± 26	164 ± 34	63	0.0008	*0.0088	-51 ± 27
pH	pH	6	2	2	6.0 ± 0.08	5.7 ± 0.08	0.12	0.014	0.14	0.2 ± 0.2
Exchangeable pH	pH	19	6	3	5.4 ± 0.2	5.2 ± 0.1	0.3	0.032	0.29	0.2 ± 0.2
Zn	μg/ml	3	30	51	4.4 ± 0.8	6.9 ± 2.3	3.2	0.15	ns	
P	μg/ml	3	58	54	1.3 ± 0.5	2.3 ± 0.8	0.9	0.15	ns	
Organic C	%	3	23	26	3.4 ± 0.5	4.1 ± 0.7	1.2	0.17	ns	
Fe	μg/ml	19	13	10	94 ± 7.8	97 ± 6.0	9.7	0.38	ns	
Cu	μg/ml	19	57	54	1.9 ± 0.7	2.3 ± 0.8	1.1	0.43	ns	
K	μg/ml	3	53	52	192 ± 64	164 ± 55	94	0.48	ns	
Ca	Meq/100ml	19	29	16	0.60 ± 0.11	0.58 ± 0.06	0.17	0.53	ns	
Mg	Meq/100ml	19	32	29	0.43 ± 0.09	0.40 ± 0.07	0.09	0.62	ns	
Pasture Properties										
Leaf Litter Cover	%	19	67	35	10 ± 4	41 ± 9	8	<0.0001	*<0.0006	-30 ± 9
Herbaceous Cover	%	22	12	38	83 ± 6	49 ± 12	9	<0.0001	*<0.0005	34 ± 13
Woody Cover	%	3	35	145	3 ± 0.6	7 ± 6	6	0.33	ns	
Bareground Cover	%	22	112	122	2 ± 2	4 ± 3	2	0.37	ns	
Animal Activity	Rank	19	45	22	2.4 ± 0.7	2.5 ± 0.4	0.6	0.74	ns	

[1] Denominator degrees of freedom used for mixed model analysis of treatment effects.

[2] 95% confidence intervals of the test for treatment means were computed using least mean squares in Proc Mixed (Littell *et al.* 1996).

[3] Probability that the treatment means are equal.

[4] Probability that the treatment means are equal after applying a sequential rejective bonferronni test (Holm 1977).

[5] 95% confidence intervals for the difference between treatment means was computed using least mean squares in proc mixed.

[6] 95% confidence intervals for treatment means were computed using the Proc Mean function (SAS Institute Inc. 1999)

* Significant differences are discussed at $\alpha = 0.05$ using adjusted p-values.

Table 4.3 Nutrient intervals for biological significant categories as determined by Panamanian Agriculture Investigation Institute (IDIAP).

Soil Property	Units	(Low) Very Acidic	(Medium) Acidic	(High) Slightly Acidic	Neutral	Alkaline
P	µg/ml	0 –18	19 – 54	55+		
K	µg/ml	0 – 44	45 – 150	151+		
Ca	Meq/100ml	0 – 2.0	2.1 – 5.0	5.1+		
Mg	Meq/100ml	0 – 0.6	0.7 – 1.5	1.6+		
Cu	µg/ml	0 – 2.0	2.1 – 6.0	6.1+		
Fe	µg/ml	0 – 25.0	25.1 – 75.0	75+		
Zn	µg/ml	0 – 4.0	4.1 – 14.0	14.1+		
Mn	µg/ml	0 – 14.0	14.1 – 49.0	49.1+		
Organic C	%	0 – 2.0	2.1 – 6.0	6.1+		
pH	pH units	4.0 – 5.1	5.2 – 5.9	6.0 – 6.9	7.0	7.1+

Table 4.4 Assessment of biological significance for soil variables in the present study on the basis of Panamanian Agriculture Investigation Institute defined biologically significant intervals.

Soil Property	Units	Statistically Significant	Biologically Significant	Potentially Biologically Significant
Exchangeable pH	pH units	Yes	-	Yes
PH	pH units	Yes	-	Yes
P	µg/ml	No	No	-
K	Meq/100ml	No	-	Yes
Ca	Meq/100ml	No	No	-
Mg	Meq/100ml	No	No	-
Cu	µg/ml	No	-	Yes
Fe	µg/ml	No	No	-
Zn	µg/ml	No	-	Yes
Mn	µg/ml	Yes	No	-
Organic C	%	No	No	-

Table 4.5 Correlations of pasture and soil variables on four farms in the tropical moist forest life zone of Herrera, Panama, in the dry season of 2003.

Associated Variables	Correlation Coefficient	P-value	Adjusted P-value	Test Type	Variable Held Constant
Pasture to Pasture					
Litter : Herbaceous Cover	-0.93	<0.0001	<0.0136	Pearson	-
Soil to Soil					
Calcium : Iron	-0.73	<0.0001	<0.0135	Pearson	-
Zinc : Copper	0.77	<0.0001	<0.0134	Spearman	-
Zinc : Manganese	0.71	0.0001	<0.0133	Spearman	-
Zinc : Manganese	0.62	0.002	-	Spearman	Copper
Pasture to Soil					
Litter Cover : pH	-0.70	0.0002	<0.03	Pearson	-
Litter Cover : pH	-0.53	0.01	-	Pearson	Herb. Cover

Figure 4.1 Map of Herrera province and the judicial district of El Cedro with the towns of Marañón, El Cedro, Tierras Blancas and Pedrenal Abajo indicated.

Source: EoN Systems (2002).

Figure 4.2 Average monthly and annual precipitation in Los Pozos and La Pitaloza (1983-1997 Instituto de Recursos Hidraulicos y Electrificación).

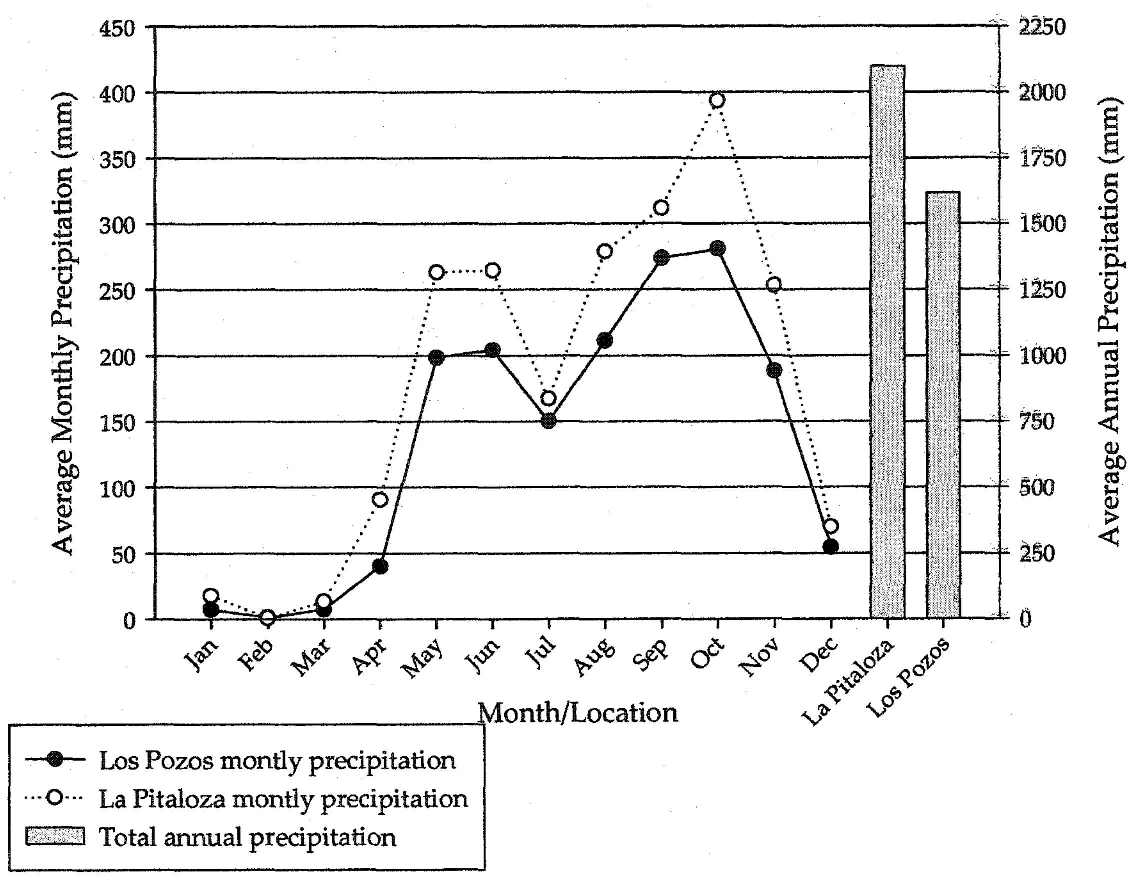
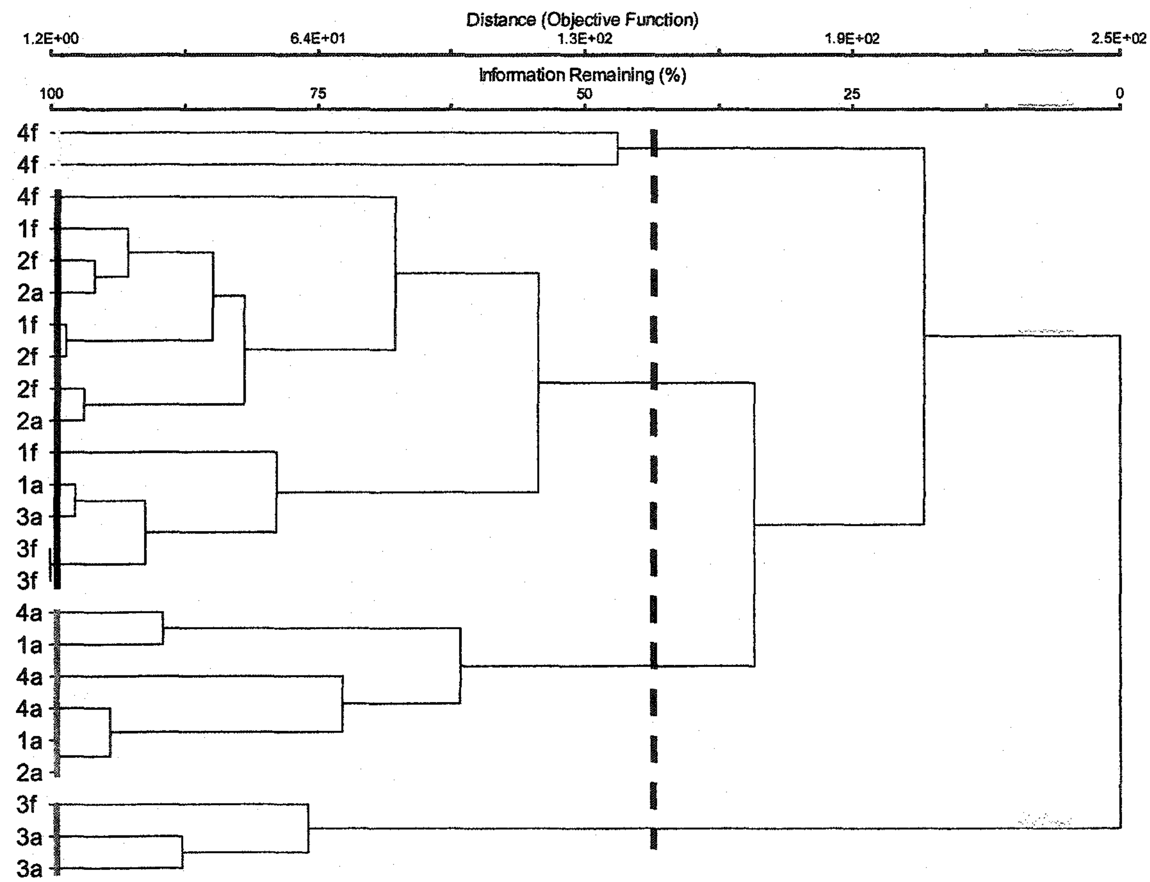
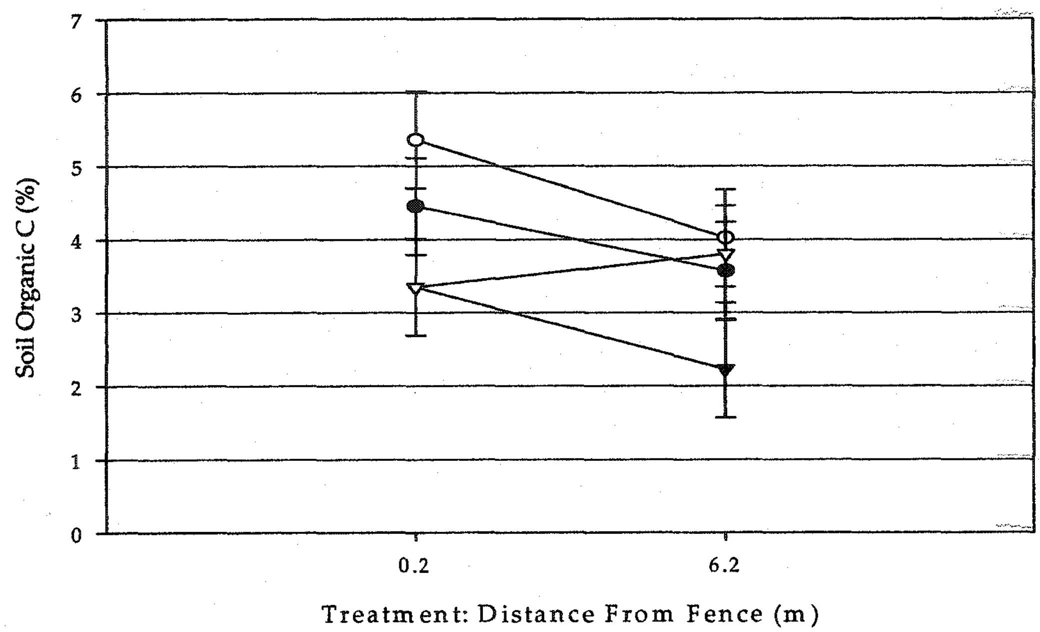


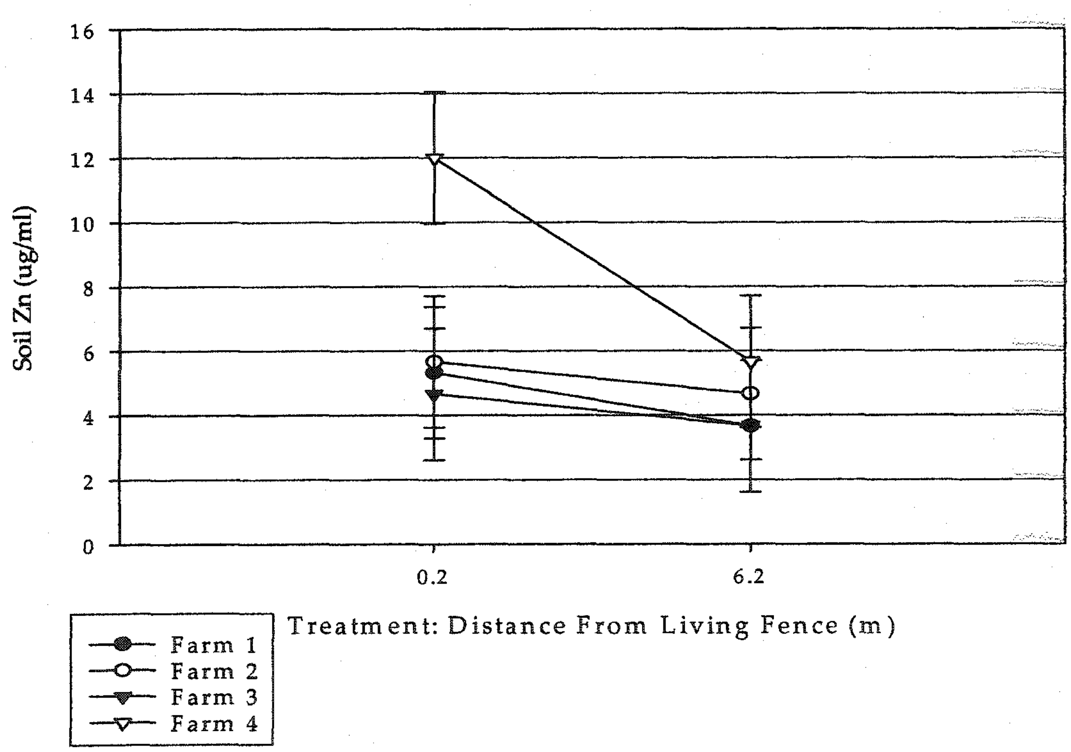
Figure 4.3 Cluster* dendrogram of sites (n=24), using P, K, Ca, Mg, Mn, Cu, Fe, Organic C, Zn, pH (H_2O, 2:1) and Exchangeable pH ($CaCl_2$, 2:1) soil properties at the base of and 6 m away from living fences on four farms in the tropical moist forest life zone of Herrera, Panama in the dry season of 2003.**



*Cluster analysis employed Ward's Method with a Euclidian distance measure after relativizing the data by adjusting to the standard deviate (McCune and Grace 2002)
**Treatment: Soil samples at 6.2m (a) and 0.2m (f) away from the base of a given living fence. Blocks: Four different farms, farm 1 (1), farm 2 (2), farm 3 (3), farm 4 (4).

Figure 4.4 Organic C and Zn content of soil at different distances from living fences (0.2 and 6.2m) on four farms in the tropical moist forest life zone of Herrera, Panama, in the dry season of 2003. Data Are Means ± 95% C.I., n=3.





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5.0 General discussion and conclusions

Herrera province is considered the heartland of small-scale agriculture in Panama (Jaen-Suarez 1978). Trees in pastures in Herrera are worthy of study because Herrera is dominated by pasturelands (Contraloria 2000), and trees are an important part of pasture landscapes in Central America (Harvey and Haber 1999). Small-scale farmers owning pasture are of interest because multipurpose trees (Hedge and Daniel 1992; Winrock International 1988) and agroforestry systems (Sepulveda 1987; Winterbottom and Hazelwood 1987) are viewed as being particularly appropriate for small-scale farmers. Among the many benefits of agroforestry systems, improvement of soil fertility has been intensively studied. Isolated trees in parklands have received much attention in the literature, but living fences and their effects on soil fertility have not. These boundary plantings may be of importance on smaller-scale farms because they affect a greater proportion of the farms' area than is the case with larger-scale farms. *Bursera simaruba* is common living fence species in Central America (Budowski 1987) but is not a leguminous species (Gentry 1996). As such, it does not affect soil fertility through biological nitrogen fixation, one of the major mechanisms cited for how agroforestry systems can improve soil fertility (Rao *et al.* 1998).

This thesis work consisted of three lines of investigation: 1) year 2000 unpublished, published and to be published census data was analyzed to describe the generalities of agriculture in Panama and Herrera, with particular emphasis on household dependence on farming, the effects of title status on land use, and the importance of cattle and pastureland. 2) Semi-structured interviews with small-scale pasture owners were used to identify multipurpose tree species of importance in Herreran silvopastoral systems, and to describe the management of these species. This study included all of Herrera's districts and was stratified on the basis of ecozone and informant gender. Special attention was given to the use of protein banks by small-scale pasture owners. 3) An on-farm study was used to assess the effects of *Bursera simaruba* living fences (in the tropical humid forest life zone of Herrera) on chemical soil fertility and pasture vegetation. Biological significance was considered alongside statistical significance. Mixed model statistical techniques amendable to analyses of on-farm experiments, and a rejective test amendable to examining suites of variables, were employed.

The specific objectives of these lines of investigation were to:

Agricultural census

1) Describe Panamanian agriculture in the year 2000 using census data and compare Herreran agriculture to agriculture in Panama as a whole.

Multipurpose trees

1) Describe the use of trees in Herreran pastures and their multipurpose nature, considering the effects of ecozone, informant gender and different types of uses on species richness.
2) Investigate the current status of protein banks in Herreran silvopastoral systems.
3) Prioritize multipurpose species in Herrera for further research.

Living fences and soil fertility

1) Employ an on-farm study to quantify the impact of *Bursera simaruba* living fences in El Cedro pastures on soil chemical properties and vegetation characteristics, and examine associations within and between soil chemical properties and vegetation characteristics.

The major and minor findings of this thesis are as follows:

5.1 Major findings

Panamanian Agriculture

- Household dependence on farm income in Panama is greater for farms managed by male household heads than those managed by female household heads. Overall dependence on farm income is low but it is lowest for smaller farm size classes. This indicates the importance of off-farm sources of income, especially for women and small-scale farmers. Off-farm work may make it difficult to adopt intensive-intensive agroforestry technologies.
- Dependence on farm income is greater in Herrera than in Panama as a whole, while productivity of major food crops is similar. This suggests that dependence on farm

income may be due to lack of alternative sources of income in Herrera compared to Panama as a whole.

- Forested lands cover a smaller percentage of titled than untitled lands in all provinces with the exception of Darién, while pastures cover a higher percentage. This indicates that titling land has resulted in the reduction of forest cover and an increase in pastureland. This situation was likely fuelled by past policies requiring removal of forest cover in order to obtain title, and the promotion of cattle ranching as a land use strategy.
- Percent forest cover tends to increase on untitled lands with increasing farm size in both Herrera and Panama. However, this trend is less apparent for titled land. This indicates an incentive to deforest titled agricultural land regardless of farm size, whereas untitled land holdings might only be deforested for basic production activities.
- Titled pasturelands in both Herrera and Panama have a higher percentage of pasture under improved grasses than untitled pasturelands. This may be because titled lands are more likely to receive investment because improvements are secure. Alternatively, farmers with the resources to title land may be more likely to have the capital required to improve pastures.

Multipurpose Trees

- Trees are retained in Herreran pastures for stakes, living fences, fruit, fodder, animal shade, water shade, medicinal use, firewood, and construction wood. There are differences in the popularity of these uses, with medicinal use being the least popular. This suggests that Herreran silvopastoral systems provide a number of tree products and services, but that these products and services are not equally sought after within these systems.
- There are differences in species richness between use categories, whether considered in terms of all informants, or only informants reporting use. In general, species richness is low. This suggests that pasture owners only use a few tree species in their pastures for any given use.
- Reported species richness is less than actual on-farm species richness because not all tree species are used by a given pasture owner, despite having known uses. Also, it is impossible for a pasture owner to recall all trees present on their farm, so only the most important or abundant are mentioned.

- Most of the species that receive a high multipurpose rating are native species (Nance – *Byrsonima crassifolia,* Guácimo – *Guazuma ulmifolia,* Laurel – *Cordia alliodora,* Cedro Amargo – *Cederla ordonata,* Espave – *Anacardium excelsum,* Carate – *Bursera simaruba,* Corotú – *Enterolobium cyclocarpum,* Macano – *Diphysa robinioides*) although Mango – *Mangifera indica* is an exception. This suggests that native species play an important role in Herreran silvopastoral systems with regards to multiple uses.
- Protein banks are not prevalent among small-scale pasture owners in Herrera. Cattle ownership by small-scale farms as a security net may place emphasis on animal survivorship rather than weight gain. Thus, adoption of protein banks is difficult. Supplementary feeding activities using agricultural residues are already common practice. Capital-intensive dairy farmers residing close to major centres expressed some interest in protein banks. This suggests that small-scale pasture owners may have limited use for protein banks.

Soil Fertility and Living Fences

- Exchangeable pH and pH are lower at the base of *Bursera simaruba* living fences (0.2m away) than 6.2m away. Mn is higher at the fence base than 6.2m away. While these differences may be biologically significant in the case of pH, they are not biologically significant for Mn.
- Litter cover was greater at the base of *Bursera simaruba* living fences while herbaceous cover was less.
- Generally, there is a strong negative association between percent litter cover and percent herbaceous cover, and a less strong negative association between percent litter cover and vegetative biomass. A non-significant correlation between pH and herbaceous cover while holding litter cover constant suggests this impact is not due to pH.
- Generally, pH is negatively associated with litter cover, even when holding herbaceous cover constant. This suggests that leaf litter of a *Bursera simaruba* living fence may reduce associated soil pH.

5.2 Minor findings

Panamanian Agriculture

- Pasturelands cover a greater percentage of titled and untitled land in Herrera compared to Panama as a whole, while forested lands cover a smaller percentage of titled and untitled lands. This suggests that the reduction of forests and the creation of pastures on Herreran agricultural lands has been greater than elsewhere in Panama.
- When titled and untitled lands are considered in terms of all landuses, titled and untitled lands in the various provinces of Panama tend to cluster together. This indicates that title status influences land use strongly enough to cut across biophysical attributes of agricultural landscapes from the same province.
- A higher percentage of farmers own cattle in Herrera than in Panama as a whole, indicating the importance of cattle ranching in Herrera. Ocú is the district of Herrera with the most cattle-owning farmers and number of cattle.
- Draft bulls make up a very small percentage of all cattle both in Herrera and Panama. This indicates that draft bulls are not popularly used for transport or tilling.
- Improved pastures make up a small percentage of pastureland in Panama and an even smaller percentage of Herreran pastureland. This probably reflects the high cost of establishing such pastures, and the relatively recent introduction of improved pasture grasses to Panama.

Multipurpose Trees

- Ecozone did not affect use category species richness. This may be because, although tree species abundance changes with ecozone, species richness for use categories does not.
- Women mentioned more fruit species while men mentioned more fodder species when only users are considered. When all pasture owners are considered, only the difference for fruit species remains significant. This supports the claim that men and women have different interests with regards to agroforestry. However, lack of significant differences also suggests that women are reasonably knowledgeable about trees in pastures despite pastures being a male-gendered space.

- There is a slight preference for retaining multipurpose tree species in pastures. This is in accordance with the claim that multipurpose trees are appropriate for small-scale farmers.
- Caoba (*Swietenia macrophylla*) and Caratillo (*Bursera tomentosa*) are popular single purpose species for construction wood and living fences, respectively. This popularity allowed them to score high multipurpose ratings despite being single purpose trees.

Soil Fertility and Living Fences

- Use of a rejective test may not always be appropriate when some of the rejected results are explicable in terms of current theory.
- Crossover interactions for organic C and pH appear to be related to past cropping on one farm. In both cases values are higher at the base of a living fence (0.2m away). However living fence effects on soil organic C are not biologically significant.
- Differences in Fe, Ca, Mg, and P due to living fences are neither statistically nor biologically significant. However, non-significant differences for Cu, Zn, and K may be biologically significant, and power analysis using simulation is advisable.
- Independent of living fence findings, soil Zn is positively associated with Cu and Mn while soil Ca is negatively associated with Fe.

5.3 Contributions to knowledge

This thesis work uncovered some of the notable differences between agriculture in Herrera province and the Republic of Panama. It made apparent that agricultural census data can be used effectively to discuss regional differences and evaluate how consistent trends are across regions. Land tenure was shown to have an important impact on land use. The observation that forest cover is not as prevalent on titled land contributes a caveat to research asserting that tree planting is more likely to occur on titled land. Description of pastures and cattle ownership by district in Herrera province makes an important contribution in terms of establishing a context in which Herreran silvopastoral research can be carried out in the future.

Multipurpose species were identified in most cases to the species level and their uses in pastures enumerated. This contributes baseline data on existing Herreran silvopastoral systems and their species composition. The study reaffirmed differences in knowledge and/or preference of agroforestry trees on the basis of gender. It also indicated that women are knowledgeable of tree species in male-gendered agricultural spaces such as pastures. Knowledge about the lack of protein banks in Herrera and the difficulties associated with potential adoption is contributed against the backdrop of ongoing research into protein bank technology in Herrera. There is evidence that protein banks may be entirely inappropriate for small-scale farmers given these farmers' current management practices and economic goals. Specifically, cattle survivorship is likely more important than cattle productivity (weight gain). A rating scheme for multipurpose species that does not require farmers to rank trees contributes an efficient prioritization approach, which is not dependent on farmers' ability/willingness to rank trees.

Investigation of living fences' impact on soil chemical properties contributed species-specific information on *Bursera simaruba*'s effects on soil. Living fences are not often studied for their effects on soil, and this study contributes knowledge about an overlooked type of boundary planting. Use of biologically significant intervals to assess the biological importance of differences in chemical fertility contributes an alternative to labour-intensive ex-situ bioassay techniques.

5.4 Recommendations for future research and practical application

The research carried out over the last two years has taught me a great deal about silvopastoral systems in Herrera with regards to their species composition and management. When I return to Panama I intend to pursue the following lines of research:

1) Investigation of the variation in multipurpose tree germplasm in farmers' fields and its collection for testing and potential development of multipurpose tree varieties. Fodder species may be characterized in terms of quantity, quality, and distribution of fruit drop during the dry season to select superior individuals. Attention may be given to Guácimo (*Guazuma ulmifolia*) and Corotú (*Enterolobium cyclocarpum*).
2) Investigation of mineral fertilization strategies for fodder trees such as Guácimo (*Guazuma ulmifolia*) and Corotú (*Enterolobium cyclocarpum*). This may identify management strategies that increase the quantity and nutritive value of fruit produced, and improve the distribution of fruit drop during the dry season.
3) Investigation of species composition of silvopastoral systems in different villages using interviews and pasture tree censuses. This information may help clarify to what extent

species are spatially constrained and if their use is due to seed limitation and/or farmer preferences.

4) Investigation of living fence species diversity and soil fertility (chemical, physical, biological) to evaluate the impacts of different living fence species and/or species combinations. Use of ex-situ bioassays to more accurately assess the biological significance of altered soil properties. This may clarify the impact living fences have on soil fertility.

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6.0 Appendices

Appendix 6.1 Question guide* for semi-structured interview administered to 45 small-scale pasture owners in Herrera province, Panama.

1. Como se llama usted? / What's your name?
2. Cuando se nació usted? / When were you born?
3. A que se dedica? / What's your occupation?
4. Cuantas hectáreas tiene su finca en total? / How many hectares is your farm?
5. Cuantas hectáreas tiene en potrero? / How many hectares is in pasture?
6. Cuantos años tiene el potrero? / How old is the pasture?
7. Cuantos años ha estado usted utilizando el potrero? / How many years have you used the pasture?
8. Queman el potrero? Sí, 9. No, 11. / Do you burn the pasture?
9. Cada cuantos años lo quema? / How often do you burn the pasture?
10. Usan herbicida dentro del potrero? Sí, 11. No, 14. / Do you use herbicide in the pasture?
11. Para matar cuales plantas? / To kill which plants?
12. Alquilan el potrero a otra gente? Sí, 13. No, 14. / Do you rent pasture to others?
13. En cuanto lo alquila? / How much is rented?
14. Alquila usted potrero de otra gente? Sí, 15. No, 16. / Do you rent pasture from others?
15. Cuánto cuesta? / How much does it cost?
16. Tiene usted acceso a potreros de un familiar o amigo para sus animales? / Do you have access to the pastures of family or friends?
17. Tiene usted ganado? Sí, 18. No, 23. / Do you have cattle?
18. Cuantas cabezas? / How many head?
19. Cuantos son becerros, becerras, novillos, novillas, vacas, y toros? / How many are calves, yearling bulls, heifers, cows, and bulls?
20. De que raza son? / What breed are they?
21. Son para leche, carne, o doble propósito? / Are they beef, dairy, or dual purpose cattle?
22. Por que tiene usted ganado? / Why do you own cattle?
23. Tiene usted caballos? Sí, 24. No, 27. / Do you have horses?
24. Cuantas cabezas tiene? / How many?
25. De que raza? / What breed?
26. Por que tiene usted caballos? / Why do you own horses?
27. Tiene usted ovinos o caprinos? Sí, 28. No, 32. / Do you have any sheep or goats?
28. Cuantas cabezas? / How many?
29. De que raza son? / What race?
30. Son para leche, carne o doble propósito? / Are they beef, dairy, or dual purpose animals?
31. Por que tiene usted ovinos o caprinos? / Why do you own sheep or goats?
32. Cada cuanto tiempo vea usted sus animales? / How often do you see your animals?
33. Pastan sus animales juntos o apartes? / Do your animals graze together?
34. Es su potrero dividido? Sí, 35. No, 36. / Is your pasture divided?
35. Por que? / Why?
36. Tiene usted árboles en su potrero? / Do you have trees in your pasture?
37. Tiene usted árboles para una cerca viva dentro de su potrero? Sí, 38. No, 41. / Do you have a living fence in your pasture?
38. Lísteme los árboles que están en su cerca viva / List the trees that you maintain in the living fence.
39. Cuál arbole es lo mejor para cerca vivas? / Which tree is the best for living fences?

40. Por que? / Why?
41. Tiene usted árboles para leña dentro de su potrero? Sí, 42. No, 45. / Do you have trees for firewood in your pasture?
42. Lísteme todos los árboles que mantiene para leña? / List the tree you maintain for firewood.
43. Cual arbole es lo mejor para leña? / Which tree is best for firewood?
44. Por que? / Why?
45. Tiene usted árboles para fruta dentro de su potrero? Sí, 46. No, 49. / Do you have trees for fruit in your pasture?
46. Lísteme todos los árboles que mantiene para fruta? List the trees you maintain for fruit.
47. Cual arbole es lo mejor para fruta? / Which tree is the best for fruit?
48. Por que? / Why?
49. Tiene usted árboles para sombra de ganado dentro de su potrero? Sí, 50. No, 53. / Do you have trees for cattle shade in your pasture?
50. Lísteme todos los árboles que mantiene para sombra de ganado? / List the trees you maintain for cattle shade.
51. Cual arbole es lo mejor para sombra de ganado? / Which tree is the best for cattle shade?
52. Por que? / Why?
53. Tiene usted árboles para sombra de agua dentro de su potrero? Sí, 54. No, 57. /Do you have trees for water shade in your pasture?
54. Lísteme todos los árboles que mantiene para sombra de agua? / List the trees you maintain for water shade.
55. Cual arbole es lo mejor para sombra de agua? / Which tree is the best for water shade?
56. Por que? / Why?
57. Tiene usted árboles para forraje dentro de su potrero? Sí, 58. No, 61. / Do you have trees for fodder in your pasture?
58. Lísteme todos los árboles que mantiene para forraje? / List the trees you maintain for fodder.
59. Cual arbole es lo mejor para forraje? /Which tree is the best for fodder?
60. Por que? / Why?
61. Tiene usted árboles para medicina dentro de su potrero? Sí, 62. No, 65. / Do you have trees for medicine in your pasture?
62. Lísteme todos los árboles que mantiene para medicina? / List the trees you maintiain for medicine.
63. Cual arbole es lo mejor para medicina? / Which tree is the best for medicine?
64. Por que? / Why?
65. Tiene usted árboles para estacones dentro de su potrero? Sí, 66. No, 69. / Do you have trees for posts in your pasture?
66. Lísteme todos los árboles que mantiene para estacones? / List all the trees you maintain for posts.
67. Cual arbole es lo mejor para estacones? / Which tree is the best for posts?
68. Por que? / Why?
69. Tiene usted árboles para madera de construcción dentro de su potrero? Sí, 70. No, 73. / Do you have trees for construction wood in your pasture?
70. Lísteme todos los árboles que mantiene para madera de construcción? / List the trees you maintain for construction wood.
71. Cual arbole es lo mejor para madera de construcción? / Which tree is the best for construction wood?
72. Por que? Why?
73. Tiene árboles en su potrero para otro usos? Cuales? / Do you have trees in your pasture for any other uses? What are they?
74. Estos árboles estaban antes de que se creyó el potrero? / Were these trees there before the pasture was created?

75. Sembraron estos árboles? Sí, 75. No, 76. / Did you plant the trees?
76. De donde consiguió semilla? / Where did you get the seeds?
77. Llegaron estos árboles por regeneración natural? / Did the trees arrive through natural regeneration?
78. De donde consiguió las estacas para su cerca viva cuando sembró la cerca por primera vez? / Where did you get your living stakes when you first constructed your living fence?
79. De donde consigue estacas vivas para hacer la resiembra de su cerca? / Where do you get living stakes to repair your living fence?
80. Compra usted estacas vivas? Sí, 80. No, 81. / Do you buy living stakes?
81. Cuánto cuesta? / How much do they cost?
82. Vende usted estacas vivas? Sí, 82. No, 83. / Do you sell living stakes?
83. En cuanto vende? / How much do they cost?
84. Poda usted su cerca viva? Sí, 84. No, 85. / Do you prune your living fence?
85. Por que la poda? / Why do you prune it?
86. En cuales meses la poda? / In what month do you prune it?
87. Cuándo poda la cerca, hecha las ramitas a su ganado? / When you prune the fence do you give your cattle the branches?
88. Tiene usted rastrojo dentro de su potrero? Sí, 88. No, 90. / Do you have secondary growth in your pasture?
89. Por que? / Why?
90. Para que sirve? / What is it useful for?
91. Da usted una ayuda a su ganado durante verano? Sí, 91. No, 92. / Do you supplement your cattle during the summer?
92. Que da al ganado? / What do you give the cattle?
93. Ha visto usted a sus animales comiendo partes de árboles? Sí, 93. No, 94. / Have you noticed your animales eating parts of trees?
94. Cuales árboles? / Which trees?
95. Tiene usted un banco de proteína? / Do you have a protein bank?
96. Pierden sus animales peso o rebaja producción de leche durante el verano? / Do your cattle lose weight or produce less milk during the summer?
97. Sí pierden los animales peso durante el verano y sí comen partes de árboles durante el verano por que no maneja usted los árboles como alimento en un banco de proteína para los animales? / If the animals lose wieght and eat parts of trees during the summer why don't you manage trees as food in a protein bank for the animals?

*The list of questions was used as a guide during semi-structured interview with any given interview having slightly different wording and ordering of questions depending on the informant.

Appendix 6.2 Number of informants from each ecozone (lowland, transition, upland) and gender (male, female) category.

	Ecozone			Gender	
	Lowland	Transition	Upland	Male	Female
Number of Informants	15	15	15	31	14

Appendix 6.3 Approval granted by the Human Research Ethics Board to conduct research.

Faculty of Agriculture, Forestry, and Home Economics
Human Research Ethics Board
Approval

is hereby granted to:

Dean Spaner, Principal Investigator for

02-21 Investigating the current and potential use of shrubs (fodder) as feed for ruminants in Panama with emphasis on Cratylia aregenta and small farmers

for a term of one year, provided there is no change in experimental procedures. Any changes in experimental procedures must be submitted in writing to the HREB.

Granted: April 30, 2002

for *Rhonda Bell, Acting Chair, HREB*

Appendix 6.4 English translation of the information sheet presented to informants prior to obtaining their signed consent.

<u>Investigating the Current and Potential Use of Shrubs (Fodder) as Feed for Ruminants in Panama with Emphasis on *Cratylia aregenta* and Small Farmers</u>

The purpose of this study is to evaluate the current and potential use of forages by small farmers in the Peninsula D'Azuero region. We are inviting small farmers and agricultural extensionists in the region to be interviewed in order to understand their opinions, situations, and activities. We are also inviting small farmers to allow direct observation of their pastures, animals and management practices. We hope that this research will help to improve extension activities in the region that focus on small farmers.

We would like an hour or two of your time for an interview on this topic. If you agree, we would like to tape-record our interview as well as take notes. The interview will be transcribed either by the researchers or by a transcriber. Only the researchers and/or transcriber of the project will have access to the tapes from the interview. You may also be asked to permit direct observation of your pastures, animals, and your management of your pastures and animals. This will require giving the researcher access to your pastures and animals for a few days. Small amounts of material may be removed from your field for testing. The information from the interviews and direct observation will be used in a Master of Science thesis at the University of Alberta, as well as other publications resulting from the research. The University of Alberta is located in Canada. If you desire copies of any publications resulting from the research they can be sent to the nearest post office in your name.

Upon completion of the interview all participants will be referred to by a code rather than by name to ensure confidentiality. Your name will not appear in any publications and you will only be referred to by your organizational affiliation (e.g. small farmer, government exstensionist, NGO extensionist). However, we cannot guarantee that the text of your response, if used in a thesis or publications, will not reveal your identity. You may decline to answer any of the interviewer's questions and can stop the interview at any time.

If you choose to participate in this study, its interviews, or direct observation of your pastures, animals, and management practices will require your time and may result in your participation in the study being known to others. The research being conducted is of no commercial value. There is no monetary compensation for participation. A summary of the proposed research can be provided to you upon request. Questions regarding the interview, direct observation or the study can be addressed to any of the researchers listed below. Alternatively, you may contact Fred Judson at the address listed below. Fred Judson is not directly involved with the project and is willing to hear any future complaints or concerns you may have.

Appendix 6.5 English translation of the consent form used to aquire signed consent of informants.

Title of the Research Project:

Investigating the Current and Potential Use of Shrubs (Fodder) as Feed for Ruminants in Panama with Emphasis on *Cratylia aregenta* and Small Farmers

Consent:

I acknowledge that I have been asked to participate in a research study and have received and been orally presented the attached information letter. I am aware of the risks associated with participating in this study and know that I can refuse to answer questions, or may stop the interview at any time. I also know that I may refuse to allow direct observation of my pastures, animals, and/or my management of my pastures and animals at any point in time. This includes the right to refuse the taking of material from the pastures. I have been given the opportunity to ask questions and know that I may contact either of the investigators listed below with any further questions. I am aware that the interview will be tape recorded and that only the investigators and/or transcriber will have access to the tape and transcriptions. I know that information from this interview may be used in publications and as part of a Master's thesis. I understand that in these publications I will be referred to only by my organizational affiliation and that my name will not be used.

Name of Participant (Please print) | Signature of Participant

Appendix 6.6 List of 82 species reported by 45 small-scale pasture owners in Herrera province Panama.

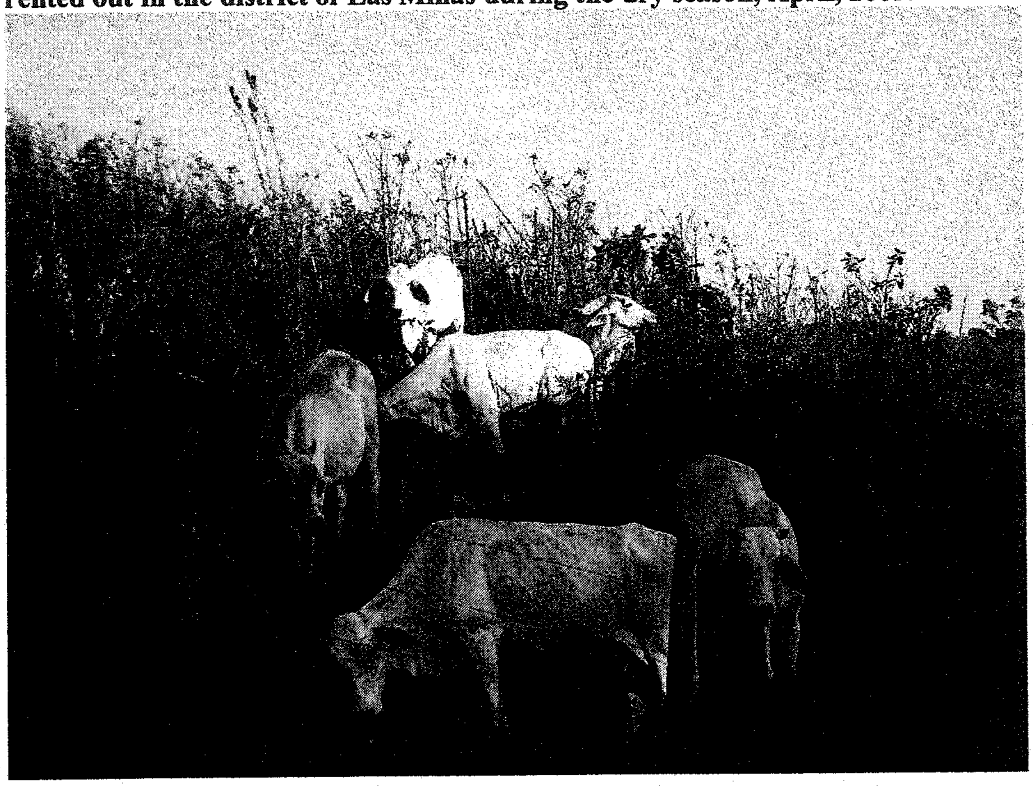
Common Name	Species Name	Common Name	Species Name
Agallo	*Caesalpinia coriaria*	Jobo	*Spondias mombin*
Aguacate	*Persea americana*	Jobo lagarto	*Sciadodendron excelsum*
Alcabu	*Zanothoxylum sp.*	Juagua	*Genipa americanus*
Amarrilla	*Terminalia sp.*	Laurel	*Cordia alliodora*
Arraijan	*Miconia sp.*	Lazo	*Matayba sp.*
Balo	*Gliricidia sepium*	Lazo macho	*Cupania guatemalensis*
Bamboo	*Bambusa sp.*	Leucaena	*Leucaena leucocephala*
Biyuyu	*Cordia sp.*	Macano	*Diphysa robinioides*
Cabimo	*Copaifora aromatica*	Malagueta	*Xylopia frutescens*
Caimito	*Chrysophyllum cainito*	Malagueto	*Xylopia aromatica*
Camaroncillo	*Hirtella racemosa*	Mamey	*Pouteria sapota*
Cañaza	*Bambusa sp.*	Mangle boton	*Conocarpus erectus*
Canillo	*Miconia argentea*	Mango	*Mangifera indica*
Caoba	*Swietenia macrophylla*	Marañon	*Anacardium occidentale*
Carate	*Bursera simaruba*	Maria	*Calophyllum longifolium*
Caratillo	*Bursera tomentosa*	Nance	*Byrsonima crassifolia*
Carbonero	*Colubrina glandulosa*	Naranja	*Citrus sinensis*
Cedro Amargo	*Cederla ordonata*	Negro	*Pollalesta discolor*
Cedro Espino	*Bombacopsis quinatum*	Olivo	*Sapium glandulosum*
Ciruela	*Spondias purpurea*	Palma Pacora	*Aculeata acromonia*
Coquillo	*Jatropha curcas*	Palma Real	*Attalea butyracea*
Corotú	*Enterolobium cyclocarpum*	Palo Santo	*Erythrina poeppigiana*
Cortezo	*Apeiba aspera*	Papo	*Hibiscus rosa-sinensis*
Espave	*Anacardium excelsum*	Pazmo	*Siparuna sp.*
Espino Amarillo	*Chloroleucon mangense*	Pino Nacional	*Podocarpus oleifolius*
Espino Vaca	*Chomelia spinosa*	Pitajaya	*Acanthocereus pentagonus*
Eucalipto	*Eucalyptus globulus*	Pito	*Erythrina costaricensis*
Guabilo	*Albizia sp.*	Puma Rosa	*Psisigium lambo*
Guabito	*Inga sp.*	Rascador	*Licania arborea*
Guachapalí	*Samanea saman*	Roble	*Tabebuia rosea*
Guácimo	*Guazuma ulmifolia*	Rosetillo	*Randia sp.*
Guacimo macho	*Luhea spinosa*	Sajinillo	*Sinamomum*
Guanábana	*Annona muricata*	Sapote	*Licania platypus*
Guava	*Inga vera*	Sastra	*Garcinia sp.*
Guayacan	*Tabebuia guayacan*	Sigua	*Phoebe cinnamomifolia*
Guayacan	*Tabebuia ochracea*	Tamarindo	*Tamarindus indica*
Guayaba	*Psidium guinensis*	Teca	*Tectona grandis*
Guinda	*Zyzyphus mauritiana*	Tuli Viejo	*Jacquinia macrocarpum*
Herrero	*Mimosa tenuiflora*	Tumpito, Zumbo	*Allibertia edulis*
Higo	*Ficus sp.*	Uvero	*Coccoloba lasseri*
Jarino	*Andire inermis*	Uvito	*Ardisia revoluta*

Appendix 6.7 List of species found in surveys of living fences in Parita, Herrera, Panama in July 2002.

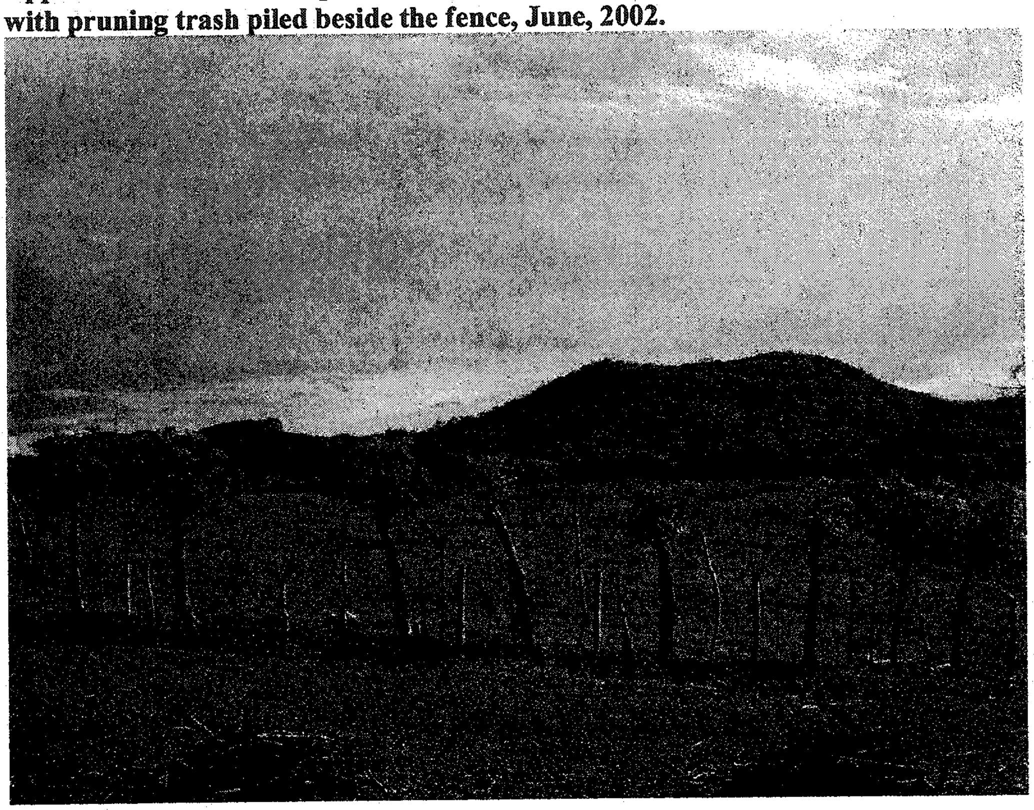
Farm 1		Farm 2	
Common Name	**Species Name**	**Common Name**	**Species Name**
Balo	*Gliricida sepium*	Balo	*Gliricida sepium*
Carate	*Bursera simaruba*	Carate	*Bursera simaruba*
Ciruela	*Spondias purpurea*	Ciruela	*Spondias purpurea*
Caratillo	*Bursera tomentosa*	Caratillo	*Bursera tomentosa*
Olivo	*Sapium glandulosum*	Nance	*Byrsonima crassifolia*
Guabilo	*Albizia sp.*	Laurel	*Cordia alliodora*
Guayacan	*Tabebuia ochracea*	Lazo	*Matayba scrobiculata*
Coquillo	*Jatropha curcas*	Coquillo	*Jatropha curcas*
Marañón	*Anacardium accidentale*	Marañón	*Anacardium accidentale*
Alcabú	*Zanothoxylum sp.*	Alcabú	*Zanothoxylum sp.*
Jobo lagarto	*Sciadodendron excelsum*	Jagua	*Genipa americana*
Guácimo	*Guazuma ulmifolia*	Guácimo	*Guazuma ulmifolia*
Chirimoya	*Annona cherimola*	Palma pacora	*Acrocomia aculeata*
Jagua	*Genipa americana*	Poro-Poro	*Cochlosermum vitifolium*
Jobo	*Spondias mombin*	Jobo	*Spondias mombin*
Guachapalí	*Samanea saman*	Guayaba	*Psidium guinensis*
Morpho 1	*Trichili hirta*	Guarumo	*Cecropia*
Morpho 2	*Sapindus sp.*	Morpho 1	*Stemmandenia*
Morpho 3	*Casearia arguta*	Morpho 2	*Casearia arguta*
Morpho 4	*Xylosma sp.*	Morpho 3	*Casearia arguta*
Morpho 5	*Spondias sp.*	Mropho 4	*Nyctaginaceae*
Morpho 6	*Albizia sp.*	Morpho 5	*Erythroxylum sp.*
Morpho 7	*Combretaceae*	Morpho 6	*Alibertia sp.*
Morpho 8	*Myrtacea*	Morpho 7	*Randia sp.*
Morpho 9	*Chomelia spinosa*	Morpho 8	*Myrtacea*
Morpho 10	*Acacia*	Morpho 9	*Chomelia spinosa*
Morpho 11	*Melic bijuga*	Morpho 10	*Eugenia sp.*
Morpho 12	*Caesapindacea*	Morpho 11	*Ficus sp.*
		Morpho 12	*Ardisia revoluta*
		Morpho 13	*Cedrela ornatum*
		Morpho 14	*Chomelia guetarda*
		Morpho 15	*Myrtacea*
		Morpho 16	*Casearia sylvestris*
		Morpho 17	*Copaifora aromatica*
		Morpho 18	*Berbenacea*
		Morpho 19	*Zwelania titonia*
		Morpho 20	*Ficus sp.*
		Morpho 21	*Myrtaceae*
		Morpho 22	*Cogoba rufescens*
		Morpho 23	*Pouteria stipitata*

Morpho = Species for which no common name was known by the farmer but which differs from others.

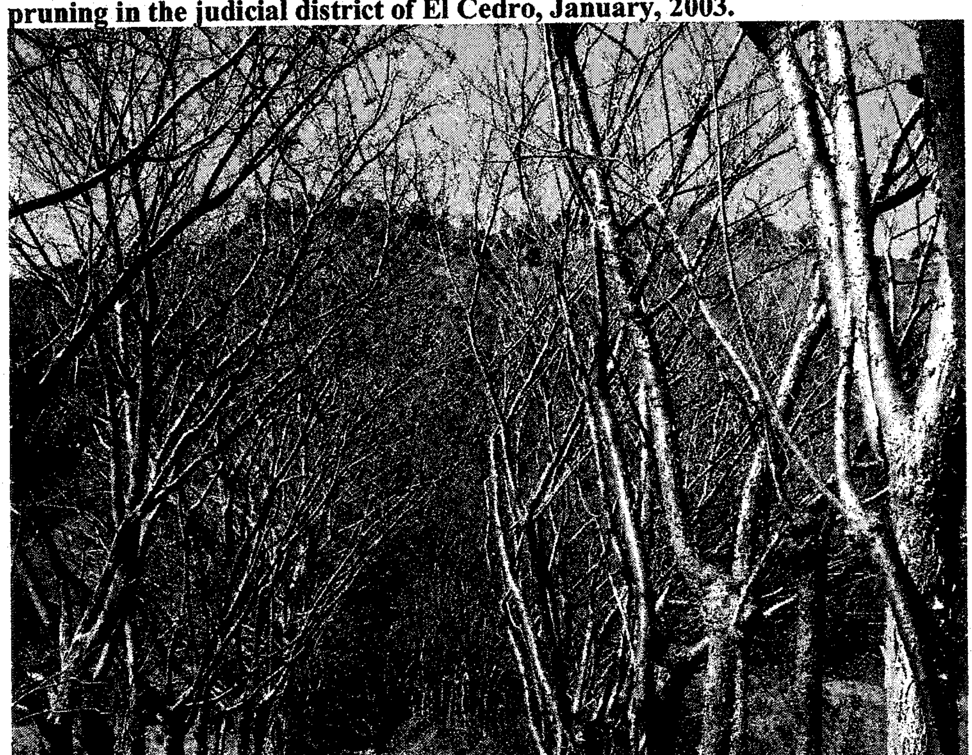
Appendix 6.8 Cattle browsing on the first few months of secondary growth in a pasture rented out in the district of Las Minas during the dry season, April, 2003.



Appendix 6.9 ***Gliricidia sepium*** **living fence after pruning in the district of Parita with pruning trash piled beside the fence, June, 2002.**



Appendix 6.10 ***Bursera simaruba*** **living fences after leaf drop and before pruning in the judicial district of El Cedro, January, 2003.**



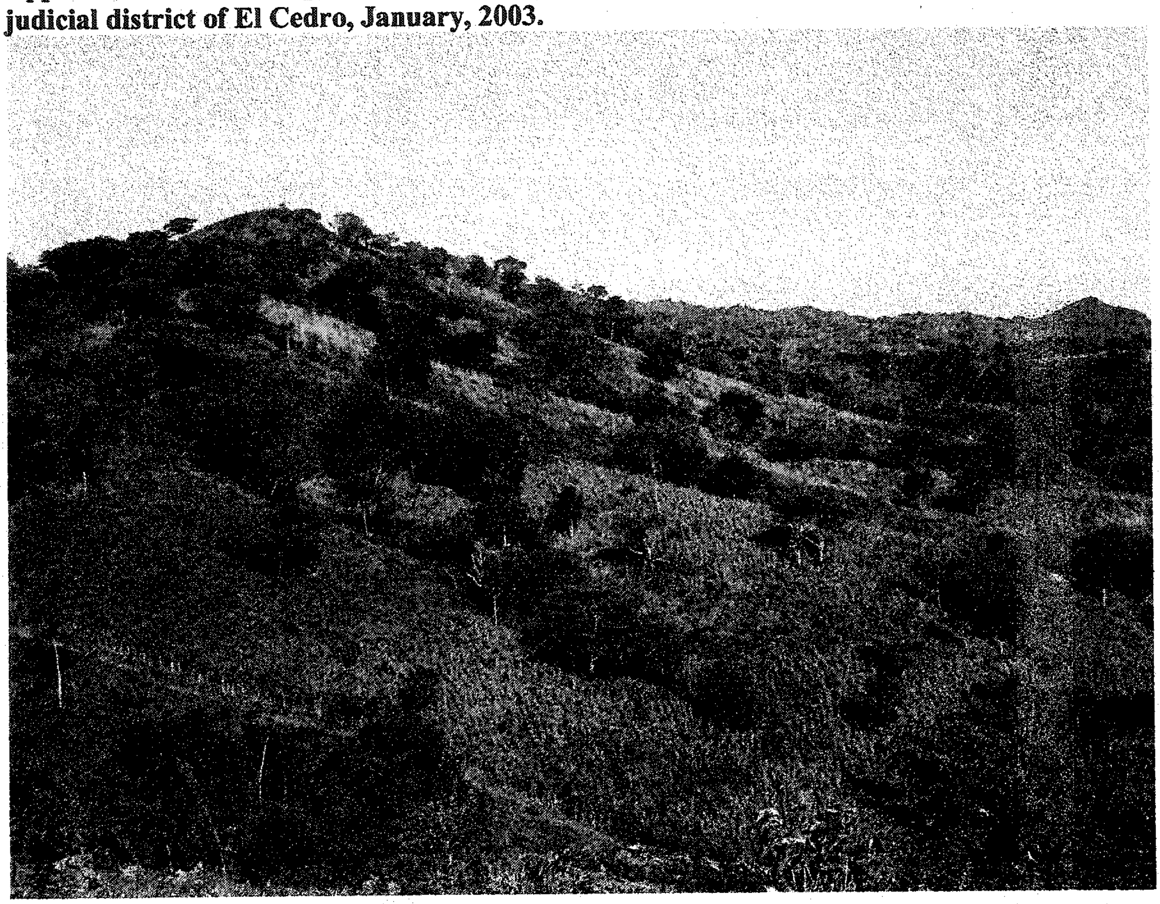
Appendix 6.11 SAS program used to analyze soil data for living fence treatment effects with farm employed as block (mixed model analysis using Proc Mixed).

```
proc mixed;
class farm trt;
model ph = trt/ddfm=satterth;
random farm trt*farm;
estimate 'sediff' trt 1 -1/alpha=0.05;
lsmeans trt/pdiff alpha=0.05;
run;
```

Appendix 6.12 Mixed model analysis general form for partitioning degrees of freedom.

Effects	**Degrees of Freedom**
Treatment (distance from living fence)	1
Block (farm)	3
Block × Treatment	3
Residual error (sample(treatment*block)	16
Total	23

Appendix 6.13 Photo of pasture containing remnant trees and desiccated maize fields in the judicial district of El Cedro, January, 2003.



Appendix 6.14 English and Spanish names for tree species that have applicable translations.

Spanish Name	English Name
Caoba	Mahogany
Marañón	Cashew
Cedro Amargo	Spanish Ceder
Balo	St. Vincent Plum
Bobo	Purple Coral Tree
Carate	West Indian Birch
Corotú	Elephant Ear
Guácimo	West Indian Elm
Guachapalí	Rain Tree
Guava	Pan chock
Higo	Fig
Jobo	Yellow Spanish Plum
Palma Real	Royal Palm
Eucaplito	Eucalyptus
Guanábana	Custard Apple
Ciruela	Spanish Plum
Naranja	Orange
Aguacate	Avocado
Laurel	Spanish Elm
Teca	Teak
Nance	Golden Spoon
Palo Santo	Coral Tree
Caimito	Golden Leaf
Tamarindo	Tamarind

English names were obtained from the International Centre for Research in Agroforestry's "Agroforestree Database" on November 4th, 2003 at (http://www.worldagroforestry centre.org/sites/treedbs/aft/aft.htm).