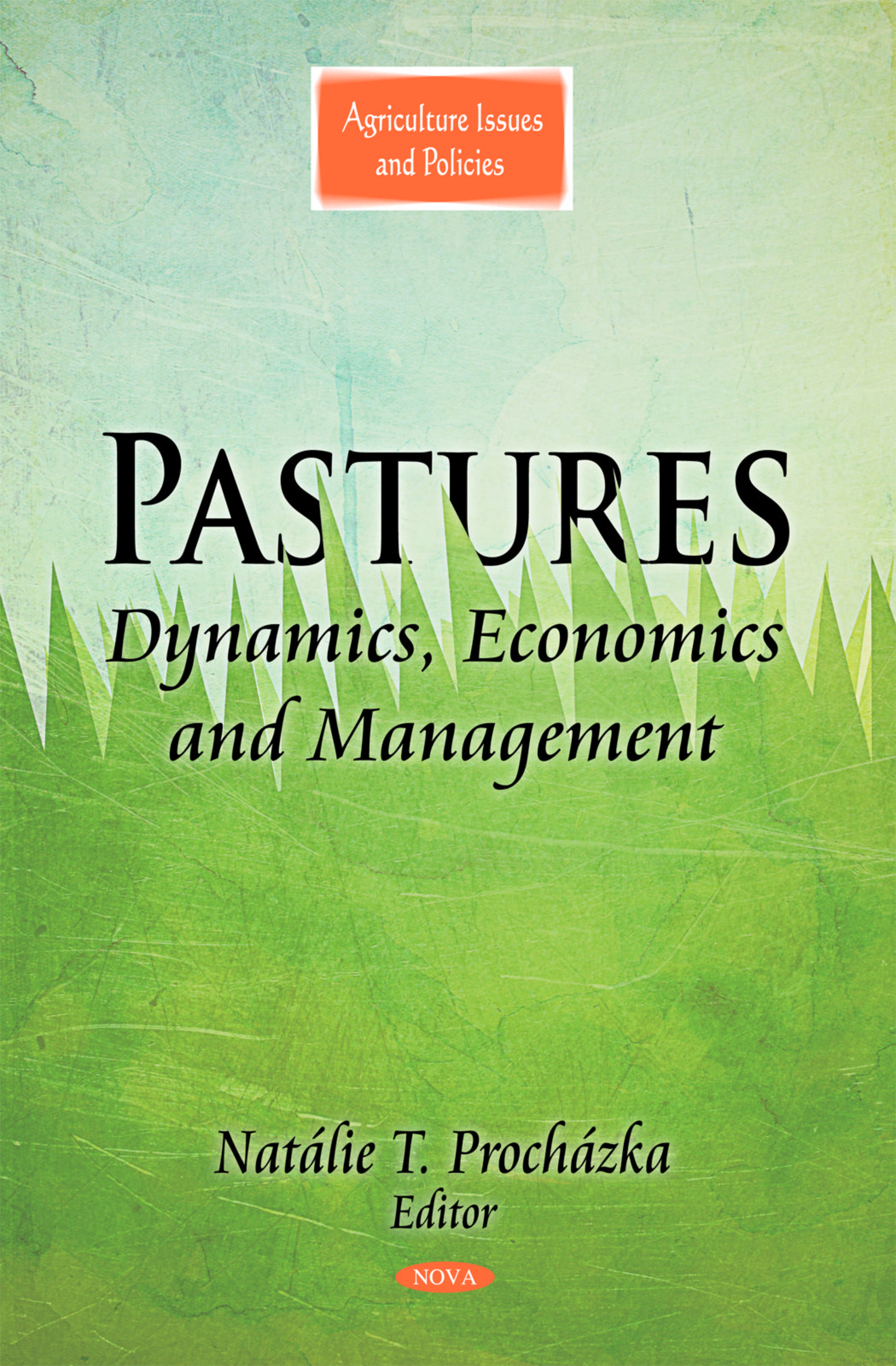

Agriculture Issues
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PASTURES

Dynamics, Economics and Management

Natálie T. Procházka
Editor

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NATÁLIE T. PROCHÁZKA
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CONTENTS

PREFACE

This book presents current research data in the study of pastures, including rainforest regeneration in abandoned pastures of Southeast Mexico; pastures in temperate climate zones and the U.S. western Gulf Coast region; a discussion of the dynamic value of pasture phases in intensive agriculture and the restorative capacity of pastures; the wet pastures of the Moroccan mountains; and the management of pasture phases in Western Australia.

Chapter 1- Accelerated land use change in the tropics has resulted in heterogeneous landscapes where secondary rainforest patches of different ages are immersed among agricultural areas. Due to soil productivity exhaustion, agricultural areas may be left to fallow or definitely abandoned due to several socio-economic processes. Rainforest regeneration in abandoned areas may be impeded by numerous biotic and environmental barriers which filter propagule arrival and establishment in open areas. Isolated trees play a key role in favoring rainforest regeneration in abandoned pastures. Several intrinsic (e.g., height, phenology, architecture, and crown structure) and extrinsic (micro-environmental) factors related to isolated trees may influence forest regeneration in pastures, however, other site-quality factors may influence seedling recruitment, but these effects are still to be clarified. This study describes the effect of isolated trees, pastures grasses, microclimate, and seed predation on the early regeneration community of rainforest species in abandoned tropical pastures of Southeast Mexico. An experimental system consisting in two groups of ecologically contrasting isolated trees (*Ficus* and *Inga*), two distance-to-isolated-tree categories ((‘canopy’, 0 to 10 m, and ‘open pasture’, 15 to 48 m from tree’s trunk), and four grass removal treatments was established. Grass removal treatments were: a) *control* (no alteration), b) *cut* of above ground biomass with machete, c) *herbicide* application, and d) removal of above- and below-ground biomass using a gardening *hoe*. The tree species composition of adjacent forest fragments, and the abundance and composition of seed rain and seedlings emerged from the seed bank were considered as the main propagule sources. Abundance and composition of the seedling community recruited after one and two years of study were considered as response variables. An independent experiment explored seed predation as a barrier against establishment in open pastures, using seeds of two pioneer (*Cecropia obtusifolia* and *Ocrhoma pyramidale*) and two mature (*Brosimum costaricanum* and *Dialium guianense*) rainforest species. Several treatments were applied to seeds, according to seed size and possible predators (i.e. insects or rodents), excluding, burying or exposing seeds arranged in bunches of several individuals. Results indicate that the recruited seedling community is mainly affected by the isolated tree species and distance to isolated tree. *Ficus* sites showed significantly higher density and diversity of recruited seedlings when compared to *Inga* sites. Recruitment rate was higher under the canopy when compared to the open pasture in both species of isolated trees. Grass treatments did not have an effect on seedling recruitment. The vast majority of recruits belonged to secondary species with invasive habit (21 tree, 21 shrub, and six liana species were recorded). Adjacent rainforest fragments were very similar in abundance, however, seed rain was more abundant under the canopy of isolated trees when compared to the open pasture, and more abundant and diverse in *Ficus* sites when compared to *Inga* sites. On average, seed rain was ca. 34 times more abundant under the canopy of isolated trees when compared to the open pasture. Seed rain in *Ficus* trees was 6.7 times more abundant and 10% more diverse when compared to *Inga* sp. trees. Overall, seed rain density (seeds m^{-2}) outnumbered at least 60 times seedlings emerged from the seed bank, at least 100 times seedling recruitment (1y), and at least 353 times older seedling recruitment (2y). No species were observed across all communities, but some abundant genera (i.e. *Solanum*) were observed in all but mature forest. Pioneer species were predated in less than 8 days after seed deposition, while only mature species with defense mechanisms (*D. guianense*) survived after 64 days of seed deposition. Only buried seeds germinated. Results show that propagule sources and successional communities differ consistently in abundance and composition, most likely as a result of limited dispersal and strong biotic and environmental barriers against seedling establishment in the open field. Rainforest regeneration will be modified according to the presence and species of isolated trees in pastures, land-use history, and proximity to forested areas.

Chapter 2 - The peculiarities of historical phases of steppe ecosystems transformation influenced by grazing pressure have been analysed, estimations of well-directed modification of organic carbon and biogeochemical flows in the system “vegetation – soil” have been received. Characteristic periods of chronological organization of bioclimatic processes have been determined on the basis of analysis of observational series of annual and interannual variations in meteorological parameters and steppe pastures productivity.

The results of investigations of plant formations for natural pastures located in different ecological conditions are presented. Vegetation variety of meadow and calciphilous steppes on sample areas and pastures has been studied. Data on useful, harmful, rare species of plants, influence of species diversity of formations on the fertility of slopes have been received and connections between the number of species and main elements of soil fertility have been determined.

Methods of ecological restoration of steppe pastures on Chernozems and on slopes nearby deposition of carbonate strata have been described. The species which have the best environment transforming qualities have been revealed. In the rhizosphere of these plants the processes of parent material destruction and soil formation are occurring strongly, as a result slopes can be used for meadow formation and further utilization.

The fact is that the legume component is less stable when pastures are being established on the basis of gramineae-legumes mixes. This problem becomes more acute on eroded alkaline soils. There are results on studies of the dynamics of productivity and stability of legumes (*Fabaceae*) in the composition of mixes for cultivated pastures on the areas divided by ravines. Original data on seasonal dynamics of overground phytomass gramineae-legumes mixed crops for cultivated pastures distinguished by one legume component have been analysed. Bioenergetic effectiveness of mixed crops on the basis of various species of legumes is shown.

Chapter 3 - The native vegetation of the U.S. Western Gulf Coast Region included areas of natural grassland where an early livestock industry developed. Much of this natural grassland, along with a large portion of the upland forest following initial timber harvest, was gradually converted to pastures of introduced grasses and legumes to improve livestock production. Warm-season perennial grasses, particularly bermudagrass (*Cynodon dactylon*) and bahiagrass (*Paspalum notatum*), have been well suited for pasture use on most sites within the region. These grasses effectively support cow-calf production systems; however, supplemental sources of nutrients are required seasonally. Cool-season forage species, especially annual ryegrass (*Lolium multiflorum*), have become important components of pasture systems to supplement the warm-season grasses for cow-calf production and have also provided opportunity for stocker cattle enterprises and supplemental grazing by dairy cows on concentrate-based rations. Due largely to favorable economics of production and comparative ease of management, nitrogen fertilizer and chemical weed control have become common pasture management practices. A tremendous variety of production approaches has resulted from the number of potentially useful pasture plants, the range in levels of inputs and management providing profitable results, and the variation in size of pasture-based enterprises within the region. Recent dramatic increases in input costs have limited profitability of highly productive pastures based on high levels of inputs. Demands of society for changes in the use of pastures are reflected in a declining profit margin provided by the value of weaned calves relative to the cost of their production, while at the same time increasing income opportunities are provided by alternative uses, products, and management of pasture resources. Current opportunities appear to present diverging directions for economically sustainable pasture systems in the region. Integrating pasture systems with rather extensively managed wildlife habitat and conservation areas provides an opportunity to decrease inputs and capture alternate income. On the other hand, high-value pasture products such as grass-fed beef may provide options for pastures of appropriate plant species with very high levels of management and an associated substantial level of risk. While some rather dramatic changes may provide a distinctly different character to pasture systems within the region in coming decades, less drastic changes based on increasing efficiency of forage production and utilization will also likely allow many existing pasture-based cow-calf enterprises to persist in essentially their current form, although perhaps at less profitable levels than during most recently past decades.

Chapter 4 - Reliance on shallow-rooted annual plants in traditional crop rotations has encouraged the onset of soil salinisation throughout the Western Australian Wheatbelt by permitting a significant proportion of annual rainfall to reach saline watertables. Incorporating phases of perennial pasture between long cropping sequences is the most promising means of reducing recharge and sustaining grain production. This chapter describes the process of soil salinisation and strategies to prevent its occurrence, with a key focus on the employment of lucerne pasture to increase water use in crop rotations in the Wheatbelt. This discussion highlights the dynamic value of pasture phases in intensive agriculture and the importance of considering the restorative capacity of pastures when evaluating alternative land-use sequences and their management.

Chapter 5 - Horse production in Southern Europe mainly relies on extensive systems where rainfed pastures are a key factor. In these regions, a great part of pastures is under Mediterranean influence, with hot, dry summers and are characterized by large surfaces of native or sowed grassland, frequently associated to a sparse tree cover. One of the most important and ancient horse breed traditionally reared in these areas is the *Lusitano*. The functionality and behaviour characteristics of *Lusitano* allow its use in many equestrian disciplines, with an increasing worldwide interest. Nowadays, these horses are bred in several countries, but in Portugal, the majority of *Lusitano* stud farms are still based in extensive grazing systems (EGS). In the EGS, mares are often bred outdoors throughout the year, being pastures a significant part of diets. Besides providing a major source of nutrients at a low cost, pastures also supply free exercise areas for growing foals.

Although relying on extensive rainfed pastures, highly dependent on climatic conditions, these production systems can be sustainable and affordable, if adequate complementary feeds are timely provided and if pasture management practices are appropriate. This study describes some current practices, analysing the role of extensive grazing systems in the *Lusitano* horse production.

Chapter 6 - In the High Atlas mountains of Morocco, wet grasslands in the Oukaimeden plateau have been developed on small surface areas supported by soils water accumulation. These ecosystems, close to the sources and banks, constitute wetlands of high floristic richness with significant rate of endemism (27%) and particularly rich in alpine and boreal plants.

Furthermore, these wet pastures, coveted for their pastoral richness, have always been exploited and undergo a particular traditional management. This practice called "*Agdal*" consists of restricting rights of access and (or) uses according to the customary law. In the case of Oukaimeden Agdal, the opening date is fixed from 10 August until 15 March of each year. The phenological monitoring carried out of the Oukaimeden pastures flora shows that the opening date of the Agdal corresponds to the reconstitution of seed stocks in ground and the closure of the latest species vital cycle. The strike balance between the opening date and the resource regeneration proves the efficiency of this kind of management that aims to favour biodiversity.

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Chapter 1

RAINFOREST REGENERATION IN ABANDONED PASTURES OF SOUTHEAST MEXICO

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ABSTRACT

Accelerated land use change in the tropics has resulted in heterogeneous landscapes where secondary rainforest patches of different ages are immersed among agricultural areas. Due to soil productivity exhaustion, agricultural areas may be left to fallow or definitely abandoned due to several socio-economic processes. Rainforest regeneration in abandoned areas may be impeded by numerous biotic and environmental barriers which filter propagule arrival and establishment in open areas. Isolated trees play a key role in favoring rainforest regeneration in abandoned pastures. Several intrinsic (e.g., height, phenology, architecture, and crown structure) and extrinsic (micro-environmental) factors related to isolated trees may influence forest regeneration in pastures, however, other site-quality factors may influence seedling recruitment, but these effects are still to be clarified. This study describes the effect of isolated trees, pastures grasses, microclimate, and seed predation on the early regeneration community of rainforest species in abandoned tropical pastures of Southeast Mexico. An experimental system consisting in two groups of ecologically contrasting isolated trees (*Ficus* and *Inga*), two distance-to-isolated-tree categories ((‘canopy’, 0 to 10 m, and ‘open pasture’, 15 to 48 m from tree’s trunk), and four grass removal treatments was established. Grass removal treatments were: a) *control* (no alteration), b) *cut* of above ground biomass with machete, c) *herbicide* application, and d) removal of above- and below-ground biomass using a gardening *hoe*. The tree species composition of adjacent forest fragments, and the abundance and composition of seed rain and seedlings emerged from the seed bank were considered as the main propagule sources. Abundance and composition of the seedling community recruited after one and two years of study were considered as response

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variables. An independent experiment explored seed predation as a barrier against establishment in open pastures, using seeds of two pioneer (*Cecropia obtusifolia* and *Ocrhoma pyramidale*) and two mature (*Brosimum costaricanum* and *Dialium guianense*) rainforest species. Several treatments were applied to seeds, according to seed size and possible predators (i.e. insects or rodents), excluding, burying or exposing seeds arranged in bunches of several individuals. Results indicate that the recruited seedling community is mainly affected by the isolated tree species and distance to isolated tree. *Ficus* sites showed significantly higher density and diversity of recruited seedlings when compared to *Inga* sites. Recruitment rate was higher under the canopy when compared to the open pasture in both species of isolated trees. Grass treatments did not have an effect on seedling recruitment. The vast majority of recruits belonged to secondary species with invasive habit (21 tree, 21 shrub, and six liana species were recorded). Adjacent rainforest fragments were very similar in abundance, however, seed rain was more abundant under the canopy of isolated trees when compared to the open pasture, and more abundant and diverse in *Ficus* sites when compared to *Inga* sites. On average, seed rain was ca. 34 times more abundant under the canopy of isolated trees when compared to the open pasture. Seed rain in *Ficus* trees was 6.7 times more abundant and 10% more diverse when compared to *Inga* sp. trees. Overall, seed rain density (seeds m^{-2}) outnumbered at least 60 times seedlings emerged from the seed bank, at least 100 times seedling recruitment (1y), and at least 353 times older seedling recruitment (2y). No species were observed across all communities, but some abundant genera (i.e. *Solanum*) were observed in all but mature forest. Pioneer species were predated in less than 8 days after seed deposition, while only mature species with defense mechanisms (*D. guianense*) survived after 64 days of seed deposition. Only buried seeds germinated. Results show that propagule sources and successional communities differ consistently in abundance and composition, most likely as a result of limited dispersal and strong biotic and environmental barriers against seedling establishment in the open field. Rainforest regeneration will be modified according to the presence and species of isolated trees in pastures, land-use history, and proximity to forested areas.

Keywords: isolated trees in pastures, seedling recruitment, grass competition, seed rain, seed bank, barriers against rainforest regeneration, land-use history.

INTRODUCTION

Rainforest tree communities maintain their composition and structure throughout space and time due to a continuous replacement of species through gap-phase regeneration (Brokaw 1987; Whitmore 1991). Some processes which allow this replacement are seed production and dispersal, seed germination, seedling emergence, and seedling establishment, survival and growth (White & Pickett 1985). These regenerative communities differ in abundance, composition and the array of dominant species (Watt 1947; Martínez-Ramos and Soto-Castro 1997; Wenny 2000). The assemblage of species found in the mature tree community is, therefore, a result of shifts in the abundance, diversity, and composition as individuals pass from one stage to the next in their life cycle (Brokaw & Scheiner 1989).

Rainforest area has decreased worldwide over the past decades under the pressure of agricultural activities (Laurance 2008), undergoing ca. 50% reduction of its original extent (FAO 2003). In the Neotropics, most of the deforested area is converted to livestock-raising pastures, and often abandoned after productivity decline or due to socioeconomical reasons (e.g., human migration; Grau et al. 2003). However, abandoned lands may not undergo the regular successional processes described above, leading to secondary forests that resemble the original old-growth forest, but to communities that differ in structure, composition, and ecosystem properties (Ehrlich & Mooney 1983, Mesquita et al. 2001). As the proportion of forest transformed to agricultural land increases, it is highly relevant to clarify the early regeneration patterns resulting after land abandonment. The patterns followed by the early successional communities may suggest which direction the secondary forest will follow, and if the recovery of the original forest is possible without intervention. Understanding the factors that participate during early succession may enlighten our perspective of the value of the remaining mature forest, and the possible management options of abandoned pastures.

BARRIERS AGAINST NATURAL REGENERATION IN PASTURES

Natural regeneration in abandoned tropical pastures is mainly affected by a) the degree of propagule availability (i.e. seed bank, seed rain, and seedling community composition and abundance) and b) the degree of site quality (i.e. biotic and abiotic conditions found in the open field; Connell & Slatyer 1977, Martínez-Ramos & García-Orth 2007). How these two aspects are found in the open field, and how they interact with each other, will generate a certain condition which in turn will determine the community’s successional pathway, speed, and result (Mesquita et al. 2001). However, even if the degree of (a) or (b) is favorable for plant establishment, several mechanisms can impede natural regeneration. Such mechanisms are commonly addressed as barriers against natural regeneration in tropical pastures (Table 1). Since the first paper published in 1984, 121 research published papers address, from several perspectives (i.e. descriptive, experimental, etc.), the barriers that impede natural regeneration after man-made disturbances in the tropics. Among such studies, low seed availability is the most frequently addressed obstacle against natural regeneration (28%), followed by competition with pasture vegetation (21%), stressful microclimatic conditions in the open field and low soil nutrients (21 and 12%, respectively), seed predation (9%), and low germination (3%), among others. These barriers can occur simultaneously and their particular relevance and/or intensity can vary between even close-by sites (Holl & Lulow 1997, Jones et al. 2003). In some cases, an obstacle for regeneration in a certain place may have a positive effect in another location (i.e. exotic species dominance; see Chapman *et al.* 2002; Holl, 1999), and some barriers may not even be considered so in certain sites (i.e. Aide & Cavelier, 1994). Based on the published data, the on-site mechanisms which contribute to create the most commonly addressed barriers against regeneration are described below.

Table 1. Barriers against rainforest regeneration in tropical pastures

Main factor that affects regeneration in abandoned pastures	Barrier against rainforest regeneration	Modified properties in fragmented landscapes	Charasteristics in the open field	Example studies
Propagul availability	Low Seed Bank	Low density, richness, diversity, and viability	If any, composed by pionerr, shrub species	Uhl, et al. 1987, Orozco-Sergovia & Vasquez-Yanes 1993, Quintana-Ascencio, et al. 1999
	Low Seed Rain	Low density, richness and diversity	Seeds of <3mm diamter, bird and/or wind-dispersed	Aide & Cavelier 1994, Holl 1998, Slocum & Horvitz 2000, Guevara, et al. 2004b
	Absent seeding bank	If any, low density due to livestock consumption	If any, mainly colonizing non-palatable species	Vierira, et al. 1994, Nepstad, et al. 1996
	Scarce trunk resprouting+	If any, scarce due to pasture maintenance practices	If any, from remaining trunks of non-palatable species	Uhl, et al. 1988, Sampaio, et al. 1993
Site quality	High grass/invasive vegetation density*	Grass/invasive species presence	Possible succession arrest	Toh, et al. 1999, Baer & Groninger 2004
	High seed and seedling predation by animal vectors	Modified faunistic communities	High and rodent density, different composition from mature forest	Holl & Quiroz-Niertzen 1999, Pena-Claros & De Boo 2002
	Soil compaction and fertility	Higher compaction and lower fertility than in the forest soil	High compaction due to livestock trampling; low fertility due to burning	Reiners, et al. 1994, Holl 1999
	Stressful microenvironment	Significantly different microenvironment from mature forest	Higher radiation, low air and soil humidity; higher air and soil temperature	Williams-Linera, et al. 1997, Holl 1999

+ Not in the case of dry forests.

* Not always considered a barrier in natural regeneration (Chapman, et al. 2002).

1. Low Seed Availability

Propagule availability will depend directly in the two main seed sources present in the open field: the remnant seed bank and the local and foreign seed rain (originated from close forest remnants or dispersed by diverse vectors from further seed sources, respectively; Pickett et al. 1987). While seed banks are mainly affected by the disturbance intensity and frequency (Uhl 1987, Quintana-Ascencio et al. 1996), the abundance and richness of the seed rain are mainly affected by the magnitude of the disturbance (i.e. as fruiting trees are located further from the open area, seed supply through seed rain will be lower than in mature forest; Galindo-González et al. 2000), and the composition and distribution of seed sources in remaining landscape matrix, among other reasons.

Periodical burning and management practices of diverse intensities (i.e. silviculture, agriculture, cattle herding, etc.) tend to shift the content of rainforest soil seed banks into a different composition of species (Quintana-Ascencia et al. 1999), often resulting in poor or highly limited seed banks (Uhl 1987, Holl 1999, Benitez-Malvido et al. 2001, Hooper et al. 2002). Fire use may eliminate several native species which are not adapted to high temperature shocks (Holl 1999, Quintana-Ascencio et al. 1996), but in turn enhance germination of those species which are frequently found in recently burned lands (e.g. *Trema micrantha, Ochroma pyramidale,* and *Trichospermum mexicanum*, among others; Martinez-Ramos, in prep.) Soil turnover (i.e. bulldozing) may impede regeneration definitely (Nepstad et al. 1996, Parrotta et al. 1997). However, if management practices are relatively low in intensity and disturbance (e.g. no fire use), the seed bank can remain in a relatively viable status, which in turn allows prompt seedling emergence when management practices are stopped (Mesquita et al. 2001, Guevara et al. 2004). The amount of viable seeds contained in the soil is the result of several biological and environmental interactions (Garwood 1989). Species morphological and physiological traits (i.e. dormancy and germination mechanisms), biotic factors present in the open field (i.e. potential seed removers or eaters), and micro-environmental conditions determine the period which seeds can remain in the pasture floor before germination or death (Connel & Slatyer 1977, Vázquez-Yanes & Orozco-Segovia 1993, Wenny 2000). For example, recalcitrant seeds can prevail for relatively shorter periods in the soil before being dehydrated, while orthodox species can remain viable in the bank for relatively longer periods (Baskin & Baskin 1998), as has been observed in tropical habitats (Quintana-Ascencio et al. 1996; Guevara et al 2004). Regarding seed size, small seeds –with low maternal resources- are most likely to be predated by insects and fail to germinate and establish in the open field, while larger seeds may contain higher maternal resources (i.e. secondary metabolites which could protect them against predation agents) and remain for longer periods in the pasture floor, increasing germination and establishment probability (Peña-Claros 2001, Corzo-Domínguez 2007, García-Orth & Martínez-Ramos 2007). Seed banks in tropical pastures are mainly constituted by seeds with diameters of less than three millimeters, and mainly wind-dispersed species (Guevara et al. 2004), due to low seed input by animal vectors (Da Silva et al. 1996), and high seed predation by vertebrates and invertebrates (Peña-Claros & De Boo 2002, Woods & Elliot 2004, García-Orth and Martínez-Ramos 2007).

Seed rain is generally very limited in open pastures, especially in areas with several hectares of extension. Seeds may reach less than ten meters from the forest edge towards the open area (Martínez-Garza & González-Montagut 1999, Wijdeven & Kuzee 2000, Cubiña &

Aide 2001). However, the distance at which seeds are dispersed will depend on several landscape components, including the composition and abundance of the isolated tree community, and the composition and abundance of rainforest remnant patches of different sizes (Martínez-Garza & González-Montagut 1999, Guevara et al. 2004). The group of species that reach the open field will be limited by the bird species that disperse them (i.e. bird size, flight patterns, and feeding capacity and habits, among others; Da Silva et al. 1996, Galindo-González et al. 2000), as well as the wind currents and topography of the area in the case of wind-dispersed species. Though studies report bird and bat visits to perches in between flights over open areas (Holl 1998, Da Silva et al. 1996), the abundance and richness of seed rain is still very low in pastures (Chapman & Chapman 1999, Duncan & Chapman 1999). Several efforts have been made in order to increase seed rain in pastures. The use of perches can be useful in attracting birds, particularly if perches are saplings with fresh fruits (McClanahan & Wolfe 1993, Holl 1998). In large scale restoration programs, seeds contained into agar capsules are spread from airplanes over degraded fields in Amazonia. However, this method is restricted to seeds of <3mm diameter (Governo do Stado de Sao Paulo 1990). But even if seeds arrive to open fields, further obstacles may impede germination and establishment (Holl 1998), which brings us to another barrier against regeneration in pastures: competition with several exotic species, particularly pasture grasses used as forage for cattle.

2. Competition with Pasture Vegetation

Site quality consists in high proportion in the community of grasses and weed species that establish after rainforest cutting and burning, along with the soil and microclimatic conditions found in the open field (Uhl 1987, Martínez-Ramos & García-Orth 2007). As mentioned before, propagule availability and site-quality are the main vectors that will determine natural regeneration in pastures. In Southeast Mexico and other Neotropical areas, pasture establishment usually involves direct seeding of livestock forage grasses after a few annual cycles of maize growing (De Jong et al. 2000). Some common pasture maintenance practices, such as slashing and burning, modify soil properties and the native species seed bank, allowing invasive species to establish and thrive, impeding other agricultural land uses or rainforest succession in the long term (e. g. *Pteridium aquilinum*; Aide et al. 1995, Den Ouden 2000). The fact that some effects of disturbance can prevail for thousands of years (Gomez-Pompa, 1991) indicates that some site properties can be modified permanently as a result of intense management practices (Den Ouden 2000). In the rainforest areas of Southeast Mexico, for example, pastures may be abandoned to fallow when grasses show deficient growth, frequent attack by pests, or low preference by livestock (X. García-Orth, pers. obs.). By the time pastures are abandoned, physical and chemical soil properties are usually consistently degraded due to livestock constant stamping and urine input (Reiners et al. 1994), resulting in the characteristic conditions which allow the establishment of numerous invasive exotic weeds (e.g. foxtail grass and bracken fern, X. García-Orth, pers. obs.).

However, grass removal has not proven to be a plausible method in order to eliminate competition between native colonizing species and pasture vegetation (see for example: Hau & Corlett 2003, Holl 2002, Benitez-Malvido et al. 2001, Holl 1998, Aide et al. 1995, but see Chapman et al. 2002). Grass removal may result in stressful environmental conditions which in turn lessen seedling establishment (e.g. higher soil and air temperatures, low soil humidity, and higher radiation at ground level; González-Montagut 1996, Chapman et al. 2002). For some rainforest species, grass presence may be beneficial in early stages of germination and establishment, but later turn to be detrimental for seedling growth (Zimmerman et al. 2000, Benitez-Malvido et al. 2001). On one hand, pioneer species have more probabilities of overcoming competition with grasses due to resource optimization, tolerance to stressful conditions, and high growth rates. However, small-seeded species, as pioneers usually are, may face difficulties to reach the soil, and further emergence of the seedlings, due to the thick layer grasses form after pasture abandonment (X. García-Orth, pers. obs.). On the other hand, larger-seeded species may establish successfully if helped to reach the soil (Camargo et al. 2002), but this is not necessarily true for all studied species (Benitez-Malvido et al. 2001, Ganade & Brown 2002, Guevara et al. 2004b). Grass growth is usually depleted under isolated trees, if enough shade is projected by the canopy (Guevara et al. 2004a). Thanks to this reduction in grass density and height, a higher amount of resources are available for seed germination and seedling establishment. The change in microclimatic conditions produced by the tree's canopy is addressed later in this section.

On the other hand, nursery-grown seedlings and saplings may show better performance when transplanted to the open field if grass is eliminated in their immediate vicinity (Holl et al. 2000, Sweeney et al. 2002). Several studies show how reducing competition between transplants and grasses is beneficial for sapling survival and growth (Hooper et al. 2002, Hau & Corlett 2003), though other factors may affect such interaction (i.e. transplant species, micro-environmental conditions, and mycorrhizae presence, among others; Allen et al. 2003). Transplanted seedling and sapling success will be determined by the specific microclimatic conditions suited best for each species development (i.e. nutrient availability, relative humidity, root architecture, and space requirements), and the effect that grasses have on such traits (Otsamo et al. 1997, Baer & Groninger 2004).

3. Stressful Microclimatic Conditions and Low Soil Fertility

Most tropical forests have relatively low fertility soils and show dynamic nutrient cycling processes, where forest biomass (either standing or litterfall) is the main nutrient storage. Barely any nutrients are found in the soil due to high precipitation levels, weathering, and paedogenetic processes (Vitousek & Sanford 1986). Pasture establishment involves several changes in soil chemical and physical properties (Reiners et al. 1994), particularly if fire is frequently applied. Furthermore, microclimatic variables such as radiation, temperature, and humidity are consistently different between pastures and secondary or mature forests (González-Montagut 1996, Holl 1999, Holl et al. 2000). Levels of radiation, air and soil temperature can be similar at ground level between pastures and mature forest if the grass cover is dense, however, if grasses are removed, air temperature can be higher than in forest understory (e.g. 5ºC; González-Montagut 1996, Holl 1999). Air relative humidity and soil moisture may be lower in pastures than in the forest understory, and even lower if grasses are removed, particularly during the dry season (González-Montagut 1996, Holl 1999). Soil properties such as organic matter content, however, may be higher in pastures than in mature forest, due to biomass release after burning and fertilizing (Reiners et al. 1994, Nepstad et al. 1996). Overall, soil fertility can be higher in pastures than in mature forest due to a decrease in acidity and an increase in exchangeable bases, but low in nitrate concentration (Reiners et al. 1994). Carbon and nitrogen cycles can be affected by soil physical properties like infiltration, percolation, aeration, and others, which are directly affected by cattle stepping and manure inputting (Reiners et al. 1994). Such alterations in microclimatic conditions affect the regenerating community in several ways. Microclimatic conditions at ground level affect the period that seeds remain viable in the seed bank, as well as germination, and seedling survival (Holl 1999, Vázquez-Yanes & Orozco-Segovia 1993). The seedling-sapling stage may also be affected by soil chemical and physical properties. Soil compaction can be a severe obstacle for seedling establishment, due to root inability to penetrate soil aggregates (Nepstad et al. 1996). Therefore, soil and microclimatic conditions in the open field limit the set of species which will reach the adult stage, making natural regeneration scarce in pastures (Aide & Cavelier 1994).

4. High Seed Predation

Pasture establishment results in changes in the fauna community abundance and composition (Dunn 2004). Seed removal by animals may impede seed germination and further seedling establishment, therefore affecting the density and composition of the successional community (Guariguata & Pinard 1998). Seed-eater community abundance and composition are usually altered with deforestation, particularly ant and rodent species (Peña-Claros & De Boo, 2002). While some studies register higher rodent densities after deforestation (Fornara & Dalling 2005), others report lower rodent density in open areas (Pizo & Vieira 2004). Rodents can also affect regeneration by consuming seedlings parts and/or transplants (Holl & Quiroz-Nietzen 1999). Ants can be important seed eaters in the open field (Elliot & Woods 2004, García-Orth & Martínez-Ramos 2007), and associate to isolated trees or other vegetation elements in the landscape (Mull & MacMahon 1997), modifying the group of species which can establish in the open field.

Seed predation in pastures is highly variable throughout the landscape (Jones et al. 2003), and not all species are equally preferred by predators (Holl & Lulow 1997, Peña-Claros & De Boo 2002). Seed properties as size (transportation ease), color, pulp presence, nutrient content, and secondary metabolites, among others, can make some species more appealing to predators than others. In some cases, relatively smaller seeds might suffer high predation rates compared to relatively larger seeds (Peña-Claros 2001; García-Orth & Martínez-Ramos 2007). There can be major differences in predation according to site (and even micro-site), distance to forest fragments, or seed deposition density (Hulme 1994, Jones et al. 2003, Myster 2003, Hulme). However, in some particular sites, seed removal can be low and not considered a barrier against natural regeneration (Holl 2002, Aide & Cavelier 1994).

Few studies have explored the potential implications of predator exclusion as a way of increasing seedling establishment. Holl & Lulow (1997) observed significantly lower predation rates in excluded seeds (average 0.006 seeds · day^{-1}) than in exposed seeds (0.1529 seeds · day^{-1}) for a variety of tropical tree and shrub species. Notman & Gorchov (2001) registered 90% predation by rodents in exposed seeds and less than 10% predation in exclusion treatments, caused mainly by insects. Woods & Elliott (2004) observed no effect of exclusion against rodents, due to heavy predation by ants, but did observe germination enhancement due to seed burial. Thus, in two of three studies, exclusion seems to increase seed survival substantially.

THE ROLE OF ISOLATED TREES IN PASTURES

In several tropical agricultural landscapes, isolated trees are an important vegetation component, and have been addressed as “keystone ecological structures” during forest regeneration in abandoned pastures (Guevara 1986, Manning et al. 2006). Regeneration is higher under such trees, where the shade and soil conditions provided by their canopies may reduce several regeneration barriers, while dispersers provide continuous seed input (Guevara 1986, Guevara & Laborde 1993, Galindo-González et al. 2000). However, the structure and dynamics of the regenerating community may change depending on several factors associated to isolated trees. For example, the microenvironment conditions at ground level may vary with the height (e.g., Slocum & Horvitz 2000), foliage density, and canopy shape of the isolated tree (e.g., Slocum 2001). Seed rain under isolated trees producing fleshy fruits (attractive for potential seed dispersal animals) may be more abundant and diverse than under those producing dry fruits (Slocum & Horvitz 2000, but see Otero-Arnaiz et al. 1999). Soil nutrient availability under isolated trees may depend on mutualistic interactions between the isolated tree and soil microbes, such as the case of some legume trees with nitrogen-fixing bacteria (e.g., Rhoades et al. 1998).

Most studies that assess the effect of isolated trees on rainforest regeneration in pastures have focused on the area under tree’s canopy (10 -20 m radius from the tree’s trunk), whereas fewer studies (e.g., Slocum 2001) have explored effects beyond this area. The regeneration effect of an isolated tree may not only depend on its attractive potential to seed dispersal agents, but also on the microenvironmental conditions that prevail under the canopy and in its vicinity (Slocum & Horvitz 2000). Furthermore, being the mayor vegetation component in pastures, pasture grasses may interact with the attraction potential of the isolated tree and the microenvironment produced by the canopy, resulting in variations in composition and diversity of the colonizing community. Isolated trees may be considered as recruitment foci during successional processes in abandoned pastures, but the effect of the species of isolated tree and its interaction with pasture grasses may enable us to grant differential regeneration potential to different isolated tree species, even beyond the canopy area.

OBJECTIVE

During this study, the isolated and interactive effects of two different genus of isolated trees and the presence of pasture grasses on the structure (abundance, diversity, and composition) and dynamics (recruitment and survival) of the regenerating woody community (trees, shrubs, and lianas) were explored. I studied such effects under the isolated tree’s canopy and extended vicinity, and analyzed whether isolated trees of *Inga* sp. (nitrogen-fixing trees which produce dry fruits) would have a differential effect on recruitment when compared to *Ficus* sp. (non nitrogen-fixing in trees which produce fleshy fruits). In particular, the following questions were approached: how do isolated trees and grasses affect the microenvironment in abandoned pastures? What is the effect of isolated trees on pasture grasses through time? What are the single and combined effects of isolated trees and pasture grasses on the structure and dynamics of the regenerative community? What is the spatial frontier to which an isolated tree influences the natural regeneration processes? What is the composition of the early succession community?

The effect of the two contrasting genera of isolated tree species on the regenerative (seed rain and seed bank), and the early succession communities (one-year-old recruited seedlings, and two-year-old recruited saplings) was explored through the communities' abundance and composition attributes. In particular, the following questions were addressed: what are the attributes of the seed rain and seed bank under the influence of isolated trees and in the open pasture? How are the propagule sources and early regeneration communities different from the potential seed sources (adjacent forest fragments)? Do the propagule sources and early regeneration communities resemble the composition of the potential seed sources (adjacent forest fragments)?

Regarding seed predation as a barrier against rainforest regeneration, a separated experiment explored the dynamics of sown seeds of four rain forest tree species with contrasting life-histories (two pioneer and two mature forest species) in recently tropical abandoned pastures. Exclusion and burial treatments for all species were applied to enhance the probability of seed survival and germination, and test alternative restoration practices. Because small seeds of pioneer species are adapted to forest gap colonization, have low maternal resources, and low secondary metabolite content (Vázquez-Yanes & Orozco-Segovia 1993), I hypothesized that these seeds would suffer high removal by invertebrates, but faster germination rates in the exclusion and burial treatments. On the other hand, large-seeded mature forest species would suffer high removal rates when exposed (mainly due to vertebrate presence), but very low removal rates when excluded or buried, showing lower removal rates overall. The high energetic seed content of large seeded species would mean high anti-herbivore defenses (Janzen 1969), and therefore lower predation rates (Camargo et al. 2002; Moles et al. 2003).

MATERIALS AND METHODS

Study Site

The study took place in the Marqués de Comillas region, State of Chiapas, in Southeast Mexico (16°01' N, 90°55' W). The region is surrounded by the Lacantún River in the W, E and N sides, and by the Guatemalan border in the S (Figure 1). The Montes Azules Biosphere Reserve (the largest area with tropical rain forest in Mexico, ca. 400,000 ha) is located to the North of Marqués de Comillas. Mean monthly temperature is 25ºC and average annual rainfall is 3,000 mm, with a dry season with less than 60 mm month^{-1} during February-April, and a long rainy season between June and November (Siebe et al. 1995). Vegetation in the area is tropical rainforest; along alluvial terraces forest canopy reaches up to 50 m, while in low-hilly sites as well as in *karstic sierras*, it reaches up to 30 m in height (Siebe et al. 1995, Ibarra-Manríquez & Martínez-Ramos 2002).

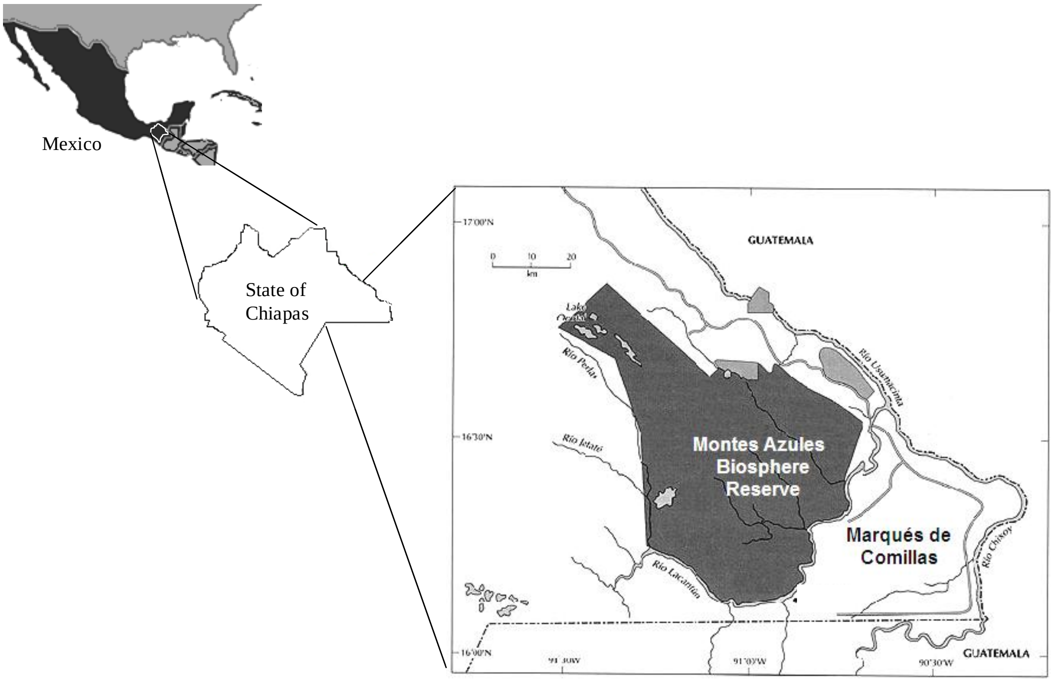

Figure 1. Study site.

Tropical rain forest in Marqués de Comillas is considerably fragmented and degraded due to human settlements and agricultural activities established four decades ago (De Vos 2000). By 1996, *ca*. 31% of total forest area had been converted to pastures and 43% of the original rainforest area was left in a fragmented condition (De Jong et al. 2000). Landscape consists of a matrix of rainforest fragments, secondary forests, extensive pastures, and agricultural fields, temporarily left to fallow due to land rotation practices or permanently abandoned due to human migration, among other reasons (De Jong et al. 2000, Grau et al. 2003). Productive activities include extensive livestock grazing, agriculture (maize, beans, and peppers, mainly), and, to a lesser extent, non-woody forest products (Zermeño-Hernández 2008).

Pasture Study Sites and Experimental Design

In July 2004, four pastures separated by at least 4 km were located. An area of one hectare (100 x 100 m) was delimited in each pasture, and fenced to exclude cattle and mimic pasture abandonment. Each hectare had a single isolated tree in the center; two pastures had *Ficus* spp. and two had *Inga* spp. trees. The study sites will be further addressed as “Ficus A”, “Ficus B”, “Inga A”, and “Inga B”. Focal tree properties, site characteristics and land use history of selected pastures are detailed in Table 2. To assess effects of “distance to focal tree” on regeneration, two distance categories were defined: 0 to 10 m (hereafter referred to as “canopy”), and 15 to 48 m from the tree’s trunk (hereafter referred to as “open pasture”). To evaluate the effect of pasture grasses on regeneration, four grass removal treatments, each with eight replicates of 1 x 2 m plots, were randomly assigned to each distance category: (a) *control* (no removal), (b) *cut*, grass vegetation was cut with machete, (c) *herbicide*, a glyphosate-based herbicide (10%) was applied and dry biomass was left lying on the ground, and (d) *hoe*, vegetation was completely removed with a traditional gardening hoe, leaving the soil exposed. We assumed that each treatment altered the interaction between native vegetation and grasses as follows: the control treatment represented no alteration of the interaction, the cut treatment reduced above-ground interaction, the herbicide treatment reduced below-ground and, to a lesser extent, the above-ground interaction, and the hoe treatment reduced both above- and below-ground interaction. All treatments were applied in October 2004 and re-applied every six months, except for the herbicide treatment, which was only applied in July 2004. Grass barely resprouted in the hoe and herbicide treatments throughout the experiment.

Table 2. Focal tree characteristics and land-use history per site corresponding to four studied pastures in Marqués de Comillas, Southeast Mexico

Trait	**Fiscus A**	**Fiscus B**	**Inga A**	**Inga B**
Focal tree species	*Ficus maxima (Moraceae)*	*Ficus obtusifolia (Moraceae)*	*Inga pavoniana (Fabaceae)*	*Inga punctata (Fabaceae)*
Focal tree's height (m)	15	10	8	10
Focal tree's DBH (m)	0.96	0.45	0.22	0.28
Focal tree's fruiting period	Year-round	Year-round	October-April	October-April
Dispersal vector	Bird and bat	Bird and bat	Bird and mammal	Bird and mammal
Distance from focale tree to closest remnant (m)	150	250	150	140
Closest rainforest remnant	Selectively logged mature forest (trees <30m high)	Selectively logged mature forest (trees <25m high)	Secondary forest (17 y old; trees ,20m high)	Mature forest (trees <40m high)
Initial forest cut and first burn	1985	1983	1990	1989
Burns before experiment	2 times	10 times	4 times	14 times
Last burn before experiement	1991	2001	2003	2003
Pasture use before experiement	2 years	12 years	7 years	11 years
Livestock density regime	Livestock rarely introduced	1.25 head/ha	2.5 head/ha	1 head/ha
Grass introduction Slope	1991	1992	200	1997
Slope	0^0	0^0	0^0	ca.37^0

Microclimate and Grass Biomass

Air temperature, photosynthetic active radiation (PAR), soil temperature and soil relative humidity were measured in all plots with applied grass treatments, in the canopy and open pasture areas, and in all sites. All measurements were made during the dry season, in April 2005, between 1300 and 1500 h. PAR measurements were recorded with a photon flux density sensor (Campbell quantometer LI 1905B, Campbell Scientific Inc., Cambridge, UK) held *ca.* 15 cm above the ground. PAR values were recorded during one minute and averaged for a single value per plot. Values were scaled to the maximum value obtained in the hoe treatment in the open pasture (100%). Above-ground air temperature was recorded with a thermistor (Campbell thermistor T108 C_2, Campbell Scientific Inc., Cambridge, UK) held ca. 15 cm above the ground. The temperature value recorded was that shown by the thermistor for one minute after stabilization. Values were recorded at the center of each plot. Soil relative humidity and temperature were recorded at a depth of 10 cm using a soil moisture meter (Aquaterr EC-200, Jae Sung International Co., South Korea) and a soil thermistor (Cambell thermistor T108 C_2). Values were recorded after measurements did not vary for one minute.

Aboveground biomass of grasses was determined as fresh plant weight (kg m^{-2}) at the beginning of the experiment (July 2004) and after two years in all sites. We cut and collected the biomass enclosed in a 1 m^2 area delimited on the ground. Due to differential area available for sampling in the canopy and open pasture areas, we took 10 and 15 samples at each site, respectively.

Sampling of the Regenerating Community

In order to explore recruited seedling dynamics through time, recruitment and survival of seedlings of woody species were monitored from October 2004 to July 2006 and recorded every three months. Ficus B was accidentally burned in May 2006, and therefore real data from that site reach up to 15 mo after the start of the study. Only native rainforest tree, shrub, and liana seedlings were recorded. A local expert helped with identification to the species level when possible. The values corresponding to one-year-old seedlings recorded only in the "control" grass treatment were used to compare one-year-old seedlings with the seed rain, seed bank, and two-year-old sapling communities (see below).

Seed Rain

Seeds were collected with litter traps. Each trap consisted in a plastic hose tied up in a loop, where three holes were made to insert iron poles (65cm long), in order to sustain the loop 50cm above the ground. Fine mesh cut in the shape of a circle was attached to the hose loop with *velcro* brooches. The mesh pieces were cut large enough to allow each trap to have ca. 30cm depth towards the ground. A pebble was placed inside the trap in order to hold the mesh downwards, and so the seeds would not be pulled out of the trap as the mesh wobbled with strong winds. Collecting area was calculated as the area enclosed by the loop. Traps placed in the canopy area were 30cm in diameter and traps placed in the open pasture area were 70cm in diameter. Traps were randomly placed throughout the canopy area (15 traps), and throughout the pasture area (30 traps). A total of 1.06m^2 were sampled in the canopy area (1.35% of the canopy area), and 11.54m^2 were sampled in the pasture area (0.16% of the pasture area). Seed collecting was done between July 2004 and May 2005. Collecting periods were July-August (2004), September-October (2004), December-January (2004-2005), and April-May (2005). Seed collection consisted in holding the deepest part of the mesh (were the pebble laid) and carefully emptying it in a paper bag which was correspondingly labeled. Paper bags with seeds were later emptied on plastic trays at the laboratory. Seeds were counted and separated by morphospecies, with the help of magnifying glasses and paint brushes. In all studied communities (see below), a local expert helped with identification to species level when possible. Identified species were confirmed to be part of the recorded flora for the area as reported by Martínez et al. 1994.

Seed Bank

Seed bank was recorded as the emerged seedlings from collected soil samples. Soil samples were collected throughout the rainy season in 2004. Four dates were defined for soil collection: July 15th, July 24th, August 6th, and September 12th. At each date, six samples were collected from each study site: three samples in the canopy area and three samples in the open pasture area. Soil samples were collected with a metal cylinder (6.9cm, diameter and 8cm, depth). Each sample consisted in 299.14cm^3 of soil. Samples were collected by turning the cylinder's handle into the ground, penetrating the ground surface. The cylinder was removed from the ground and the soil contained in the cylinder was emptied with the help of a pointed instrument into a plastic bag. Samples were taken to a rustic nursery consisting of a fine cloth tent, to avoid seed input through the seed rain while seedlings emerged. The samples were placed in round plastic containers (22cm diameter x 5cm depth) which held soil but allowed drainage through tiny holes at the bottom. Samples were watered regularly and received partial sun throughout the day. Emerged seedlings were recorded throughout three months. Seedlings were identified to the genus level when possible by a local taxonomist. After emerged and recorded, seedlings were removed by hand and discarded, in order to avoid redundant counting. Only tree and shrub species were considered.

Seedling Recruitment (1y)

The cohort of one-year-old seedlings was obtained from the values recorded only in the control grass treatment plots described above. A total of 8 plots were considered for the "canopy" and "open pasture" areas in each studied site, for a total of 16 plots per site. Other grass treatments were not considered for the one-year-old seedling cohort since the grass treatment factor could affect the amount of seedling recorded in each plot. All quadrants were established in October 2004. Seedling recruitment was measured in October 2005. Only tree and shrub species were considered. A local expert helped with identification to the species level when possible

Sapling Recruitment (2y)

Sapling recruitment after 2 years was recorded in October 2006. In *Inga* sites, all tree and shrub individuals with $\geq$1.5m height were recorded throughout the fenced area (1ha). Individuals were recorded as recruited in the canopy or open pasture areas depending on their location. One of the *Ficus* sites was accidentally burned in April 2006, and therefore I was unable to measure recruitment after 2 years. For the other *Ficus* site, I randomly established in the open pasture area five quadrants of 5 x 5m and recorded all recruited individuals as described above. In the canopy area, I established one 5 x 5m quadrant and recorded all recruited individuals. Values were extrapolated to estimate the total canopy and pasture areas. Sapling stems were carefully observed in order to know whether they were recruits or resprouts. Resprouts were not considered as recruited individuals.

Species Composition of Adjacent Forest Fragments

Five Gentry transects were randomly established at each of the closest adjacent forest fragments to each pasture site. Fragments varied consistently in shape and extension. In each transect, all individuals with >10cm diameter at 1.30m height were recorded and identified to species level when possible.

Seed Predation Experiment

Studied Pasture Fields

Three active cattle pasture fields, ca. 6 ha in extension each, were selected for this study. Hereafter, these will be addressed as site-1, site-2, and site-3. All sites were located in low-hill, poor sandy soil areas (Siebe et al. 1995) and separated by at least 4 km. Sites had similar land use history: original vegetation consisted of rainforest, which was cut and burned for the first time between 1985 and 1990. Maize was grown for 2-3 years, after which forage grasses were established. The sites were burned every one or two years while used as cattle pasture. In July 2004, an area of 1.4 ha in each pasture was fenced to exclude cattle and left undisturbed. The experiment was initiated in July 2005.

Seed Collection and Treatments

In each study pasture, we established five plots of 5 x 5-m which were cleared of grass with *machete* to set seed containers on the ground, and make seed finding and counting possible (see details below). The plots were separated by 5 m along a 50 m transect which was established 70 m from any isolated tree located inside the fenced area.

Seeds of four abundant forest tree species were used: two small-seeded, early successional species (ES, *Cecropia obtusifolia* and *Ochroma pyramidale*), and two large-seeded, late successional species (LS, *Brosimum costaricanum* and *Dialium guianense*). Species characteristics are described in Table 3. We will refer to species by genus name hereafter. The species selection included species that would usually reach pastures by animal

(*Cecropia*) and wind dispersal (*Ochroma*), and species with limited dispersal into pastures (*Brosimum* and *Dialium*). Except *Cecropia*, the rest of the species are useful for local resource management, *i.e.*, wood production and/or nutritional value for cattle and people (Vázquez-Yanes et al. 1999).

Table 3. General attributes of the four tree species studied at Marqués de Comillas, Southeast Mexico during a seed predation experiment. Mean dry seed mass is as reported in Ibarra-Manríquez et al. (2001)

Species	Family	Successional status	Dispersal vector	Seed dry mass (g)	Species related benefits
Cecropia obtusifolia Bertol.	Cecropiaceae	Early successional	Bird and mammal	0.0009	Ecological
Ochroma pyramidale (Cav. ex Lam.) Urb.	Malvaceae	Early successional	Wind	0.0068	Ecological, productive
Brosimum costaricanum Liebm.	Moraceae	Late successional	Bird and mammal	0.92	Ecological, productive
Dialium guianense (Aubl.) Sandwith.	Fabaceae	Late successional	Bird and gravity	0.25	Ecological, productive, alimentary, medicinal

Except *Ochroma* (collected in March 2005), all seeds were collected two days before the start of the experiment. *Cecropia* seeds were collected from two mature trees located less than 4 km from experimental sites. Seeds were rinsed with water to remove fruit tissue and dried with absorbent paper. *Ochroma* seeds were collected from naturally fallen fruits belonging to more than ten road-side mature individuals, and the cotton-like tissue containing seeds was completely removed by hand. Seeds were stored in paper bags in the shade at the study area, until the start of the experiment. *Brosimum* and *Dialium* fruits were collected from three to ten different individuals located in forest remnants close to the studied pastures. Fruits were picked up from the ground, rinsed with water to remove fruit tissue, and dried with absorbent paper.

For setting seeds of ES species, we used inverted cone-shaped containers (7-cm diameter, 10-cm depth) made with metal mesh (5-mm aperture), filled with commercial garden soil. We used commercial garden soil in order to facilitate finding the small seeds. Local soil was coarse and not homogenous, making it easy to lose ES species seeds. Fifty seeds were used per experimental container. Three treatments were applied to the seeds: burial, exclusion from invertebrates, and complete exposition. Seeds in the burial treatment were sown and covered with garden soil up to 0.3 cm. Seed germination of photoblastic (*Cecropia*) or thermoblastic (*Ochroma*) seeds could be affected by the soil cover. However, it has been shown that the exposure of seeds of *Cecropia obtusifolia* to direct sun light for short periods (>10 min) are enough to activate seed germination mechanisms (Vázquez-Yanez & Smith 1982). Other studies have registered quantifiable germination rates in *Cecropia obtusifolia* seeds covered with soil (Alvarez-Buylla & Martínez-Ramos 1990). For *Ochroma*, soil temperature changes operating in the open field at 0.3 cm depth are enough to promote germination (Vázquez-Yanes et al. 1999).

Invertebrate exclusion was achieved by placing the seeds at the soil surface and a fine nylon cloth mesh (less than 0.1 mm aperture) was fixed over the containers. The cloth covered half of the container's height and was held tightly by rubber bands. While seeds were accessible from below ground (if invertebrates dug across the section of the container without cloth), the seeds were unreachable from the surface level. Exposed seeds were placed on the surface of the garden soil without any protection. The surface of the ground barely surpassed the containers' height, making them not visible at ground level. During each census, one container from each plot was removed from the ground and placed inside a plastic bag for transportation to the laboratory, where seeds were separated from the commercial garden soil with the help of a thin painting brush under a stereoscopic microscope and registered as germinated (seeds with an emerged radicle), damaged (with evidence of invertebrate partial consumption or fungal tissue), or present. Censuses were made 2, 4, 8, 16, 32, and 64 days after the start of the experiment. Five containers were removed at each census, per species, per site.

For LS species, we used 10 seeds per deposition spot. The treatments applied to the seeds were: burial, protection from vertebrates, and complete exposition. For the burial treatment, we made wire mesh (5-mm aperture) box-shaped containers (5 x 5 x 10-cm), half-filled with local soil. The seeds were placed in the containers and covered with local soil. Containers were placed in hand-made holes (5 x 5 x 10-cm) in the ground. To exclude seeds from vertebrate seed-eaters, we made small cages (15 x 15 x 5-cm) with wire mesh (5-mm aperture). Seeds were placed directly over the pasture floor and the cages were placed over them, firmly fixed to the ground with metal hooks. Invertebrates could remove the seeds through the wire mesh. Exposed seeds were placed directly on the pasture floor and kept in one spot with a circular metal ring (1-cm high), though seeds remained completely accessible to seed-eaters. Censuses were made 2, 4, 8, 16, 32, and 64 days after the start of the experiment. Subsequently, we combed through the soil to find buried seeds of LS species. The remaining seeds were counted and placed back in the container as originally. During each census, seeds were registered as germinated, damaged or present. Each plot had six containers for each treatment, for a total of 30 containers inspected at each census, per species, per site.

Data Analyses

Isolated Trees and Pasture Vegetation Effect

Response variables of the regenerative community were seedling density, mortality rate, and species diversity and composition. These variables were calculated lumping the values from the eight plots corresponding to each grass treatment, at each distance category, at each of the four studied sites. Recruitment rate ($R = R_t / t$) was determined as the number of recruits recorded at a given period (R_t) over the time (t, months) elapsed since the start of the experiment. Mortality rate [$M = M_t/TR)^{1/t}$] was determined as the number of dead recruits recorded at a given period relative to the total of recorded recruits (TR) over the time elapsed since the start of the experiment. Diversity values were determined for isolated tree identity, distance category, and grass removal treatments after 21 mo of study. Species richness indexes (i.e., Mao Tau) and diversity indexes [i.e., Shannon (H'), and Simpson (S)] were calculated using Estimates 7.1 (Colwell 1997).

In our experimental design, the factor "grass treatment" was nested into "distance to isolated tree", and the latter nested into "isolated tree identity" (*Ficus* vs *Inga*). To test the effects of each nested factor we used analyses of deviance over additive models (General Linear Models, GLM). When deviance was not reduced as nested factors were added, factors were tested independently (not nested). In these analyses, we used a binomial error and a logistic link function for binomial variables (e.g., mortality rate), and a Poisson error and a log link function for count variables (e.g., density and species richness; Crawley 1993). To assess the contribution of tree, shrub, and liana species to the regenerating community abundance we applied a contingency table analysis using GLM with a Poisson error and a logarithmic link function. In GLM, the binomial and Poisson errors mean the deviance explained by independent variables can be considered to be an approximated χ^2 value (Crawley 1993). We rescaled the model when overdispersal was detected (Crawley 1993). These analyses were made with the statistical program GLIM 3.77 (Royal Statistical Society, Nottingham, UK).

To assess treatment effects on seedling density and species richness along time, we used repeated measures nested analyses of variance (Systat ver. 11, Systat Software Inc., California). The repeated subjects (isolated tree identities, distance-to-focal tree categories, and grass treatments) were fixed. Seedling density and species richness values were log-transformed before statistical analyses to meet homoscedasticity criteria.

Seed Rain, Seed Bank, Seedlings (1y), and Saplings (2y)

Density (individuals per unit area) and diversity (Shannon-Wiener Index H’, Sorensen Index, Species Richness) values of all studied communities were obtained by adding up individuals for each site and treatment, so *Ficus* A and *Ficus* B sites were added up for “*Ficus*” values, while *Inga* A and *Inga* B sites were added up for “*Inga*” values. Values indicated as “overall” are the result of considering the four sites’ abundance and composition as one single sample. Density and diversity values for each studied community were obtained with the software ESTIMATES (Version 6.8.5), randomized to 100 samples. Shannon-Wiener index (H’) for each community, with the corresponding standard error, was obtained with the program ECOSIM, randomized to 100 samples. To assess the differences in density and richness between communities, contingence table analysis was applied using GLM, with a Poisson error and a logarithmic link function. In the binomial and Poisson errors the deviance explained by independent variables can be considered to be an approximated X^2 value (Crawley 1993). These analyses were made with the statistical program GLIM 3.77 (Royal Statistical Society, Nottingham, UK). The probability of transition (P_t) from one stage to latter stages was estimated through the relative abundance of a particular species in each of the studied communities. The probability was estimated with the number of individuals of a species found in the regenerative community in stage P (e. g., seed rain), and the number of individuals of that species found in further life stage C (e. g., one-year-old seedlings). The probability was obtained as follows $P = (D_c/D_p)*100$ where D_c is the density of the species in the regenerative community in stage C and D_p is the density of the same species recorded in the community in stage P.

Seed Predation

Observations for each species within plots and sites were not independent from one another, so we added up the total of seeds per species per treatment per site. For ES species, the bundle of 50 seeds in each of the five plots was added up, resulting in an accumulated proportion of remaining or germinated seeds out of a total of 250 seeds per site per census date. For LS species, the six observations in each of the five plots (60 seeds per plot) were added up and resulted in a proportion of remaining seeds out of a total of 300 seeds per site for each census. Because seed predation was more than 90% after eight days for ES species and after sixteen days for one of the two LS species (see results), we assessed the influence of treatments on initial seed predation rates restricting the analysis to the early census periods. We obtained initial predation rates as $[(\log N_f) - (\log N_i)]/t$, where N_f is the remaining number of seeds, N_i is the initial number of seeds and t is the number of days from the sowing date to the final census (eight days for ES species, and 16 days for LS species). For each species and treatment, we report a mean (± standard error) predation rate from three site values. We used survival analyses (Cox's proportional hazard model) to determine the effects of treatments on mean time of seed survival. Because sites could not be considered as replicates (due to variation regarding land-use history, surrounding forest matrix, and structural composition of pasture vegetation), we carried out survival analysis for each species at each site separately. Conclusions were derived from the results' regularity across sites. For *Cecropia,* a survival model with constant hazard, no censoring, and exponential error structure with reciprocal link function was defined (following criteria given by Crawley 1993). For the rest of the species (where a few seeds remained alive at the end of the study) a survival model with constant hazard, censored data, and Poisson error structure with log link function was defined (Crawley 1993). To evaluate effects of site and treatments on the final proportion of germination (64 days after sowing date), we used an Analysis of Deviance which considered a binomial error and a logistic link function, following criteria given by Crawley (1993). In these analyses the deviance explained by each factor can be considered to be an approximated X^2 value (Crawley 1993).

RESULTS

Microclimate

Air temperature changed significantly ($F_{15, 16} = 2.43$, $p = 0.04$) between distance categories, particularly in the *Inga* sites (Table 4). Overall, air temperature (mean $\pm$ SE: 30.3 $\pm$ 0.8°C) was almost five degrees lower under the canopy of isolated trees than in the open pasture (34.9 $\pm$ 1.2). Also, percentage of PAR changed significantly ($F_{15, 16} = 15.6$, $p < 0.0001$) between distance categories, particularly in the *Ficus* sites where light availability under tree's canopy was less than 5% of full radiation (hoe treatment). In the open pasture of *Ficus* sites (control treatment) light radiation showed values close to the ones recorded under the canopies of the isolated trees. The effect of the canopy was less strong in the *Inga* sites. Grass removal increased light availability in the open pasture, more in the hoe treatment. Soil relative humidity differed significantly only between distance categories in the *Inga* sites ($F_{8,}$

$_{16}$ = 2.54, *p* = 0.05), where the canopy was less humid (33.8% ± 0.8%) when compared to the open pasture (44.3% ± 3.4%).

Table 4. Micro-environmental variables recorded in four studied pastures of Marqués de Comillas, Southeast Mexico

Air Temperature (^oC)

Grass treatment	Canopy	± *s.e.*	Pasture	± *s.e.*
Control	30.76	*0.99*	34.97	*.95**
Cut	30.14	*0.84*	34.78	*1.41**
Herbicide	30.23	*0.85*	35.33	*1.67**
Hoe	30.08	*0.81*	34.68	*1.25**
Total	30.30	*0.79*	34.94	*1.21**

Soil Temperature

Grass treatment	Canopy	± *s.e.*	Pasture	± *s.e.*
Control	32.80	*1.64*	35.06	*0.94*
Cut	32.88	*1.37*	35.13	*1.21*
Herbicide	32.63	*1.46*	35.61	*1.53**
Hoe	32.58	*1.47*	35.63	*1.05**
Total	32.72	*1.48*	35.36	*1.18*

Soil Relative Humidity (%)

Grass treatment	Canopy	± *s.e.*	Pasture	± *s.e.*
Control	40.88	*4.35*	37.74	*4.91*
Cut	31.41	*4.11*	45.75	*5.00*
Herbicide	38.86	*4.13*	49.46	*6.63*
Hoe	43.80	*5.50*	45.79	*7.09*
Total	38.53	*2.30*	44.45	*2.92*

Photon Flux Density (%)

Grass treatment	Canopy	± *s.e.*	Pasture	± *s.e.*
Control	7.62	*3.09*	21.09	*5.92**
Cut	21.77	*6.93*	71.25	*8.52**
Herbicide	37.36	*18.07*	50.75	*9.61*
Hoe	16.88	*3.95*	100.00	*0.00*
Total	60.77	*8.09*	20.91	*5.27**

* Significant differences between canopy and pasture values (p<0.05).

Grass Biomass

Grass biomass changed significantly between distance categories when sampled at the beginning of the experiment ($F_{2, 96}$= 19.8, $p < 0.0001$) and two years later ($F_{1, 94} = 59.6$, $p < 0.0001$). At the beginning of the experiment, grass biomass was similar for *Ficus* and *Inga* sites and was ca. 50% lower under the tree's canopy than in the open pasture. After 21 mo, grass biomass was significantly higher in the open pasture of *Inga* sites (Figure 2).

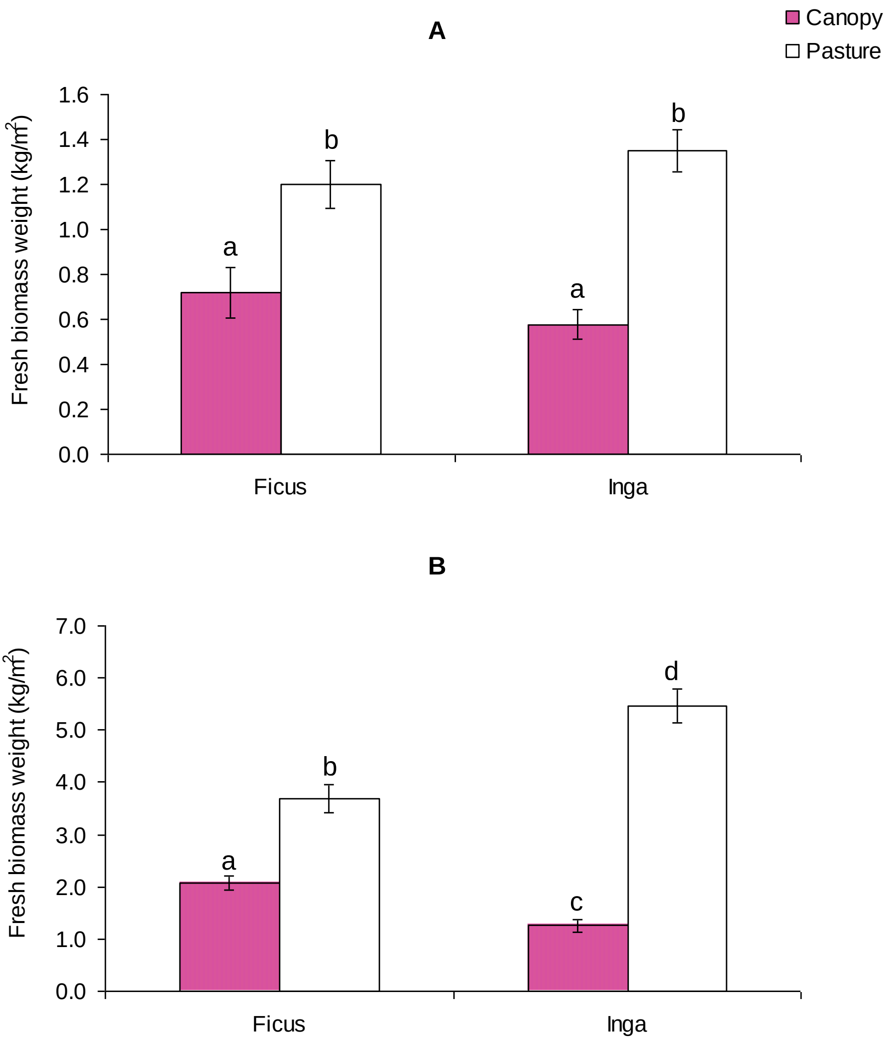

Figure 2. Grass density expressed as fresh biomass weight (kg/m2) according to isolated tree species and distance to focal tree at the beginning of the experiment (A, July 2004), and two years later, at the end of the experiment (B, July 2006), in tropical pasture fields at Marqués de Comillas, Southeast Mexico. Significant differences in A correspond to F= 37.64, df = 1, P > 0.0001, and in B to F = 15.79, df = 1, P = 0.0002.

Seedling Recruitment

A total of 665 recruits were recorded in 512 m^2 (1.3 seedling m^{-2}) after 21 mo in the four studied pastures. Isolated tree identity ($\chi^2 = 11.78$, df = 1, $p < 0.01$) and distance category ($\chi^2 = 3.83$, df = 1, $p < 0.05$) significantly affected recruitment; no interaction effects were observed among these factors. Sixty five percent of the recruits were recorded in the canopy and 35% in the open pasture. More recruits were recorded in *Ficus* sites when compared to *Inga* sites (Figure 3). Lumping isolated trees and distance categories, final recruitment was significantly different among grass treatments ($\chi^2 = 12.42$, df = 3, $p < 0.01$). The highest proportion of recruits was recorded in the cut with machete treatment (28.8%, 1.6 seedling m^{-2}), while the lowest was observed in the herbicide treatment (19.6%, 1.3 seedling m^{-2}). The control and hoe treatments accounted for 26.5 and 25% of the recruits, respectively (each, *ca.* 1.5 seedling m^{-2}). No interaction was observed between grass treatment and distance category within isolated tree identity.

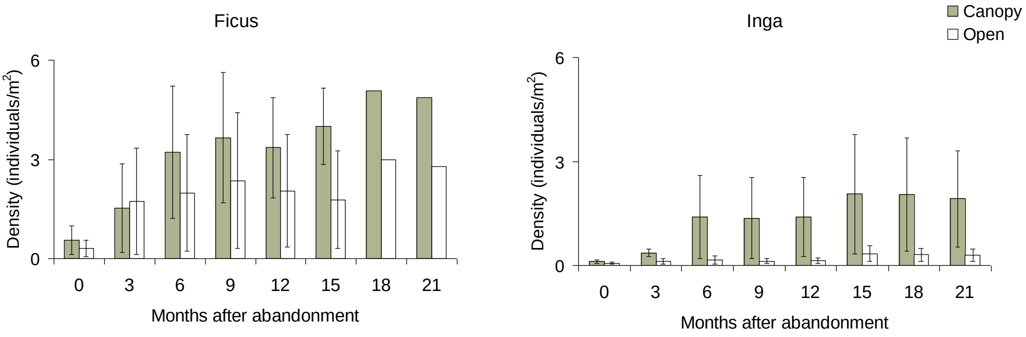

Figure 3. Effect of focal tree species (*Ficus*, *Inga*) and sampling area (canopy, pasture) on observed seedling density along a 21-month period in pastures of Marqués de Comillas, Southeast Mexico. Bars correspond to mean ± one standard error.

Seedling Density

After 21 mo, overall mean seedling density across all sites and treatments was 1.48 ± 0.24 seedling m^{-2}. Isolated tree identity ($F_{1, 30} = 5.4$, $p = 0.02$) and distance category ($F_{1, 29} = 7.4$, $p = 0.01$) affected seedling density. *Ficus* sites outnumbered approximately two times the values observed in *Inga* sites (2.9 ± 1.0 and 1.2 ± 0.9, respectively). Overall, higher density was recorded under the canopy (2.1 ± 0.3), while relatively less than half was recorded in the open pasture (0.9 ± 0.3). The interaction between isolated tree identity and distance category was not significant ($p > 0.05$). Grass treatments did not have a significant effect on final seedling density ($p > 0.05$), when considered overall or nested within other factors. Repeated measures ANOVA showed that the change in seedling density through time was significantly different between *Ficus* and *Inga* sites ($F_{7,161} = 4.92$, $p < 0.001$), and between the canopy and open pasture area ($F_{7,161} = 4.44$, $p < 0.001$), but not within grass treatments nested within other factors ($F_{42,161} = 0.34$, $p > 0.05$).

Species Density and Diversity

In total, 48 woody species (21 tree, 21 shrub, and six liana species) were recorded. The mean species density across all sites and treatments was of 0.10 species m^{-2}. After 21 mo, species density in *Ficus* sites was of 0.49 ± 0.14 and of 0.26 ± 0.06 in *Inga* sites ($\chi^2 = 3.43$, df = 1, $p < 0.10$). Final species density did not differ between grass removal treatments ($\chi^2 = 1.82$, df = 3, $p > 0.05$) or between distance categories ($\chi^2 = 1.75$, df = 1, $p > 0.05$; canopy: 0.07 ± 0.02, open pasture: 0.05 ± 0.02), although it was significantly higher under the canopy of *Ficus* trees ($\chi^2 = 25$, df = 2, $p = 0.04$) than under the canopy of *Inga* trees. Repeated measures ANOVA showed that the change of species density through time was significantly higher in *Ficus* when compared to *Inga* sites ($F_{5,120} = 8.5$, $p < 0.001$), for both canopy and open pasture areas.

Diversity values (H') for each distance category at each isolated tree are shown in Table 5. In one of the *Inga* sites, 81.4% of total recruits belonged to seedlings produced by one isolated tree (*Inga punctata*). In this site, species diversity in the canopy was significantly lower than the open pasture, unlike the other sites. Diversity was higher under the canopy of *Ficus* trees than under the canopy of *Inga* trees. Diversity in the open pasture of *Ficus* sites was higher when compared to both the canopy and the open pasture of *Inga* sites.

Table 5. Average values showing seedling abundance, seedling density, species richness, and species diversity observed in the final regenerating community after 21 months of study in four pastures of Marqués de Comillas, Southeast Mexico

		Ficus			*Inga*	
Response variable	C	P	Overall	C	P	Overall
Recorded individuals (seedlings)	128 ± 37	57 ± 47	92.5 ± 31.88	66 ± 55	11 ± 7	38.5 ± 27.65
Recruitment density (ind m^{-2})	4 ± 1.16	1.78 ± 1.47	2.89 ± 1	2.06 ± 1.72	0.34 ± 0.22	1.2 ± 0.86
Species density (spp m^{-2})	0.61 ± 0.2	0.38 ± 0.22	0.49 ± 0.14	0.3 ± 0.08	0.22 ± 0.13	0.26 ± 0.06
Species richness (Mao Tau)	19.5 ± 6.5	12 ± 7	15.75 ± 4.46	9.5 ± 2.5	7 ± 4	8.25 ± 2.06
Shannon Index (H')	2.35 ± 0.42	1.89 ± 0.66	2.12 ± 0.34	1.5 ± 0.35	1.61 ± 0.57	1.56 ± 0.27
Simpson Index (S)	9.22 ± 3.8	6.74 ± 3.74	7.98 ± 2.29	6.42 ± 4.59	8.47 ± 2.47	7.44 ± 2.21

Plant Growth Forms and Composition

From the total number of recruited plants, 38% belonged to tree species, 53% to shrubs, and 9% to lianas. *Ficus* sites recruited 12.5 times more liana seedlings, 5.8 times more shrub seedlings, and 1.4 times more tree seedlings when compared to *Inga* sites. Density of shrub seedlings under the canopy of *Inga* trees was 40% less when compared to the open pasture of *Ficus* sites. The highest density of tree recruits occurred under the canopy of *Ficus* trees (0.92 ± 0.50 seedling m^{-2}), followed by the canopy of *Inga* trees (0.78 ± 0.64).

At the end of the study, isolated trees harbored a distinctive species composition with very little overlapping among them. The most abundant genera were *Inga*, *Solanum*, *Vernonia*, and *Cordia*, although abundance and frequency were not corresponded (Table 6). Most species were encountered in less than four sites. Only *Cordia spinescens* and *Vernonia patens* were present at every site. Thirty species were only recorded in one site, and 14 of them recruited one single individual along the study.

Table 6. Ten most abundant recruited species observed throughout a 21-mo study under the canopy and in the vicinity of four isolated trees in Marqués de Comillas, Southeast Mexico

						Relative abundance per site			
Species	**Family**	**Lifeform**	**Dispersal Syndrome**	**Number of recruited individuals**	**Percentage of total recruitment**	**Ficus A**	**Ficus B**	**Inga A**	**Inga B**
Inga punctata	Fabaceae	Tree	Bird and mammal	151	18.90%	0.00%	0.00%	0.00%	100.00%
Solanum rudepanum	Solanaceae	Shrub	Bird and mammal	79	9.89%	52.00%	44.00%	0.00%	4.00%
Cordia spinescens	Boraginaceae	Shrub	Bird	75	9.39%	56.00%	37.00%	3.00%	4.00%
Vernonia patens	Asteraceae	Shrub	Wind	66	8.26%	82.00%	2.00%	3.00%	14.00%
Solanum globferum	Solanaceae	Shrub	Bird and mammal	65	8.14%	66.00%	0.00%	12.00%	22.00%
Vismia camparaguey	Clusiaceae	Shrub	Bird and bat	54	6.76%	100.00%	0.00%	0.00%	0.00%
Dalechampia heteromorpha	Euphorbiaceae	Liana	Explosion	34	4.26%	97.00%	0.00%	3.00%	0.00%
Psidiumguajava	Myrtaceae	Tree	Bird and mammal	33	4.13%	33.00%	67.00%	0.00%	0.00%
Piper hispidum	Piperaceae	Shrub	Bird and bat	32	4.01%	81.00%	13.00%	0.00%	6.00%
Tetracera aspera	Dilleniaceae	Shrub	Bird	32	4.01%	97.00%	3.00%	0.00%	0.00%
Total				**621**	**77.72%**				

Seed Rain

A total of 248,496 seeds were collected throughout the study, and we could identify 90.7%. A total of 5,416 seeds (2.18%) were from shrub species, while tree species accounted for 24,540 seeds (9.8%). Almost 97% of the seeds of tree species were produced by the focal isolated trees ("local seed rain"; 23,678 seeds). Local seed rain was produced mainly by *Ficus* trees (99.7%), while 0.2% was produced by *Inga* trees. The remaining seeds, from "foreign seed rain", were 862 seeds (3.5%). A total of 59,644 seeds (24%) were from the Poaceae family, mainly forage grasses grown at the sites. Herb species accounted for 20,793 seeds (0.37%). One genus of liana species was recorded: *Mikania* sp. with a total of 114,991 collected seeds (46.27%). The following results describe the foreign seed rain of tree and shrub species solely.

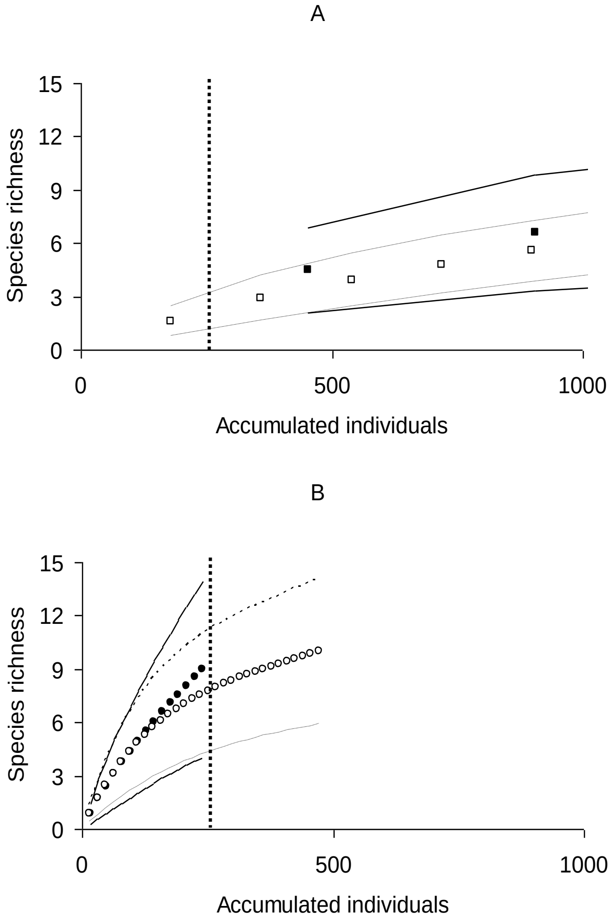

Figure 4. Species-individual-based accumulation curves (mean ± 2 SE) for seeds of tree and shrub species recorded in the seed rain of *Ficus* (A) and *Inga* (B) isolated trees, under the canopy (full symbols) and in the open pasture (open symbols). Confidence intervals (95%) are expressed as straight lines (for canopy values) and dotted lines (for open pasture values). The vertical dotted line represents species richness with similar number of individuals (ca. 250) within canopy and open pasture areas.

Table 7. Abundance, richness, and diversity parameters for tree and shrub species recorded at the seed rain, seed bank, one-year-old seedling, two-year-old saplings, and adjacent forest fragment communities in four abandoned pastures of Marqués de Comillas, Southeast Mexico

Isolated tree	Smapled area (m to tree's trunk)	Described community	Recovered individuals	Sampled area (m/2)	Density (inds/m2)	Observed species (Mao Tau)	Species Density (sp/m2)	Shannon Index (H')	Simpson Mean
Ficus sp.	Canopy (0-10m)	Seed rain	3748.00	1.06	3534.89	10.00	9.43	1.19	2.33
		Seed bank	52.00	3.36	15.48	7.00	2.08	1.41	3.25
		Recruitment (1y)	68.00	16.00	4.25	22.00	1.38	2.79	14.99
		Recruitment (2y)	83.00	25.00	2.88	21.00	0.84	2.63	12.02
	Pasture (12-48m)	Seed rain	1382.00	11.55	119.70	10.00	0.87	1.43	2.86
		Seed bank	1.00	4.48	0.22	1.00	0.22	0.00	
		Recruitment (1y)	52.00	16.00	3.25	15.00	0.94	2.38	9.82
		Recruitment (2y)	158.00	175.00	0.90	18.00	0.10	2.18	5.99
						12.00			
	Ocerall	Seed rain	5130.00	12.61	406.96	7.00	0.95	1.37	3.05
		Seed bank	53.00	7.84	6.76	23.00	0.89	1.42	3.34
		Recruitment (1y)	120.00	32.00	3.75	31.00	0.72	2.85	15.78
		Recruitment (2y)	241.00	200.00	1.21		0.16	2.72	10.27
						27.00			

	Adjacent forest fragment		**198.00**	**500.00**	**0.40**		**0.05**	**2.52**	**8.34**
						10.00			
Inga sp.	Canopy (0-10m)	Seed rain	297.00	1.06	280.11	3.00	9.43	1.21	2.35
		Seed bank	8.00	3.36	2.38	3.00	0.89	0.90	2.55
		Recruitment (1y)	3.00	16.00	0.19	9.00	0.19	1.10	-
		Recruitment (2y)	15.00	78.54	0.10		0.11	1.35	5.50
	Pasture (12-48m)	Seed rain	471.00	11.55	40.80	10.00	0.87	0.64	1.35
		Seed bank	0.00	4.48	0.00	0.00	0.00	0.00	0.00
		Recruitment (1y)	1.00	16.00	0.06	1.00	0.06	0.00	-
		Recruitment (2y)	533.00	9921.46	0.03	52.00	0.01	2.71	7.97
	Ocerall	Seed rain	768.00	12.61	60.93	15.00	1.19	1.23	2.41
		Seed bank	8.00	7.84	1.02	3.00	0.38	0.90	2.55
		Recruitment (1y)	4.00	32.00	0.13	4.00	0.14	1.39	-
		Recruitment (2y)	548.00	10000.00	0.05	53.00	0.01	2.74	8.14
	Adjacent forest fragment		**144.00**	**500.00**	**0.29**	**29.00**	**0.058**	**1.75**	**10.93**

Regarding seed rain density (seeds m^{-2}), the *Ficus* sites recorded 6.7 times more seeds than *Inga* sites. Seed rain under canopies of *Ficus* trees was 12 times more abundant than under canopies of *Inga* trees (Table 7). Seed rain under the canopy of *Ficus* and *Inga* sites was 30 and 7 times more abundant than in the open pasture area, respectively. One of the *Inga* sites recorded 399 seeds of *Cecropia* sp. in the open pasture, collected as bird feces lumps. Without those *Cecropia* sp. seeds, the canopy of *Inga* trees recorded 6.26 seeds/m^2, 44.7 times less seeds than under the canopy of *Ficus* trees (Table 7).

Seed rain in *Ficus* sites was less rich (ca. 2.5 species) than in *Inga* sites (ca. 9 species) considering the first 250 recorded seeds (Figure 4). No significant differences in the cumulative species-individual relationship were recorded among canopy or pasture areas in both *Ficus* and *Inga* sites, however, canopy areas accounted for more species than pasture areas when considering the same amount of recorded seeds.

Seed rain was dominated by animal dispersed seeds, which outnumbered wind dispersed seeds in all treatments. No seeds dispersed by wind were recorded below the canopy of *Inga* sites. The highest densities of both animal- and wind-dispersed seeds were recorded below the canopy of *Ficus* sites. All the recorded shrub species in the seed rain were dispersed by animals. Considering seeds from tree species, seeds dispersed by animals were 216 times more abundant than seeds dispersed by wind. Only three tree species dispersed by wind were recorded in the seed rain: *Cordia alliodora*, *Terminalia amazonia*, and *Trichospermum galeottii*. These species accounted for 42 seeds in total.

The most abundant species in *Ficus* sites was *Psychotria costivenia*, which dominated the seed rain community (55.1%). This species was recorded in the canopy and open pasture areas of *Ficus*, and in the open pasture of *Inga*. In the case of *Inga* sites, *Solanum* sp. dominated the seed rain in the canopy area (75.8% of total seeds recorded), and *Cecropia* sp. in the open pasture with 405 seeds recorded in total (86% of total seeds recorded). In the case of *Ficus* sites, the most abundant tree species in the seed rain were presumably produced by the isolated tree. Wind dispersed species (e. g. *Trichospermum galeottii*) were more abundant in *Inga* sites when compared to *Ficus* sites, where animal-dispersed species were predominant. Relative dominance of shrub and tree species is shown in Figure 5.

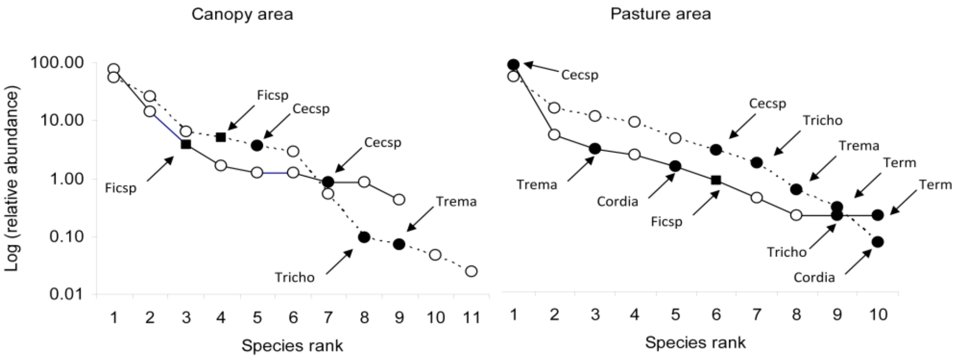

Figure 5. Relative abundance of tree species recorded in the seed rain community. Legend as follows: *Inga* sp. trees (straight line), *Ficus* sp. trees (dotted line), shrub species (open circles), pioneer tree species (dark circles), mature tree species (dark squares). Species keys as follows: Cecsp (*Cecropia* sp.), Cordia (*Cordia alliodora*), Ficsp (*Ficus* sp.), Term (*Terminalia amazonia*), Trema (*Trema micrantha*), and Tricho (*Trichospermum galleottii*).

Seed Bank

A total of 61 seedlings emerged from the sampled seed bank. Most seedlings were found in the canopy of *Ficus* trees (85%), while the rest were recorded in the canopy of the *Inga* trees. One single seedling was recorded in the open pasture of the *Ficus* sites, while no seedlings were recorded in the open pasture of the *Inga* sites. Overall, seedling density was 6.62 times more abundant in *Ficus* sites than in *Inga* sites (Table 7). *Cecropia* sp. accounted for 40% of the seedlings emerged from the seed bank. *Solanum* sp. accounted for 23% of the recorded seedlings. The rest of the seedlings belonged to other six species.

Seedling Recruitment (1y)

A total of 124 seedlings from 24 species and 16 families were recorded after one year of study. Sixteen *Inga* sp. seedlings were recorded under the canopies of *Inga* trees, presumably coming from local seed rain. Aside from those seedlings, *Inga* sites recruited three seedlings under the canopy and one in the open pasture area. *Ficus* sites recorded 64 seedlings under the canopy and 50 seedlings in the open pasture. *Ficus* sites showed 30% more seedlings under the canopy than in the open pasture, while this value for *Inga* trees was of 300%. Overall, *Ficus* sites recorded ca. 30 times more seedlings than *Inga* sites (120 and four seedlings, respectively). Overall, the canopy recruited 1.16 times more seedlings than the open pasture (Table 7). The most abundant species were *Cordia spinescens* and *Vismia camparaguey* (together accounting for ca. 40% of all recorded seedlings). Several species accounted for less than five seedlings each.

Sapling Recruitment (2y)

After two years of study, a total of 868 saplings were recorded throughout the four sites. *Ficus* sites recorded a total of 241 individuals per hectare, while the *Inga* sites recorded 627 individuals per hectare. Shrub species accounted for 78% of the recorded individuals, while the rest were tree species. In the *Ficus* sites, shrubs were 6.3 times more abundant than trees, while in *Inga* sites they were 1.83 times more abundant. In *Ficus* and *Inga* sites, density (individuals m^{-2}) of the sapling community in the canopy was double than in the open pasture (Table 7).

A total of 66 species of 21 families were recorded. The top three species were recorded in the open pasture of *Inga* sites (*Vernonia patens*, *Blepharidium mexicanum*, and *Acalypha* sp.). *Piper hispidum* was dominant in the canopy area for both *Ficus* and *Inga* sites.

Adjacent Forest Fragments

Forest fragments were similar regarding abundance and richness traits (Table 7). The most common recorded species was *Trichospermum galeottii*, which accounted for ca. 20% of total individuals. *Cordia bicolor* and *Xilopia frutescens* were the following observed species, with 12 and 11% of recorded individuals, respectively. A total of 36 species from 19 families were recorded.

Comparison between Regenerative Communities

Density of individuals was highest in the seed rain, and decreased throughout the seed bank, the seedling, and the sapling communities (Figure 6A). Higher densities of propagules were recorded in the *Ficus* sites for all studied communities, than those values observed in the *Inga* sites. Seed rain and seed bank densities were not significantly different between *Ficus* and *Inga* sites ($P > 0.05$). Significant differences in density were recorded between sites for the seedling community after one year ($X^2 = 38.07$, df = 1, $P = 0.0001$), and after two years ($X^2 = 17.42$, df = 1, $P = 0.0001$; Figure 6A).

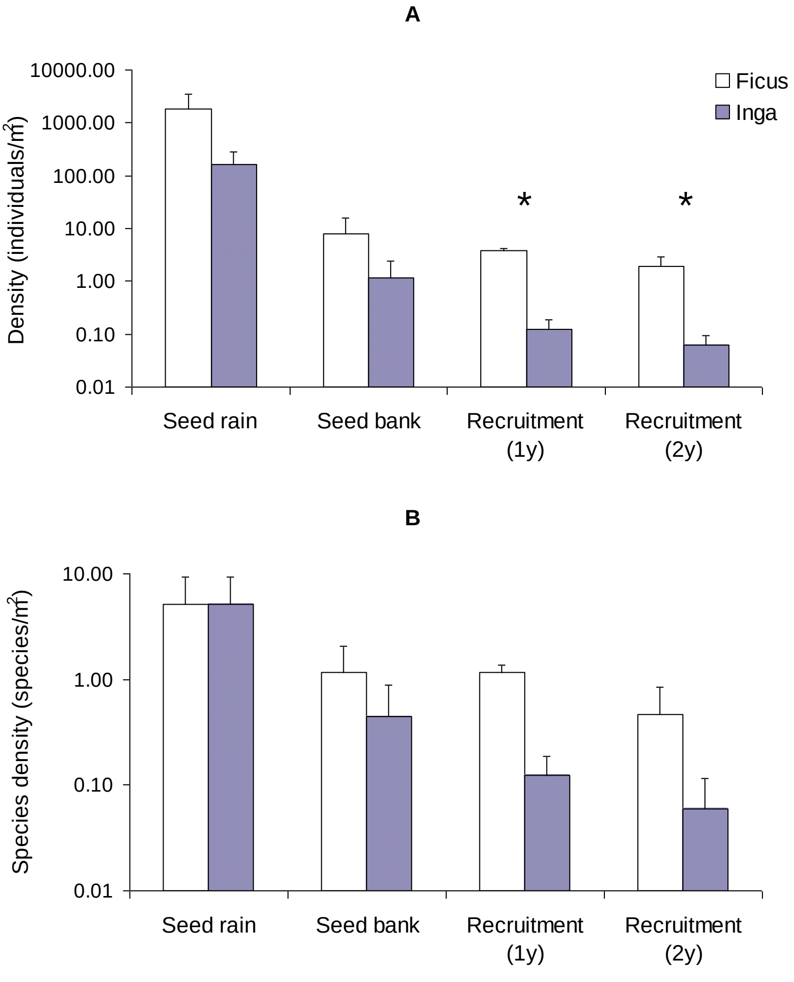

Figure 6. Recorded individual density (A) and species density (B) for the seed rain, seed bank, community of 1-year-old seedlings, and community of 2-year-old seedlings for *Ficus* and *Inga* sites, in pastures of Marqués de Comillas, Chiapas. Values correspond to the mean of two sites + one standard error. Notice the y-axis is in logarithmic scales. Significant differences are indicated with a star ($P < 0.001$).

Species density gradually decreased from the values observed in the seed rain through the seed bank, recruitment after one year, and recruitment after two years (Figure 6B). Higher species density values were observed in the *Ficus* sites, except for the seed rain, which was equal for both *Ficus* and *Inga* sites. No significant differences were observed in between sites for any of the studied communities (P > 0.05).

Ficus and *Inga* sites shared less than 40% of the observed species in all studied communities (Table 8). The one-year-old seedling community showed the least species in both *Ficus* and *Inga* sites (16%). Seed rain showed the highest number of species observed in both *Ficus* and *Inga* sites, sharing 33.3% of the recorded species.

Table 8. Total observed species, percentage of shared species, and Sorensen Index values between sites with *Ficus* sp. and *Inga* sp. isolated trees, corresponding to four studied pastures of Marqués de Comillas, Southeast Mexico

	Total Observed Species	Shared Species (%)	Sorensen Index
Seed Rain	27	33.3	0.667
Seed Bank	9	22.2	0.444
Recruits (1y)	25	16.0	0.320
Recruits (2y)	80	22.5	0.450
Forest	54	37.0	0.741

Table 9. Percentage of shared species (above grey area) and Sorensen Index values (below gray area) between sampled communities for sites with *Ficus* sp. (A), and *Inga* sp. (B) isolated trees, corresponding to four studied pastures of Marqués de Comillas, Southeast Mexico

A	Seed Rain	Seed Bank	Recruits (1y)	Recruits (2y)	Forest
Seed Rain		3.0	22.0	14.8	8.3
Seed Bank	0.061		7.7	14.6	14.0
Recruits (1y)	0.444	0.154		52.2	9.5
Recruits (2y)	0.296	0.292	0.303		29.4
Forest	0.167	0.281	0.190	0.588	

B	Seed Rain	Seed Bank	Recruits (1y)	Recruits (2y)	Forest
Seed Rain		3.3	16.7	0.0	5.8
Seed Bank	0.067		7.1	0.0	11.8
Recruits (1y)	0.333	0.143		0.0	6.3
Recruits (2y)	0.000	0.000	0.000		7.5
Forest	0.115	0.237	0.125	0.151	

In the case of *Ficus* sites, 3% of the observed species were shared by the seed rain and seed bank, the least similar communities. The two-year-old seedling community shared the most species with the mature forest (29.4%). In the case of *Inga* sites, no species were shared between the two-year-old recruits and the seed rain, seed bank, and one-year-old recruits. However, the two-year-old recruits shared 7.5% of the observed species with the adjacent mature forest (Table 9).

Species diversity (H') was highest in the two-year-old seedlings (mean ± one standard error; H' = 2.15 ± 0.2), and this community showed the closest diversity values to the sampled adjacent forest fragments (H' = 2.89 ± 0.3). The rest of the studied communities showed lower diversity values to the adjacent forest areas (Figure 7). The one-year-old seedling community followed in diversity values (H' = 1.89 ± 0.6). The lowest diversity was recorded in the seed rain community (H' = 1.06 ± 0.18). No significant differences were recorded among studied communities (X^2 = 2.81, df = 3, P = 0.09). For each studied community, *Ficus* sites showed higher values than *Inga* sites, but diversity varied across canopy and pasture areas (Figure 7A).

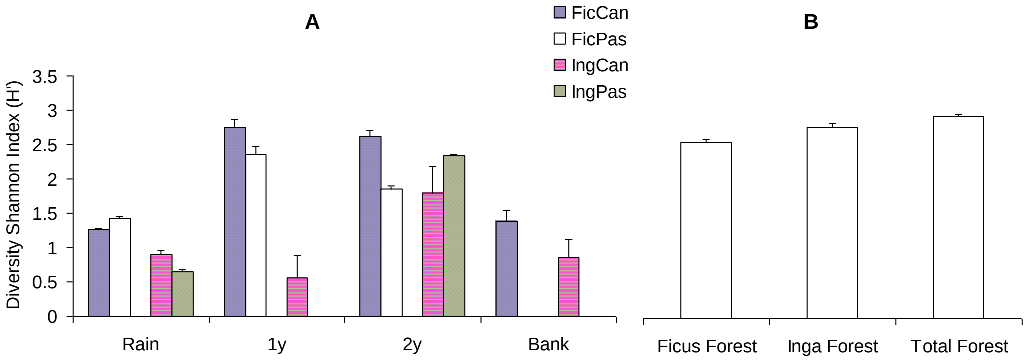

Figure 7. Shannon Diversity Index values (H') for the studied communities in pastures (A) and adjacent forest fragments (B) in Marqués de Comillas, Chiapas. Values correspond to mean + one standard error. Legend as follows: in (A) *Rain* = seed rain, *1Y* = one-year-old seedlings, *2Y* = two-year-old seedlings, *Bank* = seed bank, *FicCan* = canopy area of *Ficus* sites, *FicPas* = pasture area of *Ficus* sites, *IngCan* = canopy area of *Inga* sites, and *IngPas* = pasture area of *Inga* sites, in (B) *Ficus Forest* = diversity values for adjacent forest fragments to *Ficus* sites, *Inga Forest* = diversity values for adjacent forest fragments to *Inga* sites, and *Total Forest* = diversity value for all forest fragments studied. Refer to text for significant differences.

Seed Predation

ES Species

Lumping all treatments and sites, ES species were consumed faster (mean ± SE = 0.48 ± 0.07 seed · seed^{-1} · day^{-1}) than LS species (0.09 ± 0.02 seed · seed^{-1} · day^{-1}). In all species, rates of seed predation were very high during the first 16d of observation and diminished after 32d. For ES species, 40% of all seeds were removed within the first 48h, and within the first 4d we observed more than 50% predation.

Seeds of *Cecropia* were removed faster than any other species: 80% predation by day four and 100% predation after 8d of observation (Figure 8). Overall, the predation rate for *Cecropia* was the highest of all studied species (0.598 ± 0.018 seed · seed^{-1} · day^{-1}). Seed predation rate was not significantly different among treatments in any site for this species. *Ochroma* showed the second fastest predation rate (0.310 ± 0.117 seed · seed^{-1} · day^{-1}) with more than 60% of seeds removed after 32d, and 92-100% predation at the end of the experiment. Buried seeds were almost completely removed by day 32, excluded seeds were completely removed by day 16, and exposed seeds were completely removed by day 8. Significant differences between treatments in removal rates were recorded within each site ($X^2 = 11.7$, d.f. = 2, $P < 0.001$).

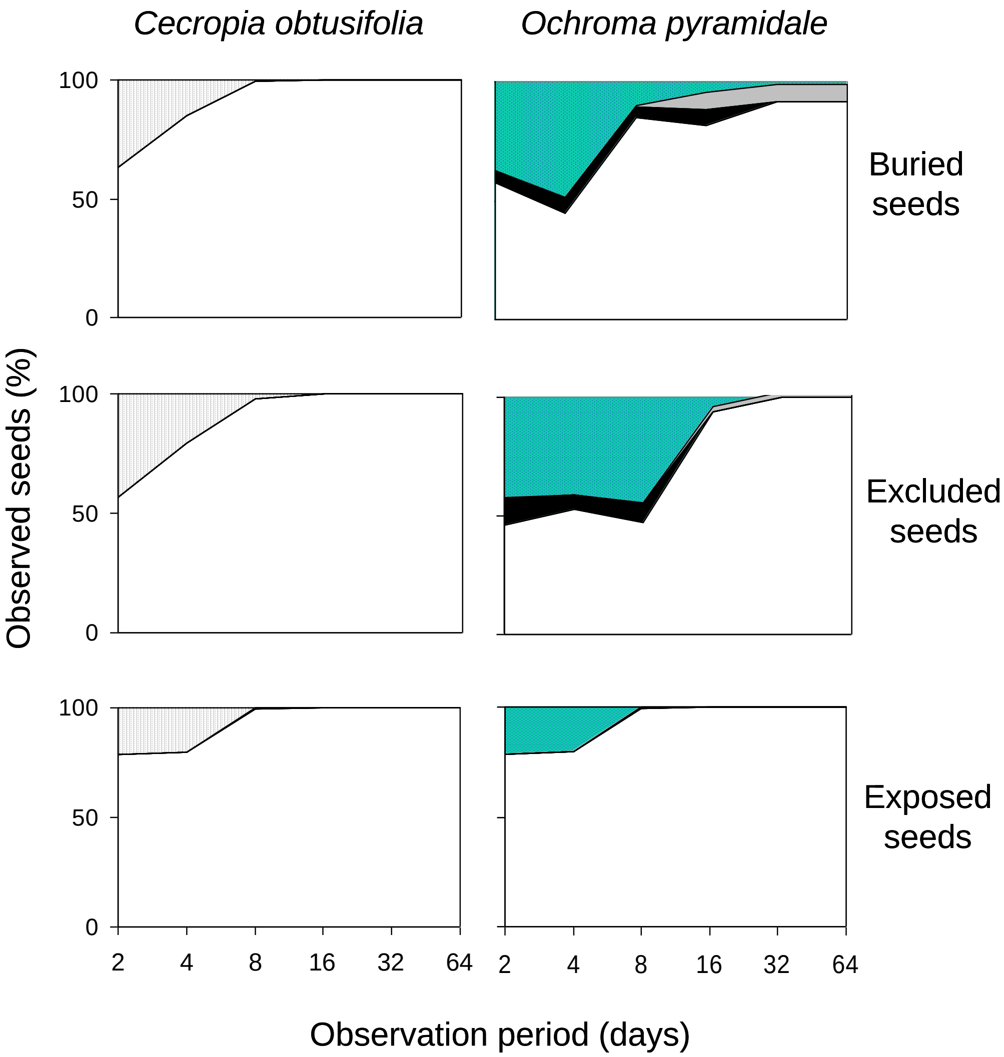

Figure 8. Dynamics (along a 64d period) of seeds from two early successional species (*Cecropia* and *Ochroma*) sown under different treatments in abandoned pasture fields at Marqués de Comillas, Southeast Mexico. Areas correspond as follows: percentage of remaining seeds (dotted), percentage of germinated seeds (gray), percentage of damaged seeds (black), and percentage of removed seeds (blank). Values correspond to averaged sites.

LS Species

Lumping all treatments and sites, LS species showed 20% predation after 8d, and 70% predation after 64d of observation, except for *Dialium* when buried (66.6% predation, 64d). *Brosimum* showed a strong increase in predation from ca. 20% to ca. 90% in most treatments, between 8 and 16d of observation (Figure 9). Differences in predation rates were observed between sites, and treatments within some sites. Overall predation rate for *Brosimum* was of 0.146 ± 0.031 seed · seed^{-1} · day^{-1}. Site-1 and site-3 exhibited significant differences in seed predation rates between treatments ($X^2 = 19.4$, d.f. = 2, $P < 0.001$). *Dialium* seeds showed the lowest predation rates of all studied species (0.028 ± 0.002 seed · seed^{-1} · day^{-1}). For this species, the main increase in predation occurred between 16 and 32d of observation. Predation of *Dialium* varied significantly between sites, and more than 20% of the seeds remained at the end of the observation period. Exposed and excluded seeds exhibited higher predation percentages (ca. 60%) after 32 days of observation, while buried species showed similar predation percentages until the end of the experiment. Significant differences in predation rates were observed between treatments in site-1 and site-2 ($X^2 = 16.4$, d.f. = 2, $P <$ 0.001). *Dialium* was the only species to show seeds that were not removed or germinated by the end of the experiment.

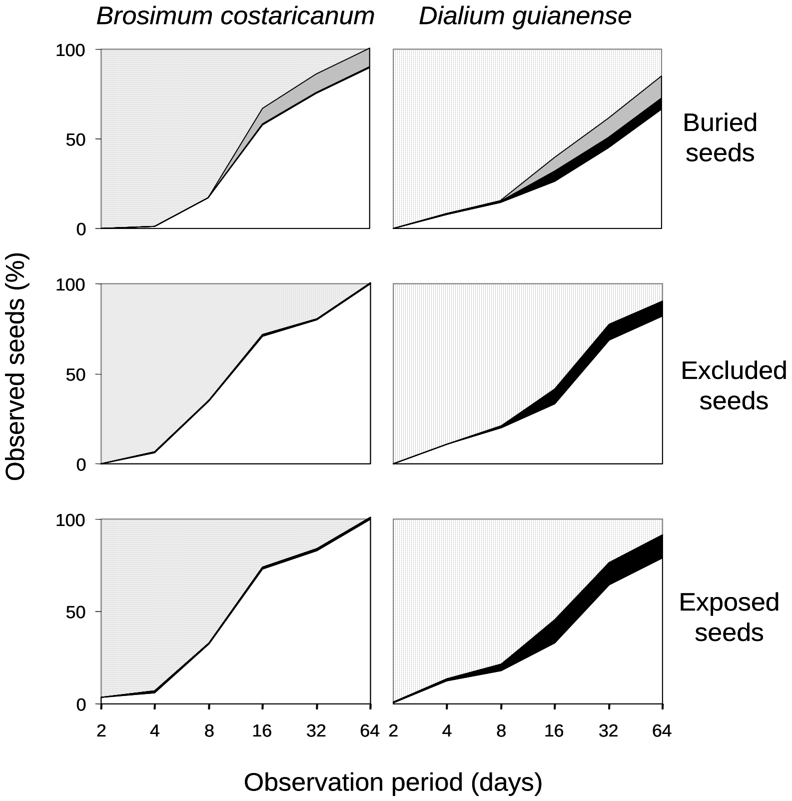

Figure 9. Dynamics (along a 64d period) of seeds from two late successional species (*Brosimum* and *Dialium*) sown under different treatments in abandoned pasture fields at Marqués de Comillas, Southeast Mexico. Areas correspond as follows: percentage of remaining seeds (shaded), percentage of germinated seeds (gray), percentage of damaged seeds (black), and percentage of removed seeds (blank). Values correspond to averaged sites.

Germination

No germinated seeds of *Cecropia* were recorded throughout the experiment. *Ochroma* showed germinated seeds four days after sowing and continued until 32d of observation, when 7.4% germination was recorded. Higher germination percentages were observed in the burial treatment, though some germination also occurred in the exposed seeds in some sites.

Seeds of LS species only germinated in the burial treatment. Germination was recorded initially at the 8d census, and continued to occur throughout the experiment. *Brosimum* showed 10.3% germination after 64d; the rest of the seeds had been completely removed. Buried seeds of *Dialium* showed 12.4% germination after 64d. Significant differences in final germination percentages were observed between sites.

DISCUSSION

Isolated Trees and Pasture Vegetation Effect

Results indicate that the effect of the species of isolated tree and the influence of the canopy in abandoned pastures is predominant over the effect of pasture grasses on early succession stages. Though seedling recruitment tends to be lower in the open pasture, we observed that pasture grasses may not act as a filtering barrier against establishment as long as isolated trees are present and are highly attractive to dispersal agents. Results also show that the influence of isolated trees on regeneration goes beyond the area directly covered by the tree’s canopy, enriching knowledge provided by previous studies (Guevara & Laborde 1993; Guevara et al. 2004a). The spatial extension of such regenerative influence depended on the identity of the isolated tree. The effect of *Ficus* trees was considerably higher than the one of *Inga* trees, even beyond the area below the canopy. The difference could be attributed to the attractiveness of each species to animals that disperse seeds (Galindo-González et al. 2000). The seed rain under different species of isolated trees has been observed to vary according to the potential attraction of the tree to birds and bats, regarding fruit type (e.g., fleshy or dry), among other attributes (Carriere et al. 2002, Slocum & Horvitz 2001). The studied isolated trees recorded more abundant and diverse seed rain in the *Ficus* sites when compared to the *Inga* sites. *Ficus* trees produce abundant and frequent crops of fleshy fruits, edible for several seed dispersal bird and mammal species (Guevara et al. 2004b, Eshiamwata et al. 2006). In contrast, *Inga* species produce dry pods during a short period of the year with ariled seeds that are mainly consumed by birds of the Psittacidae family, usually triturating the seed in the foraging process (Galetti 1993; Norconk et al. 1998; Francisco et al. 2002). However, some seeds are likely to escape predation and fall to the ground, germinate, and eventually establish, even more when seed predators are absent. This was possibly the cause of the high proportion of conspecific seedlings recorded in one *Inga* site. Such differences between the two types of studied trees are likely to result in less abundant and frequent visits and lower probabilities of seed arrival beyond the canopy and in the vicinity of *Inga* trees.

The fresh-weight grass measurements at the beginning and end of the experiment show how grass increased significantly more in the open pasture for both isolated tree species, and it was higher in the *Inga* sites at the end of the experiment when compared to the *Ficus* sites.

This could be explained by the amount of radiation intercepted by the canopy of each isolated tree: higher radiation was recorded under the canopy of *Inga* trees, where the foliage was less dense than that of *Ficus* trees. Other studies have highlighted the importance of each species strategy with the presence of grasses. In the case of pioneer species, the absence of grasses may be beneficial for seedling development, given that such species can stand stressful microclimatic conditions (Duncan & Chapman 1999). For other species (e.g., non pioneer, shade-tolerant species), grass presence may not be detrimental at early stages of germination and establishment (Camargo et al. 2002; Benítez-Malvido et al. 2001). However, non pioneer species are less likely to reach open spaces, due to dispersal limitations (Duncan & Chapman 1999, Guevara et al. 2004a). During the experiment tolerant species were barely recruited, and the few recorded seedlings mainly established under the canopy of isolated trees. In sites where a more intense management is applied (i.e., large pasture extension, high fire use frequency, grass introduction, livestock density, among others), the possibility of propagule establishment may be reduced compared to sites with less intensive management (Uhl et al. 1988). The increase in grass fresh biomass after almost two years of study also reveals a more intense management in the *Inga* sites when compared to the *Ficus* sites, since grass vegetation was overall more dense in the former. Intense management can deplete soil nutrients and therefore counteract the possible effect of nitrogen fixation by the isolated *Inga* trees (Reiners et al. 1994).

The composition of genera recruited in the studied sites included taxa which are typical colonizers, and/or species widely consumed by animal dispersers, such as *Piper*, *Cecropia*, *Solanum*, and *Ficus* (Galindo-González et al. 2000; Slocum & Horvitz 2000), frequently recorded in Neotropical pastures (Guevara et al. 1994, Duncan & Chapman 1999, Mesquita et al. 2001). Shrub species were more abundant under the canopy of *Ficus* than *Inga* trees. However, we did not find differences between distance categories or among grass treatments on the recruitment of a particular life form. This may be a result of the identity of the community dispersed to the open pasture (e.g., pioneer species with copious seed production, dispersed by birds and bats), which is characteristic of open field succession in tropical pastures (Guevara et al. 1994, Zimmerman et al. 2000), and therefore efficient in surmounting some barriers against establishment. The species that establish successfully in pastures may be restricted to genera with fast-growth and weedy habit (Pascarella et al. 2000, Howe & Miriti 2004).

Seed Rain, Seed Bank, Seedlings (1y), and Saplings (2y)

The results of the study show that abundance and composition of regenerative communities change considerably throughout the life cycle stages of trees and shrubs, from the potential seed sources to the recruitment of saplings after two years of pasture abandonment. The amount of individuals recorded in the seed rain decreases throughout the seed bank community, the recruited seedling community after one year, and the recruited sapling community established after two years. Results suggest that less than three individuals in a thousand seeds recorded in the seed rain will be found after two years as recruited saplings. There are several barriers or filters that produce such effect, as demonstrated by other studies (Aide & Cavelier 1994; Chapman & Chapman 1999). The abundance and composition of species found in the seed rain are already a subset of the species found in the potential seed sources, as not all species found in nearby remnant forest disperse effectively to open areas (Martínez-Garza & González-Montagut 1999, Cubiña & Aide 2001), due to dispersal limitations and the distance between seed sources and the open pasture. Once seeds have reached the open areas, their distribution will not be even in space, but higher concentrations of seeds will be found in places were animal dispersers perch (Dunn 2000, Manning et al. 2006). Hence the higher density and richness found below the canopy of isolated trees. The seeds which attain to be dispersed into open areas can reach the soil and germinate, or such process be halted by seed removal by invertebrate and vertebrate vectors (Holl & Lulow 1997). Seed removal in open pastures can be intense and drastically reduce the probability of establishment of deposited seeds (García-Orth & Martínez-Ramos 2007). Even if seeds are buried or hidden among the low-stand vegetation or litter, seed removal agents can unbury seeds and predate or remove them. In such case, a small fraction of the seeds contained in the seed rain will be found in the seed bank. Results show that less than two seeds in every 100 seeds contained in the seed rain will be later found in the seed bank.

Once a seed is part of the seed bank, the probability of survival decreases as the seed remains in the open field. The seed may be removed or lose viability due to the microenvironment (i. e. predation by fungi, rot by excessive moisture, or drying up due to high radiation; Vázquez-Yánes & Orozco-Segovia 1993), which all result in the loss of viability in the seed and therefore the impossibility of germination. On the other hand, if the seed is found in a spot where the microenvironment is favorable, it may germinate and establish as a seedling. Environmental conditions under isolated trees resemble in higher degree those of secondary or mature forest, unlike open spaces with no canopy, where radiation and temperatures are high and possibly stressing for recalcitrant seeds (Guevara et al. 2004). In the studied *Ficus* sites, the probability of a seed in the seed bank to be found as a one-year-old seedling is higher in the open pasture than in the canopy area. This could be explained by the extremely poor or even absent seed bank recorded in open areas in both species of isolated trees, as recorded by other studies (Quintana-Ascencio et al. 1996). This could indicate that seeds do not spend considerable periods of time in the seed bank in viable condition. Seedlings may be predated or germinate, and therefore be more likely to be found as seedlings than seeds. Due to the factors mentioned above (i.e. seed predators, harsh environmental conditions), the seed bank may be low in seed content in disturbed areas, such as pastures (Benitez-Malvido et al. 2001).

Following the nucleation model (Yarranton & Morrison 1974), one-year-old seedlings in *Ficus* sites were more likely to prevail in time and grow into saplings below the canopy of isolated trees than in the open pasture. Nevertheless, land use history plays an important role in site quality, and therefore in the probability of seeds to be recruited and survive as seedlings (Uhl 1987). The *Inga* sites have had much more intense management (i.e. burning regime, livestock density, period under pasture use) than the *Ficus* sites, where livestock herding was done rarely. The grasses in the *Inga* sites were growing in a denser and more homogenous way when compared to the *Ficus* sites. This may have affected the amount of seedlings which establish and survive up to two years. However, it is important to notice that *Ficus* sites received much higher densities of seeds in the seed rain than *Inga* sites, and therefore seed input is restricted in the latter since the first stages of the colonization process.

Several filters operate over seedling survival in the open field (DeSteven 1991, Benitez-Malvido et al. 2001). Seedlings can be predated by herbivorous insects and small mammals (Holl & Quiroz-Nietzen 1999, Hewitt & Kellman 2004). Competition with pasture grasses is another common barrier which halters survival and growth for some rainforest species, while others are able to compete and survive (Chapman et al. 2002). As the projected shade of isolated trees has a diminishing effect on grasses, this suggests competition between seedlings and grasses is less intense below the canopy of isolated trees. In the open pasture where grasses thrive, competition is higher and therefore seedling survival would be lower. The microenvironment can be stressful in the open pasture and decrease seedling survival. Both *Ficus* and *Inga* sites showed higher density of two-year-old seedlings below the canopy of isolated trees than in the open pasture. I suggest this could be the beginning of a nucleated succession process, as described by other studies (Guevara et al. 1986).

Given that no single species was found across all studied regenerative communities, species replacement occurs dynamically throughout the dispersal and colonization processes. The potential seed sources in this study were the adjacent forest fragments to each of the studied pastures; however, other studies have demonstrated seed rain can be local or foreign, in the latter case when seeds come from further potential seed sources (Duncan & Chapman 1999; Martínez-Garza & González-Montagut 1999). Several factors affect if a seed reaches an open area (e.g. topography, wind currents, dispersal vector routes), which may have influenced the array of seeds found in the seed rain compared to the species assemblage of the potential seed sources.

The community which most closely resembles the potential seed sources was the two-year-old seedling cohort. This may indicate that the array of species found in the seed rain, seed bank or one-year-old seedling cohort does not necessarily reflect the assemblage of species that will be found in further stages of succession, at least with the sampling effort made in this experiment. However, species replacement throughout successional processes may be different from the original community, as has been showed by previous studies (Zahawi & Auspurger 1999). The mature forest species which were also recorded in the two-year-old seedling community speak of a very partial array of ecological strategies, particularly species which produce high number of orthodox seeds, which are dispersed great distances by birds or wind (*Bursera simaruba, Casearia nitida, Cordia alliodora, Cordia spinescens, Lonchocarpus belizense, Piper hispidum,* and *Tabernamontana alba*). However, these were not the most abundant species in the two-year-old seedling community, where other species dominated. Such dominating set of species is characteristic of arrested succession or deviated successional pathways of communities where mature species are less likely to establish eventually (*Vismia camparaguey, Conostegia xalapensis,* and *Vernonia patens,* among others).

Seed Predation

Removed seeds may be secondarily dispersed and not always predated (Vander Wall et al. 2005). However, most likely the removed seeds during the study were predated because most of the experimental containers exhibited fragments of damaged seeds (except for *Cecropia* seeds, which were either present or removed, but not damaged). Both the small and large seeded species we studied suffered higher predation levels in open pasture fields. However, the small-seeded pioneer species were removed faster than primary species, as originally hypothesized. Other studies have recorded similar results in recently abandoned agricultural fields (Nepstad et al. 1996; Peña-Claros & De Boo 2002; Holl 2002; Fornara &

Dalling 2005; but see Aide & Cavelier 1994) or non-altered habitats (Moles et al. 2003). The present study has also documented limited seed dispersal and a limited seed bank in the studied sites which could also explain the low recruitment rates. Similar results have been reported for tropical old-fields elsewhere (e.g., Widjeven & Kuzee, 2000). The present study suggests that under conditions of high seed predation, exclusion may reduce predation rates in some sites and for some species, but burial will be necessary to attain germination (see also Woods & Elliott 2004). However, direct sowing in pastures is not always a guarantee of seedling emergence and establishment, presumably due to competition between seedlings and grass vegetation, especially in small seeded species (Camargo et al. 2002).

Studies which address direct seed sowing show that seed removal tends to be lower as seed size increases (e.g, Nepstad et al. 1996; Holl 2002; Jones et al. 2003, but see Peña-Claros & De Boo 2002), at least within a particular habitat type (Moles et al. 2003). Furthermore, the probability of seedling emergence also increases with seed size in old fields (Holl 1999: Zimmerman et al. 2000; Camargo et al. 2002; Holl 2002; Hooper et al. 2002, but see Holl & Lulow 1997) and natural forest habitats (e.g., Paz et al. 1999). The obtained results concur with these studies as small seeded species were removed at faster rates and at higher levels than large seeded species. Ease of transportation may influence the seed species chosen by different animals (Nepstad et al. 1996). In our pasture sites, small seeds were preferred by small invertebrates (e.g., ants of the genus *Solenopsis* and *Pheidole*), while larger seeds were preferred by leaf-cutter ants (*Atta* spp.) and rodents. Ants have observed to be stronger removal vectors than rodents in tropical agricultural lands (Woods & Elliott 2004).

Similar to this experiment, high seed predation rates have been observed in the genus *Cecropia* (>80%) only after few hours or days of deposition in open fields (Nepstad et al. 1996; Fornara & Dalling 2005). In fact, it has been shown that copious seed rain is needed to replenish the seed bank of *Cecropia obtusifolia*, exhausted by heavy seed predation rates (> 95% in few days, Alvarez-Buylla & Martínez-Ramos, 1990) in mature forest. Thus, seeds of *Cecropia* are generally labile to consumption by insect granivores. Matrix population models indicate that when seed rain is poor or null, regeneration is impeded (Alvarez-Buylla & García-Barrios 1991). At the studied pasture fields, we recorded seed rain density of less than one seed per square meter which is three orders of magnitude lower than the one recorded in forest habitats (Alvarez-Buylla & Martínez-Ramos, 1990). In order to insure regeneration under conditions of low seed rain, it may be necessary to manually sow seeds and protect them against granivores. Alternatively, to avoid the high risk of mortality at the seed stages, juveniles of *Cecropia* could be raised in greenhouses and transplanted to open fields (Kobe 1999).

For *Ochroma*, direct sowing may demand high energy input due to high predation rates and the low seed germination rates (Camargo et al. 2002), at least in pastures (Levy-Tacher & Duncan-Golicher 2004). In the study area, previous attempts to establish *Cecropia* and *Ochroma* in abandoned pastures through direct sowing have failed. Regardless of high seed sowing density (groups of 50-100 seeds sown every 3 x 3 m in 20 x 100 m plots, 36 plots distributed in six different pasture fields in total), no seedling recruitment was recorded possibly due to observed heavy seed predation by ants (M. Martínez-Ramos, unpl. data). The present study exhibited that exclusion decreased predation significantly, but seeds germinated mainly in the burial treatment. If seeds of *Ochroma* are introduced in open pastures, exclusion and burial will be needed. However, as with *Cecropia*, we recommend to transplant juveniles into pastures (Miyawaki 2004, but see Camargo et al. 2002).

Both LS species were heavily predated by vertebrate and invertebrate vectors, contrary to what was expected. Since the experimental design only tested seed predation by rodents, the large-seed predation by invertebrates was not quantified, particularly by leaf-cutter ants, which were observed to consume *Dialium*. Nevertheless, as excluded and exposed treatments showed no significant difference, we can infer seed predation by invertebrates is, if not higher, at least as strong as seed predation by vertebrates. Though overall seed predation rates were different among sites for *Brosimum*, this species is generally attractive to rodents and has little probability of surviving in pastures if not excluded and buried. It is relevant to mention that *Brosimum* was also removed under exclusion cages, indicating predation by invertebrates. *Dialium* seeds contain secondary metabolites (i.e., protease inhibitors) potentially poisonous for some seed-eaters (Calderón et al. 2001), possibly one of the reasons that allowed seeds of this species to remain after 64d of observation. Similar to *Ochroma*, germination only occurred in large seeded species when buried.

Results show that seed predation of large seeded species is highly site specific and patchy, even within the apparently homogeneous pasture field landscapes. Other studies have also registered differences within pastures for some large seeded species (Holl & Lulow 1997; Jones et al. 2003) and may indicate heterogeneous distribution of small vertebrate (e.g., Sánchez-Cordero & Martínez-Gallardo 1998) and invertebrate seed-eaters (Mull & MacMahon 1997) among micro-sites. Therefore, it is important to emphasize that the efficacy of direct sowing of large seeds will depend on site characteristics. In contrast, small seeds were highly predated in all sites, indicating that insect seed-eaters are abundant across all sites. Because insect seed-eaters are highly active at several depths through soil layers, superficial protection would be insufficient for avoiding invertebrate access to the seeds. However, it is important to mention that this study is limited regarding the number of pastures in which seed predation was explored. As the number of sites considered increases, patterns in seed predation may be more clearly understood (e.g. Moles et al. 2003).

CONCLUDING REMARKS

Overall, results show that isolated trees act as recruitment foci in abandoned pastures, but that they vary in their regenerating potential, as well as in the spatial dimension up to which their effect is noticeable on regeneration. Recruitment may be recorded beyond the immediate area under the canopy, and vary in density and composition according to the isolated tree attraction to dispersal vectors. Forage grasses did not have an effect on recruitment. The regenerative community mainly consisted in shrub species and showed relative low richness and diversity values. Results also show that propagule availability interacts with site quality and results in the establishment of a particular set of species, which change through early successional stages. Given that rainforest species are adapted to certain variation in environmental and biological conditions, once such variation upper and lower limits are exceeded by disturbance, the set of species which will cope with the new conditions will be restricted. Due to the numerous mechanisms which operate in the open field, the array of species which establishes successfully in later successional stages may resemble the original community in an inconspicuous way. This may lead to further stages where a new successional pathway is identified. The resulting community of such pathway may lack the biodiversity characteristics of the original community, and therefore operate differently regarding environmental services provided by the original rainforest. Land use is continuously changing due to economical, political, social, and environmental drivers, resulting in modified ecosystems which have different properties from the original ones (Geist & Lambin 2002). It is a challenge still to be met by research to clarify if the services once provided by the new successional communities resemble those once produced by the original ecosystems.

In addition to directly sowing seeds, restoration attempts in tropical pastures must also consider monitoring and nurturing seedling development. In direct sowing attempts, high survival and germination are more likely if seeds are sown during the rainy season. On one hand, a more varied array of resources would be available for seed-eaters, perhaps allowing satiation and reducing predator pressure over sown seeds. On the other hand, the pasture floor is moist, increasing germination probability (Blain & Kellman, 1991). Furthermore, during the rainy season the emerging seedlings have better conditions to grow. Finally, as pointed out before, considering the high predation and low germination levels suffered by sowed seeds of ES species (Camargo et al. 2002), transplanting of juveniles may be reccommended over the sowing of seeds (Miyawaki 2004, Martínez-Garza et al. 2005, García-Orth & Martínez-Ramos, 2009). Nevertheless, the costs of raising and transplanting juveniles need to be considered (Martínez-Ramos & García-Orth 2007).

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Chapter 2

PASTURES IN THE ZONE OF TEMPERATE CLIMATE: TRENDS FOR DEVELOPMENT, DYNAMICS, ECOLOGICAL FUNDAMENTALS OF RATIONAL USE

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ABSTRACT

The peculiarities of historical phases of steppe ecosystems transformation influenced by grazing pressure have been analysed, estimations of well-directed modification of organic carbon and biogeochemical flows in the system “vegetation – soil” have been received. Characteristic periods of chronological organization of bioclimatic processes have been determined on the basis of analysis of observational series of annual and interannual variations in meteorological parameters and steppe pastures productivity.

The results of investigations of plant formations for natural pastures located in different ecological conditions are presented. Vegetation variety of meadow and calciphilous steppes on sample areas and pastures has been studied. Data on useful, harmful, rare species of plants, influence of species diversity of formations on the fertility of slopes have been received and connections between the number of species and main elements of soil fertility have been determined.

Methods of ecological restoration of steppe pastures on Chernozems and on slopes nearby deposition of carbonate strata have been described. The species which have the best environment transforming qualities have been revealed. In the rhizosphere of these plants the processes of parent material destruction and soil formation are occurring strongly, as a result slopes can be used for meadow formation and further utilization.

The fact is that the legume component is less stable when pastures are being established on the basis of gramineae-legumes mixes. This problem becomes more acute on eroded alkaline soils. There are results on studies of the dynamics of productivity and stability of legumes (*Fabaceae*) in the composition of mixes for cultivated pastures on the areas divided by ravines. Original data on seasonal dynamics of overground phytomass gramineae-legumes mixed crops for cultivated pastures distinguished by one legume component have been analysed. Bioenergetic effectiveness of mixed crops on the basis of various species of legumes is shown.

INTRODUCTION

In the Holocene history of steppes (the past 10–13 thousand years) a consistent series of plant formation modifications were determined by both natural rhythms and changes in economic modes. An analysis of different conditions of steppe vegetation evolution determined by nature and man's impact and total estimation of productional process in historico-ecological periods are of great interest. By means of annual production from natural grasslands’ dependence on climatic parameters, one can reconstruct the basic stages of steppe vegetation evolution determined by nature and anthropogenic impact in the zone of temperate climate.

Demutation processes begin when grazing pressure is reduced, that is progressive pastoral succession which is the most common kind of secondary autogenic succession of grass ecosystems (Skarpe, 1992; Zhang, 1992). According to structure and species composition, changing demutation belongs to progressive autogenic succession; it carries out with enrichment of species composition and complication of plant community organization (Trophimov, 2001).

The estimation of the most common extant plant communities in pastures within gully plantings is of great interest in the view of their biological productivity in changing climate conditions.

The comprehension of natural grasslands adaptation to the influence of ecological factors allows us to control their structure and productivity (Bennet, 1985; Dover, Hopkins, Manning, 1986).

In the East European Plain, the forest-steppe zone stretches greatly from the north to the south because of moderate continental climate and broken relief. It is the main soil-vegetable zone in the southern part of the East European Plain; it covers a vast territory, which is more than the steppe zone area (Fig. 1). There are two steppe subzones in the forest-steppe zone. Northern subzone of meadow (northern) steppes is characterized by its southern variant that is herb-grass. On the test area the second subzone of herb-bunchgrass steppe (in the south) is characterized by northern variant of southern steppes, that is herb–sheep’s fescue–feather grass steppe.

In Ukraine, the steppe zone stretches from the Danube lower reach to spurs of the Central Russian Upland (more than 1000 km), more than 100 km wide in the west and 300–450 km wide in the east. It covers the vastest area (40% of Ukraine territory) in comparison with other natural zones. As arable lands dominate in the steppe zone (61–67% of territory) the proportion of natural grasslands area (pastures and hayfields) varies from 12% in the north to 10% in the south. The proportion of pastures in the total area of natural grasslands is 92% within the northern subzone of the steppe zone (on the rest area there are hayfields in high-water beds and terraces). In the southern steppe, the proportion of pastures reaches 96%.

An analysis of land transformations of the last 10 000 years in the south of the East European Plain (the forest-steppe zone in Russia and the steppe zone in Ukraine) have been carried out on the basis of archaeological and spore-pollen data; and the transformations of the last two centuries in Kherson province and Kherson uezd (region) have been analyzed according to statistics.

That part of the East European steppes (1802–1917) belonged to Kherson province, an administrative territory in southern Ukraine (between the late 18 century and early 20 century) that stretched from the river Dniester (in the west) to the Dnieper (in the east) and from northern coastlines of the Black Sea to 300 km north. The total area of the province was 71.935 km^2. Kherson uezd (region) was one of six uezds (regions) of Kherson province and its area was 19.25 km^2.

Figure 1. Study subjects on the territory of the East European Plain: 1. The territory of former Kherson Province, Ukraine; 2. Belgorod Region, Russia.

THE CHANGING OF ORIGINAL AND PHASIC COMMUNITIES IN THE STEPPE ZONE

In the south of East European Plain there were bunchgrass steppes at the Dryas–Preboreal transition (approximately 10300 years ago). This fact confirms that extant indigenous nucleus *in situ* (in the period of Pleistocene cooling) of the steppe vegetation was the basis of Holocene steppes formation.

The Preboreal and Boreal (10 000-8000 years ago) were characterized by the formation of landscape zonal structure in the East European Plain. Those days decreased proportion of goosefoot, wormwood, halophyte and increased dominance of grasses and mixed herbage distinguished the steppe zone according to spore-pollen complexes. Wild animals (auroch, tarpan, saiga and others) influenced on vegetation development. In the second half of Holocene the characteristic of the steppes stretched from the river Danube to the Dnieper, according to archeological data, was the influence of hunting on population number of wild animals. The result was a considerable reduction of dominance of open species of biotopes (tarpan, saiga) due to increase of population level of semi closed and closed biotopes in theriocenosis.

In the Atlantic period of the Holocene (8000-5000 years ago) climatic conditions of steppe zone were characterized by temperature decline and moistening increase. Under maximum temperature (6200 – 5500 years ago) in present northern and southern steppe subzones the proportion of mixed herbage and composite family (aster family) increased, grasses dominance was lost, meadow steppes were formed. According to changes in the Holocene annual average temperature and climatic chronology there was identified climatic conditions for transition form meadow mesophytic to xerophitic vegetation at the turn of 5350-5250 years ago. The next period, the neoglaciation was marked by temperature decline and increase of climate instability. There was a determined tendency of natural evolution of steppe ecosystems under those conditions. The tendency defined the consistence of steppe ecosystems which is appropriate to environment conditions. Dinesman (1984) made a clear statement concerning virgin steppes described by geobotanist; they are anthropogenic digression variant of steppes which had more mesophytic aspects in the middle Holocene. This fact also concerns the protection plot of the sheep’s fescue–feather grass steppes in Askania-Nova where plain vegetation got zonal thick bunchgrass basis during eighty years' absence of grazing and hay harvesting, but not pyrogenic factor (Veden’kov, 1979).

On the virgin plot near the Bug estuary (the south of Ukraine) the productivity of feather grass *(Stipeta capillata)* was estimated. The productivity is more typical for local groupings of the zonal aspect in the sheep’s fescue–feather grass steppes. Feather grasses (*Stipa pennata*) reach maximum phytomass earlier (between late April and June), than *S. capillata* does, but in this period it is only 52% of phytomass *Stipeta capillata* in August. According to average data of the period between 1981 and 1992 (Lisetskii, 1992) the sheep’s fescue–feather grass associations of local aspect retrospectively correlated with the late Atlantic phase of the Holocene could give an annual amount (12000 kg/ha) of the plant substance, that is equal to the humus formation rate 2000-2500 kg/ha per year. Taking into consideration the decay rate of separate structural particles and the proportion of main organogen elements (Ca, K, P), it is calculated that root necromass (in the 0–20 cm soil layer) of the feather grass is a source of these ash constituents (58 and 131 kg/ha), and *Festuca valesiaca* (sheep’s fescue)

38 and 66 kg/ha, respectively. As a result, the soil with feather grass gets organogen elements 1.8 fold more than with sheep's fescue. Thus, feather grass is more valuable in humus formation. This fact is confirmed by researchers who determined that the humus proportion in the 0-30 cm soil layer with feather grass is 1.7 fold more than with sheep's fescue.

In the forest-steppe and northern steppe the first palynological signs of productive arable-and- cattle-raising economy (pollen of cultivated grasses, segetal vegetation) are found in the late Atlantic phase related to climatic optimum: 5500-5200 years ago. Arable-and- cattle-breeding tribes of Neolithic Gumelnița culture on the Black Sea basin territory are known near the Danube in Ukraine. According to data by Subbotin L.V. (1983) cattle was dominant in gumelnița tribes (36% of farm animals), but the number of small cattle (mainly sheep) differs not much, and beside that the horses ratio was higher (9%) in comparison with earlier epoch.

The nature management experience of the late Tripolye culture was similar to Gumelnița culture. Cattle-breeding of that period had the steppe aspect; there was not only adjoining the farm pastoral form near the river-valley but also outrun. Faunistic data of settlements suggest the dominance of small cattle (68%), cattle (18%) and horses (14%). The finds of wild animals bones in the settlements make it clear that the objects for hunting were the representatives of the open steppes (tur, saiga, Asiatic wild ass) and valleys (red deer, wild boar).

Important natural and anthropogenic changes occurred during the transition from the early to the middle subboreal phase (over 4200 years ago). Subboreal thermal maximum, equal to the Bronze Age (it lasted 1000 years), predetermined the prevalence of dry climate. Cooling and siccation of climate (manifested mostly between 4200 and 3700 years ago) determined xeromorphic characteristics of herbaceous cover in steppes. The grazing pressure and steppe vegetation fire became significant factors for evolution.

Feather grasses *Stipeta capillata* and *Stipa pennata* disappear under the grazing influence, anthroporesistant digressive formation of sheep's fescue dominated. It occurs because tussock failure of feather grass reaches 50% and sheep's fescue – 5% at phytomass detachment (Tanphilyev, 1939). It is recorded that in sheep's fescue–feather grass and sheep's fescue associations some indices decreased. Phytomass productivity reduced to 14000-15000 kg/ha, organic matter reserve (aboveground mortmass) to 1300-4600 kf/ha, rate of annual humus formation to 1400-1900 kg/ha, the amount of main organogen elements to 100 kg/ha. Special examination of steppe fires influence on the vegetation performed rapid postfire recovery and intensive bearing of sheep's fescue (Shalyt, Kalmykova, 1935). The structural particles of aboveground mass reach their starting value in 2 years after the fire in sheep's fescue–feather grass associations of the Black Sea basin (Lisetskii, 1987). Changes of vegetation cover are determined by pyrogenic factors with natural reiteration. These changes make for the graminoid proportion increasing of the steppe phytocenosis. Coenotic value of sod grasses especially increases. The amount of legumes reduces; this fact is rather significant for description of changing of biochemical conditions for humus formation. In the judgment of Whittaker (1975) low biomass of graminifolious plants is the result of short living period of aboveground plant parts adapted to fires. It is performed that under sheep's fescue–feather grass associations the portion of mortmass (detritus) in the 0–20 cm soil layer varies from 27 to 32% of underground phytomass but it increases to 45% after fire. Consequently pyrogenic factor favors humus formation process in the soil. However, the absence of dead plants and litter on the plot destroyed by fire are favorable for intensive transformation and mineralization of latest necromass.

As it was presented earlier (Lisetskii, 1998) that environment potential summarized by radiation balance and annual precipitation in expenditure of energy (Q) by Volobuev formula (1974) was higher in the period between 3500 and 3000 years ago, and between 3000 and 1700 years ago it was lower than present-day values which characterize steppe zone conditions by data of the instrumental period. The past 3500 years were more favorable for steppe ecosystems than the whole of the Holocene history of development. The value Q was estimated at 950 mj/ m^2 per year in comparison with averaged value for the past 10 000 years - 665 mj/ m^2 per year.

The Bronze Age in the north-west of the Black Sea basin (between 25 – 9 century ago BC) is defined by distinct dominance of cattle-breeding tribes (especially before emergence of the settled population of sabotinov type – between 14 and 13 centuries BC). The comparison of spore-pollen spectra in the humus horizon of the middle Holocene buried soil (under “suslikovina” – small hills as a result of burrowing activity of ground squirrels in their habitat) and the present day soil on the absolute reserved territory in Askania-Nova (Dinesman, 1977) showed that the middle Holocene pollen complex was characterized by high portion of Compositae and mixed herbage, lower portion of grasses and goosefoot family and the part of wormwood was similar to the modern-day one.

Relative moderation of grazing pressure in this historic and ecological period is explained by the fact that cattle were predominant domestic animals in the occupation layer of the Late Bronze Age. It is notable that on settled areas in the period between 13 and 12 centuries BC (the present territory of Moldova) bone remains of tarpan were not found in contrast to Asiatic wild ass. Apparently, in the Late Bronze Age not numerous (5-15 animals) tarpan flocks coexisted with the flocks of domestic animals only on the territory between the Bug and Dnieper rivers.

In the Early Iron Age the role of small cattle increased greatly (firstly it concerns sheep) in the cattle-breeding in the north of the Black Sea basin. As a result, the cattle-breeding of settled tribes had some nomadic characteristics. Internal causes for steppe ecosystems formation lost their leading role due to cattle-breading development beginning from the 1st century BC by Dinesman (Paleoclimate…, 1989). Teyetsman admitted that the first examinations of the vegetation of Askania-Nova revealed (Alyokhin, 1986) that the wormwood portion of Austrian in zonal groupings was estimated at 6% of the total phytomass. The digressions (fig. 2) characterized by the presence of 12 and more species on the plot (25 x 25 cm) have little proportion of wormwood in phytomass in the steppes near the Black Sea basin (the ratio of species on the plot 1 m^2 and 25 x 25 cm in separate color aspects was estimated at 2.00-2.67). *Artemisia austriaca* forms the wormwood steppe in conditions of overstocking. This steppe becomes degraded only due to sheep grazing. Overstocking (grazing, toloki - pounded lands) next to building zones developed qualitatively new phase of vegetation influence on soil formation having completed the series of digressive successions. The role of wormwood necromass in biochemical flows of the steppe ecosystems increased according to wormwood concentration. It is connected with two reasons: chemism distinctions and higher rate (1.4-1.8 fold) of wormwood phytomass transformation in comparison with other edificators of evolution changes. Green phytomass and Austrian wormwood roots differ in the amount of organogen elements (Ca, K, P) not much. This amount is estimated to 41-49% of the total ash level, which is 2 and 3.4 fold more than sheep's fescue and feather grass, relatively. Aboveground phytomass of Austrian wormwood and Crimean wormwood is more enriched in nitrogen than grasses phytomass. The result is the value of elements of potential (humus, total nitrogen) and effective (active forms of phosphorus and potassium) soil fertility under wormwood plants is higher than in the soil under sheep's fescue (Lisetskii, 1992).

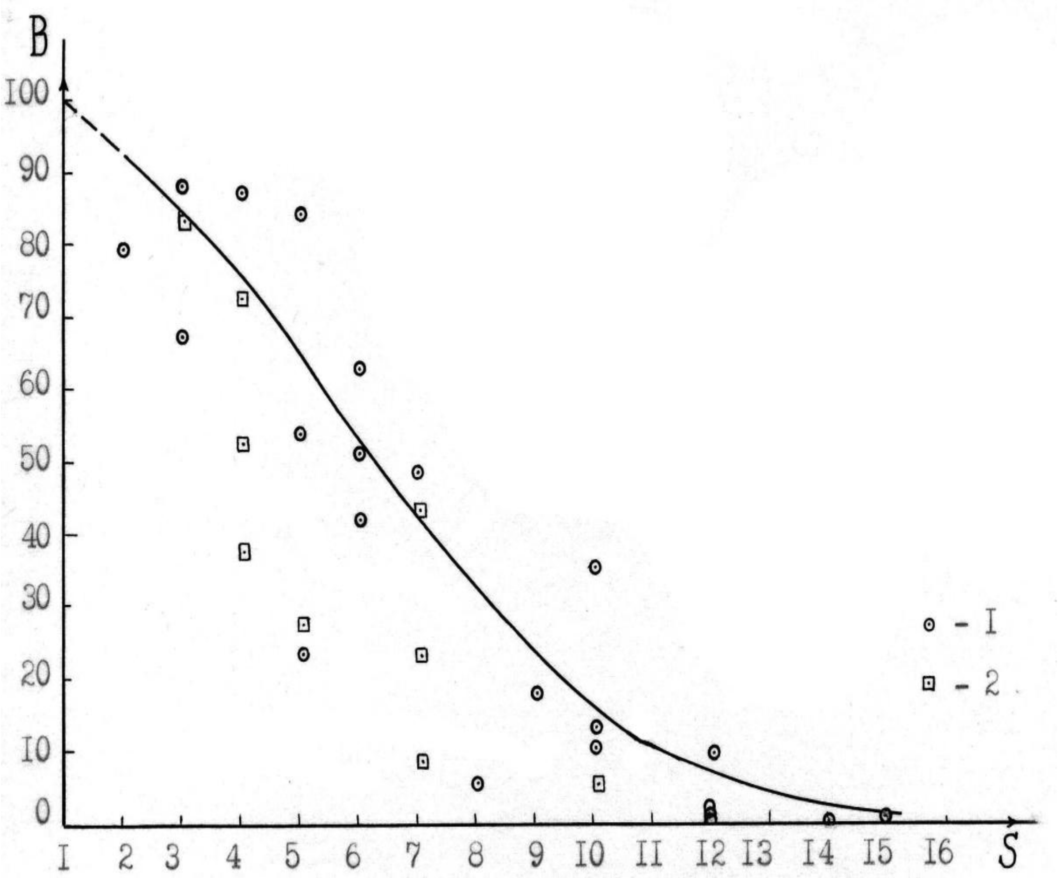


Figure 2. The dependence of Austrian wormwood (1) and Crimean wormwood (2) concentration in aboveground phytomass (B,%) on the amount of species(S).

$$B = 100 \cdot e^{-0.0015 \cdot S^{2.1}}.$$

According to our field examination, based on sheep's fescue sowing on the sample plots with the soil chosen under associations of different proportion of wormwood, sheep's fescue productivity relative to edafotop with its total dominance (100%) averaged between 1989 and 1992: for wormwood-sheep's fescue association (the wormwood portion – 32% of phytomass) – 130, for wormwood association – 145% (table 1).

Table 1. Conditions and results of field microplot trial

Parameters	Associations		
	sheep's fescue	wormwood-sheep's fescue	Wormwood
Associations phytomass, g/m^2	38.56	50.56*	60.00
Chemical parameters of soils in plots:			
Humus,%	3.21	2.82	3.64
Nitrogen gross,%	0.204	0.198	0.224
C:N	9.1	8.2	9.4
pH	6.85	6.86	6.85
Absorbed bases, mEq /100 g:			
Ca^{2+}	19.2	19.2	17.2
Mg^{2+}	4.8	4.6	4.4
Na^+	0.43	0.43	0.43
Water extract ,%:			
Dry residues	0.034	0.060	0.066
Ca^{2+}	0.005	0.006	0.005
Mg^{2+}	0.001	0.001	0.001
Na^++K^+	0.002	0.003	0.006
HCO_3^-	0.015	0.018	0.018
Cl^-	0.005	0.007	0.009
sheep's fescue phytomass in the experiment**, g/0.004 m^2:			
August 27, 1988	0.64	0.33	0.79
May 27, 1989	0.71	1.42	1.31
October 29, 1989	0.21	0.89	0.68
May 23, 1990	1.32	1.94	1.78
June 20, 1991	9.64	8.77	13.00
May 29, 1992	8.43	6.92	10.48
Relative productivity of sheep's fescue in the experiment (1989-1992),%	100	130	145

*Wormwood mass is included – 16 g/m^2.

** Cultivated sheep's fescue in special field trial (from August 27, 1987 to May 29, 1992) was used as a phytometer of edaphic conditions.

However, it's unlikely that sheep's fescue and other grasses replace wormwood habitat in natural conditions. Wormwood *(Artemisia austriaca)* having high level of allelopathic potential overtops the growth and development of the species which are involved in its synusia (Grodzinskiy, 1965). Thus, more favorable soil conditions formed with wormwood necromass are directed towards expansion of their species. We believe that continuous grazing pressure causing the breaking point of phytocenosis is only a trigger (starting point) for virtually permanent process of steppe desertification. The use of analytical methods proves it by the fact that the amount of exchange calcium in soil absorbent complex decreases under the wormwood plants, the amount of chlorine and sodium in water extract increases; it is recorded the considerable increasing of the limiting sulfur portion in phytomass which is fixed for free-salined habitats. Xerophytisation of vegetation layer under the influence of excessive grazing leads to the development of the series of halomesophytes during the transition from wormwood plants pasture to grazing (*Atriplex, Polygonum* and others) (Pachoskiy, 1917).

The peculiarities of the Early Iron Age in northern Black Sea basin are connected with the neighborhood of nomadic and seminomadic farming of the Scythians and the Sarmatians and the agricultural regions of Greek poleis located near the sea and estuaries. Archaeological data make it clear that in steppe Scythia and Olvia there was dynamics of sectoral structure of farming which depended upon the changes of ecological conditions. The Black Sea basin steppes (100 ha), slightly changed by grazing pressure with the forage productivity value 6000 kg/ha (3500-4300 fodder units per year) according to present-day standard of rational density of cattle stock, could provide with forage 90-10 head of cattle and 330 head of sheep. Osteolytic data suggest the optimum ratio of cattle and small cattle (1:3) could be observed in earlier archaic period of development of rural region of Olvia (Zhuravlyev, 1987). Increased grazing pressure could lead to the formation of soils with humus portion 25-28% (in the 0–20 cm soil layer) less than root associations. Moreover soil salinity and consistency strengthened due to biotic accumulation, unproductive moisture loss increased, degree of geochemical cycle control in biomass and soil horizon was determined (Lisetskii, 2008).

Reduced productivity in the steppe ecosystems with continuous grazing pressure determined the necessity of adjustment for the flock structure. It is recorded that the productivity of plant associations is 1300 – 3700 kg/ha or 800-2200 fodder units per year. The formation of these plant associations reflects the transition to digression changes. It is notable that during the Classical and Hellenistic periods of Olvia development increased cattle ratio was balanced by reduced small cattle ratio. Increased cattle ratio was caused by farming needs (Zhuravlyev, 1987). The period of the 5th century BC is the turning-point in evolution of socionatural relations and the transition to a new strategy of nature management in Olvia farming region. In this period the use of principles of distinct regulation and equal territorial anthropogenic pressure replaced elemental development of economic system. This scenario is observed in the last phase of the Scythian economic history (the period between 3 century B.C. and 3 century AD) when under the influence of Greek settlers sectoral structure of farming was harmonized with agricultural districts in the Crimea and along the lower Dnieper river being formed.

The steppes near the Black Sea basin were characterized by similar landscape ecological situation because of the dominance of cultural and economic type, nomadic cattle-breeding, from the fifth century to the eighteenth century. Grazing became the leading factor of the evolution of vegetation layer in the steppes under the same anthropogenic influence of the tribes which changed one another (Huns, Pechenegs, Cuman, Nogais, and Crimean Tatars). Steppe mat burning down, especially during the wars, had material effect on improving of pastures. Wild ungulates ((tarpan, saiga, roes) dominated in the steppe ecosystem formation.

The steppes were used for cattle grazing in the 17th century, there were wild ungulates, but they were not numerous to change steppes into tramped pasture (Kirikov, 1983).

Natural plant groupings disappeared rapidly because of increased area of arable lands since late 18th century when all allotments of lands of Novorossia were confirmed. For example, in Kherson uezd (region) the area of natural grasslands reduced quickly (pastures, virgin lands, fewer portions of hayfields) for 130 years (figure 3). By the 1860s the areas of arable lands and natural grasslands were equal on the territory of Kherson uezd (region).

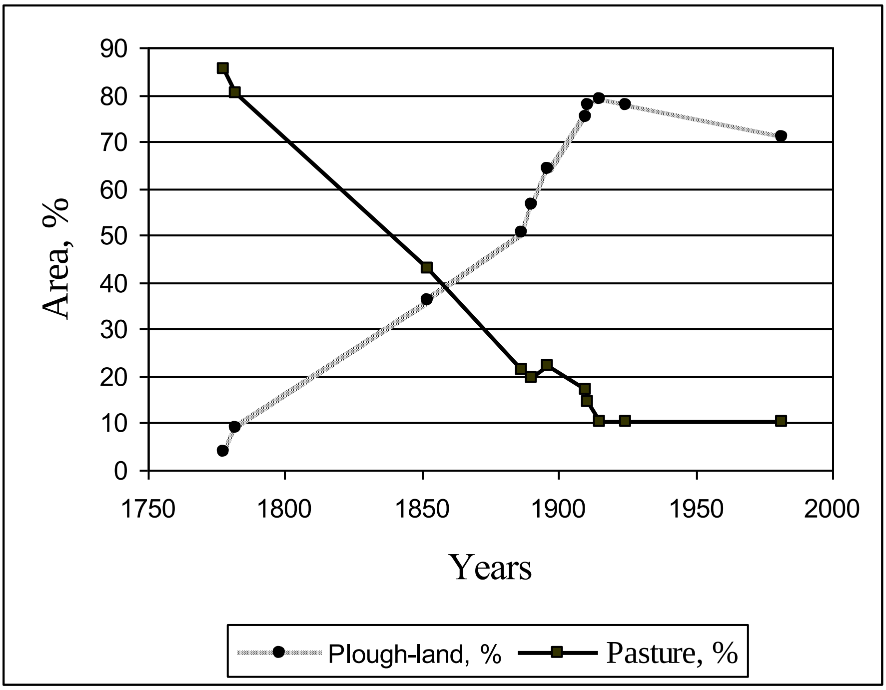


Fig. 3. Dynamics of area proportions of arable land and natural grasslands on the territory of Kherson uezd (region).

Cattle-breading (breading of sheep, oxen, and other domestic animals) predominated over agriculture until the 1930s. Ploughing up maximum value was observed in the period between 1830 and 1850 (from 10-30% to 75%).

Cattle pressure per 100 hectares of lands having existed by the middle of the 19th century in Kherson province (table 2) was typical for other territories of southern Russia (Tavricheskaya and Eketerinoslavskaya provinces, Bessarabskaya region, Don Army Lands). The development of sheep breeding had specific features. Arable lands and hayfields in Kherson province accounting for 19% of its total area, and accommodated 23% of the total sheep stock (and 33% of the fine-wool sheep stock) in southern Russia (12.2 million head).

Table 2. The cattle-breading development in Kherson province in the middle of the 19th century

Year	Head per 100 ha of arable lands and hayfields			
	Horses	Cattle	Sheep	Fine-wool sheep
1856	3	9	14	18
1864	2	11	10	47

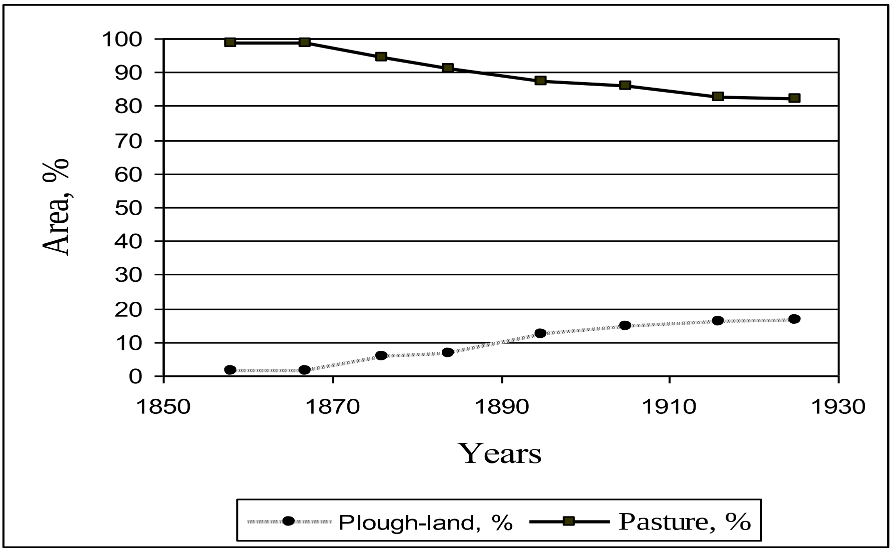
By the late 19th century due to ploughing up in Kherson province pastures area reduced from 80 (in the beginning of the century) to 20% (table 3), 1.41 x 10^6 ha.

Table 3. Lands allocation in farmlands of Kherson province (Statistical-Economic Review …, 1897)

Farmlands	Territories*						
	1	2	3	4	5	6	7
Plowed land	59	47	57	65	62	64	59
Pastures	20	29	18	15	18	22	20
Hayfields	12	14	10	8	9	4	9
Virgin land	-	2	7	1	1	3	3

* 1- Aleksandriysky uezd; 2 – Ananyevsky uezd; 3 - Elizavetrdsky uezd; 4 - Odeskii yuezd; 5 – Tiraspolsky uezd; 6 – Khersonsky uezd; 7- Kherson province.

In the 19th century some large sheep farms were formed in dry steppe (annual precipitation – 375 mm). Thus, in the biosphere reserve "Askania Nova" it was decreased only 16% of steppe pastures due to increasing arable lands at the pasture periphery (fig. 4).



Used data by Kovarsky, 1930.

Fig.4. The correlation between the amount of arable lands and steppe pastures on conditions that farming is extensive in cattle-breeding (e.g. "Askania Nova").

Nowadays on the territory of the biosphere reserve “Askania Nova” named after F. Falts-Fein virgin steppe (11000 ha), the largest lot of guarded land in Europe, is kept.

By the end of the 19th century it was attained time equality of arable lands with natural phytocenosis,and by 1915 practical limit of ploughing up was set. Also the localization of natural vegetation in unsuitable for ploughing lands was reduced in 10%. By the beginning of XX in Kherson province land developing by ground landlords and peasants reached 78.2/79.2% correspondingly. Such extend of land ploughing was at high level: “among all other provinces of Russian Empire, ploughing in Kherson one takes the first rank” (Russia, 1910, V. 14, P. 263). According to summary data from table 1.4 great decreasing of hayfield areas and pasture lands (on the assumption of increasing of arable land ratio) took place in the period of 1887-1914 from 47.0% to 12.5%. Thus, from the end of the 19th century the maintenance of pasturable cattle breeding became impossible. From 1897 till 1912 the livestock of fine-wool sheep decreased in 70%, other cattle – in 5-9%. The value of grazing pressure counting on natural forage lands was changed from 0.19 conventional head per hectare in the middle of the 19th century till 1.00-1.26 head per hectare in the first decade of the 20th century (see table 4).

Table 4. The dynamics of farmland areas and grazing pressure in Kherson province in the period between the 18th and 20th centuries

<table>
<tr><td rowspan="2">Years</td><td colspan="5">Land types,%</td><td rowspan="2">Grazing pressure, conventional head/hectare</td></tr>
<tr><td colspan="2">virgin lands</td><td colspan="2">pastures</td><td>hayfields</td></tr>
<tr><td>1774</td><td colspan="2"></td><td colspan="2">83</td><td></td><td>-</td></tr>
<tr><td>1796</td><td colspan="2">72</td><td colspan="2"></td><td></td><td>-</td></tr>
<tr><td>1846</td><td colspan="2"></td><td colspan="2">36.4</td><td></td><td>-</td></tr>
<tr><td>1850-1852</td><td colspan="2"></td><td colspan="2">11.2</td><td>38.3</td><td>0.19</td></tr>
<tr><td>1856</td><td colspan="2">-</td><td colspan="2">-</td><td>-</td><td>0.17</td></tr>
<tr><td>1864</td><td colspan="2">-</td><td colspan="2">-</td><td>-</td><td>0.29</td></tr>
<tr><td>1872</td><td colspan="2"></td><td colspan="2">36.0</td><td></td><td>-</td></tr>
<tr><td>1881</td><td colspan="2">-</td><td colspan="2">45.1</td><td></td><td>-</td></tr>
<tr><td>1887</td><td></td><td colspan="2">32.3</td><td></td><td>14.7</td><td>-</td></tr>
<tr><td>1890</td><td>3.8</td><td colspan="2"></td><td>20.8</td><td>11.3</td><td>0.38</td></tr>
<tr><td>1894</td><td>2.1</td><td colspan="2"></td><td>21.7</td><td>10.4</td><td>0.41</td></tr>
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<tr><td>1900</td><td></td><td colspan="2">24.7</td><td></td><td>7.1</td><td>0.50</td></tr>
<tr><td>1905</td><td></td><td colspan="2">20.0</td><td></td><td>7.3</td><td>-</td></tr>
<tr><td>1910</td><td></td><td colspan="2">15.3</td><td></td><td>4.5</td><td>1.00</td></tr>
<tr><td>1911</td><td></td><td colspan="2">13.6</td><td></td><td>3.8</td><td>1.26</td></tr>
<tr><td>1914</td><td></td><td colspan="2">9.2</td><td></td><td>3.3</td><td>-</td></tr>
<tr><td>1915</td><td>-</td><td colspan="2"></td><td>10.0</td><td>4.1</td><td>-</td></tr>
<tr><td>1921</td><td>-</td><td colspan="2"></td><td>6.4</td><td>4.4</td><td>-</td></tr>
<tr><td>1925</td><td>-</td><td colspan="2"></td><td>19.5</td><td>5.9</td><td>0.86</td></tr>
<tr><td>1989*</td><td>0.7</td><td colspan="2"></td><td>10.0</td><td>0.6</td><td>-</td></tr>
</table>

* Modern data from 63 administrative regions within former Kherson province.

On the whole in Kherson province in the period of 1886-1900 (each subperiod – 5 years) hay-producing power on uplands was from 1000 to 1200 kg/h (Statistical Information..., 1902). According to generalized data in Kherson province virgin lands (usually used as hayfields by May, and as pastures in the years of low productivity) had average crop-producing power – 1000 (450-2550) kg/h, and under favorable conditions – 3750 kg/h. In the west sector of Black Sea steppe zone and area between Dniester and Bug rivers (Odessa uyezd), in the end of the 19th century hay-producing power in steppes depended on weather conditions: from 600 to 1800 kg/h, that is in average – 1200 kg/h (Materials ..., 1883). All these data reveal that annual bioproductivity of aboveground layer averages 1700 kg of dry mass per hectare with maximum value till 4000 kg/h, at that bioproductivity was calculated according to the correction for moisture of air-dry hay (16%) and persisted ratio of phytomass below shear line.

Thus, at the turn of the 20th century natural herbaceous vegetation, mainly under influence of hay harvesting, provided only 36% of aboveground layer productivity of aboriginal zone communities. As a result of requisitioning some operational vegetation output (65-75%), average value of neogenic humus is 1.7 t/ha.

Zone growth, forming prospective coverage of soil surface within the bounds of 60-90%, was the effective regulator of erosive soil loss in preagricultural period, as it was set equilibrium of wash up and pedogenesis rates for the range of prospective coverage from 50 till 75% (Lang, McCaffrey, 1984).

The analysis of nature management forms connected with plant substance alienation in zonal phytocenosis allows to correct productivity changes caused by anthropogenic factor in different historical and ecological periods. It gave the possibility to describe numerically syngenetic evolution of steppe ecosystems during Holocene:

$$F_t = 2 \cdot t^{0.13} + A_0 + \sum_{k=1}^{7} A_k \cdot \sin(k\tau + f_k),$$

where F_t – vegetation output ridden on nature and anthropogenesis, t/h per year; t -dates from the absolute time scale, years; τ – time readings; A_k и f_k – amplitude and phase of fluctuation k: $A_0 = 1.02$, $A_1 = 1.95$, $A_2 = 0.80$, $A_3 = 1.33$, $A_4 = 0.47$, $A_5 = 0.38$, $A_6 = 0.18$, $A_7 = 0.09$; $f_1 = -3.03$, $f_2 = 1.57$, $f_3 = -1.62$, $f_4 = -0.74$, $f_5 = -0.26$, $f_6 = 0.48$, $f_7 = 0.89$ (Lisetskii, 1996).

Thus, the estimator of vegetation output changes ridden on nature and anthropogenesis for last 10 thousand years can be reconstructed sufficiently by means of calculated method through energy consumption.

SPECIES AND NATURAL PASTURES PRODUCTIVITY IN FOREST - STEPPE ZONE

Examinations of natural pastures in forest-steppe zone were carried out on the territory of Belgorod region (one of five regions in Central Black Earth zone, Russian Federation).Natural pastures average 18.66% (3995.46 km^2) from all farm lands. At present time availing natural grasslands of ravine-gully complex can only partly provide cattle stock by full and cheap fodder.

In previous years during intensive agriculture development abnormal cattle grazing contributed considerable degradation of natural communities on slopes: species was simplified, ruderal component was increased, herbaceous layer productivity was reduced a lot.

At present cattle stock was greatly reduced. Thus in comparison with 1985-1986 by 2000 the cattle abundance in Central Black Earth region (167.7 thousand km^2) was diminished on average 59.8%, in particular smalls-93.4%. In Belgorod region smalls were reduced on 51.3%-sheep, and 94.7%-goats, in Kursk region 63.3% and 94%, in Voronezh region 57.1% and 92.3% accordingly. It contributed the reduction of anthropogenic pressure on nature communities.

Persisted unique steppe communities on small areas of gully-ravine complexes can be considered not only as pastures, but as reserves for scarce herbs conservation, entomological preserves, provider of pollinators for agriculture crops, areas for recreation. They can become the important part of steady development of agriculture production, carrying social function.

We laid some statsionars (polygons of permanent monitoring) in several nature-territorial complexes, in different kinds of biotopes. Full geobotanic examination was made.

Examination results made it clear that communities had different species saturation, above- and underground mass. On the study areas alpha diversity (species quantity per meter^2) depends on two main factors: the level of anthropogenic pressure and the area's size (table 5). The less pronounced pasture degression and more statsionar area are, the more polytypic genera are.

Plant diversities study in statsionar № 1 made it clear that average crop-producing power of aboveground mass was varied from 437 to 589 g/m^2, but underground mass – from (layer 0-15 cm) – 1121-2284 g/m^2.

In species of pasture phytome it was emitted 8 life-forms which correspond to meadow-steppe phytocenosis. There are more herbaceous plants; they average 95.26% from general number of species quantity. The most numerous plant group is permanent grasses – 79.47%. The number of species index of communities under study varied from 14 to 32 species per meter^2 .

Comparison of aboveground phytomass of communities with different dominants reveals that the average in all study areas was maximum in *Caraganeto (frutexai) – Bromopsiseta (inermisi) – herbosum* communities and reached 789 g/m^2, minimum in *Stipeteto (pennati) – Festuceta (valesiaci) – herbosum* (385 g/m^2).

Harmful and poisonous plants for cattle [*Echinops ritro* L., *Chelidonium majus* L., *Vincetoxicum rossicum* (Kleop.) Barbar., *Saponaria officinalis* L., *Echium vulgare* L., *Carduus acanthoides* L, *Chamaecytisus ruthenicus* (Fisch. ex Woiosz.) Klaskova] average about 8% from general species. It can be considered a high index. However, in this case, we can speak only about potential infestation danger as the part of harmful species is in significant in the general communities’ phytomass.

Average productivity of above- and underground phytomass in this statsionar is rather lower in comparison with another statsionars situated in dewier conditions. Great relief ruggedness of the area also influences negative on phytomass productivity.

Main species of communities typical for zonal feather-herb grass steppes were presented in another statsionar (№2).

The area peculiarity is that against a background of pasture and mowing exploitation its vegetaion is represented fully by persisted feather-herb grass communities with rich flora (197 species of highest tracheal plants) and the great part of stocked rare species which are in Red data book of Russia (this book includes rare plants and animals to be protected). On average 32 species grow per 1m^2. Study area can be a model of rational usage of natural communities in agrolandscapes (Degtyar', Chernyavskikh, 2004, 2006).

The results of communities productivity count made it clear that the greatest above- and underground phytomass is formed by *Caraganeto (frutexai) – herbosum* communities of *Caraganeta frutexae* formation accordingly 896, 3948 g/m^2 air-dry substance. It is explained by considerable proportion of bushes.

Plants communities of statsionar № 3 are typical for ravine-gully complex. Among herbaceous communities the greatest above- and underground phytomass was formed in *Paeonieto (tenuifolii) – herbosum* community and amounts accordingly 729, 3588 g/m^2. The least phytomass in *Salvieto (nutans) – herbosum* is accordingly 528, 2299 g/m^2. 187 species of highest tracheal plants grow in them.

Plants communities of statsionars № 4 (the total area is above 1000 ha) were used strongly for cattle grazing. Plants communities of pastures were exposed to strong exploitation by a man.

Grasses in cut varies from 18.2 to 36.5% by mass of air-dry substance, legumes – from 9.5 to 18.0%, all the rest is mixed herbage. The portion of weed, harmfull and poisonous species in dry mass of herbaseous layer varies from 12 to 23%.

Species saturation of communities varies from 18 to 24 forms per meter^2. Average size of aboveground phytomass in the statsionar is 686 g/m^2 of air-dry substance and varies from 631 to 708 g/m^2 (it depends on a tract). The maximum yield of aboveground mass was supplied by communities with great part of *Medicago falcate* L.

Statsionar № 5 is of interest as crucial model area situated in the dewier conditions. Plant communities of this territory are represented by meadow and northern steppes. Maximum phytomass is formed by communities with predominance of tall-growing grasses, sage and mixed herbage. Cut weight of mixed herbage communities is different and depends on edificator. Communities have high species saturation (26-30 species per meter^2), the total amount of vascular plants species is 112.

Estimation of how species variety influences the productivity elements of steppe pastures in ravine-gully complexes was fulfilled by methods of correlated analysis and multiple regression. It was ascertained the tendency when increasing of above- and underground mass correlation depends on increasing of species saturation, that is subject to weak, medium and vigorous correlations (r = 0.409....0.838 in different statsionars). Another tendency is that the increasing of underground mass is up to growing of species saturation of communities (r = 0.411...0.732).

Evaluation of study factors influence: alpha-diversity and beta-diversity (species quantity in a statsionar) on sizes of above- and underground phytomass made it clear that these indexes depend on alpha-diversity (60-93.4% of total dispersion).

To a greater extent species diversity influences the size of uderground phytomass, and to a lesser extent aboveground phytomass depends on species diversity.

In this connection it is essential to estimate influence of communities with the same dominant on productivity of species saturation in details. Rather often just dominant has strong influence upon community growth and development. Knowing the mechanisms of productivity formation in homotypic natural communities gives the possibility to forecast the behavior of anthropogenic formed phytocenosis. For studying it was chosen communities predominated at different stages of succession: *Stipeteta (pennati)*, *Bromopsiseta (inermisi)*, *Elytrigieta (repensi)* and *Salvieta (nutansi)*. As in the case of regressive models, the increasing of aboveground mass in feather grass communities is evident under increasing of species saturation to 17-19 forms per meter^2, but then it began decreasing when species quantity is growing. At the same time stable decreasing of underground mass and the correlation of above-and underground mass of plants communities takes place when species saturation is increasing.

The results of mathematical analysis and building models made it clear that interdependence between species saturation and main data of productivity are described with high confidence by polynomials of the second power (fig. 5).

Domination of *Stipa pennata* L. is typical for climax communities. In this case there is the most stable accumulation of above- and uderground phytomass. Communities aim at monodomination *Stipa* – uderground phytomass is large, fullness of ecological niches in underground sphere is rather high (first of all it is connected with the distribution of resources which are in minimum: usually they are moiature and nitrogen), topsoil aeration, quite the contrary, is low. The great number of dead plant residues is cumulated in underground sphere; availability of feed elements is low, as their basic mass is concentrated in organic matter. The system is an abandoned condition. High density of herbaceous layers is typical for associations *Stipetum (pennata)* with small species quantity. New species intussusception into such community is unlikely.

High species saturation is typical only for thinned herbaceous layers. Species saturation increasing happens due to the species having low phytomass, such as ephemers and ephemeroids but they use well spring moisture from soil.

Our research made it clear that high species saturation is typical just for southern steppes with pronounced lack of moisture in little used territories. Species saturation increasing influences somehow different on above- and underground productivity of communities which were used as pastures or/and hayfields before.

We made the analysis of associations with rhizomatous formers of cenosis (*Bromopsis inermis* Leyss. и *Elytrigia repens* (L.) Nevski), and also with stalky-root ones (*Salvia*) having maximum structural similarity with sown cereals-legumes herbaceous layers. Correlations between species diversity and basic elements of bioproductivity in all these communities are well described by polynomial of the second order, as also in the case with feather grass communities.

However, in this case the tendency is absolutely opposite: species saturation increasing forwardes underground mass rising. Another trend is there is also aboveground mass increasing and correlation between above- and underground mass. Besides it is to the same extent significant for associations *Bromopsisetum (inermis)* and *Elytrigietum (repens)*. This correlation is most evident in communities at the early phases of succession which is propagated on defective soils. In that case introduction even some plant species and small species diversity can sudden enhance first of all underground phytomass and then aboveground one. The correlation of above- and underground mass is a more dynamic quantity and is weakly subject to forecasting.

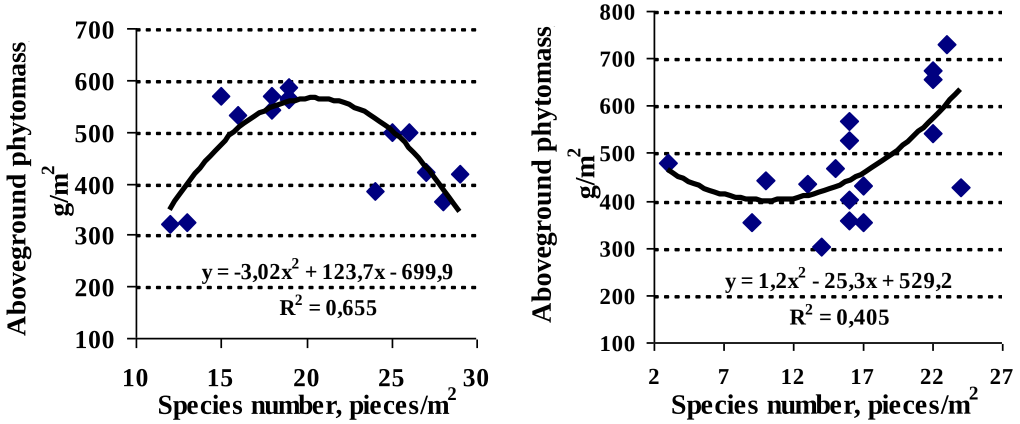
Table 5. Phytomass of herb-grass (meadow-steppe) and herb-bunchgrass steppe communities of pastures within gully plantings and their species saturation (average data for 2004-2008)

№ Statsionar	Area of planting, km^2	Communities dominants	SD, specie per meter^2	Total species amount	Total sorts amount	Phytomass of air dry substance			Correlation R/F
						F, r/m^2	R, r/m^2	F+R, r/m^2	
1	32	*Stipa, pennata, Salvia nutans, Poa pratensis, Elytrigia repens, Bromopsis inermis*	19	205	98	575	2069	2644	3.5
	3.6	*Bromopsis inermis, Stipa, pennata, Poa pratensis, Caragana, frutexae,*	17	164	68	546	2175	2721	4.0
	20	*Stipa, pennata, Salvia nutans, Poa pratensis, Bromopsis inermis,Calamagrostis erigeios, Cytisus austriacus*	23	166	124	515	1599	2114	3.1
	72	*Stipa, pennata, Bromopsis inermis, Salvia nutans, Festuca sulcata*	17	175	72	570	1916	2487	3.3
	11.1	*Stipa, pennata, Bromopsis inermis, Elytrigia repens, Salvia nutans, Calium verum*	18	163	93	589	2284	2873	3.8
	6	*Bromopsis inermis, Salvia nutans, Stipa, pennata, Medicago falcata, Festuca sulcata*	23	194	135	437	1121	1558	2.6
2	3.2	*Stipa, pennata, Galium verum, Salvia nutans, Bromopsis inermis, Stipa, pennata Salvia nutans*	32	197	129	696	2299	2995	3.2

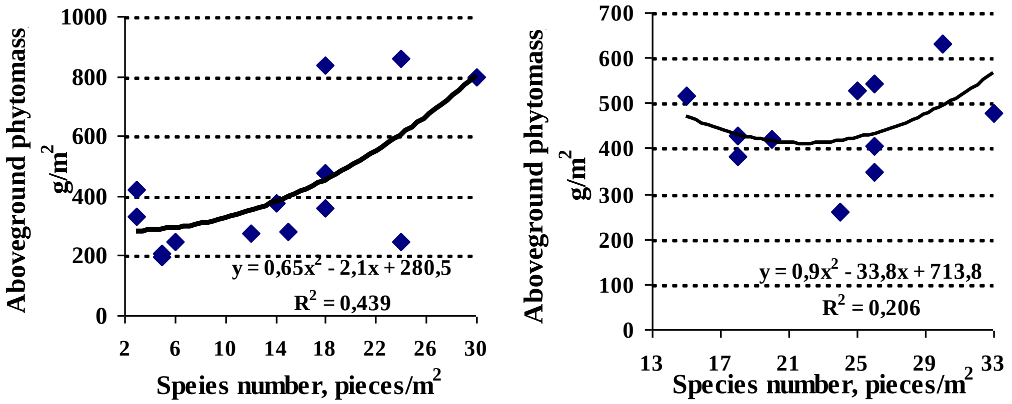
Table 5. (Continued)

№ Statsionar	Area of planting, km^2	Communities dominants	SD, specie per meter^2	Total species amount	Total sorts amount	Phytomass of air dry substance			Correlation R/F
						F, r/m^2	R, r/m^2	F+R, r/m^2	
3	1.8	*Bromopsis inermis, Elytrigia repens, Poa pratensis, Trifolium montanum*	14	123	75	370	802	1172	2.1
	3	*Stipa, pennata, Salvia nutans, Bromopsis inermis, Caragana, frutexae*	26	187	121	324	874	1203	2.7
4	3	*Poa pratensis, Agrimonia eupatoria, Salvia nutans, Medicago falcata, Bromopsis inermis, Galium verum, Achillea millefolium*	22	167	83	694	2408	3102	3.6
	6	*Galium verum, Bromopsis inermis, Festuca sulcata, Elytrigia repens, Medicago falcata, Salvia nutans, Agrimonia eupatoria*	22	184	92	708	1744	2466	2.6
	4	*Agrimonia eupatoria, Festuca sulcata, Salvia nutans, Bromopsis inermis*	21	170	78	631	1664	2295	2.9
5	4	*Bromopsis inermis, Salvia nutans, Stipa, pennata, Elytrigia repens, Leucanthemum vulgare*	28	112	85	498	1363	1861	2.9
Average			22	170	96	550	1717	2269	3.1
LSD $_{05}$			4	19	19	94	443	528	0.4

Notes: SD – species saturation; F –aboveground phytomass ; R –underground phytomass in layer 0-15 cm



Associations *Stipetum (pennata*) **Associations *Bromopsisetum (inermis)***

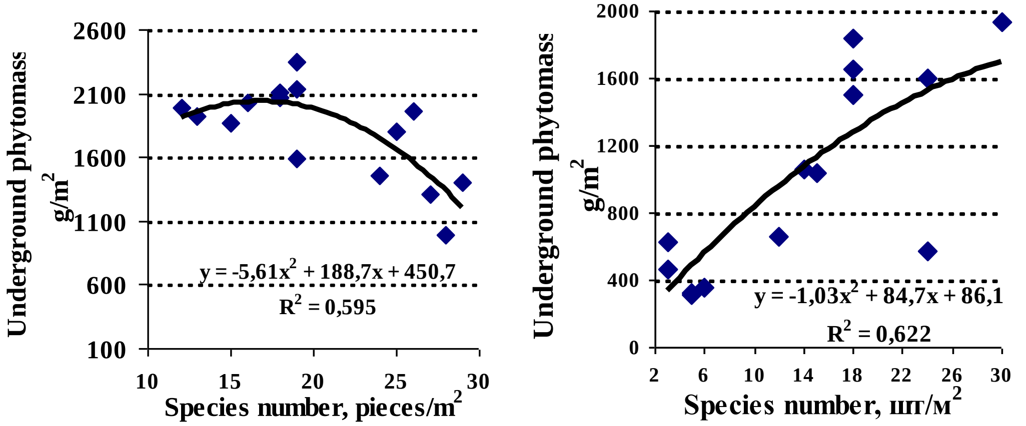


Associations *Elytrigietum (repens)* **Associations *Salvietum (nutans)***

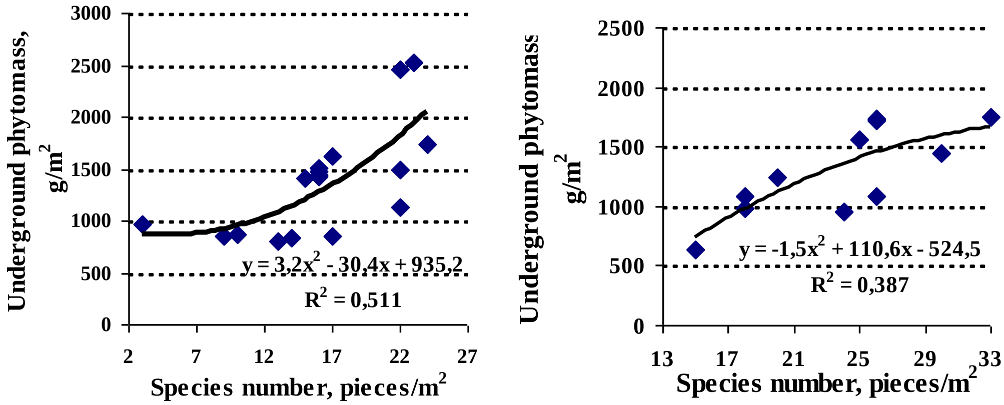
Figure 5. Correlation between species saturation (species per m^2) and aboveground productivity of natural pastures with diferent dominats of plant communities.

Increasing of species saturation causes the growth of competition between above- and underground spheres which stimulate the differentiation of ecological niches. Rate of soil infilling with rootages grows. Under these circumstances significant number of labile organic substance as root remains in oil is accumulated and humus formation is forwarded.

Associations with *Bromopsisetum (inermis)* on slopes is typical for more mature plant communities prevailing on more serotinous succession stage, species infilling is already at a high level and they began to compete with each other for resources. Moreover such conditions are favorable for free intussusception of species into communities. High-rate mineralization of labile substance of plant residues forwards infilling process of numbers of accessible forms of feeding elements and becoming additional ecological niches in plant communities.



Associations *Stipetum (pennata)* **Associations *Bromopsisetum (inermis)***



Associations *Elytrigietum (repens)* **Associations *Salvietum (nutans)***

Figure 6 – correlation between species saturation (species per m^2) and underground productivity of natural pastures with diferent dominats of plant communities.

Salvieto (nutans) – herbosum communities taking sizeable territories are of special interest. These communities have wide biodiversity, bioproductivity and feeding value. They can be considered as climax communities along with feather grass steppes (fig. 6).

Association *Salvieto (nutans) – herbosum* is similar to considered before one *Stipetum (pennata)* according to correlation between species saturation and elements of bioproductivity. But correlation between aboveground phytomass accumulation and species quantity per m^2 has not been determined. There is weak correlation of this index with underground mass. It is connected with intensive competition inside these communities in both aboveground and underground spheres.

DYNAMICS OF PASTURE ECOSYSTEM PRODUCTIVITIES AS RELATED TO CLIMATIC CHANGES

Researches were conducted in Kominternovskii District of Odessa Region (at state farm “Odesskii”), from 1981 to 1995. The representative test area chosen for observations on pasture productivity (46.6 ha) is located 5 km northeast of the city of Odessa and 8 km from the Black Sea coast. This area is characterized by an arid climate (with a precipitation–evaporation ratio of 0.45–0.48) and considerable variation in bioclimatic parameters. According to long-term data, the difference between the total amounts of precipitation in the wettest and driest years is 2.5- to 3-fold in the steppe zone near Odessa weather station and 3.45-fold within the Odessa city limits. Some years may be extremely arid. In 1921, for example, the amount of precipitation was only 192 mm, while evaporation reached 800 mm, with their ratio being 0.24.

The study region is close to a weather station, which allows a more detailed analysis of the relationship between productivity and climate.

The aboveground phytomass of herbaceous plants was estimated in sample plots (25 x 25 cm) in four to six replications, with each sample being dried in a thermostat to determine its absolutely dry weight. The relative error of means for green phytomass ranged from 9 to 13%, it increased to 18% only in grazing period. In the case of dead plants and litter, this error varied more widely, increasing to 20–30% at the peak of grazing pressure.

The study area is in the geobotanical province of xerophytic mixed herb–sheep’s fescue–feather grass steppes on dark chestnut soils and southern residually alkaline chernozems. The botanical composition of the herb–grass phytocenosis was rather diverse: the number of flowering plant species found in 1- sq m plot reached 25–34 in May and June, decreasing to 8–19 between July and September. Grasses such as *Festuca valesiaca Gaud., Koeleria cristata (L.) Pers., and Poa bulbosa L.* are chiefly dominant. Vegetation on the bottoms of gullies cutting through the slope included a large proportion of mesophytes: *Alopecurus aequalis Sobol., Elytrigia repens (L.) Nevski, Carex stenophylla Wahl., and Poa angustifolia L.* In some years flowering feather grass *(Stipa capillata L).* in late summer accounted for up to 59% of the total phytomass. Other feather grass species *(S. lessingiana Trin. et Rupr. And S. ucrainica P. Smirn)* occurred mainly on gully slopes, with the amount of green phytomass reaching a peak of 2434 kg/ha (with dead plants, 3614 kg/ha) between late April and June.

In spring (April and May), a considerable role belonged to *Crinitaria villosa* Cass., *Euphorbia seguieriana Neck.*, *Linum perenne L.*, *Medicago lupulina L.*, *Veronica seppacea Kotov*, *Jurinea mollissima Klok.*, with *Potentilla patula Walsf.*, *Astragalus pubiflorus DC.*, and *Salvia nutans L.* being less widespread. The proportion of wormwood *(Artemisia austriaca)* to the total aboveground phytomass did not exceed 10%. Beginning from the second half of summer, the contribution of wormwood in areas exposed to different grazing pressure increased to 20–90%. The improvement of the phytocenotic role of wormwood identifies the tendency to steppe desertification. The proportion of animal feces in the litter varied from 12.3 to 23.2% (120–340 kg/ha).

Biotopes partly with steppe vegetation located on gully slopes have not only definite economic influence; they are refugium for rare and endangered species. In the study area it is recorded that on ravine slopes cutting gully slopes blackthorns found, which protect *Adonis vernalis L.*, on terrace edge *Iris pumila L.* found.

The pasture functioned continuously for the past 200 years. In the 20th century the study area belonged to Kryzhanovskoy state farmland, the total area was 7825 ha. As reported in general land-surveying plans (in the 1820s) plowed farmland reached 3.7%, hayfield area was 79.4% (explicite pastures of that period were not identified). According to statistics (in 1882) the portion of hayfield with pasturage ("tolock" – pounded land) reduced to 33%, hayfields - to 14% of the total area while arable land increased to 62%.

Let us consider dynamics of the proportion changes for steppe pastures in land structure and estimation of their productivity on vaster territory for northern Black Sea basin.

The steppe grass stand, both natural and seminatural (transformed to different degrees under the effects of grazing digression and hay harvesting), lost its former economic significance during a short historical period (60 years) from the mid-19th to the early 20th century (Table 1).

In 1864, arable lands and hayfields in Kherson province exceeded 5 x 10^6 ha, accounting for 19% of its total area, and accommodated 23% of the total sheep stock (and 33% of the fine-wool sheep stock) in southern Russia (Tavricheskaya and Eketerinoslavskaya provinces, Bessarabskaya region, Don Army Lands). There were 14 head of ordinary sheep and 18 head of fine-wool sheep per 100 hectares of arable lands and hayfields, in 1856, compared to 14 and 18 head, respectively, in 1864. However, this agricultural practice radically changed already in the 1860s, especially in small farms: livestock breeding was reduced to a minimum, giving way to extensive grain husbandry (Postnikov, 1891).

Depending on weather conditions, virgin lands were used either as hayfields or as pastures. Tolock (pounded land) was called a pasturage located near inhabitants. The yielding capacity of hayfields on virgin lands varied from 450 to 3750 kg/ha. In general, farmers obtained 360 kg of hay per hectare from virgin lands, 520–730 kg/ha from fallows (depending on their age), and 1120 kg/ha from meadows (Economic-Statistical Review … 1891). In 1896, hay yield from virgin lands in some districts of Kherson province reached from 37 to 59 poods (17 kg) per dessiatina (2.7 acres), that is 560–880 kg/ha (Statistical-Economic Review … , 1897). In Odessa district, hay yield from three- to eight-year-old fallows averaged 600 kg/ha in unfavorable years, 1200 kg/ha in ordinary years, and 1800 kg/ha in favorable years (Materials …, 1883); between 1888 and 1890, hayfields yielded 410–600 kg/ha; in 1896, fallows yielded 360– 450 kg/ha.

Pastures and remaining virgin lands in Odessa district (9341 sq km) accounted for only 10.4% of its area by 1910 (Statistical-Economic Review …, 1911).

In Kominternovskii district (1500 sq km) located between the Tiligul and Kuyalnik estuaries pastures and hayfields covered 17% of its total area in the late 1950s. Today, when agricultural development of the region has reached its limit, this proportion is only 9%, or 11% of all farmlands.

Statistical data obtained in the 19th and early 20th centuries can only provide a vague idea of long-term average productivity of grasslands. There are no annual data for pastures and grasslands productivity. However, long-term observations for yielding capacity of main crops are available.

Natural and seminatural grass stands under soil-climatic conditions of the steppe zone yielded up to 900–1200 kg of hay (760–1010 kg of dry phytomass) per hectare without any agrotechnical measures.

Let us consider specific features of the production process in a pasture according to the results of studies in the stationary test area. In the period of more or less regular observations

(1981–1990) and, for comparison, in subsequent years with different socioeconomic conditions (1991, 1992, and 1995), 437 measurements of phytomass were made.

Its values in the pregrazing period varied markedly over 13 years, with the coefficient of variation in the maximum value (over 12 years) reaching 39.7%.

A considerable proportion of feather grass in the pasture was recorded in only a few years. In such cases, the maximum yield of green phytomass reached 1800 kg/ha, whereas under usual conditions when sheep's fescue was dominant this parameter averaged 1500 kg/ha over 12 years.

An annual growth was calculated according to changing capacity of seasonal phytomass of active and latent roots. The activity of roots regeneration was calculated according to Dalman (1968).

The maximum phytomass value reached 1530 kg/ha, the mortmass of aboveground layer (grass plants and litter) averaged 1450 kg/ha, the annual amount of root attrition was estimated at 700 kg/ha, the maximum phytomass value of roots (0-20 cm per m^2) was 5310 kg/ha, the annual values of root secretions reached 0.2 kg/ m^2, over 11 years' observations of the pastures.

By the onset of the grazing period, the herbaceous layer in the pasture consisted of grasses (79%), mixed herbage 15% (including 3% of euphorbia), and legumes (6%). An assessment of grazing pressure over the observation period showed that the pasture area per head of cattle averaged 0.9–1.0 ha, corresponding to medium values of the norm for pastures of the steppe zone.

Long-term green phytomass removal under conditions of moderately intensive grazing, accompanied by fires in some years, resulted in apparent adaptation of the grass stand to this kind of anthropogenic impact. For example, data on the period between the autumn of 1989 to the autumn of 1990 characterize the conditions of postfire recovery of the steppe phytocenosis.

It would be useful to present vertical (layered) structure of the steppe communities to compare economic calculation of pasture productivity (according to statistics) and estimated data for aboveground layer of phytomass in the stationary test area. Vertical structure of a feather grass–mixed herb association (with maximum growth value of feather grass) is characterized by the following proportion of phytomass (0.852 kg/ sqm) on the phytohorizon (cm): 0-0.9 cm (litter) – 36%; 0.9-10.9 – 39; 10.9-30.9 – 18; 30.9-50.9 – 5; 50.9-70.9 – 1; 70.9-90.9 – 1; 90.9-100.9 – 0.1; 100.9-106 – 0.01. The maximum root mass in the 0–20 cm soil layer reached 1488 g/ m^2 within a year, whereas in the 0-10 cm soil layer is 75% of the mass in the 0–20 cm soil layer (Lisetskii, 1987).

In the period of maximum development of grass stand the aboveground phytomass value with the height reaching 0-5 cm (before grazing period) is 26% of the total phytomass in aboveground layer for favorable year conditions. To estimate real productivity of the pasture in different years, the values presented in Table 2 should be reduced by 24–35%, subtracting the phytomass of the lower 5 cm plant parts. In this case, average productivity over the observation period would be 900–1000 kg dry phytomass per hectare or, at standard 16% humidity, 1100– 1200 kg/ha. These values are almost identical to those reported in the 19th and early 20th centuries, which is evidence that our observation period was sufficiently representative.

Steady grazing leads to increasing xerophytization of steppe cenosis, which is manifested in the reduced proportion of feather grass and increasing dominance of sheep's fescue and eventually leads to a general decrease in the productivity of steppes. Consequently, the input of organic matter to the soil with plant residues and the rate of humus reproduction decrease drastically, and prerequisites for soil alkalinization and deflation are created.

The annual amount of aboveground mortmass in the pasture proved to be lower than in virgin lands: 1390 vs. 2100 kg/ha, respectively.

The annual average amount of dead plants and litter was estimated at 700 kg/ha, whereas the amount of root attrition in the 0–20 cm soil layer reached 5300 kg/ha.

The dependence of productivity on meteorological parameters (Table 5) was analyzed using a continuous time series (1981–1992). Over this period, the annual amount of precipitation averaged 407.5 mm, varying in different years from 246 mm (1983) to 664 mm (1988); the annual average air temperature was 10.2°C. According to long-term data from the Odessa–Observatory weather station (absolute elevation 42 m) generalized in 1990, the annual average air temperature was 9.9°C and the total amount of precipitation was 446 mm, including 295 mm in the warm period (April–October). Until the past 20 years, normal annual precipitation was estimated at 374 mm. On the whole, it may be concluded that the ten-year period of our field studies adequately reflected characteristic climatic features of the study region.

Table 5. Meteorological conditions during the study period

Year	Annual precipitation, mm	Precipitation in March-November, mm	Annual average temperature, ^oC	Average temperature in March-November, ^oC	Q, MJ/m^2 per year	F+M*
1980	616.4	501.9	9.2	12.4	1214.7	-
1981	558.5	393.8	10.7	14.0	1208.7	14.34
1982	327.7	260.4	10.3	13.7	780.4	29.88
1983	246.5	188.9	10.9	14.1	556.0	12.84
1984	484.2	358.8	9.9	13.4	1076.0	10.75
1985	446.6	317.5	8.2	12.2	966.3	12.18
1986	405.6	237.7	10.1	13.9	946.6	8.98
1987	348.6	257.7	8.5	12.2	801.8	20.08
1988	663.6	513.6	9.8	13.2	1290.0	24.86
1989	310.0	292.4	11.5	14.4	745.3	23.20
1990	404.0	371.0	11.6	14.6	973.4	13.20
1991	344.0	-	10.2	-	818.1	18.40
1992	350.0	-	10.3	-	833.2	26.27
Norm	374	290	9.8	13.5	-	17.92

* F+M – the mass of aboveground phytomass (green mass and litter).
Data from the Odessa-Observatory weather station

The centennial dynamics of precipitation are characterized by alternation of dry and moist periods.

The annual amount of precipitation in Odessa between 1894 and 1974 averaged 386 mm, whereas that between 1965 and 1974 reached 471 mm (Zakharzhevskii, 1979). After the especially moist ten – year period (1960-1969), the amount of precipitation slightly decreased and stabilized between 1970 and 1992. However, significant deviations from this trend were recorded. For example, monthly precipitation in June 1984 and July 1988 reached 128 and 142 mm, with the norm being 56 and 39 mm, respectively (Table 5).

By 1991 (i.e., over 109 years), only seven warm winters were recorded in the study region, including those of 1982/1983, 1988/1989, and 1989/1990. In the same period, several winters were unusually warm. A southward displacement of the trajectories of Atlantic cyclones resulted in unusual phenomena such as the rise of daily average air temperature to 10–12°C above the norm in December 1989; the midday temperature reaching 15°C on December 18, 1989 (the highest value over the past 45 years); the average December temperature of 4.6°C (0.2°C in the norm) in 1982; the average February temperature 4.3°C (– 2.0° C in the norm) in 1990; and 18.2 °C recorded in Odessa on February 24, 1990 (the highest temperature over the century).

Climatologists analyzing the data obtained at the Odessa weather station from 1894 to 1990 revealed no definite dependence between the annual average air temperature and annual precipitation. To integrate conditions of heat and moisture supply in a given year, it appears expedient to use the bioenergetic approach proposed by Volobuev (1974). He suggested to appraise effectiveness pedogenesis through function Q – annual quantity of radiation energy consumption on pedogenesis. The function Q together with multiplier of conversion into Si-system is represented as follows

$$Q = 41{,}868\left[R \cdot e^{-18{,}8\frac{R^{0,73}}{P}} \right],$$

Q is evaluated in MJ/ (m^2 per year); R – radiation balance, kcal/(cm^2 per year); P – annual precipitation total, mm.

Generalized data on the primary production quantity of basic phytocenosis in zone with moderate climate conditions (these data are determined by appropriated climate conditions, radiation balance, precipitation total) allowed to receive (Lisetskii, 1996) analytical expression of average annual vegetation output depended (according to dry substance mass – F, t/h per year) on energy consumption on pedogenesis Q MJ/ (m^2 per year) as follows

$$F = 8.7 \cdot 10^{-8} \cdot Q^{2.69}, \eta \pm t_{05} S_{\eta} = 0.85 \pm 0.13.$$

This dependence evaluates the influence of climate factor equivalent to expenditure of energy on productivity process.

Thereupon, it is interesting to approve this approach for determining how climate conditionality influences on productivity rhythm (time development) within one natural zone, especially steppe one.

It was set negative correlation between aboveground phytomass (green phytomass and litter) in prepasture period from 1981 to 1922 and annual value of radiation energy consumption on pedogenesis (Q).

It would be incorrect to consider that the problem is in finding a direct relationship between pasture productivity and climatic conditions, since specificity of the growing period in a given year manifested itself not only in the total yield of phytomass but also in distinctive features of its regrowth after periodic removal by grazing pressure (within – year grazing period). Hence, years were arranged in series by the criterion of favorability, depending on their production potential, on the basis of data on the maximum values of aboveground green phytomass and dead parts in a feather grass–mixed herb association in the absence of grazing pressure in the 1980s (Lisetskii, 1992, updated).

In the observation period (1981–1989), a correlation was revealed between the Q value in the current year and the amount of phytomass in the next year (Spearman's rank correlation coefficient R_s = 0.50). Similar calculations for the pasture (1981–1992) showed that the aboveground phytomass (including necromass) in the pregrazing period of the next year correlated with annual radiation energy expenditures for soil formation (Q) in the current year (R_s = 0.58, $p < 0.001$), as estimated value t-criterion exceeds critical value Student's t-distribution in indicated value.

A correction was made only for 1989, which was one of the worst years with respect to bioclimatic conditions: total precipitation was only 310 mm, with 94% falling from March to December. However, the previous year was favorable, with the most abundant moisture supply over the observation period. This combination of factors apparently accounted for the fact that productivity of phytocenosis in 1989 was high both in the virgin plot and in the pasture.

The most favorable conditions for plant growth in 1988 were also accounted for by relatively low summer temperatures, in addition to abundant moistening: the average air temperature between May and September (18.2°C) had the minimum value over those years. The years 1982 and 1983, least favorable in terms of climate, were logically characterized by low productivity. However, correlation analysis revealed no connection between the maximum phytomass value and the annual amount of precipitation during the observation period. A probable explanation for this fact is that a major role belongs to the conditions of moisture accumulation in the autumn–winter period of the previous year. It is also important to take into account the amount of precipitation falling before July: after this hottest month, further increase in the amount of phytomass is observed rarely.

Data on the distribution of precipitation within the year between 1980 and 1990 were used for calculating the sums of precipitation in different periods of two subsequent years: from December to April, from June to May, from July to June, and from August to July. The closest correlation between the maximum phytomass value and the amount of precipitation was revealed for the period from July of the previous year to June of the current year.

Thus, the long-term average productivity (over the past 150 years) of pasture ecosystems adapted to climatic changes in the steppe zone equals 1100–1200 kg/ha, being subject to considerable variation. The parameter more strongly correlating with annual radiation energy expenditures for soil formation (according to Volobuev) is the amount of phytomass in the pregrazing period of the next (rather than current) year. The period in which the amount of phytomass correlates with climatic parameters most closely is the period from July of the previous year to June of the current year.

THE FORMATION OF CULTIVATED PASTURES ON LOW-YIELD ARABLE LAND

As a result of frequent using some territories as arable land, natural pastures in steppe and forest-steppe ecosystems can not supply livestock farming with pasture forage. Moreover at present some natural vegetation areas in staropakhotny regions (regions where lands were cultivated at all times, from of old) are rephugiums which have kept vegetation typical for this zone, rare and precinctive species of plants and animals. It is more efficiently to use many areas as basic territories of ecological system (for example: Pan — European) rather then subject to intensive cultivation.

Forest-steppe on the territory of the Central Russian Upland has high intensity in development of erosion processes and sizeable areas of low-yield arable lands. It is evident from the experience that under such conditions it is necessary not to use intensively some arable lands but to change them into cultivated grass- grazing lands.

To make grass stand on pastures, it is necessary to sow greater species diversity of legumes on grasslands. Great results in studying of herbaceous layers macrobiosis were obtained in some scientific institutions: Williams All-Russian Fodder Crop Research Institute (Russia), experimental station in Rotamsted (G.B.), the University of State Maryland (USA) and others. It was discovered potential for vegetative renewable of longevous agrophytocenosis which were used intensively. It was revealed that, as a result of serial processes, the dominant position in longevous herbaceous layers take rootstock and loose-bunch grasses. Most of research programs were developed for rather dewy and meadow phytocenose zones with acidic and neutral soils.

Peculiar soil group is carbonate chernozems. They have some unfavourable attributes for plant growth and development: alkali reaction from the surface, carbonate excess, weak motility of phosphorous compounds and microelements, strict water schedule.

Late research proves that calcareous soil area is increased in topsoil structure of staropakhotny forest-steppe and steppe regions of Europe. It is connected with erosion processes and more considerable, than in virgin land, gradient of soil liquor tightening to topsoil, induced by intensive physical moisture evaporation (Chendev, 2007).

Under formation of longevous cultivated pastures in ecological conditions of calcareous soils, the problems of legumes stability in mixed grass crop and increasing of their productivity are of special interest.

In the period of 2002-2007 in models of gramineae-legumes pastures herbaceous layers, where main component was legumes, they study six legumes species: *Onobrychis arenaria* (Kit.) Ser., *Lotus corniculatus* L., *Medicago falcata* L., *Trifolium pratense* L., *Medicago varia*., *Trifolium gibridum* L. Legumes component in mixed grass crop consisted of: *Lolium perenne* L. pasture ryegrass (100 pieces/m^2)+*Bromus inermise* (Leys.) Holud (200 pieces/ m^2) + *Festuca pratensis* Huds (200 pieces/m^2).

Soil is typical calcareous eroded weakly chernozem, humus content before the beginning of the experiment – 3.96-4.08%, pH$_c$ – 7.32-7.34.

Study results made it clear that maximum ratio of legumes (*Trifolium gibridum* L. (71.4%), *Medicago varia*. (85.6%), *Lotus corniculatus* L. (82.1%), *Trifolium pratense* L. (79%), *Onobrychis arenaria* Ser.(67%)) in mixed grass crop was in the second year of herbaceous layers existence. Maximum ratio of *Medicago falcata* L. was 43% in the third year. Later the tendency of cereals ratio increasing was marked. By the sixth year legumes ratio in mixed grass crop together with *Onobrychis arenaria* Ser. was maximum: 28.9%, with *Lotus corniculatus* L. (27.9%), and it was minimum together with *Medicago varia* (11.9%).

Cenopopulations of being studied species are mainly represented by even-aged examples. *Lotus corniculatus* L has significant renewal of self-seeding, but *Trifolium pratense* L. and *Trifolium gibridum* L. give only solitary coming-up.

As a whole, search revealed the stabilization tendency of ratio of all legumes species in herbaceous layer, beginning with the 4th year of existing at the same level (fig. 6).

In spite of its large ratio in herbaceous layer in comparison with another species, *Onobrychis arenaria* decreases dynamically its own participation relative to the initial status.

It is known that competition is relative. Competitive advantages are always exhibited against definite partners under particular environment conditions. In view of the aforesaid, common populations, according to the competitiveness extent of species, are usually divided into tree basic groups: predominant, indifferent and suppressed plants.

As a result of these interrelations, common legumes species are divided into different groups (in a qualitative sense) on the basis of some competitive aspects.

Competitive species can be stabile held in mixed grass crops for rather long period. This fact determines stabilization ratio of legumes after the fourth year of herbaceous layer existence and almost linear nature of its dynamics. It happens under pressure of ecotopic selection and competition between plants.

Analysis of legumes seeding done in 2002 revealed that by 2007 the ratio of therophytes or biennials in herbaceous layers *Trifolium pratense* L. was 43-54%, but *Trifolium gibridum* L. - 58-69%.

Studying cenopopulation *Lotus corniculatus* L. gave the same results. The ratio of therophytes and biennials in herbaceous layer was 28-32%. In checked variant (*Medicago varia*), seminal self-reproduction in herbaceous layer was not fixed in seeding of *Medicago falcata* L. and *Onobrychis arenaria* Ser.

It was discovered the medium-strenth positive correlation between seed quantity, getting into soil as a result of self-seeding at the end of vegetation period, and ratio of permanent grasses in crops by the sixth year of existing (r=0.653).

Close correlation was fixed between seed solidity and legumes ratio in pasture herbaceous layer by the sixth year of existing (r =0.853) and rather negative correlation – between projective coverage and quantity of coming-up received from self-seeding in mixed grass crops with *Lotus corniculatus* L. (r =-0.811), with *Trifolium pratense* L. (r = -0.912) and in herbaceous layers of Alsatian clover (*Trifolium hybridum* r =-0.776). There was not such correlation in crops with *Onobrychis arenaria* (Kit.) Ser., *Medicago falcata* L. and *Medicago varia* (r =-0.123....0.231).

Figure 7 – ratio dynamics of different plant groups in the harvest of absolutely dry substance of gramineae - legumes mixed grass crops on calcareous eroded chernozem which was used six years in the period 2002-2007,%. Notes: 1,2,3,4,5,6 – years of herbaceous layers usage.

In 2002-2007 mixed grass crops with *Onobrychis arenaria u Lotus corniculatus* have the most crop stability (Table 6)

Table 6. Yield of pasture mixed grass crops with different species of legumes on calcareous chernozem, t/ha absolutely dry substance

№	Legume component of mixed grass crops	Year for study						Average
		2002	2003	2004	2005	2006	2007	
1	*Medicago varia*	1.07	4.86	5.90	4.23	2.73	1.86	3.44
2	*Medicago falcata .*	1.04	3.74	4.03	4.29	3.36	2.45	3.15
3	*Lotus corniculatus .*	1.20	5.22	5.90	4.90	3.47	2.67	3.89
4	*Trifolium pratense .*	1.06	5.20	3.57	2.06	1.88	1.63	2.57
5	*Trifolium gibridum .*	1.49	5.07	3.72	2.12	1.07	1.02	2.41
6	*Onobrychis arenaria*	1.09	5.07	6.46	5.05	4.14	3.64	4.24
LSD $_{05}$		0.16	0.59	0.70	0.60	0.36	0.33	

Average for six years, the largest gather of feed units (3329 kg/ha) was provided by mixed grass crops with *Onobrychis arenaria*, the smallest – with *Trifolium pratense* (2242 kg/ha) and *Trifolium gibridum* (2239 kg/ha).

Within the bounds of experience, Hungarian sainfoin crops in mixed grass crops allowed to gather maximum quantity of fat (142 kg/ha), free-nitrogen extract (1895 kg/ha), ash (322 kg/ha) supplying feed unite with digestible protein 128.8 g. As the control, mixed grass crop with Medicago varia yielded these indices to mixed grass crops with *Lotus corniculatus* and *Onobrychis arenaria*.

As a whole, search revealed hard positive correlation between content of easy hydrolyzable nitrogen in soil and gather of digestible protein (r =0.876), between legumes ratio in crops and gather of digestible protein (r =0.776), between crop-producing power of dry substance and legumes ratio in mixed grass crops (r =0.854).

There was positive correlation of medium strength between pH_{KCl} quantity and gather of digestible protein (r =0.546) in mixed grass crops with *Onobrychis arenaria*. Such close correlation was not observed in other plantings (r =-0.246....0.123).

CONCLUSION

The analysis of land management forms connected with plant substance alienation in zonal phytocenosis allows us to correct productivity changes caused by an anthropogenic factor in different historic and ecological periods. This fact permits us to restore plant product changes (for the last 10 000 years) caused by natural and anthropogenic parameters due to calculation method of radiation energy consumption. Thus, the new approach prospects are well founded. According to this approach, the function of time changing in the zonal ecosystem productivity is described mathematically. This function reflects the periodicity of climatic processes and anthropogenic impact.

The long-term average productivity (over the past 150 years) of pasture ecosystems adapted to climatic changes in the steppe zone equals 1100–1200 kg/ha, with the coefficient of variation reaching 40%.

It is determined that the traditional approach in finding a direct relationship between pasture productivity and climatic conditions is unproductive. Specificity of the growing period in a given year manifested itself not only in the total yield of phytomass but also in distinctive features of its regrowth after periodic removal by grazing pressure (within – year grazing period). Years were arranged in a series by the criterion of favorability, depending on their production potential, on the basis of data on the maximum values of aboveground green phytomass and dead parts in an association in the absence of grazing pressure.

The parameter more strongly correlating with annual radiation energy expenditures for soil formation (according to Volobuev) is the amount of phytomass in the pregrazing period of the next (rather than current) year. The period in which the amount of phytomass correlates with climatic parameters most closely is the period from July of the previous year to June of the current year.

It is defined that species diversities value influences productivity of herb-grass and herb-bunchgrass communities of pastures within gully plantings. Alpha diversity is more dominant: the more diversity, the more aboveground phytomass. Beta-diversity has less impact on bioproductivity due to relative uniformity of soil and ecological conditions.

Under formation of cultivated pastures grass stand in calcareous eroded chernozems in forest-steppe longevity is formed by gramineae-legumes mixed grass crops on the bases of *Onobrychis arenaria* and *Lotus corniculatus*. The use (for six years) of mixed grass crops with *Onobrychis arenaria* yields 4510 kg/ha of dry substance, *Lotus corniculatus* – 3910 kg/ha. Under these conditions, crops of *Medicago varia, Trifolium pretense, Trifolium gibridum* can be effective when they are used no more than 3 years. The competitive influence of crop grasses in relation to legumes in calcareous eroded chernozem is higher if the portion of phosphorus and nitrogen amassed in legumes rhizosphere in relation to surrounding soil is more and pH_{KCl} of soil solution is lower. The rhizosphere of *Onobrychis arenaria* is characterized by reduced portion of total nitrogen in comparison with surrounding soil, the absence of differences in phosphorus portion and increased $pH_{KCl.}$ All these facts determine high stability of this planting in mixed grass crops in calcareous chernozem.

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Chapter 3

PASTURES OF THE U.S. WESTERN GULF COAST REGION

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ABSTRACT

The native vegetation of the U.S. Western Gulf Coast Region included areas of natural grassland where an early livestock industry developed. Much of this natural grassland, along with a large portion of the upland forest following initial timber harvest, was gradually converted to pastures of introduced grasses and legumes to improve livestock production. Warm-season perennial grasses, particularly bermudagrass (*Cynodon dactylon*) and bahiagrass (*Paspalum notatum*), have been well suited for pasture use on most sites within the region. These grasses effectively support cow-calf production systems; however, supplemental sources of nutrients are required seasonally. Cool-season forage species, especially annual ryegrass (*Lolium multiflorum*), have become important components of pasture systems to supplement the warm-season grasses for cow-calf production and have also provided opportunity for stocker cattle enterprises and supplemental grazing by dairy cows on concentrate-based rations. Due largely to favorable economics of production and comparative ease of management, nitrogen fertilizer and chemical weed control have become common pasture management practices. A tremendous variety of production approaches has resulted from the number of potentially useful pasture plants, the range in levels of inputs and management providing profitable results, and the variation in size of pasture-based enterprises within the region. Recent dramatic increases in input costs have limited profitability of highly productive pastures based on high levels of inputs. Demands of society for changes in the use of pastures are reflected in a declining profit margin provided by the value of weaned calves relative to the cost of their production, while at the same time increasing income opportunities are provided by alternative uses, products, and management of pasture resources. Current opportunities appear to present diverging directions for economically sustainable pasture systems in the region. Integrating pasture systems with rather extensively managed wildlife habitat and conservation areas provides an opportunity to decrease inputs and capture alternate income. On the other hand, high-value pasture products such as grass-fed beef may provide options for pastures of appropriate plant species with very high levels of management and an associated substantial level of risk. While some rather dramatic changes may provide a distinctly different character to pasture systems within the region in coming decades, less drastic changes based on increasing efficiency of forage production and utilization will also likely allow many existing pasture-based cow-calf enterprises to persist in essentially their current form, although perhaps at less profitable levels than during most recently past decades.

INTRODUCTION

The U.S. Western Gulf Coast Region is the portion of the southeastern U.S. coastal plain west of the Mississippi River along with adjacent and interspersed lowlands. Although extending across a rather narrow range in latitude, the area encompasses the transition from a warm-temperate to a subtropical climate within the humid zone. Soils of the uplands are typically leached, infertile, and acid with lime and fertilizer amendments needed for productive stands of most introduced pasture plants. The predominant vegetation of much of this upland portion of the region was southern pine (*Pinus* species) forest or mixed pine-hardwood forest prior to the time of initial agricultural development. Dense forest in the northern part of the region and bands of coastal marsh and prairie grassland were separated by an expansive area of longleaf pine (*Pinus palustris*) savanna on the southern coastal plain of Louisiana and extending into eastern Texas. Vegetation of the natural grasslands and the widely adapted introduced forage grasses have been predominately warm-season perennial grasses. Degradation of native grassland plant communities, often through over-grazing, and the superior production potential of the introduced perennial grasses led to conversion of most of the native grazing lands to pastures of introduced species or to other land uses. Pasture systems in the uplands are commonly based on bermudagrass and bahiagrass, with dallisgrass (*Paspalum dilatatum*) providing an additional species of importance on lowland sites. A variety of additional grasses and legumes contribute to production of individual pastures within the region. Although periodic droughts characterize the climate and impact pasture production, fertilization, particularly nitrogen, often determines pasture productivity. Natural plant succession to woodland in this humid climate requires on-going management to maintain stands of introduced pasture plants. Burning has historically provided the needed competitive advantage for grasses in the natural grassland communities, while herbicides and mowing have traditionally been used to reduce competition from forbs and woody species in pastures of the introduced grasses. Seasonal forage quality limitations of the warm-season perennial grasses constrain their value for some classes of livestock but fit well with cow-calf production systems. Continuing pasture management activities involve establishment and production of cool-season annual grasses and legumes to complement the seasonal forage production of the widely adapted warm-season perennial grasses. These high quality cool-season forages also provide opportunities in the region for pastures to contribute to other livestock enterprises including dairies and stocker cattle production for development of both feeder cattle and replacement heifers.

NATIVE GRASSLANDS

Pastures in the Western Gulf Coast Region of the U.S. have included varied and changing grazing lands and forage plants ever since grazing livestock were introduced to the region. Native vegetation of the coastal marshes and adjacent prairie of Louisiana and eastern Texas provided an existing forage resource as cattle and horses were brought into the region through the Gulf of Mexico. As the coastal plain pine-forested uplands were settled, rather small areas of naturally occurring prairies and clearings of settlers provided the rather limited pastures of northern Louisiana and the adjacent coastal plain portions of eastern Texas and southern Arkansas. Much of the southern coastal plain in Louisiana and eastern Texas was dominated by open stands of longleaf pine with a grassland understory. Commercial harvest of the natural pine forest beginning shortly before 1900 and continuing through the next few decades produced a cut-over landscape used extensively for grazing. Much of the region became a fire-maintained, open-range grazing land as timber harvest progressed. Forage plants consisted of a wide variety of native species dominated across extensive areas by the bluestem grasses (*Schizachyrium* and *Andropogon* species). The combination of coastal marsh and prairie grassland and extensively deforested upland in the region provided a substantial forage base for livestock production.

The coastal marsh area of eastern Texas along the Gulf of Mexico has been referred to as the "Cordgrass Rangeland Cover Type" or the "Southern Cordgrass Prairie" [Drawe, 1994a], indicating the dominance by various cordgrass (*Spartina*) species along with several other wetland grasses. In Louisiana, the distinct differences in plant species and grazing opportunities provided by portions of this area differing in salinity resulted in designations of separate Gulf Coast Salt Marsh and Gulf Coast Fresh Marsh plant communities [Cutshall, 1994 a&b]. Even though the forage value of fresh-water marsh is typically superior from early spring until summer and that of the salt-water marsh is better suited for winter use [Shiflet, 1963], grazing of both marsh types has often been concentrated during the cooler portion of the year due to insect problems during the warm season [Cutshall, 1994 a&b]. Water level and salinity are major determinants of plant species composition and forage value of these coastal marshes [Shiflet, 1963]. Management approaches to enhance livestock production including levee and pump systems for water control on smaller marsh areas, small levees with staggered borrow pits for cattle walkways into less-accessible areas, planting of introduced forage plants on ridges and levee-controlled areas, fences for livestock control, and even seasonal hay harvest on selected areas became recommended practices in the 1950s as illustrated by Miller [1956]. Water control allowed the desirable native forage grass longtom (*Paspalum lividum*) to dominate and provide summer grazing on fresh-water to slightly saline areas [Shiflet, 1963], where removal of surface water also provided some relief from insects. Bermudagrass, a non-native, spread into drier portions of the highly managed native-grass pastures [Miller, 1956; Shiflet, 1963]. Further development of pastures on sufficiently dry sites, either natural ridges or leveed areas, within the marsh included sowing white clover (*Trifolium repens*) and dallisgrass, which formed persisting stands in association with the native longtom and rapidly naturalizing bermudagrass [Miller, 1956]. On such sites, annual ryegrass was also planted for high-quality temporary cool-season pasture [Miller, 1956]. Even though water control was beneficial for many desired forage plants, drainage was detrimental to some highly valued forage species such as maidencane (*Panicum hemitomon*)

[Williams, 1951]. This grass and other desirable forage plants were also vulnerable to salt-water intrusion, often resulting from canal construction, and to excessive grazing pressure along with land use changes [Williams, 1951] as infrastructure development including roads and water control allowed increasing areas of crop production. In addition to these early recognized decreases in desirable forage plants, loss of the marshland itself was subsequently acknowledged in association with rather rapidly expanding rice farming, land subsidence, excessive grazing and associated pasture development, petroleum industry infrastructure expansion including access channels, and flood control efforts [Drawe, 1994a]. Louisiana coastal wetland conversion to open water has been estimated at 3,460 km^2 between 1956 and 1990 [Bourne, 2000] with primary causes suggested as high subsidence rates, rising sea level, dredging, and conversion of wetlands to agricultural and industrial uses [Coleman et al., 2008]. The mixture of natural and managed processes contributing to decreased wetlands, including the marsh grazing resource, involve even the forage and livestock management practices of the grazing resource. The pump-and-levee systems improving the forage resource and increasing livestock production also contribute to land subsidence. Subsidence, or the literal sinking of land into the sea, of Louisiana coastal wetlands cannot readily be apportioned among the complex interacting natural geologic processes and the various distinctly anthropogenic activities involved [Yuill et al., 2009]. In addition to the various on-going, long-term processes of wetland deterioration in the region, during the first decade of the 21st century additional land loss due to hurricanes contributed substantially with loss of 560 km^2 from just the 2005 hurricanes Katrina and Rita [Louisiana Department of Natural Resources, 2009]. In addition to the land losses, comparatively short-term localized loss of plant communities and forage production also occurred in response to several hurricanes during the decade. As noted by Drawe [1994a], even though marshlands are among the world's most productive lands, they are also among the most vulnerable and the future of the Western Gulf Coast marsh resource appears bleak.

The coastal prairie of the Western Gulf Coast Region has been estimated to have covered an area of one million hectares (10,000 km^2) in Louisiana and 2.6 million hectares (26,000 km^2) in Texas prior to conversion of much of the area to other land uses [U.S. Fish & Wildlife Service, 1999]. In Texas, a total area of coastal prairie approaching 26,000 hectares remains largely due to continuous use of prairie areas as hay meadows or rangeland resources for grazing livestock. Species composition changes of the remaining area largely as a result of grazing, or perhaps overgrazing, are suggested [U.S. Fish & Wildlife Service, 1999]. Loss of big bluestem (*Andropogon gerardii*) and Indiangrass (*Sorghastrum nutans*) were specifically noted. While this coastal prairie has many similarities to the tallgrass prairie of the central Great Plains, the Louisiana and Texas portions of the coastal prairie each appear to have rather distinct characteristics. Prairie remnants in Louisiana are dominated by switchgrass (*Panicum virgatum*), big bluestem, little bluestem (*Schizachyrium scoparuim*), and Indiangrass, while little bluestem, brownseed paspalum (*Paspalum plicatulum*), and Indiangrass dominate on less-disturbed coastal prairie remnants in Texas [U.S. Fish & Wildlife Service, 1999]. Other than a few small remnant areas, the coastal prairie in Louisiana has been converted to crop and pasture lands of introduced species. Along the coast of southeastern Texas immdeiately inland from the coastal marsh, the coastal prairie areas remaining have been referred to as the "Bluestem-Sacahuista Prairie" [Drawe, 1994b]. According to Drawe [1994b], much of this grassland now has sufficient woody plant composition to constitute a shrub-grass complex. Dominant grasses on areas grazed for decades include little bluestem, seacoast bluestem (*S. scoparium* var. *littoralis*) and gulf cordgrass (*Spartina spartinae*) or sacahuista, as it is commonly called locally. As a rangeland resource, fire and grazing management are important tools for maintaining the grassland plant community and its forage value.

The longleaf pine savanna typically consisted of an open pine stand with an understory plant community dominated by bluestem (both *Schizachyrium* and *Andropogon* species) grasses [Cassady, 1951; Grelen, 1978]. Natural fires from lightening apparently provided recurring disturbance interrupting succession to woodland allowing development of the savanna ecosystem. Although limited in productivity due to naturally leached infertile soils, the extensive area involved supported a livestock industry particularly important to initial development of the region. Extensive harvest of the virgin pines in the first half of the twentieth century resulted in substantial increases in forage production even on the longleaf pine savanna. In areas of the more dense-growing stands of slash (*Pinus elliottii*) and loblolly (*P. taeda*) pines and shortleaf (*P. echinata*) pine further north, timber harvest combined with repeated burning resulted in even greater increases in herbaceous plant productivity useful as a forage resource. Although recognized as useful locally and rather rapidly stocked for livestock production, forage productivity was limited by low soil fertility, and nutritive value was seasonally inadequate for efficient livestock production. The prevailing open-range stocking combined with the forage limitations to produce a highly inefficient livestock production system characterized by excessive stocking rates, low calf-crop percentages, and low weaning weights of calves. Just as similar livestock production characteristics led to interest in improving the forage resource in the coastal marsh, research programs were developed to identify the key seasonal limitations to livestock production presented by the native upland forage resource and present opportunities to overcome these deficiencies [Cassady, 1951]. Some early research focused on management of the native herbaceous vegetation as a rangeland resource [Cassady, 1953; Duvall, 1962; Grelen and Epps, 1967], while other efforts focused on animal nutrition limitations or conversion of the land to crops, introduced pasture plants, or back to forest. The upland portion of the region gradually became characterized by rather intensively managed pine forests with interspersed pasturelands of introduced forage plants supporting more intensively managed livestock production systems during the last half of the twentieth century. Throughout this period, hardwood bottomland forests across the region were widely developed for crop production with planting to pastures of introduced forage plants often serving as an alternative or secondary land use in response to economic and environmental needs, particularly on sites less desirable for crop production.

Extent of the native grazing resource greatly decreased through the last half of the twentieth century, and the open-range livestock production approach only persists in some localized areas of coastal marsh where the marsh environment along with repeated hurricanes limit both opportunity for and effectiveness of attempts at infrastructure development. Native grasslands of the coastal marsh in both Louisiana and Texas and areas of coastal prairie in Texas continue to be used as grazing lands. They are, however, often used as seasonally grazed native-grass pastures in forage systems along with pastures of introduced forage plants.

INTRODUCED PASTURES

General Pasture Characteristics

Livestock producers using the native forage resource gradually became interested in other pasture options. The list of factors contributing to this interest include: the native grasslands provided only seasonal forage production; the native plants preferred by grazing livestock were sometimes lost with heavy grazing pressure; and the native plants failed to respond with increased production when fertilized. These factors were magnified by loss of open-range grazing as large land-holdings of timber companies became unavailable for public grazing. The comparatively small size of many of the remaining grazing enterprises intensified the need for increased pasture production. Introduced forage species, initially planted as rather small supplemental pastures, became key components of forage systems to replace the lost open-range grazing land and to increase productivity of domestic livestock. One of the first widespread introduced grasses in the region was carpetgrass (*Axonopus compressus*) [Duggar, 1925], which became naturalized on moist sandy sites and increased on such sites as native grasses were weakened by heavy grazing pressure. Although supporting grazing for an extended portion of the year, carpetgrass is neither productive nor highly responsive to fertilizer. Prior to widespread use of fertilizers on pastures and development of the improved bermudagrass cultivars, however, carpetgrass was often recognized as superior to the naturalized bermudagrass varieties [Duggar, 1925]. Carpetgrass can still be an undesired, invasive plant in pastures of introduced grasses on moist, sandy sites under heavy grazing pressure and low soil fertility.

With widespread use of introduced pasture grasses, legumes became increasingly important as a source of nitrogen and forage of high protein concentration. Cool-season legumes also extended the grazing period into the dormant season of the summer-growing grasses. As rather inexpensive nitrogen fertilizer became readily available in the middle of the twentieth century, the widely adapted, introduced, warm-season, perennial grasses became the primary forages of the region, and interest in legumes decreased. Bermudagrass and bahiagrass provided both pasture and hay for winter feeding on most of the soil types within the region, while dallisgrass provided a rather extended grazing period primarily on moist, fertile soils. A wide variety of cool-season legumes, primarily *Trifolium* species, and cool-season annual grasses (the small grains and annual ryegrass) proved useful as winter annual pasture. These cool-season forages have, however, required more intensive management and involved greater cost and risk than do the warm-season perennial grasses. They have therefore been less extensively used, and the warm-season perennial grass pastures have become the base forage for most livestock production in the region. A somewhat reciprocal relationship exists between the type of forage grown and the class of livestock or animal enterprise supported. As appropriate for the comparatively low nutritive value of the warm-season perennial grasses during much of the growing season, cow-calf enterprises predominate as the primary livestock production approach in the region. The buffering capacity of mature cows due to their ability to consume large amounts of forage and contribute a consistent-quality milk component to diets of nursing calves can overcome much of the nutritional limitation of these pastures as illustrated by Rouquette et al. [1994]. More intensively managed cool-season annual grasses and legumes, which are of high nutritive value, supplement the warm-season grass pastures in cow-calf production, support stocker cattle enterprises, and contribute to dairy production in the region. Stocker cattle enterprises, which involve the rapid growth phase of young recently weaned cattle being developed for feedlot placement or as breeding-herd replacements, are often located on the more fertile bottomland soils where pastures of the cool-season annual species are particularly productive. Pastures in dairy production systems in the region contribute primarily as supplemental sources of nutrients in addition to base concentrate rations. Very high quality forages, such as the cool-season annuals, allow high levels of nutrient intake to support high milk production levels.

Management Options for Introduced Pastures

The bermudagrass varieties which initially became widely distributed and naturalized across the region were weeds of cultivated areas spread by seed and vegetative material (rhizomes and stolons). Improved bermudagrass varieties developed through plant breeding programs became important pasture and hay plants largely due to superior production potential and responsiveness to nitrogen fertilizer. A number of hybrid bermudagrass varieties [Holt and Lancaster, 1968a; Eichhorn et al., 1984; Gates et al., 1989] beginning with the use of the cultivar Coastal, which was released in Georgia in 1943 [Burton, 1943], have been important pasture and hay plants in the region. Different cultivars have been among the outstanding group in different environments and management approaches through the years. Due to lack of viable seed production, vegetative propagation is required for the hybrid bermudagrasses. Although the widely naturalized seed-propagated bermudagrasses were not as productive as the early hybrid varieties, a seed-propagated forage-type bermudagrass variety marketed as "common" bermudagrass has not been substantially less productive than many of the hybrid varieties on various sites at lower rates of nitrogen fertilizer. This common bermudagrass from seed production fields in southern California and Arizona is still widely planted in the region. In recent years, seed of a number of named varieties of bermudagrass, many including the "California-Arizona" common variety in mixtures with turf-type varieties or the poorly adapted giant bermudagrass, have been aggressively marketed. These have not been consistently superior to the available forage-type common bermudagrass. Although improved productivity has been reported for selected seed-propagated varieties [Evers, 2009], the limited seed production of these selections has allowed their use only in mixtures with seed of other bermudagrass varieties. This approach has masked or at least diluted the superior production potential of these selections in the commercially available seed mixtures. The tremendous range in bermudagrass genotypes and management approaches with pastures of bermudagrass result in substantial differences in pasture productivity, stand sustainability, and nutritive value of the forage available for grazing as illustrated by Holt and Lancaster [1968b], Nelson et al. [1980], Nelson et al. [1983], and Greene et al. [1990]. Inherent soil fertility and fertilization practices along with available soil moisture and the grazing pressure imposed largely determine the forage production of hybrid bermudagrasses, since the production potential of these grasses often exceeds the production limits imposed by available plant nutrients, moisture, and/or leaf area maintained under grazing to support photosynthesis. Bermudagrass pastures in the region, especially those of the hybrids, are highly vulnerable to invasion by undesirable species when soil fertility is not maintained and plant vigor and competitive ability are reduced by excessive grazing pressure.

Bahiagrass has been widely planted in the region because it can partially overcome some of the limitations of the hybrid bermudagrasses under less intensive management. It is established from seed; it can tolerate closer grazing; and stands are more competitive on infertile soils than are the hybrid bermudagrasses. For productive pastures, soil fertility, weed control, and maintenance of sufficient leaf area for efficient photosynthesis are required by bahiagrass just as by hybrid bermudagrasses. Flexibility with pasture maintenance is increased, however, by the tolerance of periods of less intensive management and limited resource inputs by bahiagrass pastures. Additionally, the ability of bahiagrass stands to take up and store nitrogen fertilizer for later growth responses from a single large fertilizer application [Pitman et al., 1992] further expands pasture management options with this grass. Along with extensive planting, bahiagrass has spread naturally within pastures of the region, particularly into bermudagrass pastures. When livestock grazing bahiagrass pastures have been moved to pastures of other grass species, seed consumed by the grazing animals has been passed through the digestive system and dispersed in the new pasture. The process of bahiagrass establishment or invasion from initial widely scattered individual plants recognized by their rather unique, highly visible seedheads to distinct colonies of bahiagrass sod and eventually pasture dominance can be readily detected. Although selective herbicides have been available to control bahiagrass spread into bermudagrass stands, these have often required repeated application and have provided more satisfactory results in carefully managed hay fields than in grazed pastures. As with bermudagrass, improved bahiagrass cultivars have been developed. Cultivars with superior performance potential have not consistently provided superior forage production in the region as shown by Cuomo et al. [1996], and responses of the improved varieties often depend on the environmental conditions and management provided. A few years of heavy grazing pressure on pastures of varieties improved by selection for upright growth potential within the Pensacola variety can apparently induce the population back to dominance by the more grazing-tolerant, low-growing genotypes within the highly heterogeneous Pensacola plant population.

Along with bermudagrass and bahiagrass, dallisgrass is often listed as one of the widely used warm-season, perennial pasture grasses of the region. Unlike the other two species, dallisgrass is rather limited in area of adaptation and does not form a dense sod to support development of near-monoculture stands. Holt [1956] noted that information regarding animal performance on pure stands of dallisgrass in grazed pastures was not available largely because dallisgrass pastures, in contrast to the other warm-season perennial introduced grasses, are not managed as pure stands. White clover and common bermudagrass are frequent components of "dallisgrass" pastures. Such mixed dallisgrass pastures produced higher average daily gains of nursing calves than Alicia bermudagrass at comparable levels of forage availability [Wyatt et al., 1997], while stocker steers did not gain more on dallisgrass pastures than on Coastal bermudagrass pastures at the same stocking rate [White and Hembry, 1985]. Steers grazing the dallisgrass pastures did gain more and produce more carcass marbling than steers on bahiagrass pastures [White and Hembry, 1985]. Results of such pasture comparisons among species are highly dependent upon management variables, particularly nitrogen fertilization and grazing pressure, imposed. Dallisgrass plants can be only short-lived perennials under heavy defoliation pressure with sustainable stands provided by continuing recruitment of new seedlings. Heavy grazing pressure during repeated years of low warm-season rainfall can lead to loss of stands. With adaptation to moist fertile sites and bunchgrass-type growth, dallisgrass mixtures with white clover have been particularly successful. While such pastures can provide comparatively high quality grazing through most of the year, productivity is typically lower than that of highly fertilized hybrid bermudagrass pastures. Management of dallisgrass-clover pastures is complicated by susceptibility of the associated white clover to some of the most effective selective herbicides for controlling common problem weeds in perennial-grass pastures. Also, infestation of dallisgrass seedheads by an alkaloid-producing ergot fungus can cause toxicity problems for grazing livestock. Yet another dissimilarity with the other common perennial warm-season grasses of the region is the lack of improved cultivars. When seed becomes available, the recent release of Sabine dallisgrass [Burson et al., 2009] will provide a potentially more productive variety, while further improvements in seed quality and stand sustainability are anticipated from additional germplasm now under evaluation [Pitman et al., 2005]. Dallisgrass has not been widely planted in recent years due to limited seed availability and frequent slow stand establishment of common dallisgrass plantings.

Just as the general characteristics of the widely planted warm-season perennial grasses determine to a large extent the livestock enterprise that is most readily suited to the region, the management approach of this livestock enterprise and the choice of other alternative livestock enterprises determine the suitability of other available forage species. Cow-calf production systems based on warm-season grass pastures can be managed using a fall calving season to wean heavy calves with the benefit of high-quality annual ryegrass grazing in spring. Alternatively, a spring calving season can be used with annual ryegrass grazing to stimulate milk production at calving and/or for cool-season grazing of calves following fall weaning. In such systems, productivity of base warm-season grass pastures and the supplemental cool-season annual ryegrass pastures is dependent upon nitrogen fertilization. In such cow-calf systems, at least part of the annual ryegrass component of the pasture system can be provided by over-seeding the cool-season annual grass into dormant warm-season grass pastures. Earlier and more reliable pasture stands of annual ryegrass can be provided by planting the crop on a well-prepared seedbed. Such an intensive approach is typically used for annual ryegrass pastures supporting dairies and stocker cattle operations in the region. Pasture systems of annual ryegrass for cool-season grazing combined with the warm-season annual crabgrass (*Digitaria sanguinalis*) for summer grazing are used in some intensively managed pasture systems for classes of livestock responsive to high-quality forage. Crabgrass and other warm-season annual grasses are typically higher in forage nutritive value than are the warm-season perennial grasses. As with dallisgrass, annual ryegrass can be readily grown in mixture with cool-season legumes to provide increased efficiency of production when nitrogen fertilizer cost is high.

Although a number of alternative cool-season legumes are available, the number of useful options on an individual site is somewhat limited. Only the true clovers (*Trifolium* species) have been widely used as pasture legumes in the region. Alfalfa (*Medicago sativa*) has been used commercially as a hay crop in the region; however, it has not been successfully used as a sustainable pasture plant. As noted by Evers [1976] for southeastern Texas, Louisiana S-1 white clover has been the most widely used cool-season pasture legume in the region. Other varieties of white clover have increasingly been used in recent years, and several different annual clover species are used in specific situations. Even though use of white clover in pastures within the region has been restricted primarily to bottomland sites, it is used on such pastures throughout the region. It can also be a useful component of pastures on upland soils with intensive management including planting each year [Bagley et al., 1988; Mooso et al., 1990; Morrison et al., 1994]. Evaluations within the region have identified more-persistent white clover germplasm [Brink et al., 1999], and the white clover varieties with improved sustainability now available, particularly the cultivar Durana, hold promise to expand the opportunities for use of this species. The annual clover species berseem (*Trifolium alexandrinum*) and Persian (*T. resupinatum*) clovers have also been useful in bottomland pastures. Appropriate varieties of berseem clover can provide productive pastures with grazing extending throughout the spring period; however, stands must be planted each year. Persian clover has potential to re-establish from soil seed supplies, and, under appropriate conditions, volunteer stands have provided excellent early to mid spring grazing. Bloat can be a distinct hazard with Persian clover. On upland sites, arrowleaf (*T. vesiculosum*) and crimson (*T. incarnatum*) clovers have been used to rather limited extents in the region. Although arrowleaf clover provides an extended period of growth into late spring along with reseeding potential, disease susceptibility has limited its use. Reduction in the disease problems of arrowleaf clover has been provided with development of the cultivar Apache at Overton, Texas [Smith et al., 2004]. Crimson clover can provide grazing from late winter through early spring, but the rather short grazing period and often unreliable reseeding are limitations to wider use. The potential of annual clover species to provide nitrogen, improved forage quality, and an extended grazing period beyond that provided by the warm-season grasses has been rather well demonstrated [Evers, 1985]. Considerable management expertise and commitment to successful use of the legumes, however, is required. Early termination of spring grazing is critical for effective reseeding of most annual clover species, especially crimson [Evers and Smith, 2006]. Both a reduced grazing period and increased competition with spring-growth initiation of associated warm-season grasses are incurred with the early termination of clover grazing. Ball clover (*T. nigrescens*), which is not highly productive, has been used to a limited extent largely because it can reseed even with continuous grazing pressure.

Despite the tremendous potential of clovers in the region, they continue to be highly under-utilized. Perhaps due largely to limitations regarding dependability and ease of management, even the cool-season grazing advantage of clovers has been less appreciated than that of the cool-season grasses. The availability of Gulf annual ryegrass, the first improved annual ryegrass cultivar well adapted to the region [TAES, 1958], resulted in tremendous increases in total forage production and period of forage availability from cool-season pastures. Although numerous additional annual ryegrass cultivars have been released in recent decades, Gulf annual ryegrass is still widely planted in the region each autumn. Increased cold tolerance and disease resistance are major advantages of some of the more recent annual ryegrass cultivars [Nelson, 1995]. Yield rankings and actual differences in productivity among a rather large group of improved varieties depend on growing conditions associated with rather unpredictable weather patterns [Redfearn et al., 2005]. Thus, no single individual cultivar has been consistently superior to several other available cultivars. The small grains often provide earlier grazing, although with a much shorter spring growth period, than do most annual ryegrass cultivars. Mixtures of a small grain, particularly cereal rye (*Secale cereale*), with annual ryegrass have been used to provide earlier grazing than is typically available with ryegrass alone [Bagley et al., 1988].

The potential to develop pastures of cool-season perennial species comparable in sustainability to the warm-season perennial grass pastures of the region appears to offer environmental and economic benefits. Tall fescue (*Festuca arundinacea*) was found to be adapted to fertile, but not flooded, fine-textured alluvial bottomlands in the northern and central parts of the region. Joost and Coombs [1989] estimated that there were 24,000 hectares of tall fescue pasture in Louisiana in 1980. Toxicity problems of cattle grazing tall fescue pastures infested with an alkaloid-producing fungal endophyte resulted in conversion of much of the tall fescue pasture to other species. By 1992, Alison et al. [1992] determined that tall fescue was not used to any appreciable extent in Louisiana. Useful cultivars of tall fescue without the fungal endophyte were developed in the region of the U.S. where tall fescue pastures predominate, but these endophyte-free cultivars were not persistent in Louisiana [Joost and Coombs, 1989] largely due to lack of tolerance of stresses from summer heat and associated periods of limited rainfall. In northern Texas, survival of drought stress by tall fescue was found to be enhanced by presence of the fungal endophyte [Read and Camp, 1986]. Discovery by New Zealand researchers of such a fungal endophyte, which does not produce the toxic alkaloid compounds, has led to stress-tolerant cultivars of tall fescue without the toxicity problem for grazing livestock [Bouton, 2007]. Potential for these cultivars in Louisiana has been indicated by both research [Hopkins and Alison, 2006] and a substantial amount of commercial planting. Some stand loss of the new non-toxin-producing-endophyte tall fescue plantings has occurred, thus both site of planting and management of stands may be critical for long-term stand life of even the improved tall fescue cultivars. On-going research efforts by commercial seed companies in association with university research programs in major tall fescue-producing areas is expected to result in further improvements with tall fescue including the fungal endophyte.

As with the cool-season pasture grasses grown in the region typically for specific purposes within warm-season perennial grass-based pasture systems, a few rather special-purpose warm-season grasses are also occasional contributors to pasture programs in the region. Pearl millet (*Pennisetum glaucum*) and forage sorghums (*Sorghum bicolor*) including sudangrass are somewhat similar growing and similarly used, large-stemmed, annual species. Both require rather intensive management, although pearl millet is adapted to more sandy soil than are the sorghums. Due to expense of production and intensity of management required for efficient use, these crops have been considered useful in beef cattle production primarily in emergency, forage-deficit situations [Twidwell, 2001]. They can be effectively used for stocker or dairy pasture with intensive grazing methods such as strip grazing. Toxicity hazards, both nitrate accumulation and prussic acid in sorghum and only nitrate accumulation in pearl millet, are concerns with grazing livestock on pastures of these species. Another warm-season annual grass used in Louisiana pastures, crabgrass, is a lower growing, less upright plant than the sorghums and pearl millet. It is a local weed and often volunteers in pastures and fallow fields. Livestock grazing pastures of the perennial warm-season grasses in the region sometimes benefit from the higher forage quality of interspersed crabgrass plants, which are often not even noticed in the pasture stand. Volunteer crabgrass stands on fallow fields are, on occasion, grazed opportunistically as they happen to be available, and sometimes the stubble of cool-season annual pastures or crops is lightly tilled to enhance establishment of crabgrass stands. Another weedy warm-season grass that provides opportunistic grazing in the region is Johnsongrass (*Sorghum halepense*). This aggressive-growing perennial grass can provide rapidly decreasing forage quality with plant maturity, prussic-acid hazard, and stand loss with excessive grazing pressure to complicate pasture management.

Although the warm-season perennial grasses are the base of most pasture systems in the region, warm-season legumes are used very little. During early attempts to improve the native forage resource of uplands in the region, the annual lespedezas (*Kummerowia* species) were successfully used in some instances as reseeding components of the otherwise natural vegetation. Reseeding by these annual legumes in dense stands of introduced warm-season perennial grass pastures has not been reliable. As pastures of introduced species were being developed before availability of low-cost nitrogen fertilizer, the perennial sericea lespedeza (*Lespedeza cuneata*) was recognized as an adapted and useful forage and nitrogen-fixing plant for rather carefully managed upland pastures and hay fields. The limitations of sericea lespedeza, including establishment difficulties [Pitman, 2006], woody stem development, and lack of tolerance of heavy grazing pressure early in the growing season, contributed to loss of interest in the species within the region. Thus despite potential to fill distinct gaps in pasture systems of the warm-season grasses, particularly the characteristic low mid-season forage quality and nitrogen-limitation of forage production, warm-season legumes have not been widely used. Most of the introduced warm-season perennial legumes with recognized forage potential in the region including sericea lespedeza, kudzu (*Pueraria montana* var. *lobata*), and mimosa (*Albizia julibrissin*) are now considered invasive in at least some situations [Pitman, 2009a]. Although not used as a pasture plant, mimosa has potential to produce forage of high nutritive value on some rather infertile coastal plain soils in the region [Pitman, 2008]. A distinctly non-invasive warm-season perennial legume adapted to well drained, sandy, upland soils of much of the region, rhizoma peanut (*Arachis glabrata*), has potential but little actual use due to the required vegetative establishment and high risk of establishment failure typically associated with moisture stress. In addition to the limited use of introduced warm-season legumes, the extensive variety of warm-season legumes native to the region has not provided species useful for pasture planting. Although they contributed nitrogen fixation to native grasslands and high-protein forage to livestock and wildlife grazing the native grasslands, their contributions received little attention. Recent evaluations have been limited by the low seed production, seed shattering, indeterminate flowering, and poor seedling vigor of some species [Pitman, 2009b], even though potential usefulness appears to be provided by a few species. Any use of the native legumes in planted pastures will likely be in multiple-purpose grasslands where livestock grazing is secondary to wildlife or conservation purposes.

Possibilities for Pasture Systems

The dominance of pasture systems in the region by the introduced warm-season perennial grasses during recent decades provides a sense of stability or an indication of sustained pasture production. The sustained use of the warm-season perennial grass pastures is more of a regional effect than individual pasture stability. Both land use and plant species within individual pastures have been much more dynamic than any long-term regional data for land area occupied by the various pasture species would indicate. Although some long-term pastures of individual introduced grasses have been continuously maintained for decades; perhaps more often, the management level on a pasture has gradually declined with the pasture eventually deteriorating through encroachment of undesired species. In recent years, such deteriorated pastures have often been plowed for a season of annual ryegrass production followed by replanting of a warm-season perennial grass. Substantial areas of deteriorated pasture have also been converted to pine plantations in recent years. Current economic, environmental, and social factors indicate that the dynamic aspect of pasture production in the region can be expected to increase during the next few decades. In the short-term, economics of production and government regulations and incentives will greatly influence pasture management decisions within the region. Society demands, or willingness to pay, appear to be favoring environmental, conservation, and recreational uses of land to a much greater extent than in past decades. These demands, and the associated economic benefits, may lead to highly integrated land use systems involving traditional pastures combined with other land areas where grazing livestock are used to manage the vegetation primarily for other purposes such as wildlife habitat.

The dramatic increases in fuel and fertilizer cost experienced in early 2008 demonstrated the economic vulnerability of intensively managed, nitrogen fertilizer-based pasture systems. Some degree of moderation of these prices has reduced the sense of urgency; however, modification of livestock production enterprises based on nitrogen-fertilized warm-season perennial grass pasture systems is occurring across the region. Rouquette [2008] listed several options for consideration by livestock producers using the introduced warm-season perennial grass pastures in the region. Reducing stocking rates can allow reduced fertilizer inputs and perhaps modification of individual fertilizer nutrients required. With fertilizer reductions, soil testing to assess status of individual plant nutrients can become critical, particularly in regard to potassium levels [Eichhorn et al., 1987]. Even at reduced over-all stocking rates, concentration of livestock on small areas for short periods using rotational grazing can increase distribution of recycled nutrients and efficiency of pasture production with reduced fertilizer inputs. Legumes, particularly selected clover species for specific sites and management approaches, become more valuable pasture components as price of nitrogen fertilizer increases. Previously, Rouquette et al. [1992; 1994] demonstrated the potential benefits of rotationally grazing multiple herds on hybrid bermudagrass pastures, with more-responsive classes of livestock such as stocker cattle or first-calf heifers benefiting from grazing pastures first, followed by mature cows. The lower nutrient requirements of these mature cows made effective use of the lower quality forage remaining after a short initial grazing period by the more nutrient-demanding "first" grazers. Rouquette [2008] illustrated that careful analysis of economic responses of various combinations of available pasture and hay options can reveal opportunities for profit even with high input costs. Relative cost of nitrogen compared to costs of phosphorus and potassium can determine whether annual ryegrass or clovers may provide the most profitable cool-season pasture option. Rouquette [2008] also suggested that these high quality cool-season forages may be more profitably grazed by young growing cattle or by using a limited-access grazing approach for cow-calf herds. Creep grazing of calves to allow continuing access to the high-quality pasture, while cows are on adjacent dormant warm-season grasses or hay-feeding areas can also provide additional economical production. Hazards of some cost-cutting approaches were also noted by Rouquette [2008]. Long-term effects of inadequate nitrogen application on pastures of hybrid bermudagrasses include weed encroachment, while application of only nitrogen can lead to depletion of other plant nutrients. Poultry litter from the broiler industry across a part of the region has been rather widely used as an economical source of plant nutrients. With increased interest in economical sources of fertilizer, particularly nitrogen, the potential for imbalances of nutrients to develop with repeated applications of litter must be considered [Robinson et al., 1994]. Soil testing to monitor nutrient levels, and perhaps the use of legumes rather than additional litter to provide needed nitrogen, can be used to prevent excessive phosphorus accumulation with continuing substitution of litter for commercial fertilizer. Approaches such as these will likely contribute to continuing profitability of some pasture-based livestock production enterprises in the region.

While the available pasture management options for increasing production efficiency are currently contributing to livestock enterprises to varying extents across the region, various government programs and regulations are also providing additional economic opportunities and limitations for profitable use of pasture lands. These range from legal constraints on pasture management options to incentives for including enhanced public benefits into pasture systems. Some public concerns providing current or impending effects on pasture management include herbicide movement, burning and the resulting smoke, soil erosion, nutrient transport to wetlands and water supplies, protection of species of conservation concern, soil carbon storage, and conversion of wetlands to pasture. Herbicide options represent a particularly critical component of pasture management in this warm humid region with both economic and ecological aspects involved. As pointed out by Sanders [1989] several years ago, the high cost of herbicide registration limits availability of chemical weed control options for pastures. Relative cost and differing effectiveness of alternative products complicate weed control decisions for pastures. Cost, continually changing herbicide options, and sometimes rather complex regulations and limitations provide incentives to consider available biological approaches to weed control including short-term, high-density stocking and additional livestock species, particularly goats. Along with increasing interest in the use of grazing livestock to control weeds on traditional pastures, awareness of increasing opportunities for uses of pastures other than for livestock production provides even more incentive for biological rather than chemical weed control. These increasing opportunities include conservation of various plant and animal species with direct incentive payments to obtain these public benefits from private grazing lands. Although with limitations, grazing livestock remain an essential part of such options. For enhancement of wildlife habitat on western rangelands, the concept of managed grazing for ecosystem development has been elevated to the idea of "livestock as ecosystem engineers" [Derner et al., 2009]. Because intensity, duration, uniformity, and season of grazing can tremendously affect the value of a grazed land area for various wildlife species, grazing livestock provide an economical means of manipulating land resources for different purposes. Appropriate planning of such grazing has been suggested as a means of accomplishing both profitable livestock production and public conservation objectives [Derner et al., 2009].

Public objectives can provide sources of pasture income from government programs for a general environmental or conservation benefit to society or from individuals paying for personal activities such as ecotourism and hunting. The region has experienced tremendous success in restoring white-tail deer populations and considerable success with eastern wild turkey restoration. The apparently appropriate landscape-scale habitat for both deer and turkeys provided by existing land use distribution can be further enhanced with such smaller-scale pasture considerations as increased use of clovers and distribution of cover for wildlife within large pastures. From the public perspective, considerable recent concern has been expressed regarding declining populations of grassland birds across the U.S. including populations of some species within the Western Gulf Coast Region [Brennan and Kuvlesky, 2005]. Burger et al. [2006] presented an assessment of how a large-scale conservation program benefitted the northern bobwhite and other grassland birds by meeting both economic needs of agricultural producers and habitat requirements of the birds. A longer-term, on-going effort in the Texas coastal prairie portion of the region involving the Attwater's prairie-chicken has also involved considerable cooperation between ranchers and conservationists with the rather drastic lesson of scale requirements for success learned as populations of the target species crashed following years of effort [Morrow et al., 2004]. The aspect of scale of management applies particularly to northern bobwhite, which require expansive areas of continuous habitat consisting of several specific habitat types. Both grassland and other cover types are included, with the native bunchgrasses of particular value. Very specific grazing treatments may contribute to the various habitat components of importance to the bobwhite. Although grazing is not a necessary component of many conservation efforts such as that for the threatened fire-maintained longleaf pine savanna ecosystem [Stouffer, 2006], appropriately managed grazing may supplement or partially substitute for the frequency of fire needed on smaller tracts or other areas not readily subject to burning. The concept of habitat conservation banking as a strategy for complying with the Endangered Species Act provides opportunities for landowners [Hay, 2010] and could provide a source of grazing land for livestock producers. Research is needed for such habitat management through grazing to determine the appropriate grazing treatments for management of various habitat types including control of such invasive species as privet (*Ligustrum* species), honeysuckle (*Lonicera* species), and kudzu. The apparent commitment of our primarily urban population to nature and wildlife species along with recognition that meaningful efforts for most species require landscape scale approaches indicate that sufficient incentives can be anticipated to encourage appropriate habitat conservation on portions of existing pastures and associated lands. Current USDA programs provide cost-share payments and other incentives for wildlife habitat development and establishment of stands of native bunchgrass species [NRCS, 2010]. While these incentives may not provide sufficient economic benefit for long-term conversion of pastures to conservation uses, they may justify integration of pastures and small wildlife habitat areas, particularly when some wildlife populations provide increases in income opportunities from activities such as hunting. The economic contributions anticipated from a combination of individuals, government agencies, and private conservation organizations will likely result in increasing numbers of livestock operations across the region responding to such opportunities for increased income from pastures. Some integrated pasture systems will likely be coordinated among producers to various extents and consist of some components managed primarily for grazing livestock and other components, perhaps owned by other entities, managed with grazing livestock primarily for purposes other than livestock production.

Undeveloped opportunities for intensively managed pastures also hold promise. More than 40 years ago, Chambers [1967] emphasized the potential for Louisiana growing conditions to provide forage as a substitute for grain in beef production systems. Intensively managed pastures of appropriate forage species still represent a potential substitute for grain in cattle diets when a high-value marketable product can be obtained. Pasture-based dairy production and grass-fed beef provide such opportunities. Results of a coordinated state-wide research effort in Louisiana during the 1980s indicated that sufficient levels of animal performance on pasture were obtained for grass-fed beef finished on cool-season annual forages but not on warm-season perennial grasses during the portion of the year when cool-season annuals were not available [Coombs, 1987]. A warm-season annual legume, alyceclover (*Alysicarpus vaginalis*), provided some improvement over the warm-season perennial grasses with individual daily gains of 0.8 kg by young growing cattle but only slightly over 0.3 kg for heavy finishing cattle [Bagley et al., 1987]. The need for a year-round supply of slaughter cattle to support local slaughter facilities was noted by Bagley [1987]. Although the commonly grown warm-season pasture plants did not provide sufficient quality to support adequate levels of animal performance, other adapted forage plants, with appropriate management, could provide acceptable levels of animal performance. Some other adapted warm-season annual legumes may provide opportunity for higher rates of gain during summer with daily gains of 1.2 kg per head reported for young growing steers grazing cowpeas (*Vigna unguiculata*) outside the region [Holzknecht et al., 2000]. With careful site selection and intensive management, alfalfa can be productive for periods of one to three years and has repeatedly been suggested as a viable forage option on selected bottomland and upland sites within the region in recent years [Cassida et al., 2006; McCormick, 2008; Haby et al., undated]. Although only a short-lived pasture option in the region, profit potential for grazed alfalfa has been indicated [Cassida et al., 2006]. Stocking rates for adequate individual animal gains, however, may be critical. The high rate of individual animal gain on dwarf elephantgrass (*Pennisetum purpureum*) of 1.0 kg per day reported by Mott and Ocumpaugh [1984] is about double that typically obtained on the commonly grown warm-season perennial grasses as illustrated by the results of White and Hembry [1985]. Thus, dwarf elephantgrass provides a perennial grass possibility for the needed high levels of performance for grass-fed beef. The dwarf elephantgrass, which requires well-drained soils and vegetative propagation, has persisted for several years under varying management levels at Rosepine, Louisiana. Pastures of dwarf elephantgrass, and probably those of alfalfa also, will likely require rotational grazing systems with each grazing period of only a day or two in length. Possibly a two-herd system could be advantageous. Finishing cattle would be grazed first to allow selection of the best available diet. Growing animals would graze immediately after the first herd and be moved on to the next pasture while sufficient leaf area remains to support rapid plant regrowth. Several pastures would be required. An additional possibility to help provide pastures of adequate quality during the fall is provided by tall fescue with the non-toxin-producing endophyte. This grass has provided individual animal gains of 1.0 kg per day by young growing cattle in Louisiana [Hopkins and Alison, 2006]. With appropriate management, including irrigation, this tall fescue appears capable of providing forage in early fall two or three months before cool-season annual forage species are typically available for grazing. These summer and fall pasture possibilities are unproven, involve substantial risk, and will require intensive management for the proposed purpose, but they do provide possibilities.

Additional possibilities for increased profitability from pasture systems in the region include the use of agroforestry practices and biofuel crops. Clason [1995; 1999] found that both forage and timber production could be enhanced with management for productive warm-season perennial grass pastures in pine forests. While such combinations of pine timber and warm-season perennial grasses can provide highly sustainable pasture components of agroforestry systems in the region, several additional opportunities for pastures in a variety of agroforestry systems have also been suggested [Pitman, 2010]. Another under-explored pasture option for the region, which could involve agroforestry components, involves the developing demand for goat meat. Sustainable pasture systems for goat production in the region have received little attention. Use of currently available browse, including opportunities for brush and weed control for a fee, in production systems with pastures planted to appropriate forage or browse plants for goats appear to warrant investigation. The current government emphasis on biofuel cropping also appears to provide increased opportunities for pasture systems. Switchgrass, which is proposed to be a key biofuel crop, is a useful forage plant in some situations and includes varieties adapted to some sites within the region [Pitman, 2000; Cassida et al., 2005]. Potential appears to exist for pasture systems making use of switchgrass forage available for spring grazing, while switchgrass growth for most of the growing season would be allowed to accumulate for a dormant-season biomass harvest. Such an approach could overcome the detrimental effects of repeated growing-season defoliation on switchgrass persistence in the region.

CONCLUSION

Pastures of the Western Gulf Coast Region of the U.S. have been dynamic components of ostensibly stable landscapes consisting of pastures and forests on uplands and interspersed cropland and pastures on lowlands. Just as the natural herbaceous vegetation of most of the initial grazing land of the region was replaced by introduced grasses and legumes, which were expected to provide superior pasture value, newer pasture plants with even greater promise or with potential to overcome unanticipated limitations of the previously planted pasture species have repeatedly been adopted. A grazing livestock industry initially developed in the region because a forage resource consisting of the native grasslands was available. Pastures of introduced forage species were developed and repeatedly improved to enhance productivity of livestock. From late in the twentieth century and into the twenty-first century, intensive pasture management for high forage production levels with high rates of fertilizer and frequent chemical control of undesired plant species became progressively less profitable due to increasing input cost without corresponding price increases for weaned calves. The pasture-based livestock industry is currently under economic pressure to limit cost of production to the extent that the biological production potential of many introduced pasture plants is beyond the economic level of production. Decreased carrying capacity at the reduced input levels for profitability and lower profit margins per head pose substantial difficulties for pasture-based livestock production in the region. Alternatives for at least some pasture lands and livestock producers appear to be provided by public interest in wildlife and conservation. Publicly funded conservation programs and willingness of individuals to pay for such non-livestock pasture uses as ecotourism and hunting provide current and expanding opportunities. Integration of pastures with timber production or other tree crops in agroforestry systems also provides economic opportunities. Where markets develop for such biomass crops as switchgrass, integration of seasonal grazing and dormant season harvest of a fuel crop also hold promise. Perhaps on only a rather small scale under the guidance of entrepreneurial management, some comparatively high-quality forages provide opportunities to produce high-value products such as grass-fed beef from pasture systems in the region. Even under intensive management, the widely used bermudagrass and bahiagrass are limited for such purposes due to inherently rather low forage quality. The forage plants potentially providing adequate quality are less well suited to livestock grazing within the region and require more specialized management for successful pasture use; thus, substantially greater income opportunity is required to justify their use. Holechek [2009] has recently presented an overview of the complex historic and current global conditions, including weather, political decisions, energy supplies, and population growth, affecting economic opportunities from grazing lands. He concluded that, even though uncertainty is high, there is probability that increasing cost of grain will increase the value of grazing lands and the products of such lands in the long term. Gradual change has been an on-going aspect of pastures in the region, and change in pasture management options and resource use will likely be quite dramatic in coming decades. While development of pastures in the region up to this time has primarily been based on increasing livestock production, further pasture developments may often focus on efficient returns on investment with multiple income sources, rather than just livestock, considered to be the products of pastures in the region.

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Chapter 4

DRYLAND SALINITY AND ITS MITIGATION WITH PERENNIAL PASTURE PHASES

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ABSTRACT

Reliance on shallow-rooted annual plants in traditional crop rotations has encouraged the onset of soil salinisation throughout the Western Australian Wheatbelt by permitting a significant proportion of annual rainfall to reach saline watertables. Incorporating phases of perennial pasture between long cropping sequences is the most promising means of reducing recharge and sustaining grain production. This chapter describes the process of soil salinisation and strategies to prevent its occurrence, with a key focus on the employment of lucerne pasture to increase water use in crop rotations in the Wheatbelt. This discussion highlights the dynamic value of pasture phases in intensive agriculture and the importance of considering the restorative capacity of pastures when evaluating alternative land-use sequences and their management.

Keywords. Lucerne, perennial pasture, soil salinity.

1. INTRODUCTION

Soil salinisation is the accumulation of excess salts in the root zones of plants to the extent that the yield of salt-sensitive crops and pastures is reduced by more than 10 percent (McFarlane and Williamson, 2002). Primary soil salinisation occurs naturally in virgin ecosystems; for example, in the salt-lake systems typically found at the bottom of Wheatbelt valleys in Western Australia. In contrast, secondary soil salinisation is human-induced. There are two forms of secondary salinisation: dryland and irrigation-induced. Dryland salinity arises on non-irrigated land where rainfall exceeds evapotranspiration. Irrigation-induced salinity occurs where irrigation and rainfall surpass the water requirements of plants. Dryland salinity is the focus of this review since irrigation-induced salinity is rare in Western Australia.

Dryland salinity is considered, “the most pressing land management issue facing Australian agriculture” (White et al., 2002, p. 134). It is estimated to cost Australia around $600 million each year in decreased crop production alone (Dawes et al., 2002). Approximately 960,000 hectares of previously productive agricultural land in Western Australia has developed soil salinity as a result of human activity (calculated from data in McFarlane et al., 2004) and an additional area of up to 4.4 million hectares is at threat (McFarlane et al., 2004). Apart from decreasing crop yield, soil salinisation detrimentally affects biodiversity (Keighery et al., 2004); ecosystems, particularly river systems (Hatton and Nulsen, 1999; Kefford et al., 2003); water supplies (McFarlane and Williamson, 2002); and infrastructure, particularly roads (National Land and Water Resources Audit, 2001; Ridley and Pannell, 2005).

The primary objective of this chapter is to provide a critical review of soil salinisation processes and mitigation options relevant to the Western Australian Wheatbelt. A particular focus is placed on the potential of lucerne (*Medicago sativa* L.) pastures to reduce recharge to saline water tables by drying a soil to depth and using soil moisture during summer when annual plants—on which traditional agricultural systems in the Western Australian Wheatbelt are based—are no longer actively growing. This review is important since much research has been conducted in the area of dryland salinity management over the last 20 years and its synthesis is important if key areas for further research are to be identified. Moreover, it provides a broad introduction to dryland salinity management for researchers new to this area. It is also a primary example of how regular pasture phases can help to sustain farming systems through helping to mitigate environmental constraints within crop rotations.

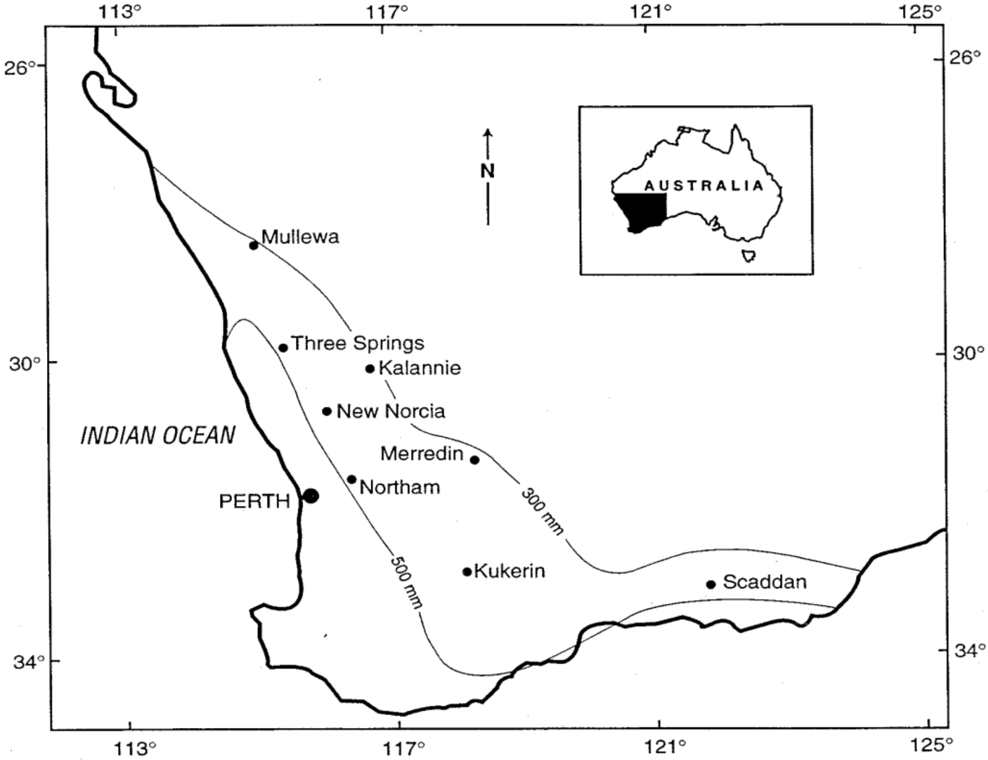
Section 2 discusses characteristics of the Western Australian Wheatbelt and relevant soil salinisation processes. Section 3 describes the use of saline land and practices to prevent its development. Section 4 outlines the advantages and disadvantages of lucerne as a pasture plant for salinity prevention in the Western Australian Wheatbelt. Conclusions are presented in Section 5.

2. SOIL SALINISATION IN THE WESTERN AUSTRALIAN WHEATBELT

The Western Australian Wheatbelt consists of around twenty-million hectares of land between the 500 mm and 300 mm rainfall isohyets in south-western Australia (Figure 1) (Cramb, 2000). Railway construction in the early 1900s stimulated the rapid expansion of cereal cropping in this area (Wadham et al., 1964; Clarke, 1986). Typical farms in this region are large, with an average size of around 2870 hectares in 2004 (Australian Bureau of Agricultural and Resource Economics, 2005). However, the farm-size distribution is very skewed, with a quarter of farms producing over half of Western Australia’s grain each year (Kingwell and Pannell, 2005).

The climate of this area is classified as Mediterranean given its characteristically hot summers, mild winters, and concentration of rainfall in winter (Gentilli, 1959, 1972;

Hutchinson et al., 2005). Mean annual rainfall varies locally and across time, but is normally between 250 mm and 500 mm (Pratley and Rowell, 1987; Webber, 1990). Similar climatic conditions are experienced globally between 30° and 40° latitude (Saxena, 1988). This includes parts of California, Chile, south-western Africa, South Australia, and, of course, the Mediterranean (Thrower and Bradbury, 1973).



Source: Siddique and Loss (1996).

Figure 1. Map of south-western Australia depicting the 300 mm and 500 mm rainfall isohyets.

The Western Australian Wheatbelt has an ancient geology with the earliest sediments deposited around 3300 million years ago. Sedimentation, deposition from volcanic eruptions, and metamorphosis over the following 1500 million years formed the Yilgarn Craton, a Precambrian shield from which most soil parent materials throughout the Wheatbelt evolved (Tille et al., 2001). The groundwater systems characteristic of the highly-weathered Precambrian shield underlying the Western Australian Wheatbelt are typified by high salt concentrations and low gradients. Soil salts, consisting mainly of sodium chloride ($NaCl$) (Teakle and Burvill, 1938), arise from rainfall deposition and the weathering of parent materials (Isbell et al., 1983). Rainfall deposition is around 20 kg ha^{-1} yr^{-1} in the Wheatbelt (Hingston and Gailitis, 1976). This amount is low given this area's distance from the ocean (~270 km) and low annual precipitation. Nonetheless, the high evaporation rates and great geological age of this region have allowed much salt to accumulate (Malcolm et al., 1978; McArthur et al., 1989). In Western Australia, on average, around 250 tonnes of salt per hectare is present in upper valley locations, while approximately 2,500 tonnes per hectare is found on valley floors (McFarlane and George, 1992). However, these figures vary widely, with up to 15,000 tonnes of salt per hectare present in some areas.

Little rainfall progressed below the root zone of deep-rooted, perennial, native vegetation throughout Australia prior to extensive land clearance. High rates of evapotranspiration usually allowed only ~0.1 mm yr^{-1}, on average, to escape into groundwater underneath such systems (George and Frantom, 1988). (Such escaping water is referred to as "deep drainage" or "recharge".) However, the replacement of native vegetation with agricultural systems based on annual crops and pastures has substantially increased deep drainage (Wood, 1924; Peck and Hurle, 1973; Nulsen et al., 1986; Allison et al., 1990; George, 1992; Sadler and Turner, 1994; George et al., 1997; Hatton and Nulsen, 1999; Hatton and George, 2000). High recharge occurs under annual plants as low evaporation rates limit evapotranspiration during the growing season and the presence of minimal plant canopy between November and May limits the use of out-of-season rainfall. Moreover, their shallow-root systems reduce their capacity to intercept soil water. Increased recharge causes water tables to rise, mobilising salt deposits and bringing them within reach of plant roots (Hatton and Nulsen, 1999; Pannell et al., 2001).

Recharge beneath rotations consisting solely of annual plants in the Wheatbelt is generally between 4 and 10 percent of rainfall (McFarlane and Williamson, 2002). However, this may vary greatly depending on seasonal rainfall and soil type (Asseng et al., 2001a). This may be demonstrated using the Leakage/Buffer model (Ward, 2002, 2006; Ward and Asseng, 2002; Ward et al., 2003). Recharge on a deep, sandy soil in the Wheatbelt over last century was between 0 and 163 mm yr^{-1}, with an estimated mean of 28.9 mm yr^{-1} (9.2 percent of mean annual rainfall). In comparison, mean recharge of 103 mm yr^{-1} occurred over the same period on the same soil type in Moora, which has a mean annual rainfall of 461 mm, compared with 314 mm in the study area. In contrast, deep drainage on an acid, loamy, sandy soil in the Wheatbelt was between 0 and 114 mm yr^{-1}, with an estimated mean of 14.2 mm yr^{-1} (4.5 percent of mean annual rainfall). These differences demonstrate the high variability of recharge, but, most importantly, emphasise the limited capacity of annual plants to intercept rainfall. For example, the average amount of recharge reported above for the deep, sandy soil in the Wheatbelt is nearly three hundred times greater than that experienced under native vegetation (~0.1 mm yr^{-1}) (George and Frantom, 1988).

Wheat (cf. barley) growth is generally affected when saline water tables are less than 1.8 m (cf. 1.5 m) from the soil surface (Teakle and Burvill, 1945; Nulsen, 1981). However, a water table shallower than two metres will ascend quickly, irrespective of water use by plants, due to capillary action caused by evaporation (McIntyre, 1982). It is therefore important to maintain a water table at least two metres below the soil surface if annual crops and pastures are to continue to be grown (Clarke et al., 2002). The importance of preventative strategies is reinforced by the general infeasibility of reclaiming saline land since a declining water table requires lateral movement over significant distances and salinisation decreases soil permeability, thus limiting any capacity to flush out salt (Pannell, 2001a). Drainage of saline land may also cause, "severe environmental consequences" (Fitzpatrick et al., 2000, p. 26), including major soil structure change, increased erosion, and the formation of acid-sulphate soils.

Crop species differ in their sensitivity to salt. Wheat production declines at salt levels above 600 ECe mS m^{-1},[1] while barley production is affected above 800 ECe mS m^{-1} (Maas and Hoffman, 1977; Maas, 1986). (These tolerances are highly variable in practice since young crops are generally more sensitive than adult plants and salt concentrations will fluctuate with soil moisture content.) Crop growth rates, and consequently yields, decline approximately linearly with increasing salt concentrations beyond these thresholds (Maas and Hoffman, 1977). Yield is further affected by waterlogging and inundation, which generally accompany high water tables, as these severely impair the salt-exclusion mechanisms of most agricultural plants (Barrett-Lennard, 1986, 2002).

3. MANAGEMENT OF SOIL SALINISATION

Potential management responses to salinity include strategies to make use of saline land or to prevent the onset of salinisation through engineering or agronomic practices.

3.1. Use of Saline Land

The use of sheep to graze plants adapted to saline environments is the most popular employment of saline land. Salt-tolerant plants important in this context are fodder shrubs, such as saltbush (*Atriplex* spp.) and samphire (*Halosarcia* spp.); grasses, such as puccinellia (*Puccinellia ciliata* Bor.) and tall wheat grass (*Thinopyrum elongatum* syn. *Agropyron elongatum* (Host) Beauv.); and legumes, such as balansa (*T. michelianum* Savi) and Persian clover (*T. resupinatum* L.) (Barrett-Lennard and Malcolm, 1995). The integration of these plants in a grazing system has particular value for the provision of autumn feed (during the traditional feed-gap) given the high cost of supplements (Bolt, 2001). Supplementary feed is required given the minimal pasture growth over the hot, dry summers characteristic of this area. Kingwell et al. (2003) lists these supplements as costly grains, such as lupins; dry pastures that deteriorate in quality over time; and grain stubbles of low nutritive value. Fodder shrubs are often employed in an alley-farming system, where rows of these plants lower the water table so that less salt-tolerant species, such as balansa and Persian clover, can establish in the inter-rows (O’Connell et al., 2006).

Saltland grazing systems are much less profitable than production on non-saline land, particularly given their low productivity, high establishment cost, and the risk of establishment failure (Kingwell et al., 2003; O’Connell et al., 2006). For example, O’Connell et al. (2006) identified a standard establishment cost of \$225 ha^{-1}, while John (2005) estimated that one-fifth of these systems will fail to successfully establish. Moreover, in some environments, water use by fodder shrubs, such as saltbush, will cause salt to accumulate in their root zones over a ten- to twenty-year period, eventually causing their death (Barrett-Lennard, 2002). However, this is less likely to occur in the Wheatbelt of Western Australia where there is minimal lateral water movement (Ferdowsian et al., 2002).

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[1] ECe mS m^{-1} measures the electrical conductivity of the soil solution in milliSiemens per metre. A higher reading of ECe mS m^{-1} infers a greater level of soil salinity.

The popularity of saltland grazing systems is partly motivated by the low opportunity cost of saline land. Profitable salt-tolerant crops are currently not available. Salt-tolerant plantation trees exist (Marcar et al., 1995), but their use is constrained by their low profitability. Aquaculture (George and Coleman, 2001; Partridge and Jenkins, 2002), salt extraction (Privett and Munday, 2000), and desalination (Chaibi, 2000; Winter et al., 2001) are potential uses of saline water. However, these are of limited practical relevance because they require significant technical expertise and are generally unprofitable for individual grain producers (Kingwell et al., 2003).

3.2. Preventative Strategies

Preventative strategies are important given the low profitability of agricultural production on saline land.

3.2.1. Engineering Techniques

The rise of saline water tables can be prevented through the installation of deep drains and/or groundwater pumping (so-called engineering techniques). These methods have limited worth for safeguarding agricultural production because of their high capital cost and limited spatial influence (McFarlane et al., 1990; Ferdowsian et al., 1997; Coles et al., 1999; Cacho et al., 2001). In addition, they require the disposal of saline water that may detrimentally impact downstream ecosystems and increase flood risk (Pannell and Ewing, 2006). Engineering options are most suited to the protection of high-value assets, particularly where evaporation basins can be used for reducing off-site impacts. Nonetheless, drainage is the preferred form of salinity management for many producers throughout the Wheatbelt (Pannell, 2001b; Clarke et al., 2002; McFarlane and Williamson, 2002; Rundle and Rundle, 2002).

3.2.2. Manipulation of Annual-based Systems

Increasing the transpiration rates of annual crops and pastures through improved management may increase crop yield and decrease deep drainage (Anderson, 1980; Nulsen and Baxter, 1982; French and Schultz, 1984; McFarlane et al., 1993; George et al., 1997; Angus et al., 2001). However, this generally has a minimal impact on recharge as evaporation decreases and largely offsets the greater level of transpiration (Eastham et al., 1999; Clarke et al., 2002).

Increasing the rooting depths of annual plants may increase their interception of soil water (Tennant and Hall, 2001). For example, the extended rooting depth of French serradella permits it to extract the greatest amount of soil moisture, in relation to other annual pastures, from more than 1.2 m below the soil surface (Tennant et al., 1999). Nonetheless, the absence of plant cover for a high proportion of the year in an annual-based system severely constrains its capacity to deal with out-of-season rainfall, thereby limiting the usefulness of this strategy for salinity management (George et al., 1997).

3.2.3. Employment of Perennial Plants to Increase Water Use

A more promising method is the employment of deep-rooted perennial plants that actively grow through periods of high evapotranspiration (Dunin et al., 1999) and create a *buffer* of dry soil to absorb recharge from annuals sown either in the vicinity or in the following year(s) (Ward et al., 2001, 2002, 2006). A dry soil buffer should be used to maintain water tables at least two metres below the soil surface, so that the yield of these annual plants is not compromised.

Lucerne is presently the most suitable perennial legume for recharge management in the Wheatbelt (Cocks, 2001; Latta, 2003); accordingly, around 171,235 ha in this region was planted to this perennial pasture in 2001 (Loo, 2001). This species is important since a lack of suitable perennial crops constrains a producer's ability to maintain traditional crop sequences without hastening the onset of soil salinisation. Perennial grasses, such as cocksfoot (*Dactylis glomerata* L.), grazed throughout southern Australia are adapted to temperate regions with an annual rainfall greater than 600 mm; thus, they are of little relevance to salinity management in the study area. Alternative perennial legumes for dryland cropping systems, such as species from the *Dorycnium* genus (Bell et al., 2005), are the focus of ongoing research.

Deep-rooted perennial fodder shrubs, such as tagasaste (*Chamaecytisus palmensis* (Christ) Hutch) (Hatton and Nulsen, 1999; Lefroy and Stirzaker, 1999), can reduce recharge (Eastham et al., 1994) and provide valuable early-autumn feed (Oldham et al., 1991). However, these shrubs are generally less profitable than perennial pasture legumes, except on deep, infertile sands (Oldham et al., 1991; Abadi, 2003).

Perennial trees, such as Tasmanian blue gums (*Eucalyptus globulus* Labill.), may be planted in rows in farmland maintained in active use (alley-farming) (Lefroy and Scott, 1994) or in large stands as a monoculture (George et al., 1999). Both systems can significantly reduce deep drainage (Greenwood et al., 1985; George, 1990, 1991; Schofield, 1990; Bari and Schofield, 1992). However, there is significant empirical evidence that trees have a limited spatial influence on recharge (see George et al., 1999). Accordingly, up to 70 to 80 percent of some catchments need to be planted with trees to avert soil salinisation (George et al., 1999; Hatton and Nulsen, 1999). This identifies an apparent trade-off between the maintenance of existing cropping systems and effective hydrological management using afforestation. In addition, these plantations are generally uneconomic in low rainfall areas (Cacho et al., 2001; Kingwell et al., 2003; Pannell and Ewing, 2006), even if the on-farm value of recharge reduction is considered (O'Connell, 2003). A key factor in these evaluations is the high opportunity cost accruing to the planting of trees, as these may take over thirty years to yield harvestable product.

Oil mallees (*E. polybractea* Baker and *E. kochii* subsp. *Plenissima* (CAGardner) Brooker) and wattles (*Acacia* spp., particularly *A. saligna* Labill.) may be grown for salinity management. Oil mallees are used primarily for the production of eucalyptus oil; however, recent research demonstrates that significant economic benefits accrue to the integration of oil harvest with electricity generation and activated carbon production (Cooper et al., 2004). In contrast, *Acacia* is most useful for timber production.

These trees may be incorporated in either an alley- or phase-farming system. Phase farming with trees involves the use of a short period of forestry (usually of three to five years duration) to create a buffer of dry soil before a cropping sequence begins (Harper et al., 2000). High establishment and removal costs are incurred in the "kamikaze forestry" phase. For example, Mueller et al. (1999) estimated that establishment costs were \$1000 ha^{-1} and removal costs were \$80 ha^{-1} in a typical system. Phase farming with trees is more profitable than large plantations in many circumstances (Abadi, 2003; Abadi et al., 2003).

However, significant parts of the Wheatbelt are unsuitable for growing these species because of climatic and soil limitations (Kingwell et al., 2003). In addition, a lack of processing capacity presently constrains industry development in the study area. Accordingly, the primary means available to producers for recharge reduction is the use of perennial pasture and not trees (Cocks, 2001; Latta, 2003). This importance motivates an in-depth analysis of the advantages and disadvantages of lucerne for dryland salinity management in the Western Australian Wheatbelt in the next section.

4. LUCERNE PASTURES FOR DRYLAND SALINITY MANAGEMENT

Endemic to the Middle East, lucerne has been used in Australian pastures for around two-hundred years. Lucerne is an herbaceous, erect pasture legume that is used primarily as a grazing plant in the Wheatbelt because insufficient growth hampers profitable hay and silage production in this low-rainfall environment (Devenish, 2001). Lucerne is typically grazed throughout November and December; however, pasture production from January to April is highly dependent on summer-autumn rainfall and soil water content (Devenish and Lacey, 2001). Lucerne is more salt-tolerant than other perennial legumes, provided the soil is free draining (Cocks, 2001). Nevertheless, it is significantly more sensitive than barley; thus, its primary contribution to salinity management is recharge reduction and not the revegetation of moderately-saline sites. This is reinforced by its intolerance of waterlogging that typically accompanies salinisation (Cocks, 2001).

Winter-active lucerne is used in the Wheatbelt because it suits the rainfall distribution of the region and is more persistent than summer-active varieties. Lucerne is generally sown between May and July. It is sown later than the primary crops to complement their demand for machinery and allow several weed germinations to occur prior to establishment to increase the effectiveness of weed control at seeding. Good weed control is essential as young lucerne is a poor competitor for nutrients, moisture, and light (Fedorenko et al., 2001; Latta et al., 2003).

4.1. Advantages of Lucerne Pasture

Lucerne has multiple benefits for cropping systems in the Wheatbelt.

4.1.1. Persistence

Lucerne is very persistent, with recorded ages of over twenty years (Hanson et al., 1988). This persistence is aided by its dormancy through extended dry periods and its ability to grow from either green stems or the top of its taproot. Stands in the Wheatbelt are often significantly weakened by disease, grazing management, insect pests, prolonged drought, and weed invasion (Bollard and Grimm, 1986; Devenish and Bee, 2001; Fedorenko et al., 2001). The maximum duration of a phase in this area is consequently around four to five years (Devenish, 2001). Lucerne is expensive to establish and produces little feed in its first year

(Maling and Lemon, 1993). For example, lucerne generally costs around \$90–\$100 ha^{-1} to establish in the Wheatbelt and will yield less than \$20 ha^{-1} in its first year under typical grazing management. This motivates extended lucerne phases; however, the profitability of long periods of pasture is somewhat constrained by the significant opportunity cost imposed by the high relative value of cereal production. Three-year phases are therefore the most common.

4.1.2. Recharge Reduction

Lucerne's ability to extract soil water at a low moisture potential (Holford and Doyle, 1978), its perennial growth habit, and deep-rooting system greatly reduce recharge, compared with that experienced beneath annual crops and pastures (Crawford and Macfarlane, 1995; Lolicato, 2000). The taproot of lucerne may grow over eight metres deep (Kipnis et al., 1989); however, rooting systems are typically much shallower than this in the Wheatbelt because of soil constraints (Isbell, 1996) and the short duration of lucerne phases. Roots in the third year of a lucerne phase may be up to three times the depth of those of subterranean clover (1.5 m compared to 0.5 m) (Latta et al., 2002; Ward et al., 2002). Moreover, Ward et al. (2002) identified that the root mass of lucerne was up to 70 percent heavier than that of subterranean clover in one experiment, reducing recharge in the lucerne stand by over six times relative to that occurring in the annual pasture.

These large rooting systems and the perennial growth of lucerne greatly increase its use of soil water. Latta et al. (2001) identified that lucerne used 30 mm more soil water in each year than annual pastures at Borden in Western Australia, where a mean rainfall of 355 mm was observed over the length of the lucerne phase. Similarly, Lyons and Latta (2001) reported that soil water content decreased by over 40 mm yr^{-1} in an established lucerne pasture in Esperance on the south coast of Western Australia. Additional experimental work has identified that lucerne will typically reduce soil water content by more than 50 mm yr^{-1} in relation to annual-based pastures (Angus et al., 2001; Dunin et al., 2001; McCallum et al., 2001; Ward et al., 2001, 2006; Latta et al., 2002). Lucerne typically creates a buffer of 50–100 mm in Australian soils (Angus et al., 2001; Dunin et al., 2001; McCallum et al., 2001; Ward et al., 2001; Latta et al., 2002). This highlights its value for salinity management in the Wheatbelt.

However, some recharge will occur despite the existence of a dry soil buffer, particularly following extreme rainfall events (Ward et al., 2001, 2002). This results from water bypassing smaller pores and moving rapidly down the soil profile (so-called "bypass flow") (Ward et al., 2002). For example, recharge of 5 mm yr^{-1} was observed under lucerne pasture by Ward et al. (2002). This rate is sufficient to substantially delay the development of secondary soil salinity, though larger than those rates of deep drainage experienced under native vegetation (George et al., 1999).

High water use by deep-rooted perennial pasture may also reduce soil acidification by preventing the leaching of nitrate (Ridley et al., 1990).

4.1.3. High Biomass Production

The deep roots of lucerne access soil moisture not available to annual plants. In addition, the storage of energy in the taproot of lucerne allows it to respond quickly to out-of-season rainfall. These factors improve lucerne's drought tolerance and biomass production, relative to that of annual pastures.

Lucerne production was 300 percent higher than that of annual medic pastures in field trials conducted in a low-rainfall area of Victoria (Ransom and Whitfield, 2001). Likewise, established lucerne was demonstrated to produce almost twice the annual biomass of subterranean clover in the Esperance region of Western Australia by Lyons and Latta (2001). Latta et al. (2002) identified that lucerne produced 42 percent more biomass than subterranean clover at a mean rainfall of 355 mm, and 29.5 percent more with an average rainfall of 428 mm. The greater production observed at a mean rainfall of 355 mm was a result of higher summer and autumn rainfall occurring during that experiment. In fact, this seems to be the primary determinant of whether lucerne production will dominate that of subterranean clover, as the latter generally produces more feed than lucerne in both winter and spring (Latta et al., 2002).

The capacity of lucerne to produce out-of-season growth is of considerable value to grazing systems. Crawford and Macfarlane (1995) identified that 30 percent more stock could be grazed on a lucerne pasture, relative to an annual pasture, in Victoria at a mean rainfall of 639 mm yr^{-1}. Flugge et al. (2004) identified that farm profit in the central Wheatbelt may increase by up to 10 percent following the inclusion of lucerne in crop rotations and by up to 19 percent if the producer also adopts new livestock enterprises that exploit this pasture's out-of-season production. Lucerne's value as a pasture plant is promoted by its high digestibility (65–75 percent), metabolisable energy (8–11 MJ/kg DM),[2] and crude protein (12–28 percent) levels (Devenish, 2001). Nonetheless, the marginal value of additional summer-autumn feed provided by perennial pasture declines past some optimal point as other factors begin to constrain livestock production (Bathgate and Pannell, 2002).

4.1.4. Weed Control Benefits

High nitrogen fixation (Ransom and Whitfield, 2001) and deep-rooting systems increase the competitiveness of lucerne with many major cropping weeds, such as annual ryegrass (Latta et al., 2001, 2002; Bee and Laslett, 2002). For example, Lyons and Latta (2003) identified that legume content in lucerne pasture was nearly 90 percent higher than that observed in subterranean clover stands due to differences in weed density.

4.1.5. High Nitrogen Fixation

Lucerne is an important legume in farming systems throughout the world. Latta et al. (2001) identified that wheat yields after lucerne were 18 percent higher than those after subterranean clover. This followed nitrogen fixation at a mean rate of 25 kg N ha^{-1} yr^{-1}. Similarly, Ward et al. (2002) reported that wheat yields after lucerne were 14 percent higher than those after subterranean clover. Lyons and Latta (2003) identified that wheat yield increased by over 38 percent following a lucerne pasture. This reflected an 18 percent increase in total soil nitrogen, relative to that experienced after an annual legume. This nitrogen will generally influence at least two crops following the removal of lucerne (Holford and Crocker, 1997; Hirth et al., 2001). It will also persist longer than nitrogen from annual pastures due to lucerne's higher legume content and greater biomass production (Hirth et al., 2001; McCallum et al., 2001). However, this nitrogen may not be available in significant quantities to the first crop following the perennial pasture phase (Angus et al., 2000; Lyons and Latta, 2003) because of slow mineralisation, particularly in dry years (Hirth et al., 2001).

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[2] MJ/kg DM denotes mega joules of energy per kilogram of dry matter.

Elevated nitrogen levels also increase grain protein. This improves the price received for grain *ceteris paribus* as a premium is paid for higher levels of grain protein in the Wheatbelt. Lyons and Latta (2003) identified that wheat protein was 10 percent higher following lucerne, relative to that observed after annual pasture. Moreover, Latta et al. (2001) reported that wheat protein was 47 percent higher after lucerne, compared with that occurring in a wheat crop following subterranean clover.

4.2. Disadvantages of Lucerne Pasture

Lucerne has multiple benefits for cropping farms in the Wheatbelt. However, these pastures also have a number of important deficiencies.

4.2.1. Low Rainfall at Establishment Can Severely Harm Persistence

The persistence of a lucerne stand can be constrained by low rainfall, particularly in its first year. Inadequate rainfall prevented the successful establishment of lucerne in a third of the trials conducted throughout the Wheatbelt by Latta et al. (2001). This is important since significant plant density is required for effective recharge reduction (Dunin et al., 2001).

4.2.2. Water Deficiencies in Subsequent Crops

The capacity of lucerne to dry the soil at depth can decrease waterlogging and reduce recharge (Cransberg and McFarlane, 1994). However, this can also lower yield and grain size in subsequent crops if insufficient moisture is available to them (Holford and Doyle, 1978; Peoples et al., 1998; McCallum et al., 2001; Ward et al., 2002).

Lucerne is typically removed with a spring application of non-selective herbicide(s). Spring removal increases nitrogen availability to the successive crop and allows heavy grazing over summer to control plants not killed by the dessicant(s). In addition, it allows soil water to increase prior to the sowing of a crop in the following autumn (Dunin et al., 2001; Latta, 2003). However, this “rewetting” will also utilise some of the buffer established underneath the perennial pasture, particularly if heavy rainfall is experienced throughout the summer and/or early autumn periods.

4.2.3. Difficult to Remove Prior to Subsequent Cropping

Lucerne is notoriously difficult to eradicate once successfully established (Lodge, 1991; Dunin et al., 2001; Bee and Laslett, 2002; Latta, 2003). For example, one-fifth of lucerne plants survived into a successive crop phase, despite the application of non-selective herbicides to terminate the lucerne stand, in one trial (Latta et al., 2001). Competition with surviving lucerne plants, particularly for soil moisture (Angus et al., 2000), may greatly reduce crop yield (Bee and Laslett, 2002).

4.2.4. Requires Intensive Management

Lucerne requires rotational grazing to maintain persistence (Oram, 1990; Devenish, 2001; Dunin et al., 2001). Set-stocking will typically cause overgrazing since a large proportion of lucerne’s above-ground biomass may be accessed by grazing animals because of its erect growth habit (Gong et al., 1996, as cited by Cocks, 2001). Rotational grazing is difficult to implement on farms where suitable infrastructure, such as adequate fencing and water reticulation, is not present (Lodge, 1991). Nevertheless, this infrastructure is important, as the profitability of incorporating lucerne in crop rotations in the central Wheatbelt may be significantly enhanced through the manipulation of traditional livestock management practices to fully utilise the high summer-autumn production of this pasture (Flugge et al., 2004).

4.2.5. Unsuitable for Acidic and Waterlogged Soils

Soil limitations constrain the wide-scale adoption of lucerne in the Wheatbelt (Hill, 1996; Cocks, 2001). First, poorly-drained soils may cause *Phytophthera* root rot in lucerne plants because of prolonged waterlogging or inundation (Barta and Schmitthenner, 1986). Second, lucerne root growth and nodulation are severely inhibited in acid soils (pH ($CaCl_2$) < 4.8) because of aluminium and manganese toxicity (Staley et al., 1989) and the poor persistence of nitrogen-fixing bacteria *Rhizobium meliloti* syn. *Sinorhizobium meliloti* in such environments (Munns, 1965; Pijnenborg et al., 1990). Accordingly, Latta (2003) identified that annual pasture was more productive than lucerne on both acidic and poorly-drained soils. Improving lucerne’s ability to withstand soil acidity and prolonged waterlogging are important areas of current research (Cocks, 2001; Humphries and Auricht, 2001; Pannell and Ewing, 2006).

5. CONCLUSION

Dryland salinity is a major threat to agricultural production throughout the Wheatbelt of Western Australia. The shallow roots of annual crops and pastures reduces their capacity to dry the soil to depth and their senescence over summer reduces their ability to intercept out-of-season rainfall. This increases recharge in relation to that which occurred beneath native vegetation prior to extensive land clearance, thereby promoting the ascent of saline water tables that restrict primary production through salt toxicity and waterlogging as they approach the soil surface. A valuable strategy to prolong the productive capacity of soils at threat of salinisation is the regular use of lucerne pasture in rotations to create a buffer of dry soil to absorb recharge from subsequent crops (Latta et al., 2002). This legume produces high quality feed for livestock, allows the control of troublesome weeds without a need to use selective herbicides, and may establish a buffer of considerable size.

The capacity of farming systems to sustain agricultural production throughout the world is becoming increasingly threatened by environmental degradation arising from management. Historically, crop yields were maintained through frequent rotation between land-uses which degrade productivity and those that restore productivity. Dryland salinity has arisen directly from economic incentives accruing to divergences from this pattern, as incorporating perennial plants in land-use sequences usually bears some cost. Overall, this review highlights the importance of pasture for environmental mitigation and the need to consider these values when determining the value of pasture to rotations.

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Chapter 5

THE ROLE OF EXTENSIVE GRAZING SYSTEMS IN SOUTHERN EUROPE HORSE PRODUCTION

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ABSTRACT

Horse production in Southern Europe mainly relies on extensive systems where rainfed pastures are a key factor. In these regions, a great part of pastures is under Mediterranean influence, with hot, dry summers and are characterized by large surfaces of native or sowed grassland, frequently associated to a sparse tree cover. One of the most important and ancient horse breed traditionally reared in these areas is the *Lusitano*. The functionality and behaviour characteristics of *Lusitano* allow its use in many equestrian disciplines, with an increasing worldwide interest. Nowadays, these horses are bred in several countries, but in Portugal, the majority of *Lusitano* stud farms are still based in extensive grazing systems (EGS). In the EGS, mares are often bred outdoors throughout the year, being pastures a significant part of diets. Besides providing a major source of nutrients at a low cost, pastures also supply free exercise areas for growing foals.

Although relying on extensive rainfed pastures, highly dependent on climatic conditions, these production systems can be sustainable and affordable, if adequate complementary feeds are timely provided and if pasture management practices are appropriate. This study describes some current practices, analysing the role of extensive grazing systems in the *Lusitano* horse production.

1. INTRODUCTION

Equines are large monogastric herbivores that have developed in vast plains over millions of years. They have a gastrointestinal tract adapted to digest rich fibre feeds. Furthermore, horse digestive system is adapted to the permanent presence of feed, provided in small quantities and in a continuous way. Allow the use of pasture by equines is therefore placing them in an environment that resembles to their natural habitat. The pastures provide, generally, all necessary nutrients for horses, including minerals and some vitamins. They satisfy the need of repletion and, for mixed systems, they may help dilute feed concentrates, preventing the quick fermentation in the gut and the risk of cramps (Pagan, 1994). According to Miraglia *et al*. (2006), in Europe, grass and preserved forages account for 50 to 80% of horses global feeding in a year and, depending on breeds and climate conditions, the grazing period length can vary between 150 and 230 days.

Equine feeding behaviour has some characteristics conditioning the use of pastures. These characteristics give some peculiarities to equines in relation to other grazing animals. One of those is the rhythm of grazing. When at pasture, the horse spends around 50-70% of the time eating and only 20 to 30% at rest or inactive. Eating is a more time consuming activity than for other herbivores, but with a lower intake speed (Micol, 1995), having also active stages during the night (Mesochina *et al.*, 1997). Compared to ruminants, horses appear to be better adapted to forage of low nutritive value, increasing the voluntary feed intake. Although cattle are more efficient at dietary fibre degradation per unit fibre eaten, horses could be more efficient per unit time due to the increase in dry matter consumption and passage rate (Vandernoot and Galbraith, 1970). Equines can also adjust intake to the environmental conditions. For example, according to the season and weather conditions, like in autumn and winter when grazing duration may increase (Micol, 1995). Another particular characteristic of equines is that they use the pasture surface in a heterogeneous way (Archer, 1973 and 1978), being known as spot grazers. As a result, certain areas become overgrazed while others are abandoned. The areas left may represent 30 to 35% of the total area, emerging already after the first year of use of pasture (Martin-Rosset *et al*., 1984). As a result, some degradation of pasture occurs, with the development in these areas of herbaceous or shrub weeds (Moulin, 2000) and, on the other hand, with the damage of the preferred species (Graffis, 1985). A kind of "islands" or so called roughs (Miraglia *et al*., 2006) develop in the pasture surface, where faeces cumulate, with the uncontrolled growth of grass and the emergence of undesirable plants. These areas are only grazed when there is shortage of food and increase progressively if adequate care is not taken. Since the animals prefer the younger and less fibrous plants, degraded areas are increasingly less utilized. This is further accentuated for extensive areas where pasture management has to cope with balancing large surfaces with adequate stock rates, as animal pressure is usually low.

Preferences for plant species can also influence the grazing patterns. Although a great variation occurs, according to characteristics of pasture, climate and animals, there are signs of greater tendency for the consumption of grasses and mixtures of species (Édouard and Fleurance, 2007). Among the commonly sowed pastures species, fescue (*Festuca arundinacea* Schreb.), italian rye-grass (*Lolium multiflorum* Lam.), and white clover (*Trifolium repens* L.) are often preferred by equines (McCann, 1996).

Equines are able to cut the grass until 1 or 2 cm above the soil (Odberg and Francis-Smith, 1972). They have soft and flexible lips and incisors in both jaws, which allow them to be very selective when compared with other herbivores (cattle, sheep, goats). They are also able to eat very discreetly, up to the selection of leaves or even parts of leaves.

Given the particular equine grazing behaviour suitable management practices for pastures must be adopted.

In equine nutrition, the place of grazing is not directly tied to the economic value and use of animals. Among several situations, there are two extreme cases. On the one side, feeding systems are based mainly on concentrate feeds and preserved forages, where grazing may be only a limited feed complement, when grass is available. In this case, grazing has a low economic weight in the context of the exploitation. It is a common situation for some sport horses. On the other hand, there are feeding systems where pasture tends to be the basis during most part of the year, constituting a useful feature for most productive stages such as horses at maintenance, gestation, lactation or growth. For broodmares and their foals it is considered the main feeding resource (Miraglia *et al.*, 2006). In Southern Europe countries horse production mainly relies on extensive grazing systems (EGS) largely based on rainfed pastures.

2. PORTUGUESE NATIVE HORSE BREEDS PRODUCTION SYSTEMS

Selected over the centuries as a battle horse, *Lusitano* is a versatile breed, whose functionality and behaviour characteristics, allow it to compete in almost all modern equestrian disciplines, with particular emphasis on dressage, driving and work equitation. Nowadays, there is an increasing worldwide interest on *Lusitano* as a sports and leisure horse, and as a breeder improver by their rare qualities of character and genetics. Although bred in several countries, the majority of *Lusitano* stud farms in Portugal are still based in extensive grazing systems. In these EGS, mares are often bred outdoors throughout the year, being pastures a significant part of diets. When grass production is scarce, supplementary feeds (concentrate feeds and preserved forages) are generally used, but farm practices vary widely. The challenge in these systems is to cope with the specific nutritional requirements of some stages of the mare productive cycle in order to maintain an adequate body condition.

In general, changes on body condition throughout the breeding cycle are small (0.25 - 0.75 in a 0 to 5 points scale) and seems to be affected by foaling month (which occurs mainly between February and May). Highest body condition scores are observed at the end of spring/beginning of summer, decreasing thereafter until weaning, in the fall. Mares that are almost exclusively fed with pasture showed higher body condition changes along the year and pasture quality and availability seem to extensively affect those changes (Fradinho *et al.*, 2009).

Lusitano studs usually have a large number of mares on their herds, frequently above ten, but considering the large surface of used pastures, the stocking rate is low (often under 0.2 – 0.5 head/ha).

The weaning of foals occurs generally late in the fall and the weaning average age is between 6 to 7 months. Foals are bred outdoors throughout the year and, like the mares, pastures also represent a large part of feeding regimens for this group of animals. During the first year of life, *Lusitano* foals bred in EGS present similar growth patterns to those described in other sport light breeds, when submitted to moderate feeding levels. Estimated body weight at 12 months of age, may vary between 275–328 kg, representing 55-65.5 % of *Lusitano* mature body weight (500 kg) (Fradinho *et al*., 2008). Foals stay usually in the pasture until the end of the spring in which they complete three years old. From this moment on they are stabled for breaking and for the beginning of training.

Besides *Lusitano*, other two native horse breeds are also raised in Portugal based on EGS: the *Sorraia* horse and the *Garrano*.

The *Sorraia* horse can be defined as a breed of small horses (1.48 m withers height), with some morphological characteristics similar to the *Lusitano*. They are characterized by the mouse dun or bay dun coat colour, with a dorsal stripe and more or less evidence of “zebra” stripes in the head and members. They are extremely resistant to harsh environmental conditions under which they were always raised.

Animals corresponding to the morphological type of the *Sorraia* horse – convex profile and “zebra” stripes – are often represented in Palaeolithic paintings of southern Iberian Peninsula, denouncing the ancestors’ characteristics of this breed. It is thought, therefore, to represent the type of primitive Iberian horse of hot southern region, indicated as one of the four ancestors types of current domestic horse breeds. The selection and improvement of this primitive type has originated the Iberian Saddle horse (comprising the *Lusitano* and the *Pura-Raza-Española* breeds) and, under the influence of these, the vast majority of saddle horse breeds in the world.

The *Sorraia* mares are maintained under extensive management conditions (sharing frequently the same areas of *Lusitano*), feeding natural pasture and very often the remains of cereal harvests. In periods of drought and less abundance of pastures, they can be occasionally supplemented with other feeds. As previously mentioned, the rusticity of these animals allows them to easily adapt to pastures of poor quality (AICS, 2006).

Garrano is an ancient pony breed from Portugal whose production mainly relays in free ranging systems, located on northern mountain areas. Such mountain systems are characterized by the use of natural resources with seasonal shortage of pasture (Santos *et al*., 2009). When grass availability is low, some shrub vegetation like gorse (*Ulex gallii* Planchon) and heather (*Erica umbellata* L., *Erica cinerea* L. and *Calluna vulgaris* L.) can be also voluntarily selected by equines in these EGS (Ferreira *et al*., 2007).

3. EXTENSIVE PASTURE PRODUCTION SYSTEMS AND UTILIZATION BY HORSE

3.1. Types of Pasture Production Systems

Southern Europe countries have common influences that lead to some general climatic traits, like an accentuated drought in summer and a wide temperature range. Pasture production is negatively affected by climate characteristics being the most limiting factors the low biomass production with an uneven distribution, leading to the need of disposing of large grazing surfaces and supplementation (Miraglia *et al*., 2006). However, climate has also a positive impact, since it allows grazing to be practiced all year round. Pastures can be natural or sown, temporary or permanent (renewed when necessary), irrigated or rainfed and they are essentially constituted by plants of two botanical families: grasses and legumes. Also, there is the possibility of improving an existing natural pasture (fertilization, liming…). For Southern Europe regions under Mediterranean climate, natural dryland grown pastures are based in annual species and have a peak production in spring, a pause in summer and a smaller peak in autumn, that further decreases due to low temperatures in winter. Figure 1 shows the schematic seasonal evolution of dry matter production for pastures under such conditions.

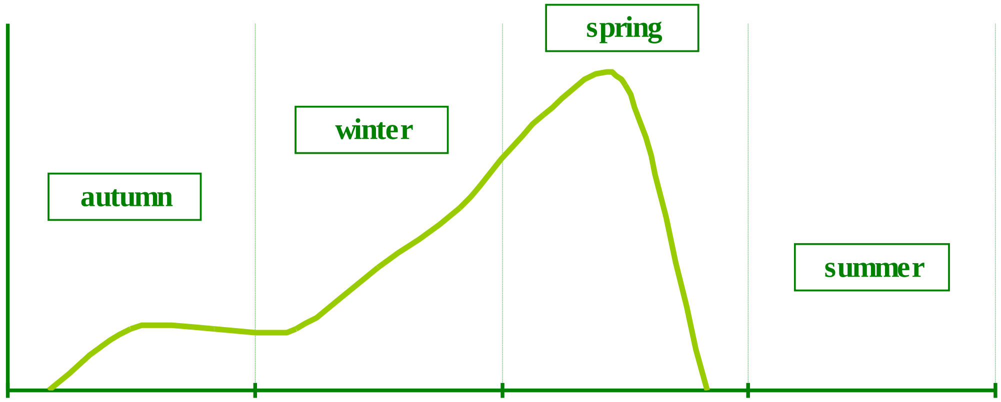

Figure 1. Schematic seasonal evolution of dry matter production for pastures under Mediterranean conditions.

Permanent grasslands in Southern Europe are distributed as depicted in Table 1, being the largest surface by country located in Spain, followed by Romania and Italy.

Table 1. Surface of permanent grasslands in several Southern Europe regions

Country or region	Area (1000 ha)
Cyprus	0.8
Greece	151
Italy	4369
Mediterranean France	1268
Portugal	1507
Romania	4845
Spain	6982

Eurostat, 2003.

In Portugal, extensive systems relying mainly on permanent grasslands can be roughly organized in two different types: those in mountainous areas, in the northern and central inland regions, and those in the south region. The systems in mountainous northern areas are mainly used by cattle, grazing permanent pastures of spontaneous vegetation, the so-called *lameiros*. Mountainous extensive areas in the north are also utilised by a native horse breed (*Garrano*, see section 2) in a free ranging system. Extensive systems in central regions are more often exploited by sheep, oriented to cheese production (Moreira, 2002). In the southern regions under Mediterranean conditions, pasture production systems often rely in the use of grasslands located in evergreen oak woodlands (called *montados* in Portugal and *dehesas* in Spain, Figure 2). The evergreen oak woodlands have a two strata structure: an understorey with herbaceous vegetation and shrubs (mainly *Cistus* sp.) and a sparse tree layer above. Tree density ranges from 5 to 80 trees per hectare, but commonly from 15 to 45 and canopy cover varies between 21 and 40% (Moreno and Pulido, 2009). The trees are essentially of two species: *Quercus suber* L. (cork oak) and *Quercus ilex* ssp. *rotundifolia* (holm oak). Wildlife and domestic grazing animals are also a part of the system and when the pasture is grazed, shrubs tend to be eliminated. The *montados* represent 33% (around 730.000 ha) of the total Portuguese forested area. They are located essentially in the south of the country, in the regions of Alentejo and Lisbon and Tejo Valley (90% of the country *montado* area, INE, 2009), in farms of large dimension (over 50 ha and often attaining 2000-3000 ha). In Spain, the *dehesas* occupy more than 5.800.000 ha in the western and south western provinces (Joffre *et al*., 1999) and more commonly they have a grazed herbaceous layer. For instance, in the region of Extremadura, half of the surface of *dehesas* is occupied with grasslands (EEA, 2005).

The *montado* or *dehesa* systems have a long history: written references for *dehesas* go back to the year 924 (Olea and San Miguel-Ayanz, 2006). They are a human shaped ecosystem and cannot be considered remnant vegetation of primordial forests. They depend on human management to persist, although apparently redirected by soil and climate resources, as noted by Joffre *et al.* (1999) who showed that, for drier zones, tree density relates to the amount of rainfall. They do, however, need human actions to prevent shrub encroachment, as they are an unstable vegetation type (Moreno and Pulido, 2009).

Being under Mediterranean conditions, *montado* systems must handle the large variability of this climate, what shows up their enhanced capacity to adapt and face unpredictability. For instance, trees must have the ability to endure recurrent multi-year drought periods (Joffre *et al*., 1999).

Montados are considered to be among the best preserved low-intensity farming systems in Europe (Moreno and Pulido, 2009). The grassland layer is frequently a natural pasture but sometimes yield and quality are improved by the use of fertilizers alone or together with the introduction of native or alien sowed species. The pastures are frequently used by cattle or sheep, sometimes by a native breed of pigs, but also by equines (Figure 2). In Portugal, besides the *montado* EGS, horse production is also traditionally linked, in some extent, to the fertile areas of over flooded *Tejo* and *Sorraia* valleys.

The *montado* system provides a limited grazing season length, given the summer drought. In spite of this, pastures still play a fundamental role in the global feeding system, often compensated by preserved forages (Figure 3). Supplementation occurs during periods with low or null levels of pasture biomass production, although remnant dry herbage is still available as feed resource during summer months. The most common situation in Portugal consists in leaving the animals in the pasture all over the year and during the entire day and supplementary feeds are given according to pasture availability.

Figure 2. Mares and foals grazing in *montado* pastures.

Figure 3. Supplementation of mares in the pasture.

Sown pastures in *montados* frequently comprehend auto-reseeding species like subterranean clover (*Trifolium subterraneum* L.) but a wide range of species and cultivars can be of interest, depending on soil characteristics and water availability (Crespo et al., 2005, Moreira, 2002).

3.2. Horse Pasture Management in Extensive Systems

Adequate utilisation of pastures in animal feeding, like referred by other authors (e. g., Miraglia *et al*., 2006) must take into account quantification of production and nutritive value of pastures or harvested forages, correct grazing and accurate pasture management. Pasture management is normally performed bearing in mind agronomic objectives, but aesthetic, ecologic and conservation objectives can be as well important. Relevant aspects in horse pasture management can be depicted as: type of grazing (rotational, continuous), stocking rates and the constitution of animal groups, fences and shelters, weed control, fertilization, control of degraded areas, pasture renewal, toxic plants, pasture biodiversity preservation, environmental and landscape concerns.

When applying a rotational grazing, animals are changed regularly between several parcels avoiding overgrazing situations. This kind of grazing also allows maintaining a better balance of pasture flora more easily and favours lifecycle break of some parasites. On the contrary, when proceeding to a continuous grazing, the animals remain in the same parcel permanently, favouring pasture degradation.

The number of animals per surface unit, or stocking rate, must balance the number of animals with the area available, avoiding situations of overgrazing or undergrazing. The stocking rate is very variable, depending on grazing conditions and feeding systems and is determined according to animal groups. It is common to separate animals into the following groups: 1) mares and foals until weaning, 2) colts with 1 and 2 years, 3) fillies with 1 and 2 years, 4) colts with 3 years, 5) fillies with 3 years (or together with the 1 and 2 years fillies group).

Fences and shelters are important elements that help organize and protect the groups of animals in the field. Open shelters are sometimes used to provide some protection for high temperatures during the summer or harsh conditions during colder months. Fences can be permanent or movable (and, frequently, temporary fences are electrified). If movable, they can be particularly useful to limit grazing, for example when high instantaneous stock rates are necessary in a specific area, to avoid undergrazing and degradation. Further information on fences for horses can be found, for example, in Wheeler and Zajaczkowski (2009) or Worley and Heusner (2009).

Weeds emerge very easily when there is undergrazing, or in areas not grazed systematically, or when pasture is still at installation stage. They can be eliminated by mechanical cutting (e.g. during flowering of the species we want to eliminate and before seed formation) or herbicides. The mechanical cut can be carried out once or twice per year, for example if the resulting green mass quantity is not very high it can be grinded and distributed on the surface. An alternative may be the use of a forage cutter (usually used for cutting silage material) and a trailer.

Fertilization must be adapted to the characteristics of pasture: rainfed/irrigated, temporary/permanent, natural/sown and also in accordance with fertility levels and characteristics of the soil. Concerning the major soil macronutrients, nitrogen (N), phosphorous (P) and potassium (K), the application of the first one is usually avoided or reduced, when the pasture has legumes, as they form a symbiotic relationship with soil bacterium *Rhizobium*, which converts atmospheric nitrogen to a form of nitrogen available for the plant. High doses of nitrogen tend to stimulate the development of grasses, competing with legumes and creating an imbalance in pasture composition. Phosphorous promotes root development and has a beneficial effect on *Rhizobium* activity. Potassium favours the maintenance of the balance of floristic composition and also promotes the fixation of atmospheric nitrogen. Phosphorous and potassium are the nutrients frequently considered for application in pastures. Others can eventually be considered like calcium (Ca), magnesium (Mg), sulphur (S) and boron (B).

The control of degraded areas might be performed using one or more of the following strategies: mechanical cutting of the plants in those areas, alternate years of grazing with years of cutting of pasture, move waterers and salt stones to the less grazed zones, promote joint/alternate grazing with cattle, use movable fences to limit grazing areas, use instant high stocking rates, gather manure and use it for composting and further spreading in the pasture.

Equines tend to be selective grazers and eat different plant species than cattle, even if their diets overlap extensively. Therefore, they can be complementary for production and management objectives (Mesochina *et al*., 1997). The practice of mixed grazing by cattle and horses is used, for instance, in extensive systems in the western coast of France for many centuries. Studies in this region (Loucougaray *et al*., 2004) showed that mixed grazing originated the most species-rich and structurally diverse swards. This practice was also capable of limiting two strongly competitive weeds on droppings deposition areas, via cattle grazing. In Spain, different combinations of animals may graze the same pasture, either serially or concurrently (Huntsinger *et al*., 1991). In Portugal, mixed grazing with ruminants occurs as well.

On average a horse might produce approximately 20 kg of manure/day (Agroscope, 2009, Lawrence *et al*., 2003). The collection, composting and spreading of manure coming from stabled horses must observe some cautions. For instance, storage should be done using waterproof base and cover to avoid leaching to watercourses and groundwater, preventing water pollution. The composting is a technique to control decomposition of organic matter that is useful to destroy parasite larvae. After composting (which takes a few months) manure can be spread as a fertilizer in the pastures.

A partial renewal of the pasture might be of interest if a certain revitalization is intended, without however sowing (e.g., light soil mobilisation with a disc harrow), or sowing only the degraded areas. The disadvantages of such an action are the possibility of damaging interesting plants and of opening spaces for the development of weeds. Total renewal takes place when the pasture is in an advanced degradation state and is going back progressively to natural conditions, being no longer of interest for the feed system implemented. Total renovation might be done by sowing the entire area with common cultural practices (recurring to soil mobilization) or by using direct sowing techniques.

Toxic plants can cause problems if ingested by grazing horses and some attention should be taken whether they are present in the field or not. It is also important to have in mind that the risk of intake of those plants increases when the availability of feed decreases (IE, 1999). Such plants often have toxic alkaloids that can cause irreversible damage to liver and produce symptoms like jaundice, poor physical condition or photosensitisation. They should be removed from the pasture by cutting or by the localized application of herbicide. Another option might be to prevent access by animals using fences.

Toxic plants may be spontaneous or cultivated. Examples of cultivated toxic plants for horses include red clover and sorghum. Red clover (that can be responsible for trifoliosis) becomes toxic when infected by fungi containing toxic alkaloids or when having estrogens, can possibly be responsible for fertility problems. Sorghum can cause urinary inflammations. Examples of spontaneous toxic plants that occur in Portugal are referred in Table 2.

Table 2. Examples of spontaneous plants that are toxic for horses

Toxic plants	
Anagallis spp.	*Lolium temulentum*
Centaurea spp.	*Papaver* spp.
Datura stramonium	*Polygonum aviculare*
Echium plantagineum	*Senecio* spp.
Equisetum spp.	*Stellaria* spp.

4. CASE-STUDIES

4.1. Natural Rainfed Pasture Based Extensive System

The first case-study presented refers to a large farm in Southern Portugal in a region with an average annual precipitation close to 600 mm and a mean annual temperature of 16 ºC.

The *Lusitano* horse breeding system in this enterprise relies on the use of extensive grasslands in *montados* combined with open areas. The data presented was collected in 1994.

The core group of animals consisted of a nucleus of about twenty *Lusitano* broodmares. The groups of animals were distributed by the different types of pasture: broodmares and foals until weaning were kept at open area pastures, one with natural grassland and another improved with oats (*Avena sativa* L.) and cock's-foot (*Dactylis glomerata* L.) two years before (125 + 49 ha); fillies and colts below 3 years were group distributed by *montado* natural pastures (16 ha) and 6-year old sown pastures in an open area (7 ha).

In this stud farm, foaling used to occur mainly in the second half of March and beginning of April. Broodmares and the nursing foals were kept at pasture during daylight in winter and taken at night to a common indoor stable, where they were supplemented with compound feeds and some hay. During summer, an alternate management was performed as the animals were allowed to stay in the pasture during the night and sheltered during the day, thus avoiding exposure to high temperatures (maximum monthly temperatures during summer are in average around 30ºC). This practice is not very common in EGS of the region, as the animals use to stay in the field during the whole day and all over the year.

Pasture production was evaluated during spring and the results are presented in Figures 4 and 5. Production was obtained using a cage technique, by collecting the biomass inside of 1 square meter cages (Abreu and Coelho-Silva, 1997), built in wood and metallic net (Figure 4, left). The objective of using the cages was protecting the plants from grazing animals, thus artificially simulating grazing by scissors cutting. The cages were randomly distributed in the pasture (4 cages in each plot). For each cut date, the cages were lifted, the grass was cut and after that the cages were located again in the same place. The aerial part of pasture plants inside the cages was cut monthly, weighed and dried to obtain dry matter production during spring of 1994. Furthermore dry matter samples were analyzed to obtain nutritive value of the pasture. For this, the following determinations were performed: crude protein, crude fibre, ashes (Weende analysis methodology, AOAC, 1990), calcium, phosphorous and magnesium.

The highest daily production, expressed as dry matter, occurs in April, varying approximately between 70 and 100 kg DM ha^{-1} day^{-1} for the four types of considered pastures (Figure 4, right). Interestingly, the lowest dry matter production was observed in the 6-year old sown pasture. However, from field observations it was clear that this pasture was highly degraded and presenting signs of regression to the natural cover.

The nutritive value of pasture (energy and protein) was calculated according to the prediction equations in the French horse feed evaluation system (Martin-Rosset and Vermorel, 2004). The considered nutritional requirements of animals were based on the recommended allowances for equines of INRA systems (INRA, 1990).

Figure 5 overlaps the daily dry matter production of a natural rainfed pasture (pasture number 3 in Figure 4) with the indicated values for dry matter intake (forage rich based diets) for 500 kg body weight broodmares (INRA, 1990). The period with the highest dry matter intake is related to an accrual of nutritional requirements due to the beginning of lactation. Generally, in these regions, most of the stud farms manage mare's reproductive cycle in order to concentrate foaling in spring, when pasture dry matter production is higher.

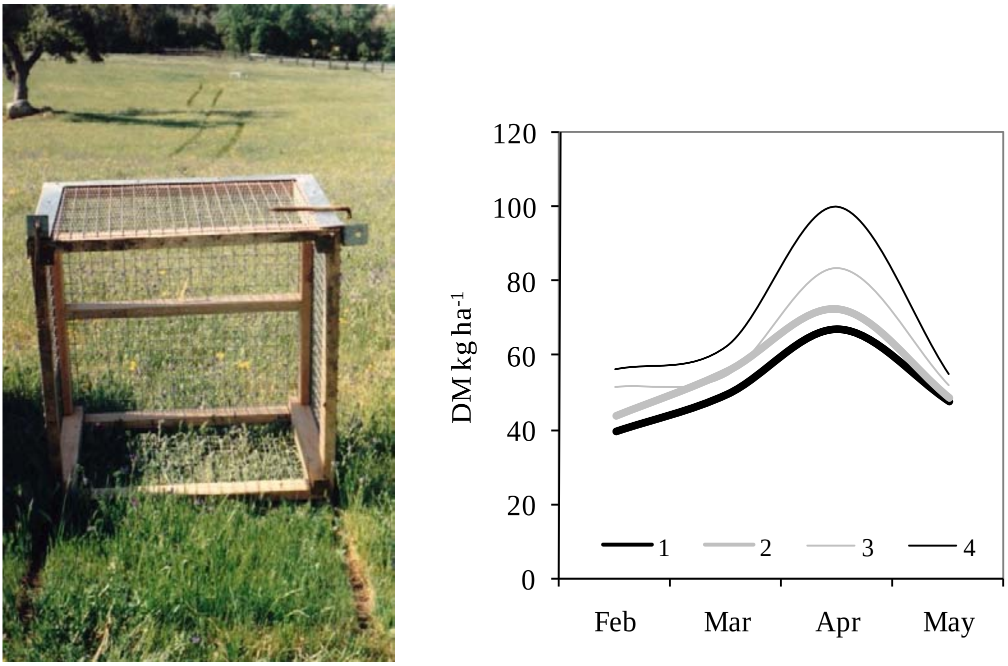

Figure 4. Protection cage (left) and rainfed pastures dry matter (DM) production (right) in an extensive grazing system in the south of Portugal (1 – 6-years sown pasture, 2 – natural pasture in *montado*, 3 – natural pasture, 4 – improved natural pasture).

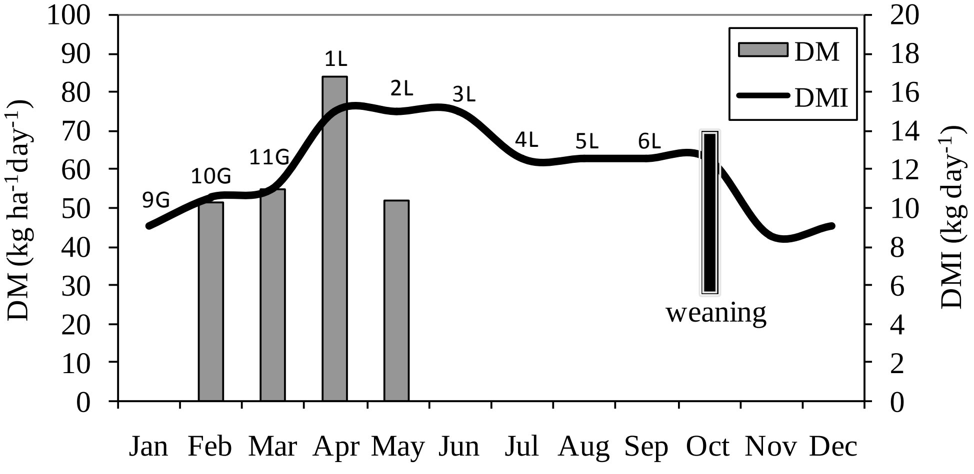

Figure 5. Dry matter production (natural rainfed pasture) and broodmare (500 kg body weight) recommended dry matter intake (DMI) (INRA, 1990), according to breeding cycle (G – gestation, L – lactation).

The results concerning chemical composition with respect to crude fibre and crude protein contents of different pastures are presented in Figure 6. The observed variations along the sampling period reflect, in a general way, the known changes of chemical composition of forages along the vegetative cycle.

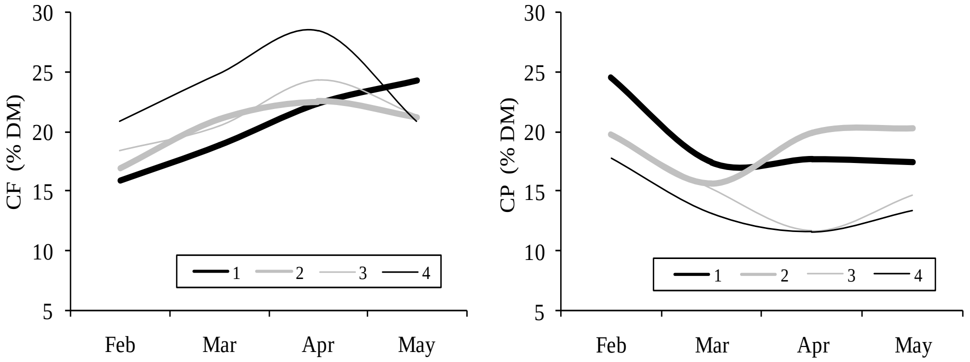

Figure 6. Crude Fibre (CF) and Crude Protein (CP) content of the four types of analysed pastures between February and May.

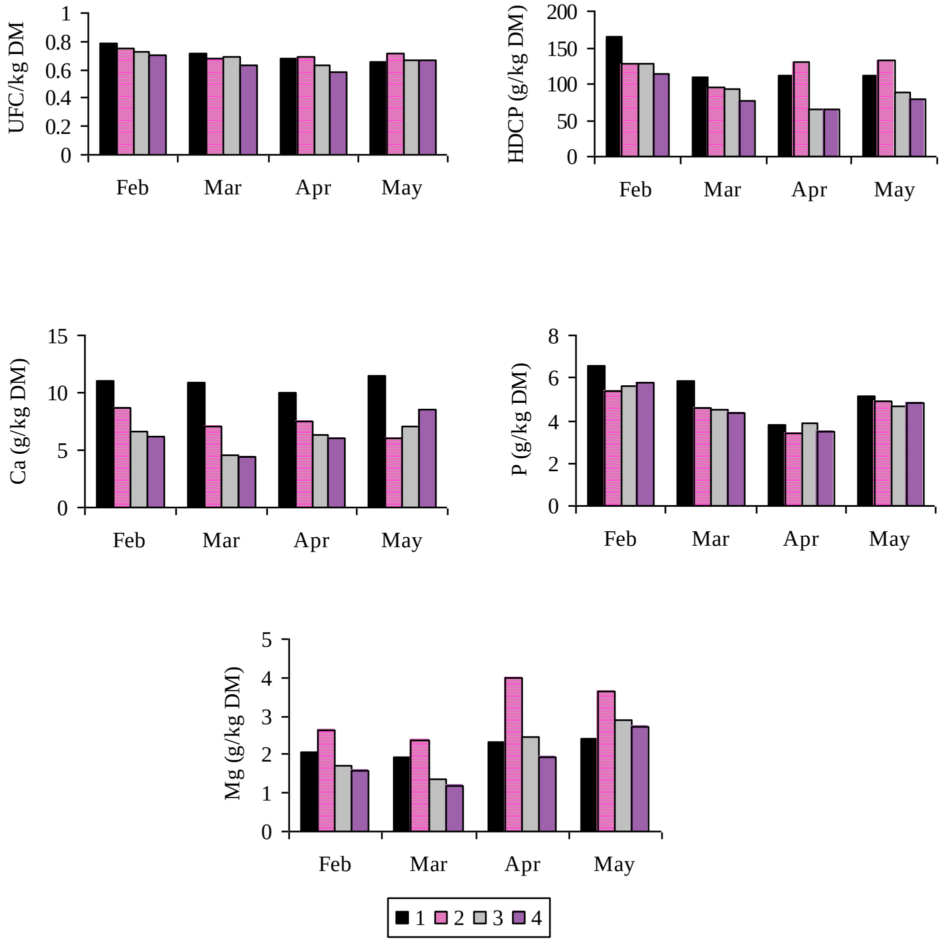

Figure 7. Nutritive value (UFC– Horse Feed Unit, HDCP- horse digestible crude protein, Ca, P and Mg) of different types of pastures in an extensive grassland system in Southern Portugal.

The nutritive value of pastures in respect to energy (UFC – Horse Feed Unit), protein (HDCP - horse digestible crude protein) and three macro minerals (calcium, phosphorus and magnesium) are presented in Figure 7. UFC values slightly decrease between February and April, rising a little in May. Protein content has also a tendency to decrease, but for pastures 1 and 2, an increase in April was observed, what is probably due to grain formation in this moment of the cycle. *Montado* pastures had a high proportion of legumes, mainly *Ornithopus compressus* L. (yellow serradella), which could explain higher protein content in those parcels, in relation to other pastures. The lower protein content found for 3 and 4 is possibly related to a different botanical composition.

In the present case-study, nutrient requirements of the different groups of animals (broodmares and growing foals) could be widely supported by pasture nutrients in the considered months. Furthermore, the low stocking rates and the daily supplements (according to pasture availability) ensures that requirements can be met even in the most critical phases, as the apparent body condition of mares and foals were always very good. However, pastures still represent a significant part of global feeding regimen.

4.2. Sowed Rainfed and Irrigated Mixed System

The second case-study presented relates to a *Lusitano* horse production system located also in Southern Portugal, at a distance of approximately 60 km in the west direction of the first case-study (see 4.1). The average annual precipitation in the area is 700 mm and the mean daily temperature is 16ºC. The production system was based in a group of 9 broodmares. Younger animals were distributed by groups in a similar way to the case-study presented before. The whole system was based in rotational grazing using both rainfed and irrigated pastures.

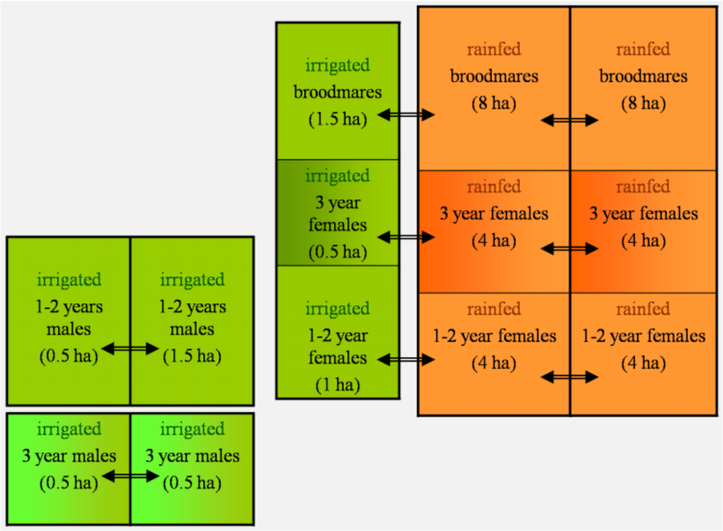

Figure 8. Rotational grazing scheme using rainfed and irrigated pastures – case-study for a *Lusitano* stud farm in Southern Portugal.

Figure 8 describes the animal circulation between plots, as well as the type of pasture and the respective surface. Broodmares and younger females were kept in nine plots, from which six were rainfed. During the year they all circulated between plots as indicated in Figure 8, according to grass availability, moment of plants vegetative cycle and general state of the pasture. All the rainfed pastures were located in the understorey of a *montado* system and were sowed using subterraneum clover (*Trifolium subterraneum*), annual rye-grass (*Lolium rigidum* Gaudin), bulbous canarygrass (*Phalaris tuberosa* L.) and cock's-foot (*Dactylis glomerata* L.). Irrigated pastures were sowed with white clover (*Trifolium repens* L.), hybrid ryegrass (*Trifolium hybridum* L.), annual rye-grass (*Lolium rigidum* Gaudin) and cock's-foot (*Dactylis glomerata* L.).

Considering that the rainfed pasture production was similar to the described in the previous case-study, two main differences could be enhanced in this system: on the one hand, a higher stocking rate for all groups; on the other hand a permanent availability of green forage, giving the existence of irrigated pastures.

Even with a high stocking rate, the rotational grazing system could allow a better use of the pastures, in order to avoid overgrazing situations. At the same time, a high animal pressure helped to control the development of weeds. If water is not a limiting factor during the summer, grass production from irrigated pastures becomes an important feed resource through that period, when biomass production in rainfed pastures is null. Besides, in the present system some supplementary feed (small amounts of commercial compound feeds and occasionally mixed grass-legumes hay) were also provided in a daily basis, according to pasture availability.

Apparently, nutritional requirements of the herd were met, as mares and foals body condition was very good throughout the year.

5. EXTENSIVE GRAZING SYSTEMS AND SUSTAINABILITY

Extensive grasslands give a great contribution for the preservation of biodiversity, by way of conserving habitats, either of a community or of rare/emblematic species. They can also allow providing the basis to modify and manage selected biotopes. Grasslands in Southern Europe comprise important wildlife habitats, in particular for birds and invertebrates. Steppe areas in western Spain, with an important range of protected birds, small-scale farms that have species-rich semi-natural grasslands and sclerophillous grazed forests – *montados* and *dehesas*, as classified in the European Union Habitats Directive (Council Directive 92/43/EEC, 21 May 1992) - can be pointed out as examples (Silva *et al*., 2008).

The *montado*, although not a natural system, is highly functional and stable, from an ecological point of view. This can be attributed to the high diversity of relationships between its components, according to Olea and San Miguel-Ayanz (2006). These authors further refer to the *dehesa* as 'a paradigm of equilibrium and mutual dependence between production and nature conservation'. Indeed, the *montados* are the main habitat for some endangered species and have a wide diversity of animals and plants (Moreno and Pulido, 2009). Particularly, the grass layer has in its natural composition highly-valued native species in what concerns agronomic interest (Joffre *et al*., 1999). The use of pastures by animals can be itself a way of preserving livestock biodiversity, as reported by Miraglia *et al.* (2008), for *Pentro* horses, an autochthonous population bred in natural pastures, in the region of Molise, Italy. In nature conservation areas horses are often combined with cattle in order to maintain biodiversity (see Miraglia *et al*., 2006, for further information).

Environmental aspects must be taken into account when managing horse pastures and this is particularly relevant for extensive systems like *montados*, where a delicate man-induced balance exists. Some environmental aspects are related to ecotourism and rural tourism that can benefit from an entourage of adequately managed pastures. Another relevant aspect is the water quality preservation, namely by the care with storage and use of manure and by restricting animal access to watercourses.

Natural and semi-natural pastures are an important resource for biodiversity. The risks arise from the intensification of grazing, abandonment, biodiversity loss, increased risk of fire and increased soil erosion (Rook *et al*., 2004). For sown grasslands, using diverse species and cultivars also favours productivity and stability (Crespo, 2005). A pro-biodiversity horse pasture management must avoid static management systems (for example, using fixed stocking rates) and must use management systems that are based on the pasture (e.g. pasture height, Rook and Tallowin, 2003).

6. THE FUTURE OF EXTENSIVE GRAZING SYSTEMS

The roles of grasslands in the future are expected to increase in diversity as new potential uses or ecosystem services are becoming recognized, like recreation or nature conservation (Hadjigeorgiou *et al*., 2005). Concerning *montados*, its regeneration is difficult in natural conditions (Olea and San Miguel-Ayanz, 2006). However, Ribeiro *et al.* (2003) state that the sustainability of the system has to be based in regeneration (natural or artificial) and that, in an 100 years cycle, it is possible to attain it with only two regeneration moments, at 40 and 60 years. There is some degradation in *montados* due to soil erosion, water stress, cork over exploitation, aggressive soil mobilisation and sanitary problems (ICN, 2006). Climate change can also become a concern, given that the most severe effects in Portugal are expected in the regions actually occupied by *montados* (Pereira *et al*., 2006). Climate change is expected to affect Portugal by the occurrence of droughts alternating with intense rain pulses, an increase in the number of days with high temperatures, a higher risk of wildfires and desertification in the southern part of the country with the disappearance of traditional vegetal species, among other consequences (Yun, 2008).

In future scenarios, it is expected that water stress will become a main constraint to primary production (Pereira *et al*., 2002). This will certainly affect *montados* and the production systems relying on them. Concerning cork oak woodlands, Pereira *et al.* (2009) state that they face an uncertain future as a result of land use changes, global changes and market trends. Climate change scenarios, indicating the increase of aridity and of unpredictability of rain, suggest that cork oak trees will tend to migrate to higher latitudes and altitudes (Pereira *et al*., 2009), being replaced by shrublands and/or grasslands (Pereira *et al*., 2002). Denser stands may suffer a natural thinning as a result of mortality (Pereira *et al*., 2002). Holm oak trees are better adapted to drought than cork oak trees and can eventually substitute these in western regions, where they are actually dominant (Pereira *et al*., 2006).

Grazing systems associated to oak woodlands will also be transferred or become open grasslands. As the length of the rain period in spring might decrease, annual plant species that have a shorter vegetative cycle will become more competitive. This will signify that lesser pasture will be available for animals, as spring production will tend to cease earlier.

Horse production based on EGS in *montados* will most probably be affected by the changes predicted for them. The effects may come from the expected migration of trees, leaving open grasslands or shrublands in actual areas of horse production, or from the shorter rain period in spring, which will lead to a decrease in rainfed pasture production.

CONCLUSION

Extensive grazing systems (EGS) in Southern Europe are often used as a basis for horse production. EGS mainly rely on rainfed pastures that, although frequently left in natural conditions, can be improved or sown. Under Mediterranean conditions, production of rainfed pastures is limited by climate, given the high temperatures and the absence of rain during summers. In the end of spring, production cesses and returns only in autumn, with the first rains. Although under these climatic constraints, horse production in EGS of such regions can be sustainable and affordable, if adequate complementary feeds are timely provided and with adequate pasture management. This is the case of the evergreen oak woodlands called *montados* in Portugal and *dehesas* in Spain, which have extensive grassland areas below the upper layer of scattered trees. *Montados* are a human shaped ecosystem, but a singular case of equilibrium.

The two case-studies presented describe *Lusitano* horse production systems based on *montado* grasslands. In these systems, one of the key points consists in synchronizing broodmares peak lactation requirements with the moment of highest pasture production, as a way of optimizing resources. In a general way, the use of pastures in horse feed management has the advantages of presenting a fair nutritional balance, at a relative low cost. In addition, pastures provide free exercise areas, promoting equine health and wellbeing.

In our time, *montado* systems endure some difficulties, like the uneasy tree regeneration, sanitary problems or soil erosion. Climate change will possibly impact this ecosystem, influencing its geographical distribution and affecting the associated grasslands and livestock production. However, horse production in extensive grazing systems could be determinant for sustainability and biodiversity preservation.

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Chapter 6

WHEN TRADITIONAL MANAGEMENT RESPECTS PHENOLOGICAL CYCLES OF PLANTS IN WET PASTURES IN THE MOROCCAN MOUNTAINS

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ABSTRACT

In the High Atlas mountains of Morocco, wet grasslands in the Oukaimeden plateau have been developed on small surface areas supported by soils water accumulation. These ecosystems, close to the sources and banks, constitute wetlands of high floristic richness with significant rate of endemism (27%) and particularly rich in alpine and boreal plants.

Furthermore, these wet pastures, coveted for their pastoral richness, have always been exploited and undergo a particular traditional management. This practice called "*Agdal*" consists of restricting rights of access and (or) uses according to the customary law. In the case of Oukaimeden Agdal, the opening date is fixed from 10 August until 15 March of each year. The phenological monitoring carried out of the Oukaimeden pastures flora shows that the opening date of the Agdal corresponds to the reconstitution of seed stocks in ground and the closure of the latest species vital cycle. The strike balance between the opening date and the resource regeneration proves the efficiency of this kind of management that aims to favour biodiversity.

Keywords: Mountainous wet grasslands, Common rangeland management, Plant phenology, Biodiversity conservation.

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INTRODUCTION

In the Oukaimeden plateau, wet grasslands constitute a common grazing that undergoes an ancestral community management locally named "*Agdal*" which consists to subject (submit) the pasture to a temporary rest of grazing, in respect of the alternation of opening and closing periods (Berque, 1955; Mahdi 1999; Franchi, 2005). Accurate indigenous knowledge and management are applied to preserve environmental conservation and local development. This is the case for Moroccan mountains as well as other several mountain grasslands and rangelands all over the world including the Himalaya, Andes and Alps (Saxena *et al.*, 2001; Buttolph & Coppock, 2004; Jeangros *et al.*, 2005; Chandrasekhara *et al.*, 2006).

In the case of the pastoral Agdals, the local populations having access rights respect a precise opening and closing calendar for grazing, aiming at the four main objectives:

- A better forage productivity
- To ensure the durability of the pastoral practice and forage resource
- A maintenance of all population’s equal access rights to the forage resources (the rangeland is always open at the same time and for everyone)
- Reduction of conflicts between the tribes around the rangeland.

The main feature of this management is to allow the vegetal resource regeneration and to preserve its perenniality.

In the case of the Oukaimeden, the *Agdal* opening period is form 10 August to 15 March. This late opening time allows for the dissemination and the reconstitution of seed stocks of all plant species.

In this context, the present work will contribute to answer two main questions:

1) Does the Oukaimeden Agdal management calendar actually allow the safeguarding of vegetal resource of the pastoral site (preservation of seed stock of the various local species)?
2) Can phenology of the major fodder species be taken as an indicator for decision-making to the pastoral management calendar (criterion of durability)?

MATERIAL AND METHODS

Study Area

The Oukaimeden plateau (lat 31°12' N and long 7°52' W) is located at 75 km south of Marrakesh and rises at an altitude of 2 650 m. This site belongs to the High siliceous Atlas with an acid eruptive Precambrian substrate comprising Rhyolites and Andesites (Dresh, 1941; Quézel, 1957).

The climate in Oukaimeden is dominated by the Semiarid Mediterranean bioclimate with cold winter variant. Rainfall varies between 400 and 500 mm/year. Snowfall is significant between December and March. The temperatures are rather low, the minima average in the coldest month is evaluated at – 2.69 °C and the average maxima of the hottest month reached 23.5 °C.

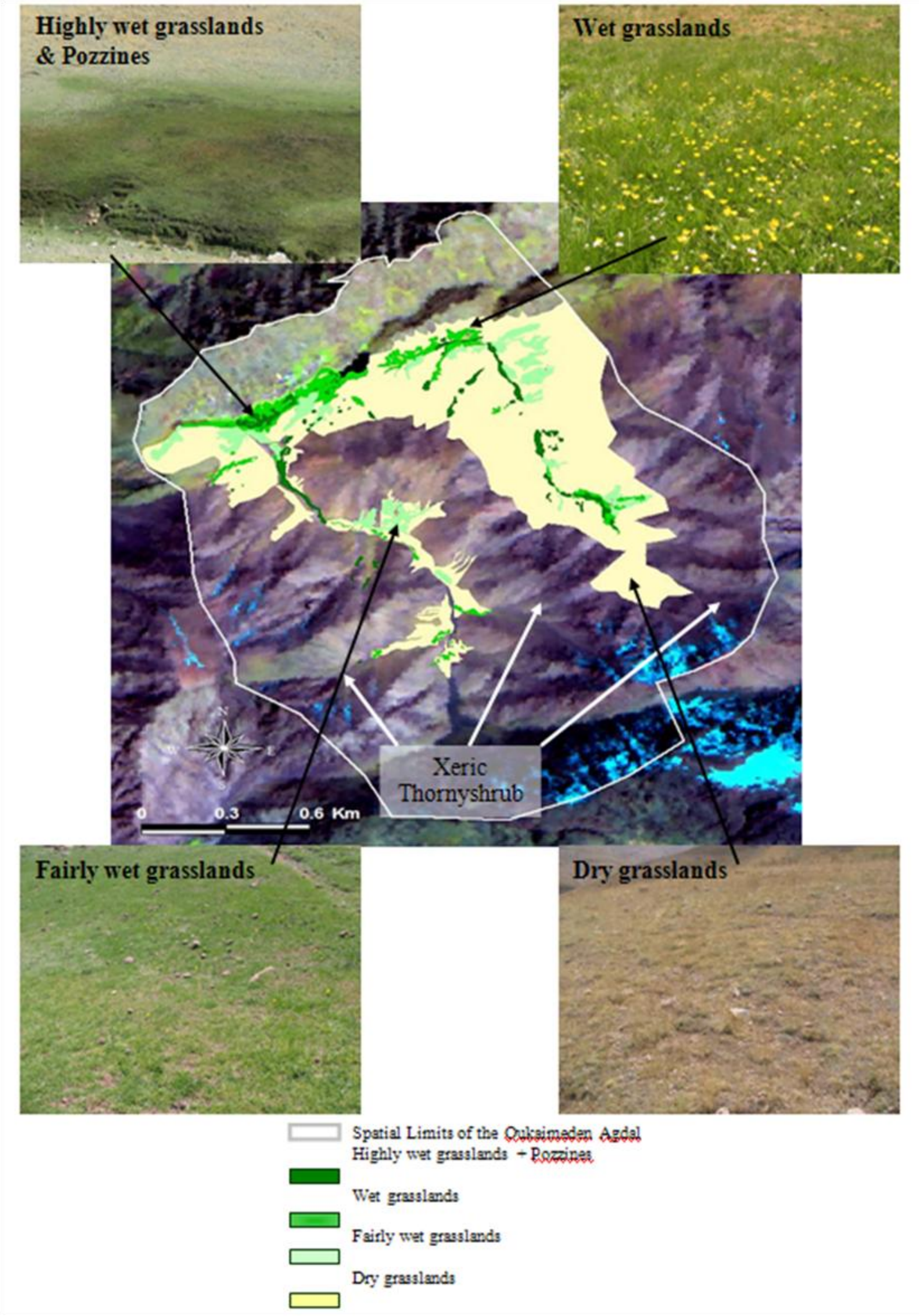

Figure 1. Actual cartography of various facies of Oukaimeden grasslands.

Table 1. Characterization of Oukaimeden grasslands

Facies	Very Wet + Pozzine	Wet	Fairly wet	Dry
Substrate nature	Peaty soil	Marly clayey soil	Sandy clayey soil	Sandy soil with some stones on the surface
Humidity	100%	80 to 100%	60 to 80%	Less thane 40%
Slope	< 5 %	< 5%	< 5%	More thane 5%
Recovery	100%	100%	90 to 80%	80%
Surface area Ha (%)	14.569 (3%)	23.952 (5%)	34.120 (7%)	386 (85%)
Spatial distribution of the livestock	Bovines stay only one month on the Agdal	Bovines and sheep	Sheep and Goats	Goats
Types of pastoral practices	Mowing	Mowing	Mowing	With out mowing
Liste of most characteristic species	*Bellis caerulescens* Coss. *Carex intricata* Tineo. *Dactylorhiza elata* Poir. *Leontodon atlanticus* (Ball.) *Myosotis atlantica* Vestergr. *Narcissus bulbocodium* L. *Nardus stricta* L. *Parnassia palustris* L. *Poa alpina* L. *Sedum surculosum* Coss.	*Blakstonia grandiflora* (Viv.) Pau *Conium maculatum* L. *Festuca rubra* L. *Haynaldia ordacea* Coss. & DR. *Hypericum pubescens* Boiss. *Minuartia tenuifolia* L. *Ranunculus aurasiacus* Pomel *Rumex atlanticus* Batt. *Saxifraga granulate* L. *Trifolium humile* L.	*Anacyclus pyrethrum* L. *Festuca marrocana* Batt. & Trabut. *Helianthemum croceum* Desf. *Hypochoeris arachnoidea* Poir. *Linaria multicaulis* L. *Lotus corniculatus* L. *Paronychia polygonifolia* (Vill.)DC. *Plantago coronopus* L. *Stachys arenaria* Vahl. *Veronica rosea* Desf.	*Aegilops geniculata* Roth. *Astragalus ibrahimianus* Maire *Catananche caespitosa* Desf. *Dianthus cintranus* Boiss. & Reuter *Festuca ovina* L. *Isatis tunctoria* L. *Paronychia argentea* Lam. *Polycnemum fontanesii* Dur. & Moq. *Pterocephalus depressus* Coss. *Scorzonera pygmea* Sbith. & Sm.

Oukaimeden grasslands are formed by vegetal formation based on hemicryptophyte and characterised by a highly rate of covering (Quézel, 1957; Gauquelin, 1988). They present various facies which correspond to 4 vegetation types namely: the very wet facies and Pozzines with *Nardus stricta* (L.) and *Carex intricata* (Tineo), the wet facies with *Ranunculus aurasiacus* (Pomel), the fairly wet facies with *Festuca marrocana* (Batt. & Trabut) and the dry facies with *Astargalus ibrahimianus* (Maire) which marks the transition towards the xeric thornyshrubs dominant on the rest of the study site (Figure 1; Table 1).

198 species, 122 genera and 38 families were recorded in the whole Oukaimeden grasslands flora while 134 species, 97 genera and 34 families were recorded in the wet entity which includes highly wet grasslands + pozzines, wet grasslands and fairly wet grasslands (Alaoui Haroni *et al.,* 2005). It represents more than 60% of the total specific richness of the Oukaimeden grasslands with a rate of endemism exceeding 25% and a degree of rarity reaching 29% (Alaoui Haroni *et al.,* 2005). This flora is supplemented with plants from alpine and boreal origin (17,4%), pushed towards the extreme southern latitudes during the last glaciations (Alaoui Haroni *et al.,* 2005).

The *Agdal* Practice and the Community Management of the Pastoral Area

The *Agdal* is an *Amazigh* or *Berber* term, describing an indigenous management and natural space appropriation practice in the Moroccan mountain. *Agdal* designate "a traditional Institution of collective pastures management of the stockbreeders in the High Atlas" (Mahdi, 1999). This practice rests on social structures, agropastoral uses, knowledge and beliefs, inherited representations of a distant past. It appears like a socio-space concept indicating a territory, resources (water, trees, fruits, range…) rules and institutions allowing the control of access and use (Franchi, 2005). It can potentially be applied to all territories, to all renewable resources; and can be defined more generally as: a territory whose access and use of renewable resources are regulated (Auclair & Alifriqui, 2005). Analysis of the *Agdal* arrangements for the communal use of pasture demonstrates how pastoral groups manipulate kinship and historical opportunities to negotiate order, grass, and subsistence in the highly variable environment of the High Atlas mountains (Ilahiane, 1990).

In the Oukaimeden plateau the various wet grasslands facies constitute a common pasture subject to a forbidden access from 15 March until 10 August each year, these dates are not applicable to other pastoral High Atlas *Agdal*s. Each one has its own opening/closing period depending of various environmental factors: altitude, climate…, to the phenology and its interaction with climate and also the availability of alternative rangelands for populations. In this case, the *Agdal* will constitute an alternative forage resource, which will be further exploited when the first one is exhausted. For instance, the opening date of *Agdal* in the Tichka plateau, located at a similar altitude as Oukaimeden plateau (between 2 600 to 2 800 m of altitude), is 17 July.

The transhumants access rights to graze this common pasture are the tribes of Ourika and Gheraya who divide the resource and the area of the pasture, bringing their families and livestock. They settle in the *"Azib"* (shepherds' houses), these camping follow a well defined and respected territoriality according to the tribe and the "*Douar*" (village) (Gellner, 1966; Gilles *et al.,* 1986; Mahdi, 1999; Franchi, 2005).

Methodology

The phenological monitoring of the Oukaimeden grasslands flora was made as follows:

- For each of the 4 facies (vegetation types) were selected the ten most dominant species, as mentioned in Table 1. Thus, the monitoring is made for the vital cycle of each species.
- 16 plots corresponding to the minimum area (Godron, 1971; Guinochet, 1973) were selected, four for each facies (the difference of plot superficies between facies is related to the different rate of covering):
    - The very wet facies + Pozzines (2 m^2)
    - The wet facies (6 m^2)
    - The fairly wet facies (10 m^2)
    - The dry facies (25 m^2)

The phenological monitoring starts at the beginning of the snow melt; that is from April until the opening of the *Agdal* on 10 August with almost a 15 days interval and this over two years period (2005 et 2006).

The phenological stages adopted and represented in our results are the following ones:

- The vegetative stage
- The flowering stage
- The fruiting stage
- The stage of seeds dispersion

Process Data

During two years, every 15 day we note phenological stage in each plot. So, the most appropriate procedure to deal with this data is the Kruskal wallis test (Kruskal & Wallis, 1952; Siegel & Castellan, 1998). This non parametric method allows carrying out the comparison of more than two samples.

The null hypothesis is “There is no difference between plots observations in the same facies”.

For each date of phenological monitoring during the two years of observation p value (calculated probability) vary between 0.1 and 1 with 3 degrees of freedom. Thus, $p > 0.05$ (alpha: significance level = 0.05) means that there is evidence to keep the null hypothesis and consequently prove that the plots of the same facies are not significantly different.

RESULTS

Climatic Conditions During the Period Study (Two Year)

The Observations Campaign of the Year 2005

Annual precipitations during this year were 250 mm, the most rainy month was October with 85.5 mm (Figure 2A). The snowfall was about of 166 mm pluviometric equivalent, the first snows period began at February with 64 mm, which constitute the year maximum peak (Figure 2B).

About temperature, the average minima in the coldest month “m” in this year was evaluated at – 4.7 °C and the average maxima of the hottest month “M” reached 22.9 °C. The spring temperature average is of 10.6 °C (Figure 2C).

During year 2005, rainfalls were therefore rather low in comparison with the average. A big deficit was recorded in the spring. 2005 presented characteristics of a dry year, with a very low snowfall.

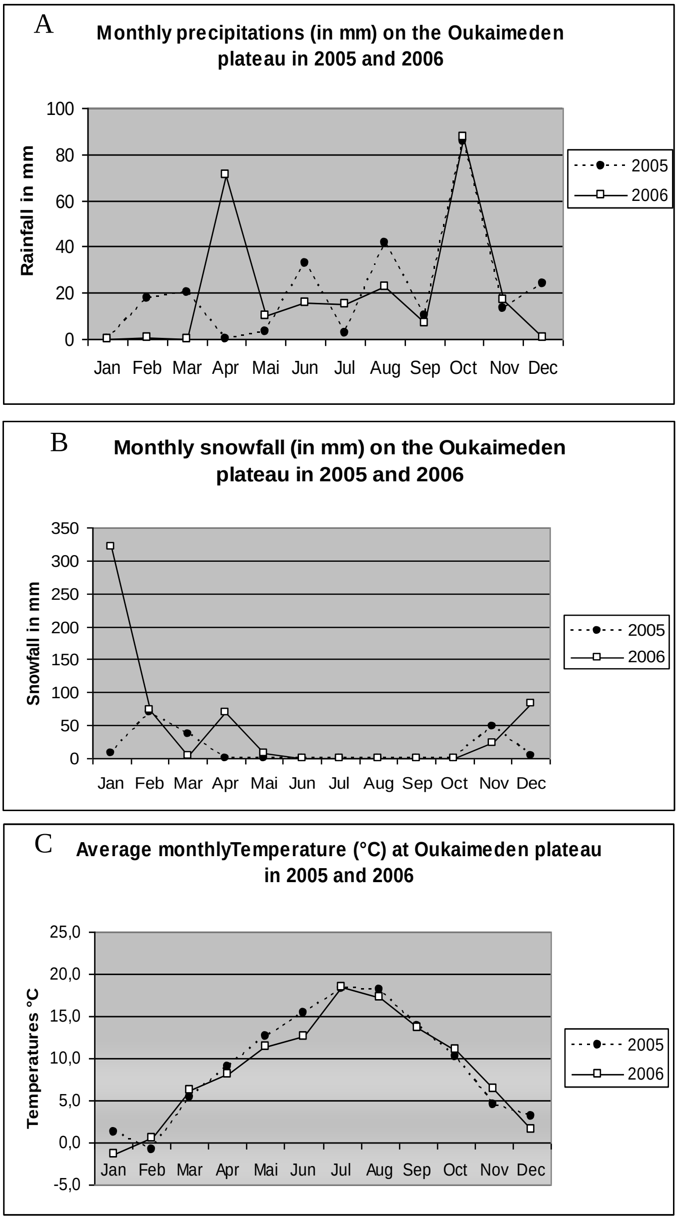

Figure 2. Climatic characteristics on the Oukaimeden plateau in 2005 and 2006.

The Observations Campaign of the Year 2006

The rainfall during this year was of 247 mm (Figure 2A). The snowfall during this year was of 584 mm. During the period between January and May the snowfall reach 478 mm (Figure 2B). The average minima temperature in the coldest month "m" in this year was – 5.7 °C and the average maxima of the hottest month "M" reached 22.4 °C. The spring temperature average was of 9.6 °C (Figure 2C).

In comparison with the average conditions, the year 2006 is humid enough and slightly colder (characteristic of a humid year).

Development Cycle of the Vegetal Species

The two years campaign of the phenological monitoring allows the following observations:

- There is no significant difference between phenological stages in the four plots of each facies ($p > 0.05$).
- The slight interannual difference of the phenological stages within the same species are generally due to differences in thermal balance intervening during the favourable vegetative period (from March to June). In general, this temperature balance differs between an early year and late year (Marquis, 1988; Walker *et al.*, 1995; Theau *et al.*, 2004 ; Jeangros *et al.*, 2005 ; Sola & Ehrlén, 2007). In the case of the Mediterranean mountains, the temperatures are not the only limiting factors. Quite apart from the permanently oozing pozzines, the others facies are very sensitive to the hydric factor that will essentially determine each facies biomass production. However, phenological stages seem to be essentially dependant upon temperature (Table 2).
- The phenological stages observed between the different facies for common species are important, and in general rule, they are reproduced in the same way, with the same successions from one year to another. There is no significant shift related to the similar thermal profile during the two years of observation.
- For each species, it is notified that the phenological stages are observed almost at the same date from one year to the next. It appears that the climatic profiles of the two years observation did not have significant effects. The annual plant biomass production is of course very different according to the pluviometry, but the phenological stages maintained themselves to fixed dates. It is due to temperature factor; we can say that during this period, the temperatures were produced approximately in the same way, even if pluviometry and the snowfall were different.

Briefly, we can present the phenological stages of some species of the Oukaimeden plateau grasslands as follows:

Very Wet Facies and Pozzine

Figure 3) As from the beginning of April with the first snowmelt appear the first flowers of the *Narcissus bulbocodium* (L.), they are the earliest species in this facies.

Table 2. Example of some species with interannual differences of the phenologic stages between 2005 and 2006

Closing of Agdal at 15 March

Opening of Agdal at 10 August

Closing of Agdal at 15 March

Opening of Agdal at 10 August

		2005										2006									
Facies	Species	1/4	15/4	1/5	15/5	1/6	15/6	1/7	15/7	1/8	9/8	1/4	15/4	1/5	15/5	1/6	15/6	1/7	15/7	1/8	9/8
Pozzines & highly wet grasslands	*Narcissus bulbocodium* L.	1	1	2	2	3	3	0	0	0	0	1	1	1	2	2	3	0	0	0	0
	Nardus stricta L.	0	0	0	0	0	1	1	2	3	3	0	0	0	0	0	0	1	2	2	3
Wet grasslands	*Ranunculus aurasiacus* Pomel	0	1	1	1	2	2	2	3	3	0	0	0	1	1	1	2	2	2	3	0
	Saxifraga granulate L.	0	0	1	1	2	2	2	3	3	0	0	0	0	1	1	2	2	3	3	0
Fairly wet grasslands	*Plantago coronopus* L.	0	0	0	0	1	1	1	2	2	3	0	0	0	0	0	1	1	2	2	3
	Lotus corniculatus L.	0	0	0	0	1	1	2	2	3	3	0	0	0	0	0	1	1	2	2	3
Dry grasslands	*Festuca ovina* L.	0	0	0	0	0	1	1	2	2	3	0	0	0	0	0	0	1	2	2	3
	Dianthus cintranus Boiss. & Reut.	0	0	0	1	1	1	2	2	3	3	0	0	0	0	1	1	2	2	3	3

0: Vegetative stage; 1: Flowering stage; 2: Fruiting stage; 3: Stage of seed dispersion

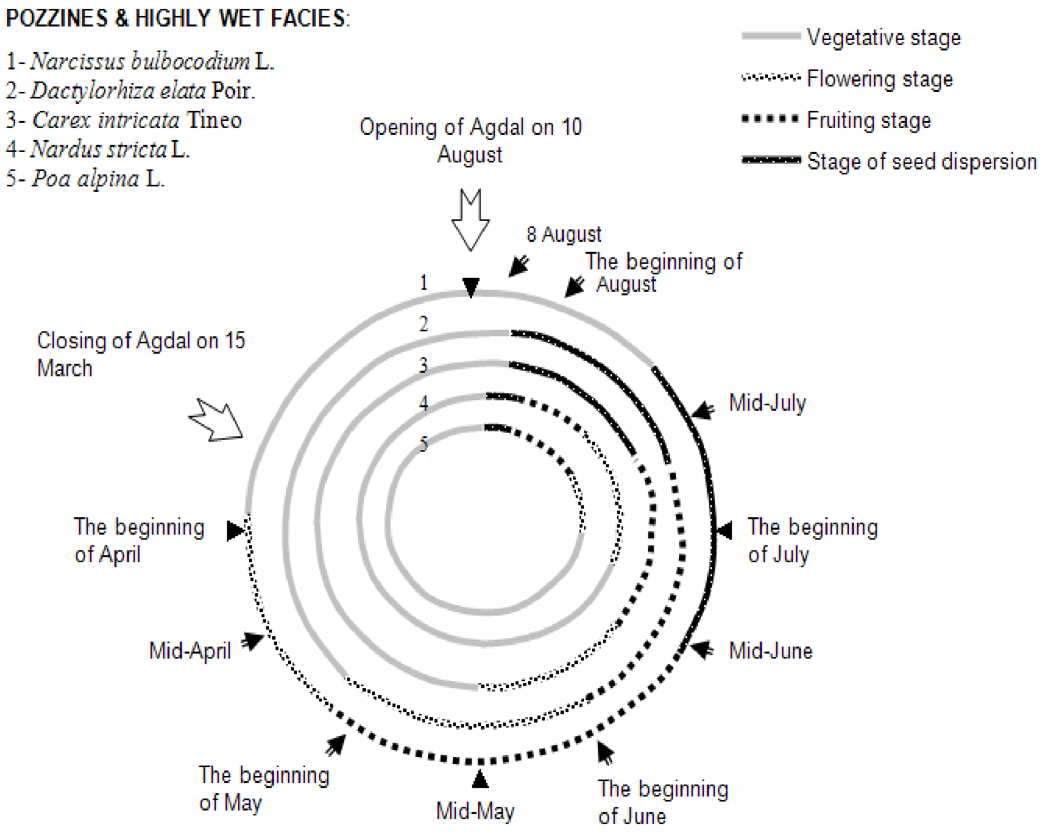

Figure 3. Temporal development cycle of the most characteristic species of the pozzines and highly wet facies in the Oukaimeden grasslands.

Towards the end of April appear the orchid flowers (*Dactylorhiza elata* Poir.) whereas the Narcissus enters in fruiting. *Carex intricata* (Tineo) flowers at mid-May, followed by *Poaceae* (*Nardus stricta* L. and *Poa alpina* L.) which flower at the end of June and at the beginning of July whereas the narcissus has already dispersed their seeds. At the beginning of August all this facies species had already started the stage of seed dispersion.

Wet Facies

(Figure 4) *Ranunculus aurasiacus* (Pomel) and *Saxifraga granulata* (L.) flower at the end of April. At the beginning of May *Rumex atlanticus* Batt. flowers followed by the *Fabaceae* (*Trifolium humile* L.) which flowers towards the beginning of the second week of May. About mid-June, the *Poaceae* (*Festuca will rubra* L.) enters in flowering. Between mid-June and mid-July, all these species are in the fruiting stage. At the beginning of August all these species dispersed their seeds *Festuca rubra* (L.) and *Trifolium humile* (L.) which partly keeps its fruit at the time of the opening of the *Agdal* on 10 August.

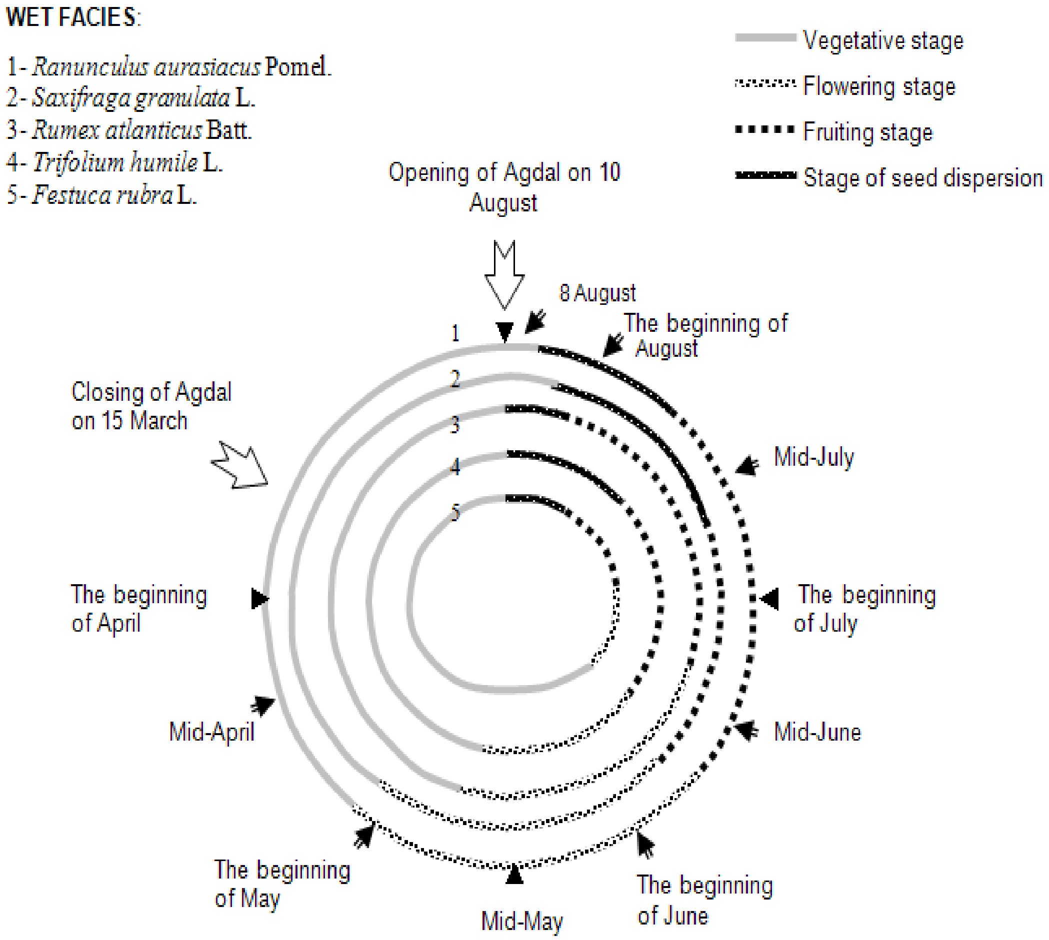

Figure 4. Temporal development cycle of the most characteristic species of the wet facies in the Oukaimeden grasslands.

Fairly Wet Facies

(Figure 5) *Linaria multicaulis* (L.) flowers before mid-May followed by *Helianthemum croceum* (Desf.) which flowers at the end of May. At mid-June *Plantago coronopus* (L.) and the *Fabaceae* (*Lotus corniculatus* L.) flower. The *Poaceae* (*Festuca maroccana* Batt.) flowers at the last week of June. At the beginning of August *Helianthemum croceum* (Desf.) and *Linaria multicaulis* (L.) dispersed seed whereas *Lotus corniculatus* (L.), the *Plantago coronopus* (L.) and *Festuca maroccana* (Beats & Trabut.) have just started this phenological stage.

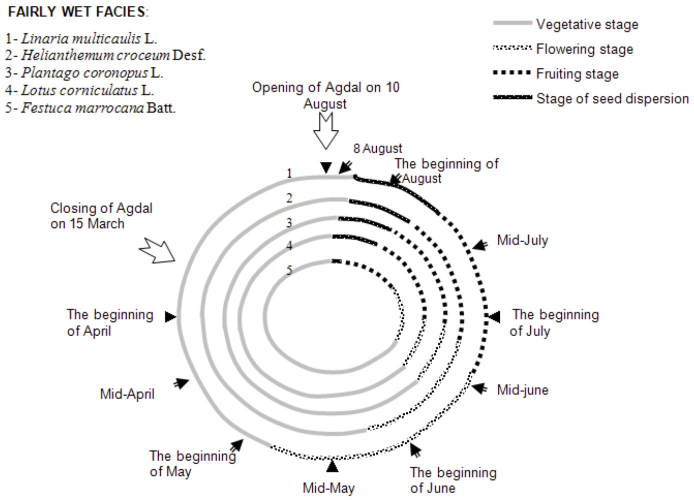

Figure 5. Temporal development cycle of the most characteristic species of the fairly wet facies in the Oukaimeden grasslands.

Dry Facies

(Figure 6) All these characteristic species flower after mid-May, the *Poaceae* (*Festuca ovina* L.) flowers about mid-June. At the beginning of August, the *Caryophyllaceae* (*Dianthus cintranus* Boiss. & Reut.) has already started the stage of seed dispersion while the other species were at the end of fruiting and dispersed seeds only as from the second week of August.

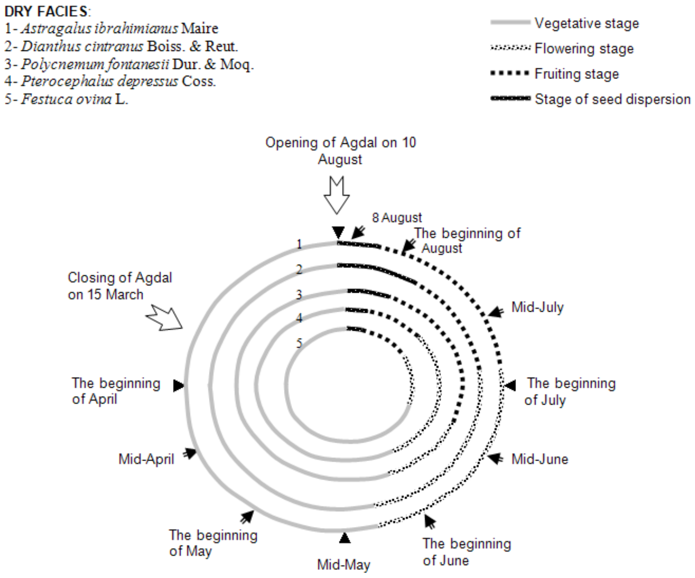

Figure 6. Temporal development cycle of the most characteristic species of the dry facies in the Oukaimeden grasslands.

Globally, all species terminated their development cycles before the opening of *Agdal* on 10 August, except some individuals of *Poaceae* (latest) and *Fabaceae* which kept partly their fruit at that time. According to the shepherds and the pastoralists, these two groups of species are most interesting for the livestock, as fodder and nutritive species.

Flora Spatiotemporal Succession

The phenological flora monitoring of the various Oukaimeden pastures facies shows a succession of phenological cycles of the species:

Narcissus bulbocodium L. appears the first as soon as the snow has melted (at the end of March, beginning of April) followed by *Orchidaceae* which start to appear about mid-April. Then follows *Ranunculaceae* about mid-May, and finally the *Poaceae* species being last, appear towards the end of June and terminate their cycles with the opening of the *Agdal* on August 10th. This succession in time and space of the very characteristic plant groups of the various Oukaimeden grasslands facies allows a great diversity of micro and macro invertebrates using these plants as habitat (ephemeroptera, hymenoptera....) (Tarrier M. & Delacre J., 2008)

The Phenology as an Indicator to the Agdal Opening

The Agdal "a traditional Institution shape of collective pastures management of the stockbreeders in the High Atlas" (Mahdi, 1999) appears like a socio-space concept indicating at the same time a territory, resources (water, trees, fruits, course…) rules and institutions allowing the control of access and use (Franchi, 2005). It can potentially be applied to all territories, to all renewable resources; and can be defined more generally as: a territory whose access and use of renewable resources are regulated (Auclair & Alifriqui, 2005). Analysis of the Agdal arrangements for the communal use of pasture demonstrates how pastoral groups manipulate kinship and historical opportunities to negotiate order, grass, and subsistence in the highly variable environment of the High Atlas mountains (Ilahiane, 1990).

The first element in the *Agdal* management process is the fixing of an opening/closing date which limits the access to the pasture in time. In the case of Oukaimeden *Agdal*, the opening is fixed from 10 August until 15 March. These dates are known by all access rights and are transmitted to each generation. The local community reproduces this rule and perpetuates it without explanation. In fact, it is further reinforced by myth and religion which play the role of documenting justification, and the threat of supernatural sanction in the event of violation of the dates. By performing a ritual to access the pasture, the community ensures the respect of the social norm (Gellner, 1966; Gilles *et al.*, 1986; Bourbouze, 1997, 1999; Mahdi, 1999).

From a biological and conservation point of view, the question that we have raised is about the coincidence of the *Agdal* opening date and the closing of the development cycles of the rangeland vegetal species. The phenological monitoring of the Oukaimeden pastures flora showed that the opening date of the Oukaimeden *Agdal* corresponds to the dissemination and the reconstitution of seed stocks of all the species; particularly latest species like *Poaceae* and *Fabaceae* which are characterized by their great fodder and nutritive value (Daget &

Poissonet, 1971; Dorioz, 1998; Daccord, 2002). Consequently, the late opening date of the *Agdal* Oukaimeden is performed to allow *Poaceae* (which represent for the pasture a significant food value) to terminate their vital cycle.

The group of the *Poaceae* and *Fabaceae*, which phenological stages are the latest one, is enjoying the collective protection during the period of pasture closing. Thus, they will contribute efficiently to the preservation of practically the whole flora and equally the fauna. For this reason this group will play the role of “**umbrella species** ", in the sense of the founder elements of the recent biology conservation approach. (Launer *et al.,* 1994; Roberge *et al*., 2004; Ozaki *et al*., 2006).

The *Agdal* opening is therefore based on the phenology of the Poaceae which are plants with great fodder value (*Festuca rubra* L., *Festuca maroccana* Batt.& Trabut., *Dactylis glomerata* L., *Holcus lanatus* L., *Lolium multiflorum* Lam., *Poa pratensis* L. and *Poa alpina* L.) (Dorioz, 1998), except *Nardus stricta* L., acidophil specie undervalued by the bovines (Loiseau, 1977) and also *Fabaceae* (*Lotus corniculatus* L., *Trifolium humile* L. and *Trifolium campestre* Schreb.) which are plants with great nutritive value (Daccord, 2002). These Nitrogen fixing species are essential to dairy cows to satisfy their needs in proteins. Therefore they graze in very wet facies characterized by fatty grass containing more rich species in proteins (the Bird's foot trefoil and the trefoil).

On the *Agdal* there are no territorial limits for cattle grazing, moreover the livestock follows a spatial zoning which has nothing to do with the space limits imposed by the transhumant.

Indeed, the bovines that stay in the *Agdal* only for a month prefer higher and fatty grass. So, they graze on the pozzines and the highly wet grasslands. As soon as women have entered the site, they proceed to the mowing of the grass which will be used as additional resource once they go back to the “*Douar*” (village). Therefore, the availability of the forage resource dictates the amount of time spent on the *Agdal*. Moreover, Sheep grazed in the wet and fairly wet facies whilst goats grazed in the dry facies and move up towards the xeric thornyshrubs located in semi and high slopes (Table 1).

At present, these wet pastures are highly vulnerable by their structure, ecological functioning and state of conservation (Alaoui haroni *et al.,* 2009). Because of their strict water and soil determinism, they are affected by the recent climatic changes (Hulme, 2005; Harris *et al.,* 2006) and for this reason constitute very good indicators of the recent environmental changes (He *et al.,* 2005). A diachronic cartography (between 1986 and 2004) could show that 8% (6.598 ha) of the Oukaimeden wet grasslands were removed (Alaoui Haroni *et al.,* 2009). Hence it’s necessary to valorize traditional knowledge like community management of the pastoral access resources, in order to preserve biodiversity and resource perenniality.

CONCLUSION

The *Agdal* as a common rangeland management is based on the settlement of the opening and closing dates of grazing. The flora phenological monitoring of this pastoral area showed that the *Agdal* opening and closing dates allows the reconstitution of the milieu by renewal of the seed stock in the ground. So, this ancestral knowledge proves highly operational in the conservation of the vegetal biodiversity in these areas to ensure the resource durability and perenniality.

Front of the failure of the nature conservation strategies in Morocco, pastoral *Agdal* appears as common protected areas, with a better management of rangelands and better guarantees for resource durability, because of a strong social acceptance.

However, the increasing promotion of the mountain tourism activity directly affects this type of local knowledge especially by regression of transhumance activities (Nejar, 2004). Also the promotion of colossal tourist projects constitutes a threat for these wet pastures and jeopardise their existence.

Thus the registration of the site as protected area according to the common laws with the establishment of green tour rigorously respected is highly recommended. It can provide a perennial resource for local populations and constitute a reasonable and educative tourism platform encouraging transhumance and perpetuation of local customs. So, if recognition of local management competences is insured, this kind of management can constitute a very judicious means of this site valorisation, including all ecological, biological and human components.

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