Agroforestry Systems 10, 213–239, 1990.

The espinal: agroforestry systems of the mediterranean – type climate region of Chile

State of the art and prospects for improvement

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Key words: espinal, espino, *Acacia caven*, silvopastoral, agro-silvopastoral systems, semiarid zone, subhumid zone

Abstract. The Central Valley of Chile is largely occupied by a pseudo-savanna called 'espinal', consisting of a single dominant tree species, *Acacia caven* (Mol.) Mol. (Leguminosae), and some 215 annuals, most of which were inadvertently introduced from the Mediterranean Basin. The probable origin and current distribution of the 'espino' (*Acacia caven*) and the espinales in Chile are described. Predominant production systems of the espinal in both the semiarid and subhumid regions of Chile are outlined, with emphasis on the later region. Causes of the current low levels of productivity are discussed, and various strategies for long-term improvement of the espinal are presented.

1. Introduction

A large portion of northern and central Chile enjoys a mediterranean-type climate of warm, dry summers and cool, wet winters. This region has been divided into five subdivisions, ranging from hyperarid in the north to perhumid in the south [Di Castri and Hajek 1976]. A great proportion of the central Valley ('Intermediate Depression'), lying between Copiapo to the north and Concepción in the south, the Cordillera de los Andes in the east, and the lowlying coastal Cordillera in the west, is covered with a plant formation known as 'espinal' (plural: espinales) (Fig. 1).* The dominant species of these espinales is a small, spiny leguminous tree, *Acacia caven*, locally known as 'espino'. It is noteworthy that a single tree species should

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* We use the term 'espinal' as it is commonly used in Chile, and not as used in Argentina [see Cabrera and Willinck 1973]. Where necessary, we will distinguish between these two uses of the term as follows: *sensu stricto* (*s.s.*) and *sensu lato* (*s.l.*) respectively.

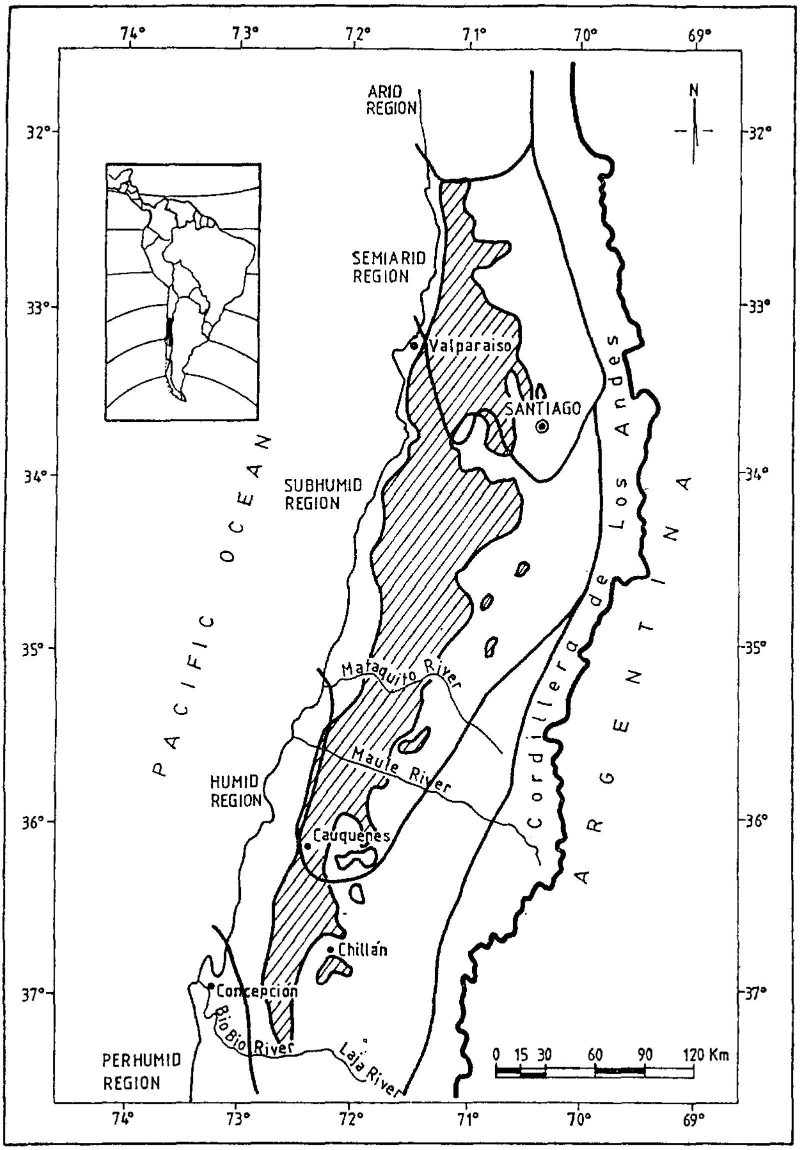

Fig. 1. Distribution of *Acacia caven*-dominated espinales in Chile (1989).

dominate a region of such diverse climatic, edaphic and socio-economic conditions.

The Chilean espinales are integrated in a wide variety of silvopastoral and agrosilvopastoral systems providing food, fodder, and firewood to a rural population of approximately 300,000 people. The most important products are domestic livestock: ca. 800,000 sheep and 250,000 cattle. However, a long history (300–400 years) of intensive disturbance and overgrazing has destroyed most of the natural vegetation of the vallies and slopes of both cordilleras, leaving all agricultural systems with serious problems of soil erosion and low levels of productivity, which in turn lead to rural exodus, and generally low living standards for the people that remain.

The area of espinales represents about 90% of what is locally known as the 'secano interior', meaning unirrigated land between the two cordilleras. (The remaining 10% is intensively cultivated – with or without irrigation – in cerealculture (wheat), vineyards, orchards, and forestry plantations (mostly *Pinus radiata*)). In a few areas, non-traditional systems of production achieve higher-than-average yields from espinales, especially in the subhumid and humid zone to the south. What is more, the individuals and populations of espino found along this 1100 km long, north-south transect are – popular opinion notwithstanding – relatively uniform in their physiognomy, morphology, phenology, and ecology.

In this paper, we describe the origin, composition, and dynamics of the espinales and the various low-energy systems practised by land-owners. We also discuss strategies and prospects for the improvement of these systems.

2. Description of the espinal

We call the Chilean espinales a 'pseudo-savanna' for two reasons: the absence of perennial grasses, and their replacement by a very large number of annual herbs and grasses, mostly of Euroasian origin, especially from the Mediterranean Basin; and secondly, the origin of the formation in anthropogenic processes of degradation (see sections 2.2 and 2.3).

2.1 Characteristics of Acacia caven

Acacia caven (Mol.) Mol. is known as 'espino', 'espinillo', or 'churqui' in various parts of Chile and the five other countries of South America in which it is found. (The fruit is called 'quirinca' in northern Chile). It is one of the most specialized members of the legume subfamily Mimosoideae (subsection *Polyseriae*, subgenus *Acacia* Vassal (= series *Gummiferae* Bentham)) [Vassal 1972; Guinet and Vassal 1978], by virtue of its large colporate pollen, diploid chromosomes, spinescent stipules, and multiseriate, indehiscent pod construction. Usually seen as a small tree or frequently-cut shrub, it can nevertheless attain a height of 8–10 mm.

In Chile, the espino is quite distinct from all other trees (apart from *Prosopis* spp.) for its small, bipinnate, deciduous leaves, brown-black pods (typically 60 × 10 mm; ca. 8–10 g DW), fragrant flowers borne on sessile or stipulate heads prior to the emergence of leaves, and above all, the hard, stipular spines 0.3–2.5 cm long at every branchlet node. It is closely related to, and often confused with, the pantropical *Acacia farnesiana* (L.) Willd., which does not occur in Chile.

There is a large amount of genetic variability in *Acacia caven*, as reflected by the recognition of six distinct varieties, which are distinguished on the basis of pod morphology as well as geography [Cialdella 1984; Aronson in prep a]. Only one of these (var. *caven*) occurs in Chile at the present time [Aronson l.c.].

2.2 Origin and dynamics of the Chilean Espinal

The pseudo-savanna dominated by *Acacia caven* in central Chile (espinal *s.s.*) is generally agreed to be the result of anthropogenic degradation of the sclerophyllous matorral vegetation (equivalents: maquis, chapparal, mallee, fynbos) [Schlegel 1966; Elizaldes 1970; Olivares and Gasto 1971; Bahre 1979; Fuentes and Hajek 1979; Rundel 1981; Balduzzi et al. 1981; Quintanilla 1981; Etienne 1986] at least in the coastal ranges and the Andean precordillera.

Certain authors [Mann 1968; Rundel 1981; Donoso 1982], have suggested that in the flatlands of the central valley, the espinal is a climax formation. It seems to us [and to Fuentes et al. 1989, in review] that the espinales in the central valley of Chile are also a recent phenomenon, i.e. no more than 500–2,000 years old, even if *Acacia caven*, as a taxon, has possibly been present in the country much longer. The exact means and date by which the espino got to Chile are of course impossible to determine [see Aronson in prep b; Aronson and Del Pozo in prep. for discussion].

The gradual opening of the matorral vegetation by fire, woodcutting and cattle grazing promotes the invasion of *Acacia caven* in the open sites. In the degraded matorral are also found various shrubs, e.g. *Muehlenbeckia hastulata* (Smith) I.M. Johnst., *Podanthus mitiqui* (DC) Lindl., *Cestrum parqui* L'Herit., *Trevoa trinervis* Miers [Rundel 1981], all of which show similarly invasive characteristics. Alternatively, when the matorral is completely removed for agricultural purposes, there follows an invasion of annual herbs and grasses [Olivares and Gasto 1971], and subsequent colonization by *Acacia caven* and/or *Baccharis* spp. [Armesto and Pickett 1985; Fuentes et al. 1986]. *Acacia caven* and the various *Baccharis* species involved in this process, as well as the numerous associated annuals, can thus be seen as pioneers in the succession of matorral following perturbation (Fig. 2).

The dispersion of *Acacia caven* is achieved primarily by cattle that consume the pods [Gutierrez and Armesto 1981]. The so-called 'gut-treatment' involved in passage through cattle (and goats, sheep, and horses) appears to accelerate germination of *A. caven* seeds [Fuentes et al. 1989], and the survival of resulting seedlings in open sites is made possible by their exceptional drought tolerance, despite predation by herbivores, [Armesto and Pickett 1985]. If livestock are not removed from the area, the espinal remains unchanged indefinitely, and the matorral does not recover [Fuentes and Hajek 1979].

As noted previously, the espinal formation also includes a large number of invasive annual herbs and grasses (see Section 2.5 for details). The impressive diversity and abundance of annuals in the espinales is clearly the result of what we would call the 'europeanization' of agriculture in Chile.

The indigenous people (Mapuches) of southern Chile practised a simple form of agriculture with native plants including *Madia sativa* Mol., *Chenopodium quinoa* Willd. and *Bromus mango* Desv. as well as potatoes and maize [Molina 1810; Parodi et al. 1964; Muñoz Schick 1975]. However, in the centuries following the Spanish Conquest, not only were new crops (wheat, grapes, cows) and farming methods (animal traction, plowing, discing) introduced to central Chile, but also new agricultural concepts, e.g. fallow seasons, all of which have favored the invasion and establishment of both native and exotic colonizers – annuals as well as woody species, including *Acacia caven* and the other shrubs mentioned above.

Additional evidence of the recent origin of espinales (*s.s.*) is found in the remnants of an older vegetation type in the secano interior. Typical mediterranean matorral elements occupy steep, untillable and inaccessable ravines of both the coastal ranges and the precordillera of the Andes, as well as numerous small patches around villages and on the edges of fields or espinales. These remnants include such evergreen, sclerophyllous trees as: *Quillaja saponaria* Mol. (periodically debarked for production of saponin), *Peumus boldus* Mol., and *Lithraea caustica* (Mol.) Hook. et Arn., *Maytenus boaria* Mol.; *Cryptocarya alba* (Mol.) Looser, *Azara petiolaris* (D. Don) Johnst., *A. integrifolia* Ruiz & Pav. and much more rarely, *Beilschmiedia miersii* (Gay) Kosterm. [Rodriguez et al. 1984]. These are all endemic to Chile and are, in our opinion, probably remnants of the kind of matorral which originally dominated this region. Many other co-occurring species may well have disappeared in the past few centuries or millenia.

In sum, the espino may have arrived in the country much earlier (10,000–1,000,000 years B.P.?) than the European conquistadores and their particular farming systems. However, prior to radical changes to the landscape brought about by European colonization in the 16th century, the espino was probably restricted to naturally disturbed habitats around the area or areas to which it was casually introduced in Chile. This introduction was probably

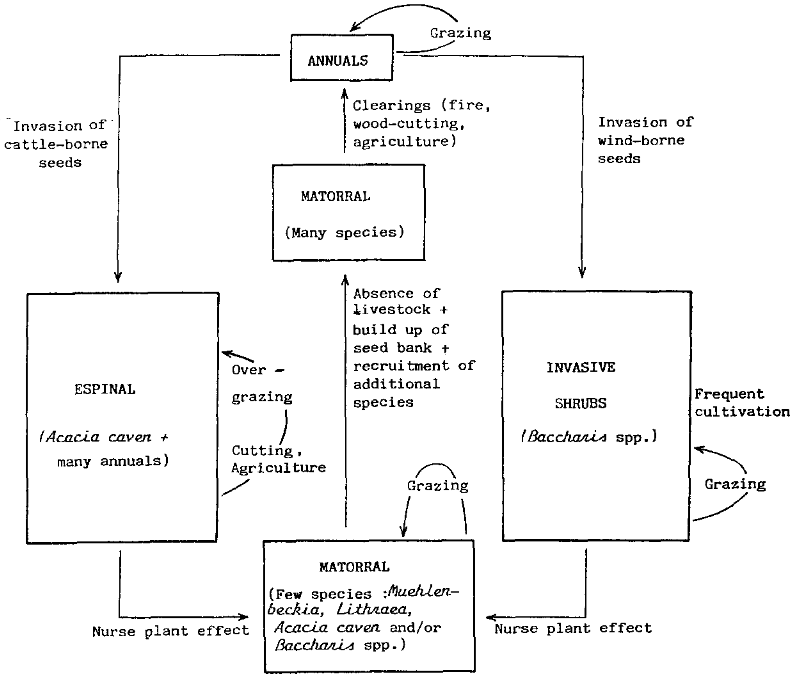

Fig. 2. A simplified model of plant succession following perturbation in the Chilean matorral, modified from Fuentes et al. 1986.

from northern Argentina by guanacos, pack animals (llamas) in trans-Andean caravans, or, just possibly, by people, as a source of natural black dye and other useful products [Molina 1810; Gay 1865; Murillo 1989].

2.3 Distribution of espinales in Chile

In central Chile today, under a mediterranean-type climate, espino grows in areas with as little as 100–150 mm mean annual rainfall, and 8–10 months of drought per year, to subhumid zones with 700–1200 mm mean annual rainfall and only 5 months of drought. Espinales, however, are not as common as the espino itself. In the northern portion of its range in Chile, espino is most often found as isolated individuals or groups of trees, and only rarely in larger populations [Follmann and Matte 1962; Bonilla et al. 1977].

Espinales are usually found in lowlying, non-irrigated sectors of the Central Valley and eastern slopes of the coastal Cordillera ('secano interior'), from the Petorca River valley in the north (32 °S) to the Laja River valley in the south (36 °S), which also marks the austral limit of the subhumid mediterranean-climate zone [Quintanilla 1981; di Castri and Hajek 1976] (Fig. 1). Although the espino is often considered a phreatophyte [e.g. Rundel 1981], both individual trees and large espinales are often found – albeit with reduced stature – on dry hillsides and other xeric sites where phreatophytes normally do not occur.

At their maximum expression, in the subhumid zone south of 32 °S, espinales form continuous and extensive populations occupying an estimated 2,000,000 ha [Ovalle and Squella 1988]. In this subregion, there are two basic types of espinales: those found in the lowlying plains or 'llanos' ('flatland espinales') and those found on the slopes of dry hills ('lomas') of the coastal cordillera or, less frequently, on drier, polar-facing slopes of the Andean precordillera ('hillsides espinales'). Espinales are completely absent in the intensively worked – and usually irrigated – fields, vineyards, and orchards, nor in rice paddies. This absence is not due to the espino's inability to invade such sites, but rather to the constant effort made to eliminate it.

North of Santiago, another 2–2.5 million ha. are marked by the presence of espino, but as mentioned above, true espinales cover only a small portion of this vast area. In the semiarid region, *Prosopis chilensis* (Mol.) Stuntz. (vernacular: Algarrobo) is often found growing with espino. Further north, *Prosopis flexuosa* D.C., *Lithraea caustica* and *Cordia decandra* Hook. et Arn., as well as several woody shrubs are sometimes intermixed with espino as well. On drier hillsides and rock outcroppings are often found columnar cacti, e.g. *Trichocereus chilensis* (Colla) Brit. & Rose and two large terrestrial bromeliads (*Puya berteroiana* Mez. and *Puya chilensis* Mol.). The Prosopis – Acacia association represents the closest approximation in Chile of the mixed 'espinales' (*s.l.*) found in east-central Argentina, in which *Acacia caven* is just one of numerous sympatric, leguminous trees and shrubs [Morello and Saravia Toledo 1959; Morello and Adamoli 1974; Aronson in prep.b.]

In early Colonial days, large algarrobos (and espinos) were far more abundant in central Chile than today, creating extensive stands known as algarrobales [Molina 1810; Muñoz Schick 1971]. The algarrobos have mostly been eliminated by overharvesting, clearing and burning, to the advantage of espinales [see Fuentes et al. 1989, in review]. A similar situation has taken place in much of northern Argentina since early colonial times [Cabrera 1971; Saravia Toledo 1988, in prep.].

Espino and, consequently, espinales, seems to be limited by cold in the south, and above a certain altitude in the Cordillera de los Andes. A second limiting factor in the south, however, may be increased levels of investment in the land, as occasioned by more favorable rainfall regime and soil conditions. In other words, just as in the best lands of the Central Valley, so moving south of Chillán, where the mediterranean-type climate region is replaced by the oceanic-type climate, in the perhumid austral temperate

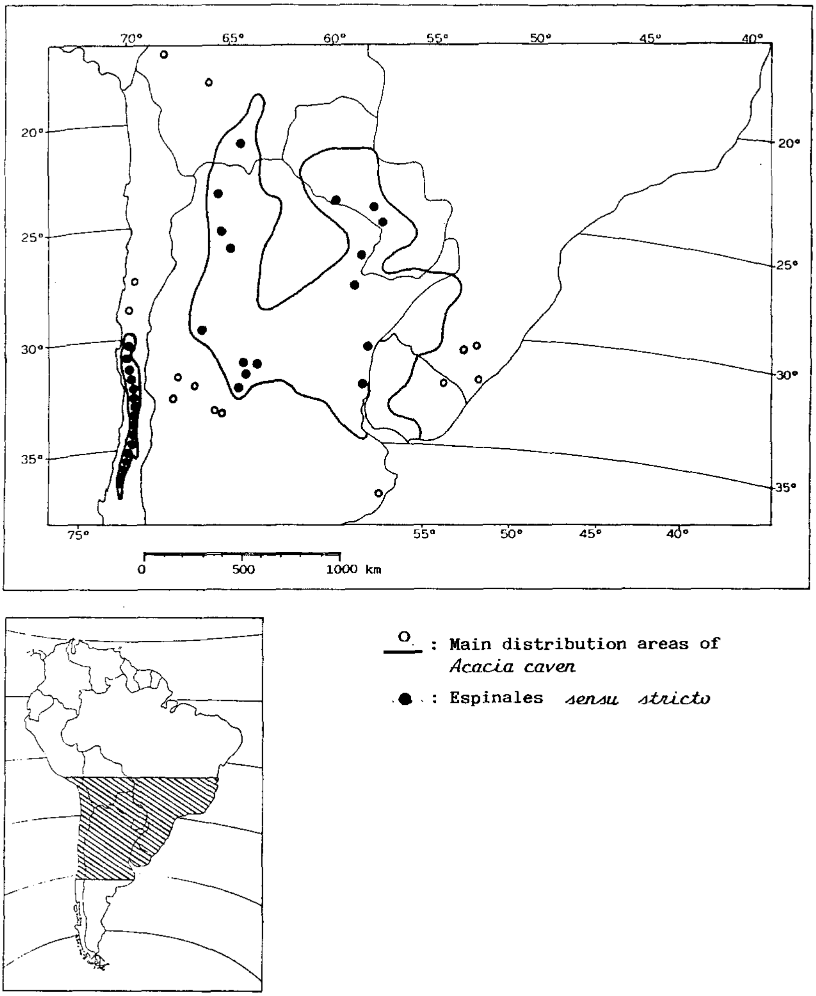

Fig. 3. Continental distribution of espinales and of espino, *Acacia caven.*

zone, and where it pays to invest capital and energy, i.e. to work the land intensively, espino tends to disappear.

2.4 Distribution of espinales outside of Chile

In addition to the considerable area they occupy in Chile, espinales (*s.s.*) also occur in many parts of northern Argentina, southern Bolivia, and southern Paraguay [Morello and Saravia Toledo 1959; Ragonese and Castiglioni 1970; Morello and Adamoli 1974; personal observations, J. Aronson 1988–89] (Fig. 3). Nowhere are espinales (*s.s.*) as strongly developed as in the subhumid zone of Chile.

Some Argentine biogeographers have been led to describe a separate Province, also known as 'Espinales' (*s.l.*) lying in an irregular arc between the Chaco Dominion [Cabrera and Willinck 1973]. Others, however, [Parodi 1934; Ragonese 1941, Ragonese and Covas, 1967; Morello and Adamoli 1967] consider these 'espinales' (*s.l.*) to be degraded Chaqueño woodlands. In order to settle this question, more detailed studies of the climatological and edaphic characteristics of this area are required, as well as experimental studies of the type conducted by Fuentes et al. [1989, in review] in Chile.

In summary, whether in espinales (*s.s.*) of purely anthropogenic, disturbed sites, or in more complex associations, *Acacia caven* occupies a huge range of climatic, edaphic, and socio-economic conditions in southern South America. It occurs from the Atlantic to the Pacific, and between 16° and 37° south latitude. Near both the Pacific and Atlantic oceans, it occurs at sealevel – but never at the seashore – and, depending on the distance from the equator, up to considerable altitudes. Thus, in southern Bolivia (16 °S) it reaches 3200 m; in NW Argentina (24 °S) 2500 m and in central Chile and Argentina (30°–33 °S) no more than 1700–1900 m; while in south-central Chile (36 °S) it stops at about 1200 m [Aronson in prep b].

Given the huge ecological amplitude of the dominant tree species, and its overall character as an invasive colonizer, it is not surprising that espinales (*s.s.*) should occur both in continental-type and mediterranean-type climates, in inundated plains and on dry hillsides, as well as mixing freely with other arborescent species in relatively open sites. Although occasionally found near roadways and other dry, neglected sites, especially around human settlements and towns, *Acacia caven* thrives best in segetal sites, especially where plowed fields are abandoned and converted to long-term cow pastures, subject to frequent cutting, overgrazing, and in some cases, fire. Under such circumstances, espino often presents nearly monospecific stands, which if left long enough (i.e. > 50 years) can become difficult to irradicate. In this, *A. caven* resembles related species of *Acacia*, e.g. *A. aroma* Gill ex Hook. & Arn., of northern Argentina, and the widespread *A. macracantha* HBK, *A. farnesiana* (L.) Willd., as well as several Argentine *Prosopis*, e.g. *P. caldenia* Burk., *P. kuntzei* Harms, and especially *P. ruscifolia* Griseb., not to mention *P. glandulosa* Torrey, *P. juliflora* (Swarz) DC, and *P. pallida* Griseb. of North America. By contrast, in moist ruderal sites between 37°–40°S, where birds may be a more important vector of seed dispersal than livestock, exotic tree weeds from temperate zones are commonly found: *Robinia pseudoacacia* L., *Acacia dealbata* Link, *A. melanoxylon* R.Br., and, in Argentina but not Chile, *Gleditsia triacanthos* L. and *Melia azadarachta* L. *Acacia caven* is notably absent from these sites.

2.5 Composition and structure of Chilean espinales

Leaving aside its presumed anthropogenic origin, which explains our use of the term 'pseudo-savanna', the espinal (*s.s.*) in Chile can be viewed as a complete, and relatively stable plant formation. Physiognomically, it consists of an arboreal stratum of variable height and cover – consisting almost exclusively of *Acacia caven* – which is complemented by an herbaceous cover of synanthropic therophytes [Ovalle 1986; Ovalle and Avendaño 1987; Ovalle et al. 1988].

The abundance and diversity of annuals is the second distinguishing feature of the Chilean espinales and has engendered a number of practical studies showing the positive effects of the tree stratum on annual pasture (see section 3.0). The floral composition of this herbaceous stratum includes a large number of coexisting species, mostly of circum-Mediterranean origin. Between 90 and 95% of total herbaceous cover consists of invasive species introduced to Chile within the past 300–400 years. In the Cauquenes area alone (35°58′S 72°12′W; alt. 200 m; mean annual precipitation 695 mm), more than 215 annual species have been identified in the espinales, of which approximately 90% are recent immigrants [Ovalle et al. 1987]. This represents about half the entire weed flora of Chile [Matthei et al. in prep.]. The dominant pasture species found in the espinales of the subhumid zone are shown in Table 1.

In espinales of the 'llanos' or plains, regularly inundated in winter, and therefore not suitable for cerealculture, the acacias show an open woodland (pseudo-savanna) structure with an average canopy height of 5–8 m, and average tree density of 25–50% total cover. Most trees grow on single trunks and regenerate by seed. However, in the first years following the irregular (± 20-year cycle) fuelwood harvest, the temporary structure of the espinal is that of low scrubland dominated by 1–2 m tall coppices. Depending on management practises, this can remain unchanged for quite some time. Alternatively, with judicious pruning of inferior stump-sprouts and protection of the selected shoots from livestock, the woodland form of espinal can return in 15–20 years.

By contrast, on the 'lomas' or emergent inselbergs of the coastal precordillera, the espinal presents a lower structure resembling a matorral, with average height of 2–2.5 m, and density less than 25% total cover. At any given time, a complex mosaic occurs on the lomas, including cleared fields recently sown to winter wheat, fallow fields, and old fields in various stages of recolonization by *Acacia caven*. The native shrubs *Baccharis linearis* (Ruiz & Pav.) Pers. and *Trevoa trinervis* are also frequently encountered; both of these are sure indicators of sites where cerealculture has been abandoned for reasons of erosion and soil depletion.

Table 1. Principal pasture species in the espinales of the subhumid mediterranean-type climate zone of central Chile and their relative forage value (Source: Ovalle and Squella 1988).[1]

Quality	Gramineae	Leguminosae	Miscellaneous
Excellent	Lolium multiflorum	Medicago polymorpha	
	Lolium rigidum	Medicago arabica	
Good	Briza maxima	Trifolium glomeratum	Erodium botrys
			Erodium moschatum
			Erodium malacoides
			Erodium cicutarum
Fair	Bromus mollis	Trifolium filiforme	Plantago lanceolata*
	Trisetobromus hirtus	Trifolium depauperatum	
	Briza minor	Hosachia subpinnata	
	Avena barbata		
	Hordeum murinum		
	Hordeum berteroanum		
	Hordeum chilense*		
	Cynosurus echinatus		
	Stipa neesiana*		
	Piptochaetium stipoides*		
	Piptochaetium montevidense*		
Poor	Aira caryophylla		Leontodon leysseri
	Vulpia dertonensis		Hypochoeris glabra
	Trisetum megalura		H. radicata
	Koeleria phleoides		H. trichioides*
	Deschampia berteroana		Hedypnois cretica
	Nassella exerta*		
	Stipa manicata*		
	Stipa speciosa*		
	Melica violacea*		
Without Value	Stipa laevissima*		Carduus pychnocephalus
	Aristida longiseta*		Madia sativa
			Plantago hispidula
			Plantago firma
			Juncus bufonius
			Juncus imbricatus*
			Chaetanthera chilensis
			Dianthus proliferus
			Plagiobotrys fulvus
			Salvia sessilis
			Bartshia latifolia

[1] Taxonomy follows Navas, 1973, 1976, and 1979
* Perennial species

3. Effect of tree stratum on associated herbaceous plants

Acacia caven is a highly efficient nitrogen-fixing tree [Aronson, Ovalle and Avendaño in Review]. In addition, the deciduous foliage allows frequent recycling of nutrients, especially nitrogen, to upper soil layers. For these reasons, and for its particular phenological cycle, espino promotes rather than hinders development of the herbaceous stratum in the subhumid and semiarid regions of Chile [Ovalle and Avendaño 1987, 1988; Olivares et al. 1983; Lailhakar and De La Paz 1988]. Here we will concentrate on effects demonstrated in the subhumid zone, where effects of the tree cover may be most pronounced, and where detailed data are available, calculated on a per-hectare basis rather than per tree basis.

At the La Estrella farm, in the Cauquenes district of the subhumid zone, the espino tree layer – when sufficiently dense – has been shown to have beneficial effects on the overall productivity and quality of annual pastures [Ovalle 1986; Ovalle and Avendaño 1988]. This is due to several factors: phenological, energetic (solar radiation), hydrological, and pedological.

As previously mentioned, the phenology of espino in Chile probably reflects its origin in the continental-climate of the subtropical Chaco Dominion. It is out-of-phase with the phenology of herbaceous plants (and other trees and shrubs) with which it occurs in the mediterranean-type climate of central Chile. Thus in winter, annual plants under espino trees in Chilean espinales are not shaded, whereas under other trees they are. Leafing-out of espino normally begins in late spring, and thus does not hinder annual plant growth during this critical period (Fig. 4). In this respect, espino is similar to *Acacia albida* (= *Faidherbia albida*) of Africa Centre Technique Forestier Tropical 1988.

Sunlight passing through espino crowns is about 35–50% of incident radiation during late spring and early summer [Ovalle 1986; Ovalle and Avendaño 1987a], which is high compared to the amount of sunlight passing through evergreen, sclerophyllous trees and shrubs in the region [Del Pozo et al. 1989a]. This level of radiation is sufficient to promote herbaceous pasture growth and reproduction [Sheehy, Green and Robinson 1975]. The open canopy of espinos is nevertheless effective in reducing evapotranspiration of the herbaceous layer, thereby allowing a longer growing season for annual plants. This is the result of reduced solar radiation, modified extremes of temperature, and increased humidity under tree crowns [Ovalle 1986; Ovalle and Avendaño 1988].

In addition, positive effects of espinos on soils are significant, as expressed in levels of organic matter, as well as of total nitrogen and accessible potassium. Carbon/nitrogen ratio decreases under trees, although pH and levels of accessible phosphorus are apparently unaffected [Ovalle l.c.; Ovalle and Avendaño 1987a]. With tree canopies of 50% and 80% at La Estrella, total leaf litter amounts to the equivalent of 700 kg and 1100 kg DW ha^{-1} yr^{-1}, respectively. This litter is rich in nitrogen (2.2–2.4%), potassium (0.2–0.4%), and phosphorus (0.1–0.2%). With 80% tree cover,

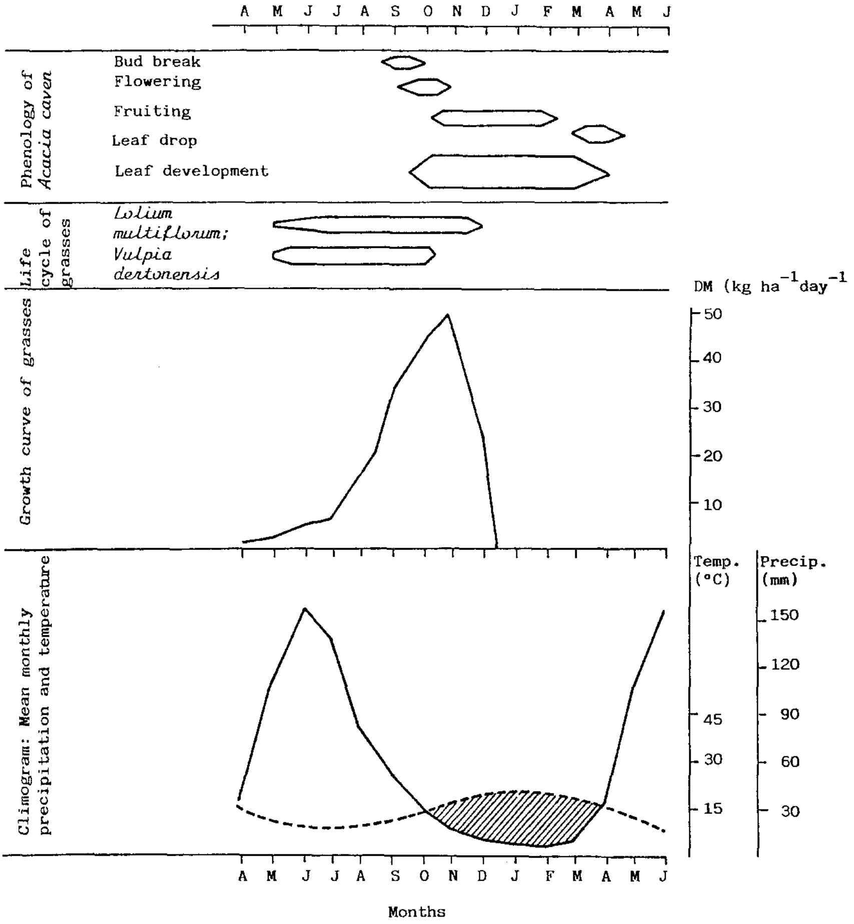

Fig. 4. Phenology of *A. caven*, and life cycle and growth of two associated grasses as compared to a typical climogram in the subhumid zone of Chile.

annual contribution to the soil is estimated at 27 kg nitrogen, 5.2 kg potassium, and 2.3 kg phosphorous ha^{-1} yr^{-1} [Ovalle 1986; Ovalle and Avendaño 1988].

In summary, under high-density stands at La Estrella, the espino represents a fundamental element in pasture production, and has highly beneficial effects on pasture in all parameters studied.

4. Predominant production systems in Chilean espinales

4.1 Silvo-pastoral system in the semiarid region

Fuelwood and charcoal are the main products of espino (and all other

Photo 1. Silvopastoral system in an arid zone espinal near Combarbala, northern Chile. (credit: Bonilla et al. 1983)

woody plants) in the semiarid region of Chile. By virtue of its density and superior burn-qualities, espino has long been recognized as a valuable fuelwood (specific gravity = 0.80–0.98) [Tortorelli, 1956]; calorific value = 3.2–4.6 kcal kg^{-1} [Prado et al. 1988]).

As the result of selective cutting of espino in the past, annual yields are very low. In much of the area, espino is no longer as important a source of fuel as some other woody species, e.g. *Cordia decandra*, which, incidentally, is now considered in danger of extinction. Wood collection for cooking and heating has reached the point that reserves of tree biomass have been virtually exhausted, and two small shrubs (*Flourensia thurifera* (Mol.) DC. and *Colliguaya oderifera* (Mol.) constitute 80% of remaining biomass suitable for firewood [Prado et al. 1988; cf. Etienne et al. 1982].

As human populations and ruminants, especially goats, have multiplied rapidly during the past century, the remaining woody biomass, including espino, in the semiarid area has come under increasing pressure. In the absence of low-priced, alternative sources of fuel, no less than 95% of energy consumed by the combined urban and rural population derives from firewood, and to a much smaller extent, charcoal [Prado et al. 1988]. In one study area north of Combarbala, it is estimated that at current rates of demand (7.8 tons fuelwood yr^{-1} $family^{-1}$), remaining woody biomass will be exhausted within the next 3–4 years [Prado et al. 1988]. In a few exceptional areas however, low-density espinales are preserved in a silvopastoral system involving goats (Photo 1), or agrosilvopastoral systems including wheat as

Photo 2. Agrosilvopastoral system in an arid zone espinal near Combarbala, northern Chile. (credit: Bonilla et al. 1983)

well (Photo 2). In this area, use of espino resembles that of khejri (*Prosopis cineraria*) in Rajasthan, India [Mann and Saxena 1980; J. Aronson pers. obs. 1981].

4.2 Silvopastoral systems in the subhumid zone

4.2a Animal husbandry in the flatlands espinales

In the subhumid mediterranean-type climate zone, espinales are most often used in a low-yielding silvopastoral system whose principal products are meat and wool. Three types of exploitation are found: a) small family holdings of less than 140 ha; b) medium-sized holdings of 140–500 ha; and c) large properties with more than 500 ha [Sara 1973]. Ovine and bovine production rely on unimproved annual pastures associated with *Acacia caven.* Animal husbandry is carried out principally on lowlying plains ('llanos') regularly inundated in winter and therefore unsuitable for winter cerealculture. In such areas, the espinal develops to full size, and presents aspects of an open pseudo-savanna (Photo 3). In this condition, the association of the 2–4 m tall tree layer presented by *A. caven* effectively increases production and raises quality of the annual herbaceous stratum. The above-detailed benefits notwithstanding, production levels are low. As in other areas, least productive lands are devoted to sheep, more productive lands to cattle. Management in both cases is devoted to meat production only.

Photo 3. Subhumid zone espinal in flatlands with grazing animals. (Credit: C. Ovalle)

The ovine breeds most commonly used are Suffolk Down, Hampshire Down, and various crosses between these two. Average stocking rates in the espinal are approximately 1 sheep (= 0.2 AU) ha^{-1} [Serrano and Jara 1975]. Levels of production of the highest-yielding ovine sectors are only about 32 kg live weight $ha^{-1} yr^{-1}$. These yields compare unfavorably with climatically similar areas in Australia or Portugal, for example, where with 600 mm mean annual precipitation and similar climatic and edaphic conditions (but with regular planting of annual legumes), production levels typically reach 100–150 kg live weight $ha^{-1} yr^{-1}$ [Crespo 1985].

Average stocking rate of cattle is higher than sheep in the subhumid zone, for the simple reason that cattle are grazed in the best available espinales. Bovine breeds most frequently encountered are dual-purpose, e.g. Holstein-Friesian and Simental. An increasing number of Hereford are being introduced as well. Current production levels of the best cattle operations reach 50 kg $ha^{-1} yr^{-1}$ [Serrano and Jara 1975].

In addition to providing favorable conditions for development of annual pasture, espino contributes some pasture supplement directly: leaves and fruits are consumed by all types of livestock. Leaves of espino can form up to 19% of the diet of sheep in summer without ill effects [Torres et al. 1987; Riveros et al. 1978]. The nutritional value of espino pods, seeds, and leaves appears in Table 2. (For additional data on nutritive value of espino, see Bastian and Grafe 1989.) *In vitro* digestibility of green leaves, mature pods, and seeds of *A. caven* has been measured as 36–52%, 46–53% and 80–82%, respectively (Lagomarsino and Prette 1982; Pichard et al. 1988). Finally, when trees are pruned or selectively removed, a certain amount of fuelwood and charcoal is harvested.

Table 2. Chemical composition of *Acacia caven* leaves, seeds and pods[1] Values shown are averages of numerous analyses; (Sources: Ciudad and Rodriquez 1982; Ovalle, 1986; Pichard et al. 1988).

Plant part	H_2O (% fresh weight)	Protein	Lipids	Fibre	Sugar	Ash	Ca	P
		[% dry weight]					[%DW × 10^{-3}]	
leaves	43–55	19–23	–	48	–	14	–	200
pods	9	6	2	36	45	11	790	30
seeds	8	24	5	18	44	9	350	340

4.2b Wheat production in hillside espinales

In general, the soils on the hillsides ('lomas') are quite poor and steep, and plowing tends to exacerbate soil erosion. The espinal presents a matorral-like aspect due to frequent cutting (Photo 4). Wheat culture is carried out in a traditional, low-technology system, in which the espinos are cut nearly to the ground but not uprooted. Soil preparation is carried out with animal traction. Wheat varieties planted are local landraces; no fertilizer or herbicides are applied.

Typically managed in annual range – wheat rotation, all trees are cut every 5 to 10 years, when a wheat crop is to be sown. Following a single harvest of wheat, the field is left fallow for several years, and espinos are allowed to grow back from stump-sprouts, while livestock is allowed to graze. Synanthropic therophytes and seedling espinos quickly reinvade from

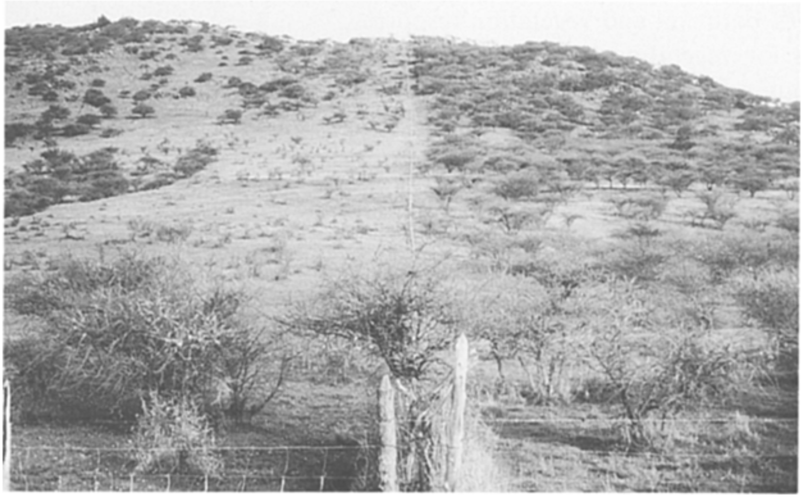

Photo 4. Subhumid zone hillside espinal + fallows. (Credit C. Ovalle)

in situ seed banks and via newly arrived disseminules. Considering the climate of this region, crop yields are low: 0.7–1.5 tons grain $ha^{-1} yr^{-1}$ [Del Pozo, et al. 1989b]. With improved varieties and fertilization, however, significantly higher wheat yields (2.5 tons) can be achieved [Del Canto 1983].

In a very few ranches, e.g. La Estrella, large, individual espinos are pruned and cared-for on a permanent basis. Direct benefit to crops however, is only rarely perceived as justification for conservation of these trees. Rather trees are left in fields as 'pajareros', or roosting sites for birds. Thus they may have more sentimental than economic value in the view of the farmers.

4.3 Negative implications of predominant production systems

Past and present systems of exploitation of the espinal since the 1600's have led to successive degradation of basic resources with inevitable decrease in productivity. (In fact, virtually all traditional silvopastoral systems in arid and semiarid lands worldwide are in a more or less serious state of decline [Le Houérou personal communication 1989].

All of the currently predominant production systems based on the espinales are of the 'mining' type, i.e. constant harvest, with no investment in long-term improvement. To take as an example the most frequently encountered system, the wheat-annual range system (section 4.2a), we see that every five to ten years the agroecosystem is 'brought to its knees', so to speak, when all trees are cut, the small amount of nutrients accumulated in the soil are taken out in the form of a wheat crop, and overgrazing subsequently recommences. Long-term, this combination leads to progressive degradation of both soil and vegetation resources.

As for vegetation, both the herbaceous and woody pasture plants are maintained at low value and low production (1.5–2.0 ton herbage $ha^{-1} yr^{-1}$ [Acuña et al. 1983]. In the wheat-annual range system of hillside espinales, where livestock are allowed to graze during the years immediately following clearcutting for wood, negative impact on the quality of the espinos and the espinal is particularly noticeable. Firstly, sheep (and cattle) graze the young leaves and shoots of espino (and other trees and shrubs), and thereby contribute to the maintenance of multi-stemmed shrubs rather than single or few-stemmed upright coppices. Secondly, no time is allowed for the more valuable grasses and forbs (e.g. *Lolium* spp., *Medicago* spp., *Stipa* spp. to reestablish. In addition, soil erosion is rampant. In the area around Cauquenes, for example, no less than 60% of agricultural soils are in mid- to advanced stages of erosion [IREN 1965].

Recent cartographic studies in one of the areas of densest, most mature espinales in Chile (near Cauquenes), reveal that only 2% of the espinales in an area of some 22,500 ha have structure suitable for longterm management. These few espinales – found mostly in flatlands – are reliable, permanently productive agrosilvopastoral systems. Some 28% of the espinals are in a state of progressive degradation but possess a structure permitting gradual improvement, through pruning and protection, within an estimated period of 10–20 years. More than 50% of the espinales in the study area, however, are in such bad shape as to be beyond recovery. (The remaining 20% of the area at any given time is fallow or planted to wheat) [Ovalle, Avendaño and Del Pozo 1988].

5. Potential for improvement of the espinal

Despite the above-mentioned problems, there is still clear hope for significant improvement of agroforestry systems in the Chilean espinales. We base our optimism firstly on the observation that a few model espinal-based systems do exist, which allow low but stable productivity in non-irrigated ('marginal') sectors of both the semihumid and semiarid regions. Secondly, we believe that with sufficient research and development, espinal-based systems can be achieved comparable to the *Quercus*-based dehesa system in southern Spain and southern Portugal [Joffre et al. 1988] or various legume-tree based systems in semiarid subtropical regions: *Acacia aneura* in Australia [Pressland 1975]; *Faidherbia albida* in various parts of Africa [Kirmse and Norton 1984; Poschen 1986; Centre Technique Forestier Tropical 1988]; *Prosopis cineraria* in NW India [Mann and Saxena 1980, Mann and Shankarnarayan 1980]; and *Prosopis glandulosa* in NW Mexico [Cornejo et al. 1982]. Clearly, to achieve this goal, much basic and applied research is needed. The basic lines of this research program have already been determined and initiated. They include:

a. development of appropriate silvicultural management practises for the best of the existing espinales, including thinning and pruning of existing trees and shrubs to achieve faster growth rate and more productive growth form and population structure (5.1).
b. the identification and introduction of tree, shrub and annual pasture plants capable of complementing the benefits offered by the espino. This aspect of the program consists of four parts:
   i) introduction and selection of superior germplasm within the widespread and genetically variable espino itself (5.2);
   ii) introduction and selection of additional multi-purpose trees and shrubs which could grow in central Chile under conditions similar to those

occupied by the espino today (5.3);

iii) introduction and selection of improved lines of the most important annual legume found in the espinales, *Medicago polymorpha* (5.4).

c. selection and utilization of efficient strains of *Rhizobium* for use with espino and other legumes introduced to the system (5.5).

5.1 Development of appropriate silvicultural management practises

Much extension work and practical demonstration are needed to convince farmers and herders of the advantages of agroforestry systems, and to promote greater conservation of existing trees and espinales of high value.

5.2 Selection of 'elite' germplasm of Acacia caven

Despite consistant overexploitation and what has been called 'artificial negative selection' [Burkart, 1976: 522], *Acacia caven* on a continental scale shows a great range of genotypic variation, especially in regards pod and leaf size and productivity, but also in other morphological traits, in phenology, and, most pertinently, overall growth rate and form. Ten provenances of distinct potential have already been identified, and will be planted in four introduction and evaluation plots in the subhumid, semiarid, and arid zones of Chile during the next three years [Aronson and Ovalle 1990, in prep.].

5.3 Introduction and selection of multipurpose tree and shrubs

To complement existing resources in the espinales, we will introduce new sources of forage, especially edible fruits and/or leaves, for the critical late-summer-autumn period (February–June), when annual pasture of the previous year is exhausted. Candidates species include carob, (*Ceratonia siliqua* L.), various oaks (*Quercus* spp.), and several algarrobos (*Prosopis* spp.), as well as some native tree species of high fodder value, e.g. Belloto (*Beilschmiedia miersii*, *B. berteroana*) and Maiten (*Maytenus boaria*). Additional candidate species have been identified from the Chaco region where the espino is presumed to have originated, including *Caesalpinia paraguariensis* (D. Parodi) Burk. and various *Acacia* species. Most of these species also grow to larger sizes than the espino, and thus could theoretically be incorporated into agro-silvopastoral systems with less difficulty for the farmer than the espino.

Finally, several shrub species have been identified for trial planting and integration in espinal-based systems: Tagasaste (*Chaemaecytisus proliferus*), *Medicago arborea*, and, for the northern, arid region, *Cassia sturtii.* All of these could provide important quantities of edible foliage during summer. All of these native and introduced species will be planted and their productivity compared to that of the ten provenances of espino.

5.4 Domestication of 'elite' lines of Medicago polymorpha

There are at least six species of annual medics (*Medicago* spp.) naturalized and widely distributed in the mediterranean-type climate zone of central Chile (mean annual rainfall 150–1000 mm) [Del Pozo, Ovalle and Avendaño 1989]. Increased use of these annual medics appears to have great potential for the improvement of production on gently-sloping hillside espinales. A collection and evaluation program has been initiated in which some 40 accessions of the most important species, *M. polymorpha*, have been assembled from the semiarid, subhumid and humid regions [Del Pozo et al. 1989b]. Selection of high-yielding lines with spineless pods will be undertaken and the resulting germplasm will be released for use by commercial farmers. This aspect of the program has the advantage of offering quick results, whereas the introduction and selection of tree and shrub germplasm will require much time and investment.

5.5 Isolation of rhizobial strains and inoculation of legumes

A. Nine rhizobial strains have been isolated from individuals of *Acacia caven*, and other native species of perennial legumes, these have been used in inoculation of the plants established in tree and shrub evaluation plots in 1989 and 1990. Greenhouse studies of comparative nitrogen-fixing efficiency of these strains, in association with *A. caven* and other tree legumes, will be undertaken in the near future.
B. Forty strains of rhizobia have been isolated from wild-growing plants of *Medicago polymorpha*, and these will be screened for relative N-fixing efficiency on the different types of soils found in central and northern Chile. Greenhouse studies will be followed by field trials with the most promising strains.

6. Discussion and conclusions

Inappropriate agriculture methods, excessive woodcutting, and systematic overgrazing have led to serious environmental degradation and socio-economic depression in the 'secano interior' of Chile. The great majority of current research efforts in Chile, however, as in most countries, is devoted to raising crop and animal yields in high-production areas where rainfall is plentiful or irrigation is currently feasible. We believe that adequate attention must be given to the non-irrigated ('marginal') areas in the arid, semiarid, and subhumid regions as well. The potential for short-term improvement of production in the secano interior is limited, but experience in many other parts of the world with similar conditions and problems leaves room for hope of significant advances in the long run. What's more, environmental as well as social considerations further justify agroforestry research in the secano interior.

In comparison with other agroforestry systems in mediterranean-climate areas, the major limiting factor of the espinales lies in the relative value of the fruits of indigenous trees in each case. Oaks are preserved in the dehesa system of southern Spain and Portugal for their production of large quantities of acorns in late-summer and autumn [Joffre et al. 1988]. (*Quercus suber*, of course, is also grown for cork.) Similarly, in the traditional hill-crop systems of central Corsica and some areas of southern France, northern Italy and Galicia, Spain,*Castanea sativa* was preserved, and indeed carefully pruned and grafted, to enhance production of chestnuts, from which derive a great number of valuable products. By contrast, the pods of espino are of relatively low-value for livestock and people.

Nevertheless as we have tried to show, the espino clearly does warrant selection and improvement, particularly in view of its nitrogen-fixing capacity, 'reversed phenology' and wide ecological amplitude. The large range of germplasm that exists suggests that genetic improvement, or what we would call 'positive selection', could in fact be carried out. For this purpose, new genetic material needs to be introduced to Chile, much as the improvement of a local breed of livestock is upgraded by importing stud animals of improved varieties.

However, the slow growth and relatively low-value fruits of the espino are serious disadvantages. Accordingly, elite germplasm of other tree, shrub, and annual plants are being sought for use in the rehabilitation of degraded espinales and reforestation of denuded sites. Nitrogen-fixing species are preferred, and will be grown with selected strains of rhizobium.

Early results in our field trials in central Chile, as well as in the high altitude Tarija basin of southern Bolivia [Bastian and Gräfe 1989] show that *Acacia caven* and a number of other South American legume trees clearly show high potential for reforestation and agroforestry projects in a wide range of climatic and edaphic conditions.

There exists a remarkable Chilean law which could be an effective tool to facilitate the inclusion of trees and shrubs into existing systems. This law

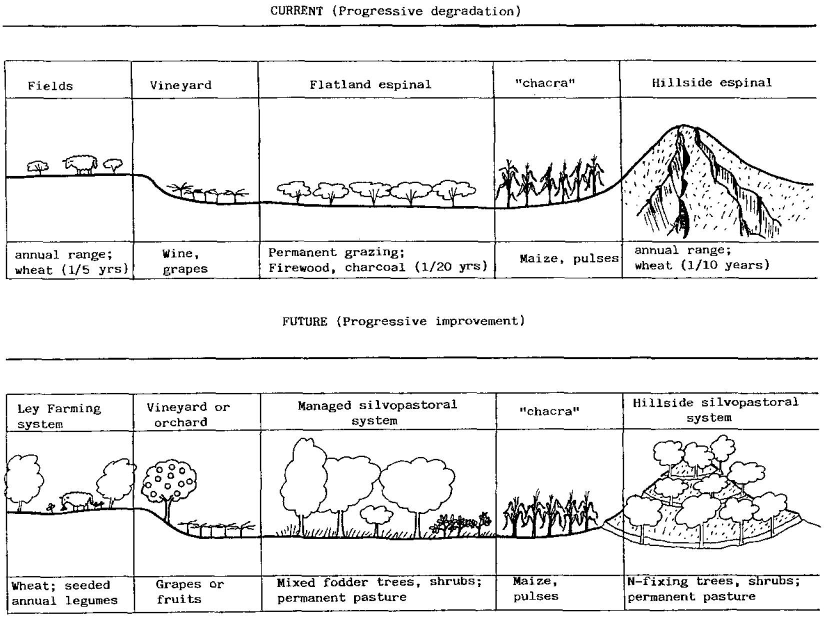

Fig. 5. Present and future situation of dry farming systems in the 'secano interior' of central Chile.

(Decreto No. 710, in effect at least until 1994), which has already been applied to the planting of silvicultural species such as *Eucalyptus*, *Pinus*, as well as desert-adapted fodder shrubs (*Atriplex* spp), provides that 75% of the cost of tree or shrub establishment is reimbursable to the planter in a) areas currently devoid of woody vegetation (arid regions) or b) areas where extent vegetation provides no economic return at present.

In Figure 5, we present our vision of the transformation of the dry-farming systems in the espinales that could be achieved through integration of current research efforts with existing patterns of land-use and land tenure in the secano interior. In the place of self-limiting systems characterized by progressive degradation, we envision systems of gradual but progressive improvement of productivity and stability. Although this is clearly a long-term goal, and success is predicated on many factors, we are confident for the future.

Acknowledgements

We warmly thank I. Ruiz and S. Bonilla of the Instituto de Investigaciones Agropecuarias for long-term support of the work described. E. Fuentes, E.

Le Floc'h, H.N. Le Houérou and P.H. Raven read an earlier version of this paper and made helpful comments. The second author gratefully acknowledges the support of a grant from the National Geographic Society (USA).

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