BIOLOGICAL CONSIDERATIONS IN DESIGNING A SEED COLLECTION STRATEGY FOR *GLIRICIDIA SEPIUM* (JACQ.) WALP. (LEGUMINOSAE)

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SUMMARY

The Oxford Forestry Institute has now completed rangewide seed collections of *Gliricidia sepium* for the establishment of an international provenance trial. Basic biological information on taxonomy, distribution, ecological amplitude, phenology, breeding systems and patterns of variation is presented. The sampling strategy is described highlighting human interference as a major factor distinguishing *Gliricidia* from traditional forest tree seed collections. Site details are provided for the 30 provenances sampled and a detailed distribution map showing provenance localities is included. The sampling strategy, coordinated evaluation and possible genetic improvement of *Gliricidia* are discussed in relation to the perceived potential and limitations of the species in tropical production systems.

RÉSUMÉ

L'Oxford Forestry Institute a maintenant achevé des collections de graines sur toute la zone d'étendue de *Gliricidia sepium* pour l'éstablissement d'un essai international de provenances. Des renseignements biologique de base sur la taxonomie, l'aire naturelle, l'amplitude écologique, la phénologie, les systèmes de reproduction et les modèles de variance sont présentés. La stratégie d'échantillonnage est décrite en se concentrant sur l'intervention humaine comme un facteur majeur qui distingue *Gliricidia* des collections traditionnelles de graines d'arbres forestiers. Des détails de station sont fournis pour les 30 provenances échantillonnées et une carte détaillée de répartition qui montre les localités des provenances est comprise. La stratégie d'échantillonnage, l'évaluation coordonnée et l'amélioration génétique possible de *Gliricidia* sont discutées par rapport au potentiel perçu et les restrictions des essences dans les systèmes tropicaux de production.

RESUMEN

El Instituto Forestal de Oxford ha completado la recolección de amplio rango de semillas de *Gliricidia sepium*, con el propósito de establecer un ensayo internacional de procedencias. Se presenta información biológica básica sobre la taxonomía, distribución, amplitud ecológica, fenología, sistemas de mejoramiento y patrones de variación. Se describe la estrategia de muestreo, enfatizando la interferencia humana como el principal factor que distingue a *Gliricidia* de las especies forestales tradicionales, con respecto a la recolección de semillas. Se dan los detalles de los sitios de 30 procedencias muestreadas y se incluye un mapa detallado de su distribución, el cual muestra las localidades de cada procedencia. Se discute la estrategia de muestreo, la evaluación coordinada y el posible mejoramiento genético, de *Gliricidia* con relación al potencial y a las limitaciones observadas para esta especie en los sistemas de produccion de los trópicos.

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Introduction

Gliricidia sepium (Jacq.) Walp. is a medium-sized, thornless, leguminous tree native to Mexico and Central America. In the past it has been introduced into many tropical areas and is cultivated and sometimes naturalized in northern South America, the Caribbean, Hawaii, west Africa, sporadically in east and southern Africa, India, Sri Lanka, south-east Asia including Thailand, the Phillippines, Indonesia and Australia. More recently *Gliricidia* was included as one of the 26 dry zone multipurpose tree species selected for species elimination trials by Hughes and Styles (1984) and seed has now been distributed in some 145 trials in 46 countries (Hughes, 1986).

Gliricidia has many enigmatic characteristics. In Central America and Mexico it is one of the commonest trees occurring in most areas below 1500 m elevation sometimes in great abundance. Yet its native distribution is not clearly known. While the literature suggests that *Gliricidia* produces a very wide range of useful products including fuelwood, fodder, poles, green manure and bee forage (Falvey, 1982; NAS, 1980) and can be used in a variety of production systems from pure plantations to intimate agroforestry mixtures, closer study reveals that its benefits and usefulness are not always clearly perceived by farmers and wood users. What is clear is that *Gliricidia* is extremely easy to establish, cultivate and manage, and on many sites is fast growing and is therefore particularly well suited for use by farmers in agroferestry or other farm situations. This makes *Gliricidia* a valuable alternative to *Leucaena leucocephala*.

It is only in recent years that *Gliricidia* has become the focus of intensive agronomic research with several regional organisations now involved. These include the International Livestock Centre for Africa, ILCA (Sumberg, 1985a), the University of Hawaii (Glover and Brewbaker, 1984), the Centro Agronomico Tropical de Investigacion y Ensenanza, CATIE in Costa Rica (CATIE, 1986) and the Australian Centre for International Agricultural Research, ACIAR.

In common with most non-industrial tree species, systematic genecological investigations are lacking for *Gliricidia* with no complete studies to define its natural distribution, phenology and ecological amplitude, to sample the range of genetic variation with rangewide seed collections or to evaluate that variation in field trials as a basis for future genetic improvement. Most early introductions were poorly documented, usually from single provenances and often from a single parent tree (in Sri Lanka, for instance, where *Gliricidia* was introduced in 1880 probably from Trinidad (Weerawardene, pers comm*) where it had been earlier imported from Nicaragua). Many land races are probably therefore sub-optimal and inbred. Atta-Krah (1986) has shown that all recent accessions tested in Nigeria have out-performed the local Ibadan land race in forage yield. More recent seed collections have concentrated on small parts of the natural distribution. Sumberg (1985a) collected a mixture of 54 family and bulk accessions from north-western Costa Rica while Chang and Martinez (1985) collected a series of provenances mainly from south-eastern Guatemala and north-western Costa Rica. *Gliricidia* research has to date been conducted with incomplete knowledge and germplasm often from a very restricted part of the distribution.

Following a collaborative initiative between CATIE, the University of Hawaii, the Visayas State College of Agriculture, ViSCA, Philippines and the Oxford Forestry Institute, OFI, in 1983 (Glover and Brewbaker, 1984), the OFI has now completed rangewide seed collections of *Gliricidia* in collaboration with nine Latin American countries. This paper outlines background biological information associated with these collections, the sampling strategy and seed availability for trials.

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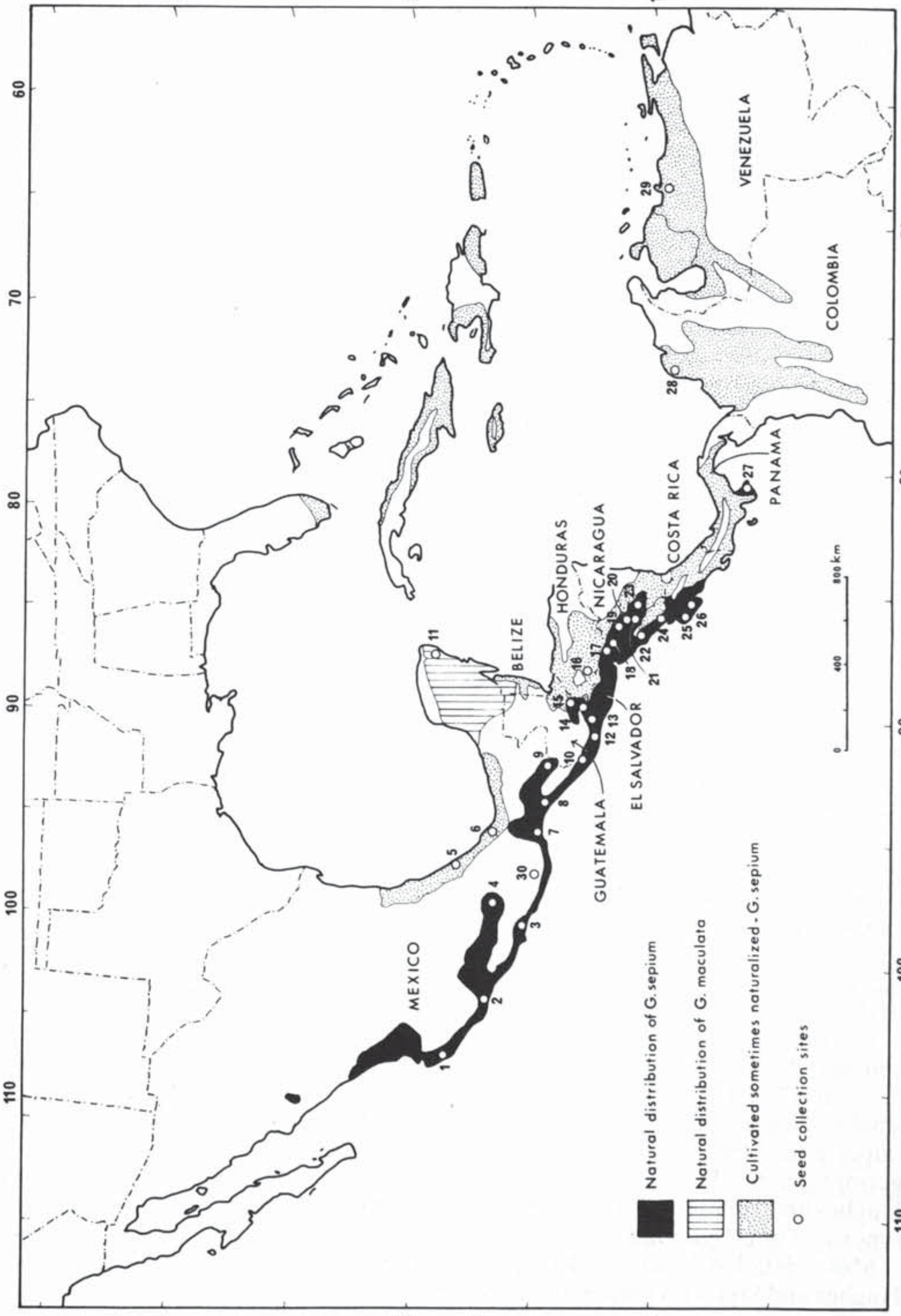
MAP 1 TENTATIVE DISTRIBUTION of GLIRICIDIA SEPIUM & LOCATION of SEED COLLECTION SITES



Taxonomy

In the past *Gliricidia sepium* (Jacq.) Walp. has been placed in the genera *Robinia* and *Lonchocarpus* indicating its overall taxonomic affinities within tribe Robinieae in the subfamily Papilionoideae of the Leguminosae. Even today, considerable taxonomic confusion surrounds *Gliricidia* both at generic and specific levels with no authoritative review of the genus available.

The tribe Robinieae has been broadly reviewed by Lavin (in press) but it was concluded that further work is needed to elucidate the relationships between the closely related genera *Gliricidia, Coursetia, Lennea, Hybosema* and *Yucaratonia*. *Lennea* is a poorly collected and little known genus of closely related Central American trees, and in several instances *Lennea* species have been placed in *Gliricidia*. The closest relative of *Gliricidia*, however, is considered to be *Yucaratonia brenningii* (Harms.) Burk. (Lavin, pers comm.*). This monotypic genus native to southern Ecuador and northern Peru was previously placed in the genus *Sesbania* and forms a small tree similar to *G. sepium*, widely used in living fences in Ecuador. Further exploration and collection is required for these closely related genera.

Confusion at the species level has arisen in *Gliricidia* through the proliferation of species combinations, most of which are either synonyms or species which belong to the closely related genera *Lennea* and *Coursetia*. Polhill and Sousa (1981) reduced the likely number of species to four. It is probable, however, that this is still an overestimate and Hughes and Styles (in preparation) present evidence for the existence of only three species:

G. sepium (Jacq.) Walp.
G. maculata (HBK) Steud.
G. guatemalensis M.Micheli.

Confusion has been particularly prevalent over the distincion of *G. sepium* and *G. maculata* with both names used indiscriminately in the forestry and agronomic literature. These two taxa have been treated almost universally as synonyms. Hughes and Styles (in preparation) however, present evidence for the reinstatement of *G. maculata* as a distinct taxon following the treatment of Rydberg (1924). *G. maculata* appears to be a separate taxon native to the Yucatan peninsula, northern Guatemala and Belize occurring at low densities in semi-deciduous forest. This slender tree is distinct from *G. sepium* in several characteristics being white-flowered with smaller pods and seeds, distinctive leaflets and an isolated distribution. Although most *Gliricidia* planted as an exotic is clearly attributable to *G. sepium*, the possibility cannot be ruled out that *G. maculata* was introduced to some areas and this might explain the variable performance of different *Gliricidia* land races. This should be investigated further.

Gliricidia guatemalensis represents a distinct highland species native to central and southern Mexico, Guatemala, El Salvador, Honduras and possible Nicaragua between 1,500 and 2,000 m altitude. It is always a small treelet or woody shrub to 3 m height with smaller flowers, leaves and pods than *G. sepium* and probably has little direct economic importance. Its possible cold tolerance could make it of some use in developing germplasm for highland areas and more complete collections would be desirable. Hughes and Styles (in preparation) conclude that *G. ehrenbergii* and *G. meistophylla* are synonyms of *G. guatemalensis*.

More detailed botanical descriptions and illustrations of *Gliricidia* are given by Hughes and Styles (in preparation), White (1980) and Standley and Steyermark (1964).

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Ecology

Distribution

Gliricidia has been used, cultivated and transported by man over many centuries and this has greatly affected not only the present distribution, making its true natural range uncertain but has also created numerous land races through cultivation. Humans have been actively spreading *Gliricidia* since early times. A wealth of common names, not only in Spanish *e.g.* Mataraton and Madre de cacao, but also in several indigenous Indian languages such as Xakyaab (Maya, Yucatan Mexico), Cacahuananche (Nahuatl, Mexico) meaning mother of cacao and Yaite (Quiche, Guatemala), indicates an appreciation of the qualities of *Gliricidia* since agricultural man appeared in Central America 200 years ago. The spread of *Gliricidia* has undoubtedly been greatly facilitated by its easy propagation either by seed or stakes and its widespread use not only for live fences and shade over cacao or coffee but also for rat poison and numerous medicinal purposes.

In addition to the direct influence of man through cultivation, population size, density and structure have been greatly altered by the wholesale clearance of the tropical dry deciduous forest of the region. *G. sepium* is an aggressive colonizer and widespread human disturbance has allowed *Gliricidia* populations to spread and increase in size and density. Populations often now form very extensive either pure stands or stands dominated by *Gliricidia* in mixed secondary vegetation. In some areas, such as south-east Guatemala, central Nicaragua and southern Honduras where bush fallow cropping is practised, *Gliricidia* is frequently the dominant woody cover, resprouting repeatedly after clearance. Continuity between populations that would previously have been isolated by climax forest has greatly increased providing greater opportunities for gene flow.

Further than this is the parentage of some *Gliricidia* populations is very uncertain. In some cases it is possible that very extensive pure stands may have spread from a few trees planted as ornamentals in villages. Heavy annual seed production, precocious flowering, usually in the first five years, and explosive dehiscence of pods which can eject seeds up to 25 m from even a small tree, mean that such populations could develop over short periods of time. The strands around the village of Masaguara in the Otoro Valley in Honduras (provenance identity number 25/84) almost certainly originated from a few planted trees and it is unlikely that *Gliricidia* is native in the Otoro Valley despite its present day abundance. It is possible that the extensive littoral populations at Monterrico, Guatemala (17/84), San Mateo, Mexico (35/85) and Playa Tamarindo, Costa Rica (12/86) have similar origins (Figure 5). It is clear also that roads provide important conduits for spread of *Gliricidia* which is able to regenerate abundantly on disturbed roadside verges and now lines long stretches of road *e.g.* the Las Maderas to Sebaco section of the Panamerican Highway in Nicaragua.

Most authors have defined the natural distribution of *Gliricidia sepium* to include all of tropical Mexico, Central America and northern South America as far south as Venezuela and the Guyanas (Pittier, 1927; Standley and Steyermark, 1946; Pennington and Sarukhan, 1968; White, 1980; Zarucchi, 1986). It is now clear that *Gliricidia* is native only to seasonally dry climates occupying early and middle successional sites such as coastal sand dunes, river banks, flood plains, and other disturbed areas. In Santa Rosa National Park, Costa Rice, large trees occur on the drier, more exposed sites and may form canopy trees (Janzen, pers. comm.*) (Figure 1).

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Small stand of mature trees, El Roblar, Guanacaste, Costa Rica.

The detailed mapping of the natural distribution has been an important part of the last three years' work and visits have been made to all areas where *Gliricidia* is found. This meticulous exploration has allowed a tentative map (see Map 1) to be drawn, showing the hypothesized natural distribution of *G. sepium*, areas where if is cultivated and sometimes naturalized and also the distribution of *G. maculata*. This shows a more restricted distribution than has been considered likely in the past. Although *G. sepium* is frequently abundant in South America, along the coast of the Gulf of Mexico and in some inland areas in Central America, no clearly native trees can be found; all regeneration is readily attributable to adjacent cultivated trees. It is therefore assumed that *Gliricidia* was introduced to these areas as discussed above. In Venezuela this is backed up by observations during nationwide phenological studies (Bennachio, 1980 and pers. comm.*) and ecological studies (Smith, pers. comm.*). Similar conclusions have been reached for populations in the Caribbean. In Panama no undisturbed seasonally dry forest survives and it is now impossible to tell whether *Gliricidia* is native to the dry Azuero Peninsula or not. Exploratory work in Mexico revealed what appears to be an isolated population in northern Sinaloa at 25°N some 400 km north of the nearest know occurrence in southern Sinaloa. It is unclear whether this represents a natural population or a naturalized introduction.

Ecological Amplitude

Gliricidia is native over a range of 18° latitude from 7°30′N in Panama to 25°30′N in north-western Mexico. Throughout the majority of the natural distribution a relatively uniform sub-humid climate prevails with rainfall in the range of 900–1500 mm and a five month dry period from December to April. Typical meteorological data are shown below for Acapulco, Guerrero, in Mexico, (altitude 3 m).

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*Dr R. Smith, Universidad Centro Occicental, Barquisimeto, Venezuela.

Mean annual rainfall: 1412.9 mm

Months	J	F	M	A	M	J	J	A	S	O	N	D
Rainfall (mm)												
Mean	8	1	0	1	37	322	231	238	353	174	32	9

Temperature (°C)

	J	F	M	A	M	J	J	A	S	O	N	D
Absolute Max	36.0	36.2	37.5	37.0	34.0	35.2	35.0	36.8	32.6	33.6	36.0	35.0
Mean Max	31.5	32.2	32.8	33.4	31.6	30.7	31.8	31.5	30.6	31.3	31.7	31.9
Mean	25.7	26.2	27.5	28.3	28.3	27.3	27.9	27.5	26.4	26.8	27.0	26.3
Mean Min	18.4	18.5	20.6	22.2	23.5	22.5	22.5	22.7	27.8	22.6	21.9	19.5
Absolute Min	14.4	12.0	16.2	17.4	20.0	20.6	21.0	19.8	20.2	18.0	18.6	11.6

Mean minimum relative humidity during the dry season rarely falls below 30% although in many areas strong desiccating winds are prevalent throughout the early part of the dry season.

In any seed collection programme it is important to encompass as much of the environmental variation as possible and to include sites at the environmental extremes. The range of variation in rainfall and altitude covered is outlined in Table 1. In several areas *Gliricidia* occurs under particularly dry conditions and at the extreme in semi-arid parts of Central Mexico and eastern Guatemala rainfall is as low as 600–700 mm with a seven or eight month dry season (Figure 2). In other areas rainfall is much higher and may reach 3500 mm but a lengthy dry season is still prevalent. *Gliricidia* has been successfully cultivated in wetter climates with no marked dry season.

Gliricidia at its extreme lower rainfall limit, Los Amates, Puebla, Mexico.

Table 1
Summary of Seed Collection Site Data for *Gliricidia*

No. on Map	Provenance	Country	Ident No.	Lat. North	Long. West	Alt (m)	Rainfall (mm)	No. Trees	Seed No. Pure Seed/kg ('000)	Quality Germination %
Gliricidia sepium										
1	Chamela, Jalisco	Mexico	41/85	19°28′	105°05′	60–100	905	30	5.5	90
2	Playa Azul, Michoacan	Mexico	38/85	18°04′	102°34′	0–30	900	60	6.5	97
3	San Jose, Guerrero	Mexico	39/85	16°48′	99°15′	30	1400	40	4.7	83
4	Los Amates, Puebla	Mexico	33/85	18°28′	98°25′	1100	650	120	5.1	96
5	Palmasola, Veracruz	Mexico	34/85	19°46′	96°25′	10–50	1130	40	6.7	96
6	Barrosa, Veracruz	Mexico	36/85	18°20′	95°06′	100–150	1500	20	6.0	91
7	San Mateo, Oaxaca	Mexico	35/85	16°13′	94°58′	10–30	950	300	6.3	96
8	Arriaga, Chiapas	Mexico	40/85	16°15′	93°51′	30	1796	50	7.6	94
9	Tzimol, Chiapas	Mexico	37/85	16°18′	92°22′	600–700	1030	35	7.9	94
10	Samala, Retalhuleu	Guatemala	14/84	14°33′	91°39′	330	3500	75	7.8	95
12	Monterrico, Santa Rosa	Guatemala	17/84	13°54′	90°29′	5	1650	200	8.1	99
13	Volcan Suchitan, Jutiapa	Guatemala	13/84	14°22′	89°46′	950	1060	70	7.4	99
14	Vada Hondo, Chiquimula	Guatemala	16/84	14°44′	89°30′	450	830	95	7.3	93
15	Gualan, Zacapa	Guatemala	15/84	15°08′	89°20′	150	700	80	7.2	99
16	Masaguara, Intibuca	Honduras	25/84	14°16′	87°58′	825	1100	65	7.9	94
17	La Garita, Choluteca	Honduras	10/86	13°26′	87′11′	450	1200	75	7.5	93
18	Guayabillas, Choluteca	Honduras	24/84	13°24′	86°58′	480	1400	180	8.0	48
19	Piedra Larga, Esteli	Nicaragua	30/84	13°16′	86°23′	605	800	35	7.4	93
20	Ciudad Dario, Matagalpa	Nicaragua	31/83	12°39′	86°07′	450	900	35	8.0	92
21	Laguna Tecomapa, Matagalpa	Nicaragua	13/82	12°37′	86°03′	380	900	87	8.0	88
22	Mateare, Managua	Nicaragua	31/84	12°14′	86°27′	60	1100	25	7.4	92
23	Oju de Agua, Boaco	Nicaragua	29/84	12°23	85°45′	220	1200	75	7.4	91
24	Belen, Rivas	Nicaragua	14/86	11°37′	85°48′	75	1650	100	7.7	94
25	Playa Tamarindo, Guanacaste	Costa Rica	12/86	10°19′	85°54′	0–10	1500	150	9.0	98
26	El Roblar, Guanacaste	Costa Rica	11/86	10°15′	85°18′	20–100	1000	50	9.4	97
27	Pedasi, Los Santos	Panama	13/86	7°32′	80°04′	0–20	850	40	11.00	97
28	Pontezuelo, Bolivar	Colombia	24/86	10°35′	75°51′	20–50	950	150	8.5	94
29	Mariara, Carabobo	Venezuela	1/86	10°17′	67°43′	520	800	100	7.0	92
Gliricidia maculata										
11	Puerto Morelos, Quintana Roo	Mexico	42/85	20°50′	86°57′	0–10	1500	15	13.0	57
Gliricidia guatemalensis										
30	Sola de Vega, Oaxaca	Mexico	1/84	16°29′	97°01′	1800	1500	1		

In its natural range *Gliricidia* occurs from sea level to 1200 m altitude where temperatures are correspondingly lower. It has been cultivated at 1600 m in Guatemala and Costa Rica. It is clear from its northern distribution limits in Mexico, which clearly follow the frost-free limits, that it is intolerant of frost.

Gliricidia is ubiquitous in its soil preferences occurring on a wide range of soil types from pure sands to unstratified rocky regosols to deep black vertisols in its native range and cultivated on soils from clays to sandy loam (Perino, 1979; CATIE, 1986). In several areas, extensive stands have been found on slightly saline coastal sand dunes (Playa Tamarindo, Costa Rica, Monterrico, Guatemala and san Mateo del Mar, Mexico). On these sites trees are thriving on pure shifting sands. Sand typically accumulates around the tree bases up to a depth of several metres and the trees apparently perform a valuable sand stabilization function (Figure 3). The dry season water table varies in these areas from 2 to 10 m below ground level. *Gliricidia* also occurs to a lesser extent on black vertisols which crack during the dry season but is intolerant of waterlogging or soil compaction on this soil type. On these sites pH is typically high. On most sites soil pH is in the range of 5.5–7.0 in agreement with results from *Gliricidia* trials in west Africa (Agboola et al, 1981), the Philippines (Perino, 1979) and Central America (CATIE, 1986). In the majority of areas where *Gliricidia* is abundant, soils are highly disturbed, freely drained stony regosols. These soils are young and superficial and primiarly of volanic origin. Soils have suffered severe abuse through slash and burn agriculture, desiccation and erosion and are often extremely rocky, shallow and skeletal.

Gliricidia resprouts even after severe fires have killed the upper part of the tree, and this has undoubtedly been a major factor in its spread and dominance in much secondary vegetation and areas subject to slash and burn agriculture.

Gliricidia stablizing shifting sand dunes, San Mateo del Mar, Oaxaca, Mexico.

Phenology

In common with the majority of tree species in the seasonally dry forest formations of the Pacific side of the Central American isthmus, *Gliricidia* is deciduous, losing some or all of its leaves during the dry season and flowering and fruiting while leafless. Although variable both within sites and from area to area, trees typically lose their leaves in December/January and flower between January and March. Flowering to pod ripening takes between 40 and 55 days and seed is shed between late February and late April. Leaves flush as the last seeds are shed about one month prior to the first rain in late May.

Although Sumberg (1985) reported an interval of 52 days between first and last trees to flower and a harvest period of 43 days in a seed orchard in Nigeria, the majority of trees followed a much more clearly defined phenology and this agrees with the author's findings in the natural range where within sites flowering and fruiting is relatively uniform with a typical harvest period of around 20 days from first seed dispersal to last. The main sources of variation is between sites, and in this study, peak ripening time was found to range from late February to late May at different sites, with a strong relationship to altitude. In Guatemala, pods were fully ripe at sea level (Monterrico, Santa Rosa) in late February, while at Jutiapa (950 m altitude) 50 km inland the collection period is two months later. Similar altitudinal effects have been observed in other parts of the range. Trees in the isolated occurrence of *Gliricidia* in Sinaloa, northern Mexico, flower and fruit 6 to 8 weeks later than other Pacific coast sites.

Gliricidia sepium in its area of natural distribution produces abundant seed in most years with highly predictable timing. This is in marked contrast to seed production in areas where *Gliricidia* is obviously cultivated. In many of the humid zones where the dry season is less clearly defined (Tabasco and Veracruz, Mexico, norther Honduras and eastern Costa Rica) seed production is apparently sparse in most years. This is a further confirmation of the limits of the natural distribution as shown on Map 1. Similar low pod set has been found in Sri Lanka and Hawaii (Glover, 1986), and could be due not only to climatic differences but also lack of pollinators or the presence of predominantly clonal material in some land races. *G. maculata* from the Yucatan Peninsula is much more variable with no clearly defined single flowering period and erratic, limited pod set.

Breeding Systems and Patterns of Variation

Knowledge of reproductive biology and breeding system is a sound prerequisite to designing optimal sampling strategies for germplasm collections. Although there have been no definitive studies of *Gliricidia sepium*, evidence from a number of sources suggests it to be insect-pollinated and largely out-crossing. Several workers have observed visitation of *Gliricidia* flowers by carpenter bees (*Xylocopa* sp) both in its native range (Janzen, 1983; Hughes, unpublished) and in areas where *Gliricidia* is cultivated (Corbet and Wilmer, 1980, in the West Indies and Aken'Ova and Sumberg, 1986, in Nigeria), and although numerous other insects visit flowers for nectar, Janzen (1983) suspected that large *Xylocopa* bees are the primary pollinators. Experimental work in Nigeria (Aken'Ova and Sumberg, 1986) with isolation of flowers using fly screens prevented pod set suggesting at least some degree of cross pollination. Further than this, Bawa and Buckley (1986), based on field work in the native range in north-west Cost Rica, showed that *Gliricidia* exhibits low fruit/flower and seed/ovule ratios in line with other outcrossing legume species. Further, more intensive, studies will be required to investigate the degree of self-compatability and possible inbreeding levels.

Several authors have documented morphological variation for *G. sepium*. Mora (1983) reported variation in a number of leaf, flower and bark characteristics for trees within Costa Rica. Sumberg (1985) also studied morphological variation in Costa Rica and showed seed and pod colour to be highly variable. Finally Salazar (1986), in a study of variation of seeds and seedlings based on material collected at a limtied series of sites in Guatemala and Costa Rica, concluded that seed size varied significantly between provenances and attributed this to elevation with a strong tendency for seed weight to increase with increasing elevation.

During the extensive exploratory work carried out during this project it has become clear that leaf and leaflet morphology, although extremely variable, do not show any clear patterns and are likely to be under strong environmental control and greatly influenced by human interference. The only consistent morphological variation noted was in the Yucatan and this has now been attributed to a species difference and placed with *G. maculata*. Pod colour differences do, however, appear to occur between individuals as noted by Sumberg (1985), with scattered individuals having consistently purple-coloured pods, even at full ripeness. Seed colour variation appears to be dependent on degree of maturity and progressive darkening of seed after dispersal which could account for some of the differences found by Sumberg (1985). Variation in seed weight is shown in Table 1 with a range from 4700 to 1,000 seeds per kilogram across provenances. It has been found that seed size is strongly influenced by pod ripeness at the time of collection and by seed moisture content, factors not discussed by Salazar (1986), and without uniform collections it is impossible to draw firm conclusions. No altitudinal relation with seed weight, as found by Salazar (1986), is apparent for the 30 provenances included. A trend of variation in seed weight with latitude, noted from the 30 collections, with decreasing seed weights from Mexico to Panama requires further investigation (see Table 1).

Seed Collections

Sampling Strategy

Unlike most traditional forest tree germplasm collections which have concentrated on industrial timber species and which sample relatively undisturbed primary genepools, collection of tree germplasm of non-industrial species is often concerned with highly disturbed populations, altered population structures and in many cases incipient domestication. The influence of man on the genetic variation of non-industrial tree species greatly affects sampling strategy as discussed by Burley *et al.*(1986).

The extreme disturbance of the natural genepools of *Gliricidia* through human interference as already discussed, means that the classical picture of provenance variation as a predictable response to environmental variation within the natural distribution is no longer applicable. Any patterns of variation whether clinical or ecotypic are likely to be masked by an unpredictable network of local variants, and environmental variation does not provide a reliable guide to designing sampling strategy.

For a species such as *Gliricidia* which can be grown in a wide range of production systems and managed under a variety of silvicultural regimes to provide a number of different products ranging from fuelwood to livestock fodder or poles to green manure it is impossible simply to select superior genotypes in the field as is practised for industrial timber species. Not only are many traits difficult or impossible to assess in the field but different genotypes will be required in different situations.

It can thus be seen that it is difficult to design optimal sampling strategies to collect the available genetic variation and that the best option is to sample over as wide a geographic area as possible, including sites at the environmental extremes, and to switch the emphasis on studying patterns of genetic variation to the field evaluation phase where conditions are relatively controlled. For an outcrossing species it is desirable to sample a large number of individuals within provenances and ensure a wide spacing between sampled trees to avoid collection of related individuals and consequent inbreeding hazards. A lack of reliable selection criteria dictates random sampling. Of great importance is uniformity of sampling design for all provenances in order to facilitate interpretation of trial results. It is also worthwhile to collect land race material and especially material from live fence populations which through repeated repropagation by stakes may have undergone significant selection (Figure 4).

Gliricidia in live fence lines, Cofradia, Cortes, Honduras.

The distribution of collection sites across the natural distribution is shown on Map 1 and site details given in Table 1. A total of 30 provenances were sampled including land race material, giving wider and more complete coverage than earlier collections (Sumberg, 1985, and Chang and Martinez, 1985) which concentrated on very restricted geographical areas. For all provenances except one land race, more than 25 trees were sampled. In a few cases where seed production was low, many more trees were sampled in order to obtain sufficient seed. For a subset of sites a combination of individual tree and bulk mixed parentage collections was carried out to provide the opportunity to establish combined provenance-progeny trials and carry out intensive studies of genetic variation in the future.

Methods

Seed collection, extraction, handling and storage are straightforward by conventional methods. Compared with most Central American woody legumes, levels of insect predation are low for *Gliricidia* and seed germinates readily with no pretreatment as found by Whiteman *et al* (1986) in Australia. Germination figures based on laboratory seed tests for all collections are shown in Table 1. Germination is generally high with an average of 92% for the *G. sepium* provenances. The low 48% germination for seedlot 24/84 collected in Honduras is attributable to poor seed extraction techniques.

Extensive pure thickets of *Gliricidia* on coastal sand dunes, Playa Tamarindo, Guanacaste, Costa Rica.

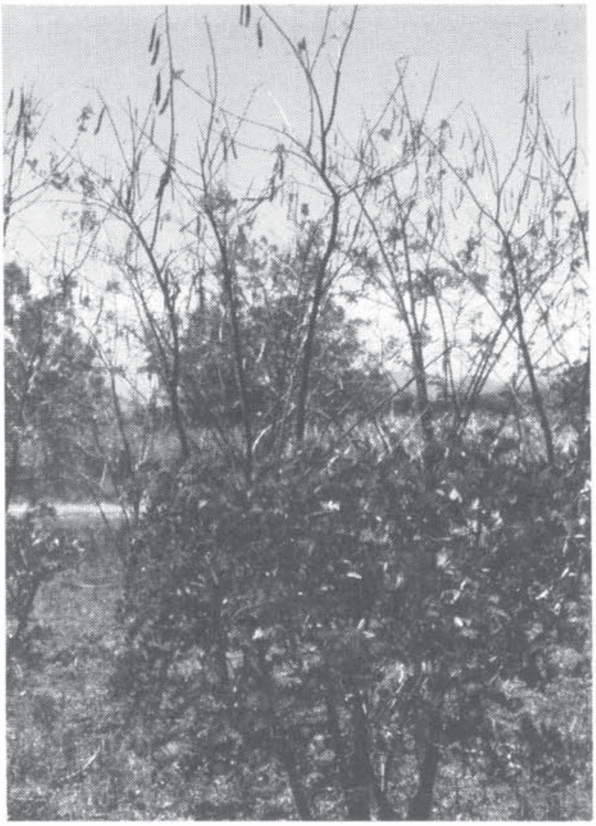
Evaluation

Seed is now available from OFI for the establishment of field trials. It is anticipated that interest in *Gliricidia* will vary from area to area and a range of different trial intensities from preliminary introductions of 1–5 provenances, limited provenance trials of 10–15 rangewide collections, complete provenance trials of all 30 sites to combined progeny/provenance trials maintaining parent tree identities within provenances will be required.

Seed will be accompanied by a detailed trial protocol giving background information on seed quality, seed collection sites, *Rhizobium* inoculation, nursery techniques, trial design and assessment. Local land races of *Gliricidia* and other control species such as *L. leucocephala* should be included in trials where possible. To date a limited set of trials including an incomplete group of provenances has been established (Glover, 1986, and Atta-Krah, 1986) in West Africa, Costa Rica, Hawaii and the Philippines, and early results are providing useful guidelines on optimal experimental designs and plot size through consideration of within-plot variances.

As discussed in the section on sampling strategy, the emphasis in selection and improvement of *Gliricidia* lies in the evaluation rather than the collection phase and innovative experimental designs and assessment procedures will be required.

Two basic designs for pure-plot and alley-cropping systems will be used and reasearch work will be required to develop suitable assessment procedures. In addition to conventional genotype-environment interactions, genotype-management interactions are likely to be very important with radically differing management/silvicultural systems. This added complexity in evaluation can be illustrated by examining the effect of a single silvicultural operation such as lopping. Timing, frequency and intensity of lopping will all affect leaf production and provenance performance (see Figure 6).



The effect of lopping on dry season leaf production in central Nicaragua: foreground lopped trees, background unlopped trees at the end of the dry season.

Discussion and Conclusions

Although *Gliricidia* is now clearly established as a valuable non-industrial tree species and is widely cultivated in many tropical countries, its value and benefits are not universally accepted. Enthusiasm about this species is patchy and opinions differ widely on the quality of its fuelwood and fodder in different countries (Stewart *et al*, 1986). Yamoah *et al* (1986) have pointed out the reluctance of farmers in Nigeria to accept *Gliricidia*, where it is locally called 'abgook maniye' meaning 'grow tall for nothing' and Mackenzie (1986) suggested that it may not prove to be a really useful exotic in rural communities in west Africa despite its abundance in the landscape.

Particular controversy surrounds the quality of fuelwood and fodder from *Gliricidia*. While *Gliricidia* produces a highly appreciated fuelwood in many parts of Central America (CATIE, 1986; Martinez, 1982, and Jones and Otarola, 1981), in other areas, such as northern Honduras, it is little used and of low acceptability being difficult to dry and store and giving low heat (Hughes, unpublished). Many factors may explain these differences. Availability of alternative species of higher quality greatly alters acceptability thresholds; different size of wood and proportion of heartwood, differing growth rate in relation to site factors, and seasonal variation in drying characteristics may account for the widely differing opinions.

The quality of *Gliricidia* leaves for livestock fodder is even more debatable as discussed by Falvey (1982). That *Gliricidia* can be considered one of the highest quality leaf fodders in some cases and yet present considerable palatability problems or even toxicity in other areas may be attributable to a range of factors. There is considerable evidence that many animals require a lengthy period of acclimatization to reach maximum intakes of *Gliricidia* leaves. Carew (1983) showed that intake continued to drop for the first seven weeks of trials with goats and sheep in west Africa before increasing to a maximum after some 15 to 20 weeks. Further, results of two studies in Costa Rica showed highly selective behaviour of monkeys (Glander, 1977) and moths (Janzen, 1983) in defoliation of certain *Gliricidia* individuals in large populations indicating possible genetic variation in leaf chemical composition.

Rapid growth rates, particularly immediately after establishment or lopping, are common for *Gliricidia* but results have not always lived up to expectations. Poor performance has been noted in many areas including subtropical zones (Terai lowlands in Nepal, north-western India and north-eastern Mexico) and semi-arid areas. Although *Gliricidia* will apparently survive considerable winter cold (Whiteman *et al*, 1986) and drought, dieback and resprouting occur. In Guatemala *Gliricidia* survives on poor, freely-drained soils with rainfall as low as 400 mm and an 8 month dry season but grows slowly and suffers periodic dieback (CATIE, 1986).

Despite these limitations, the outstanding ease of progagation either by seed or stakes and management through coppicing or pollarding make *Gliricidia* a particularly attractive species for incorporation into farms in fence lines, small woodlots or agroforestry combinations.

It is as a leaf producer that *Gliricidia* shows greatest promise and it is now seen as a valuable alternative species to *L. leucocephala* for use in alley-cropping systems for mulch and green manure (Agboola *et al*, 1981). Over-reliance on *L. leucocephala* which is now commonly planted on sites that are too dry or cold or on soils that are too acid, and which is badly affected by psyllid defoliation in some areas, makes the incorporation of alternative species an urgent priority. In addition, ease of establishment makes *Gliricidia* an excellent species for use in erosion control efforts (Perino, 1979).

Early and abundant production of seed, ease of vegetative propagation and short rotations are likely to make *Gliricidia* particularly amenable to rapid selection and genetic improvement. Progress will, however, be hindered by lack of knowledge of breeding systems and of soundly-based methodologies for assessment and evaluation. At present, selection for traits other than dry matter productivity has not been attempted, but leaf and wood quality and tree form should be investigated.

International collaboration with centrally coordinated exploration and collection organised by OFI has allowed comprehensive rangewide seed collections sampled from over 2400 individuals from 30 provenances in eight countries to be assembled. These collections represent a broad genetic base and will allow flexibility in future selection and improvement. At the same time it has been possible to study *Gliricidia* throughout its range and provide information on taxonomy, natural distribution and ecological amplitude.

The benefits of close international coordination at the evaluation phase through establishment of a network of identical trials on a wide range of sites are equally important, giving the chance to study genotype-environment interactions and promote exchange of information and genetic material. The limited networks of *Gliricidia* trials established in west Africa coordinated by the International Livestock Centre for Africa, in the Pacific coordinated by the Nitrogen-Fixing Tree Association and in Central America under the control of CATIE in Costa Rica are already giving results on a regional basis. It is recommended that these networks should now be consolidated and built on to establish a wider more complete series of coordinated trials worldwide.

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