Sesbania in Agriculture

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Sesbania *in Agriculture*, Dale O. Evans and Peter P. Rotar

About the Book and Authors

Sesbania, a member of the legume family, has been the object of study in new efforts to discover, conserve, and use plant genetic resources. This volume brings together the most recent research on the subject and combines it with previous studies and an extensive review of the literature. This work is a synthesis of biological description and applied studies related to the highly variable and versatile Sesbania species. Sesbania occurs in both annual and perennial forms in tropical and subtropical regions and is adaptable to an unusually wide variety of soil conditions, including saline. The most important uses of the plants are in nitrogen fixation (as in green manures) and in cropping systems. Auxiliary uses of the different species are as sources for pulp fibers, fuel wood, animal fodder, and windbreaks.

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Sesbania in Agriculture

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and Peter P. Rotar

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for *Sesbania* in Agriculture, Dale O. Evans and Peter P. Rotar

On page 55, the caption for the vertical axis of Figure 5.1 has been omitted. It should read "Relative Yield."

On page 64, Figure 5.5 has been positioned upside down.

1 Introduction

Agriculture is a process of bringing plant growth under control and modifying it so as to produce -- it is hoped -- the maximum benefit to man. Food production has always been the paramount goal. As agricultural systems have developed, plants for purposes other than food have come under man's control to produce feed for animals, fiber for clothing, cordage, and paper, wood for fuel and structures, and other industrial and medicinal products.

Many of these secondary agricultural commodities were once gathered from naturally occurring plant communities. Much of the firewood consumed by man is still collected from forests or from sub-arable, noncropped lands. By encroaching on these lands and bringing them under cultivation, we are destroying these natural resource systems, thus bringing upon ourselves the burden of growing what was once provided by nature. For example, we must now grow the fuelwood to cook the grain (which has usurped most lands for miles around) and to heat the homes of people whom the grain is grown to feed. We also bear the responsibility, too often unacknowledged, to manage our lands in ways which preserve them and sustain their productivity.

Unfortunately, our needs to use lands have grown faster than our understanding of ecological processes, faster than our traditional attitudes toward land use can change, faster than our imaginations can evolve to deal creatively with the dangers and challenges implicit in our actions.

We describe here the characteristics and the past and potential uses of plants in the genus Sesbania. Most of these plants are still wild, a few have been "discovered" recently, and some have long been in use by farmers in certain parts of the world.

Sesbania species are not food plants, except in some instances where leaves and flowers are consumed as vegetables. Their major agricultural use has been as green manures to improve production of food crops. To lesser extents they are grown for animal fodder and for their wood for firewood, poles, and light construction. They have been adopted for these uses because agriculturists have been impressed by their special qualities of vigorous growth, adaptation to varied soil environments, and enhancement of soil fertility where they are grown. Because of these characteristics, Sesbania species are a valuable plant resource.

Potential uses of Sesbania include the expanded use of perennial Sesbania species to improve animal nutrition. The use of annual species for pulpwood and fiber can provide cash crops and foster local industries in developing countries where increased literacy and consumerism increases demands for paper. The expanded use of Sesbania species' biologically produced nitrogen in cropping systems can provide farmers with home grown, low cost inputs to their production systems. With appropriate agronomic techniques and farm management skills, and seed grown on the farm, farmers can use these legumes to improve crop production.

There are less obvious but very important benefits to be gained by expanding the agricultural roles of legumes, including Sesbania species. Their use increases crop diversity and can make cropping systems more conservation-effective. Crop diversification implies a varied agricultural resource base and localized selfsufficiency for numerous agricultural products. Variety in plant types and functions promotes nutrition and soil fertility, insures against crop failure, and preserves genetic resources for the future. Conservation-effective cropping implies an integration of plant materials and management techniques such that soil erosion is reduced, soil structure is maintained, soil nutrients are cycled, and soil losses are minimized. Sesbania species can thus play important roles in long-term maintenance of soil productivity.

Sesbania species are plant resources which are highly valued by those who know and use them. This review of information is presented to broaden the acquaintance of scientists and agriculturists with these plants, so that they might be more appreciated, studied, and utilized. If we have neglected or misrepresented any aspect of Sesbania research and utilization, correction by our readers will be received with appreciation.

Our interest in Sesbania began when one of us (D.E.), seeking candidate legumes for green manuring experiments, obtained seeds of S. speciosa and S. cannabina. The growth of these plants provided an impressive introduction, and the search for additional germplasm then spread via correspondence and traveling colleagues.

Subsequently we were given the opportunity to conduct a research program evaluating these materials. Various field plantings and glasshouse studies were done to observe the accessions, increase seed, estimate yields, and determine edaphic tolerances. The picture of Sesbania that emerged from these experiences was of a diverse and versatile genus with manifold potentials for adoption in cropping systems.

Our work represents only a preliminary investigation of Sesbania. A number of African species remain to be collected and evaluated agronomically. Selection of cultivars appropriate for specialized purposes such as fuelwood, pulpwood, fodder, or green manure, or for tolerances of climatic or edaphic conditions such as drought or acid soils, is only rudimentary at this time. Biosystematic studies could be begun utilizing existing resources; however, for continued selection or plant breeding purposes, the lack of provenance-type germplasm collections from Africa and Asia is a serious inadequacy. In particular, acquisitions should be made among the complexes of species and varieties considered collectively as the perennial S. sesban and the annual S. cannabina (or S. bispinosa). Because of their agricultural importance and potential for expanded utilization, germplasm both from derived provenances in cultivation and from naturally occurring populations would be useful.

2
Botany of *Sesbania*

The genus Sesbania Scopoli, consisting of about 50 species, pantropically distributed, is placed in the family Leguminosae, subfamily Papilionoideae. It was recently moved from the tribe Galegeae to the tribe Robinieae by Polhill and Souza (1981).

The genus Sesbania is divided into at least four subgenera, of which two, Sesbania and Agati, contain species of potential agricultural value. The subgenus Sesbania comprises most of the species, is distributed world wide, and contains species known as green manures and as forages, such as S. bispinosa and S. sesban. The subgenus Agati of southern Asia contains the tree species S. grandiflora and S. formosa. Other subgenera contain New World species and, like Agati, have occasionally been given generic status. There is continuing disagreement over the placement of the subgenera Daubentonia and Glottidium in Sesbania; the present consensus appears to be that the monospecific, North American Glottidium is excluded (Gillett 1963, Polhill and Souza 1981).

There are taxonomic studies of Sesbania for Africa (Gillett 1963), Australia (Burbidge 1965), and Hawaii (Char 1983). New World species were reviewed by R. Montiero (unpublished PhD dissertation, University of St. Andrews, Scotland; this manuscript was not available for our review). There is a real need for a synoptic study of the Asian species of Sesbania.

Gillett (1963) recognized 33 species occurring in Africa, a diversity unknown elsewhere. Burbidge (1965) found 10 species in Australia, of which perhaps eight are endemic to that continent. All of the seven Hawaiian species described by Char are endemic to those islands, their nearest relative being, perhaps, S. atollensis, a South Pacific species. The number of Asian species is unknown. The widespread distribution, however, of *S. bispinosa*, *S. cannabina*, and *S. sesban* is undoubtedly due to their use in cultivation. *S. grandiflora*, the only species of fairly certain Asian origin, is pantropically distributed. This species has been spread principally by man. Most flora described it as introduced and in cultivation. We have not found any flora claiming it as native, or any reference to naturally occurring populations, nor have we observed any volunteer seedlings in the vicinity of trees growing in Hawaii. In contrast, most other sesbanias propagate themselves readily.

Some *Sesbania* species are relatively short-lived perennials; the majority are annuals. Taxonomic studies are generally vague in describing growth duration. Known perennials include *S. grandiflora*, which may live for twenty years or more (Char 1983), *S. formosa*, *S. sesban* (the *S. sesban* complex may be shorter lived), and the Hawaiian species. The New World shrubs *S. punicea* and *S. tripetii* are also perennial. Some degree of perenniality has been observed in Hawaii in *S. javanica* from Australia and *S. pachycarpa* from Africa. Forms of *S. macrantha* growing in different regions of Africa exhibit varying growth durations (K. Egger, personal communication). Some herbaceous species which come from subtropical zones bordering on temperate latitudes appear to be particularly short-lived when grown in Hawaii (21° N latitude), where they exhibit a determinate growth habit characterized by early flowering and senescence after a reproductive phase (Evans 1983). Examples are *S. exaltata* from the southern USA and *S. arabica* from Turkey and Afghanistan. Most other tropical annuals in the genus (e.g. *S. cannabina* from Australia and South Asia, and *S. emerus* from South America) are less precocious and have a life span of at least 6 months.

Detailed discussions of *Sesbania* species morphology may be found in the previously cited taxonomic references. Germination in *Sesbania* is epicotyl, the first leaf is juvenile and entire, and subsequent true leaves are pinnate and demonstrate diurnal solar tracking and leaf and leaflet folding at night. Flowers are usually borne in loose racemes. Seed pods are usually cylindrical but some are rectangular in section (e.g. *S. grandiflora*, *S. speciosa*, *S. marginata*), and *S. tetraptera* has four-winged pods. Pods are generally indehiscent and do not shed their seed until well after pod maturity.

Char (1983) described flower colorations: "The majority of the Sesbania species have yellow colored flowers, pale yellow to orange-yellow, which may sometimes have dark purple or purplish-brown streaks or mottling on the backs of the standard petals. The flowers range in size from 0.5 to 2.8 cm long. Two species, S. erubescens and S. coerulescens have flowers which are pale blue to deep blue. Sesbania formosa and S. grandiflora, on the other hand, have large, white or creamy colored flowers, 7.5-9 cm long. There is also a dark reddish-purple flowered variety of S. grandiflora (var. coccinea). The Hawaiian taxa as well as S. atollensis ... are intermediate in size between the smaller-flowered species and the larger-flowered species. The flowers range in size from about 2.5-4.6 cm long. The Hawaiian species have orange-red to crimson or dark red flowers, while S. atollensis has scarlet to maroon or deep red (with spots) flowers."

Sesbania flowers are most widely pollinated by members of the Hymenoptera. In Hawaii, the carpenter bee (Xylocopa sonorina) and the honey bee (Apis mellifera) are common pollinators. In India, a mason bee, the solitary Megachile lanata, has been noted (Chaudhary and Jain 1978). Char (1983) suggested that in Hawaii the native solitary bees Nesoprosopis spp. were probably the original pollinators of Sesbania. Honey bees have been noted to forage heavily on sesbanias in parts of India (Chaturvedi 1977) where Sesbania spp. pollen is a predominate source during July, and in Egypt, where Sesbania and alfalfa are major pollen sources in spring and summer (Ibrahim 1976).

Duration of seed viability varies with species and with seed storage conditions. In one weed seed survival study, 29 percent of the seed from S. exaltata germinated after being buried in the soil for 2.5 years (Egley and Chandler 1978). S. grandiflora seed lost its viability after 2 years of storage at ambient conditions in Hawaii. S. bispinosa seed probably loses viability within a few years, although for either species storage at low relative humidity and low temperature may prolong viability. Other species' seed may be longer-lived. One lot of 15-year-old seed of S. speciosa obtained from USDA was still viable.

Most species' seeds have impermeable seed coats and require scarification. Seed coat impermeability allows for survival over time, for transmittal along waterways (Trivedi 1955), and helps to assure that germination occurs when an abundance of water is available for growth. Seeds harvested from the same plant at different times of pod set were observed to have variable hardseededness (Sharma et al. 1978). Seed coat structure and related imbibition characteristics in S. bispinosa and S. punicea were studied by Graff and van Staden (1983). Increased permeability was associated with differences in the macrosclerid layer cell packing of "rust" colored seeds of both species. Variation in seed color between light green or tan and reddish-brown or brown is common in individual plants of some Sesbania species.

Seed scarification is recommended when sowing sesbanias in order to obtain uniform, complete, and rapid germination. For research purposes, soaking in concentrated sulfuric acid followed by thorough rinsing in water is common; hot water treatment may also be effective. S. grandiflora germinates well without scarification, although treatment for 15 minutes in concentrated sulfuric acid assures rapid, more even germination. Seeds of most Sesbania species germinate well when acid-scarified for 30 minutes, although seeds of several species (including (S. speciosa, S. tetraptera, and S. rostrata) require 45-60 minutes or more before all seeds will imbibe.

Vegetative propagation is possible with stem and branch cuttings of perennial sesbanias such as S. grandiflora and S. javanica. S. sesban is especially easy to propagate in this manner. In vitro tissue culture of S. sesban and S. grandiflora were reported by Khattar and Ram (1982, 1983).

Plant breeding research on Sesbania has been limited. Datta and Sen (1960) and Datta and Bagchi (1971) attempted crosses between species, but without success.

The Sesbania germplasm resource base has received inadequate attention. The collections of approximately 125 accessions maintained at the Department of Agronomy and Soil Science, University of Hawaii (Evans 1986), and of approximately 180 accessions (including many endemic Australian accessions) gathered by Australia's CSIRO, are perhaps the largest in existence. The U.S. Department of Agriculture (USDA) also maintains some Sesbania germplasm. More extensive collections of materials, particularly from Africa and South Asia, are imperative for future selection and breeding activities.

Morphological studies of various Sesbania species have been made. Datta and Maiti (1968) compared the vascular systems of Sesbania flowers with those of other legume genera. Tewari and Nair (1979) studied tissue bands on floral wing petals. Leaf cuticle structure from a number of legume genera including Sesbania was compared using electron microscopy (Kravkina 1976). Ghouse and Yunus

(1976) analyzed vascular cambium in *S. sesban* and numerous other leguminous trees. Wood characteristics were studied in *S. punicea*; Cozzo (1976) focussed on variability in stratification and other features among a population of plants. Stem bark characteristics of *S. sesban* and *S. grandiflora* were studied and related to medicinal properties of their bark powders (Chaudhuri 1966).

Pollen of *S. roxburgii* (=*S. cannabina*) was described and illustrated by Huang (1972). Pollen physiological development was studied in *S. grandiflora* (Chitaley and Naik 1971), in *S. aculeata* (*S. bispinosa*) (Singh 1957), in *S. sesban* (Ganguly and Datta 1961), and in *S. benthamiana* (Datta and Choudhury 1967). Pistil and stamen development in *S. grandiflora* was studied by Chakraverti (1953). Embryo development in *S. aculeata* (*S. bispinosa*), *S. procumbens*, and *S. grandiflora* was described by Seshavatharam (1982) and in *S. sesban* and *S. grandiflora* by Rau (1951). Mitosis was studied in *S. sesban* by Ganguly *et al*. (1962) and in *S. paludosa* by Datta and Choudhury (1968). Dana and Datta (1960) studied pollen morphology and growth, mitosis, karyotype, and meiosis in *S. bispinosa* and *S. speciosa*. Studies of the megagametophyte of *S. bispinosa* (Salgare 1975) and *S. sesban* (Salgare 1973/1974) were reported. Trivedi *et al*. (1978) studied the spermoderm of *S. bispinosa* with electron microscopy.

Reports of chromosome numbers in *Sesbania* are summarized in Table 2.1. In addition to the species entered there, *S. formosa*, *S. coccinea*, and *Sesbania* spp. from Timor have been found to have 2n=24 (R.L. Oliver, personal communication).

Many of the uses of Sesbania species are described in the following chapters. Table 2.2 provides a brief introduction to the characteristics and uses of some *Sesbania* species with known or potential roles in agriculture.

TABLE 2.1
Chromosome numbers of some *Sesbania* species (after Char 1983)

Species	Gam.	Spor.	Authority
S. arborea (Rock) Deg. & Deg. (*S. tomentosa* f. *arborea* Rock)	12		Carr (1978)
S. benthamiana Dom.	12		Datta & Bagchi (1973)
S. bispinosa (Jacq.) Wight. (*S. aculeata* Pers.)	6,7,12	12,24	Jacob (1941), Haque(1946), Sampath (1947), Bir & Sidhu (1966, 1974), Baquar & Akhtar (1968), Dana & Datta (1960)
S. cannabina (Retz.) Poir.	6		Al-Mayah & Al-Shehbaz (1977)
S. coerulescens Harms	6,7		Datta *et al*. (1973)
S. cinerascens Welw. ex Baker	12		Gillett (1963), Lubis *et* al. (1981)
S. concolor Gillett	12		Baquar & Akhtar (1968)
S. drummondii (Rydb.) Cory	6		Turner (1955)
S. exaltata (Raf.) Cory (*S. macrocarpa* Muhlenb. ex Raf.	6		Atchison (1949), Turner (1955)
S. grandiflora (L.) Poir.	12	24	Jacob (1941), Haque (1946), Rao (1946), Sampath (1947), Tjio (1948), Lubis *et al*. (1981)
S. javanica Miquel		12	Lubis *et al*. (1981)
S. keniensis Gillett		12	Gillett (1963)
S. letocarpa DC.		12	Miege (1960)
S. marginata Benth.	6		Di Fulvio (1973)

S. microphylla Harms		6,12	Gillett (1963), Datta *et al.* (1973)
S. procumbens (Roxb.) Wight. & Arn.		12	Bhaskar & Devi (1976)
S. punicea (Cav.) Benth.		12	Covas & Schnack (1946)
S. quadrata Gillett		12	Gillett (1963)
S. sericea (Willd.) Link		24	Frahm-Leliveld (1953)
S. sesban (L.) Merr. (*S. aegyptiaca* Poir.)	6,7,8	12	Jacob (1941), Haque (1946), Sampath (1947), Baquar *et al.* (1965), Lubis *et al.* (1981), Bir *et al.* (1975), Sareen & Trehan (1979)
S. sesban var. *bicolor* (Wight. & Arn.) Andr.	6,7	12	Baquar & Akhtar (1968), Bir *et al.* (1975), Sareen & Trehan (1979)
S. sesban var. *nubica* Chiov.		12	Gillett (1963)
S. sesban var. *picta* Santapau	6,7,8, 14	12,14 16,28	Bir & Sidhu (1966) Bir *et al.* (1975)
S. sesban subsp. *punctata* (DC.) Gillett (*S. punctata* DC.)		12	Frahm-Leliveld (1953)
S. speciosa Taub.		12	Jacob (1941), Sampath (1947) Simmonds (1954), Datta & Sen (1960)
S. tetraptera Hochst. ex Baker		12	Senn (1938)
S. tomentosa H. & A.	12		Carr (1978)
S. vesicaria (Jacq.) Ell. (*Glottidium vesicarium* (Ell.) Rydb.	6		Turner (1955)

TABLE 2.2
Sesbania species with potential agricultural uses

Species	Origin or Range	Description	Reported Agricultural Uses	Comments
arborea	Hawaii, Oceania	perennial tree to 5 m high	browse, ornamental	One of a group of species endemic to Hawaii, possibly related to the South Pacific species *S. atollensis*. *S. arborea* is very drought tolerant.
bispinosa (aculeata)	Africa, Asia, Australia		see cannabina	
cannabina (roxburgii)	Africa, Asia, Australia, Oceania	annual to 4 m	green manure, fuelwood, poles, fodder, pulpwood, seed gums	A complex of closely related species including *S. cannabina*, S. *bispinosa*, *S. sericea*. Fast growing. These spp. have similar appearance and uses; provenances may vary in climatic and edaphic adaptability.

emerus	Central & South America	annual		More similar to cannabina than to exaltata.
exaltata	North America	annual	green manure	Very rapid growing and quick to set seed. Not as robust in form as cannabina types.
grandiflora	pan-tropical	perennial tree, white and pink flowered varieties	ruminant fodder; flowers, leaves, and pods as food; border-planted green leaf manure; fuelwood, pulpwood, live support for twining crops, shade, ornamental	Rapid early growth.
macrantha	Africa	large-seeded		Grew as an annual in in Hawaii; arboreal and presumably perennial forms reported in Africa.
pachycarpa	Africa	annual or short-lived perennial, larger seeded than most annuals	green manure	Some utilization in traditional African agriculture as a "helpful volunteer" in crop fields.

TABLE 2.2 (Continued)
Sesbania species with potential agricultural uses

Species	Origin or Range	Description	Reported Agricultural Uses	Comments
rostrata	Africa	annual to 4 m	green manure	Nodulation sites on stems and branches.
sericea	Africa, Caribbean		see cannabina	
sesban	Africa, Asia	perennial tree	shade, windbreak, ruminant fodder, green manure	A complex of sub-species and varieties. Fast growing, many-branched.
speciosa	Africa	annual, leaves pubescent	border-planted green leaf manure, poles	Introduced to Sri Lanka and S. India. Larger leaflets & flowers than most annuals.
tetraptera	Africa	annual		4-winged seed pods.

Figure 2.1 Sesbania grandiflora trees at a lowland site (less than 20 meters elevation) in Hawaii. The tallest tree in the group of 4-year-old trees is approximately 9 meters tall.

Figure 2.2 Sesbania sesban var. nubica at a lowland site in Hawaii. The tree is approximately 2 years old.

Figure 2.3 Sesbania arborea on the Island of Molokai, Hawaii (elevation about 200 meters). Cattle and axis deer often browse S. arborea in this very dry and wind-swept area. The site shown had been protected from cattle for several months.

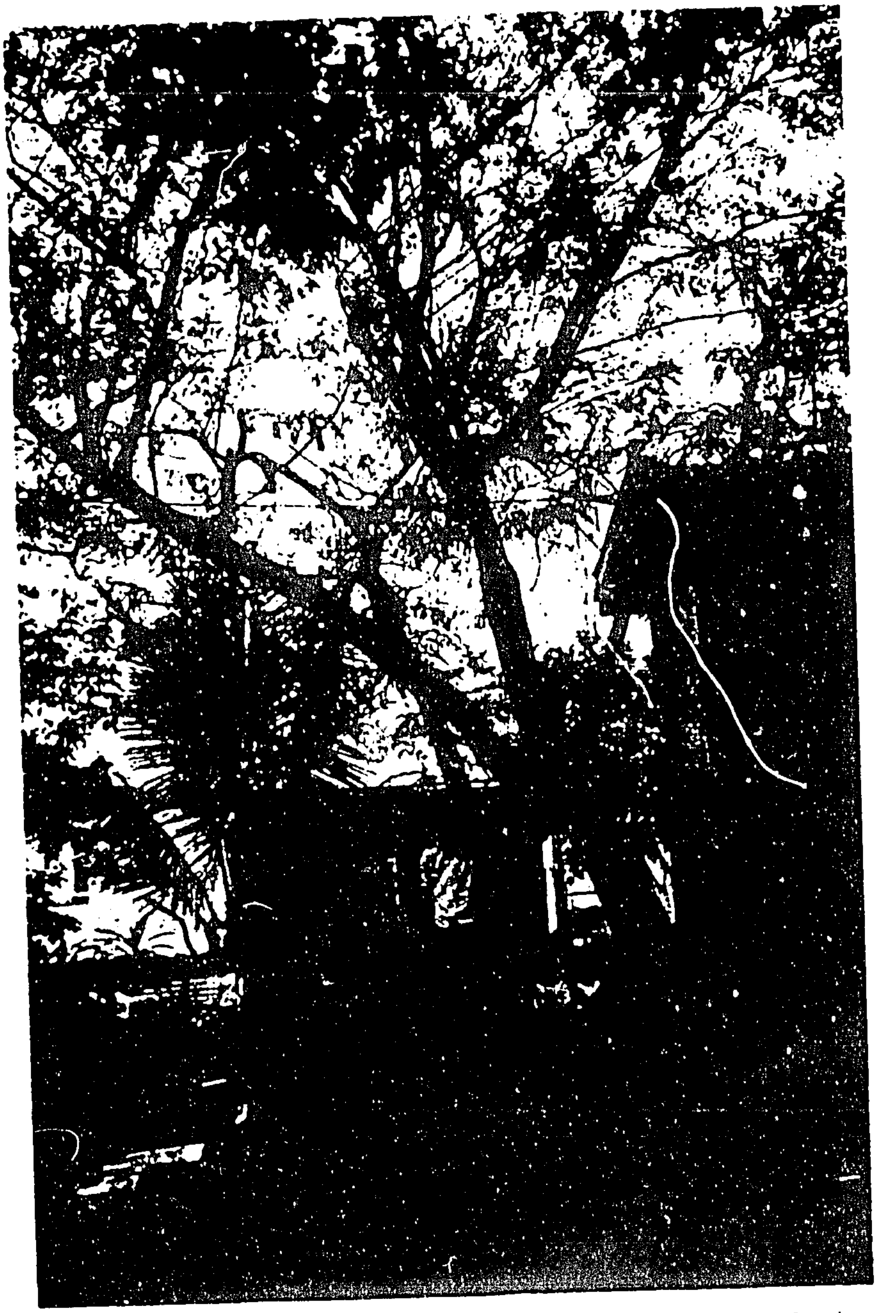

Figure 2.4 Sesbania sesban var. nubica at a lowland site (less than 20 m elevation) in Hawaii. Trunk diameter at 1 m above the ground is 25 cm. The tree is approximately 2.5 years old. At the time of the photograph, the leaf canopy had been reduced by recent storms with high winds. The upper branches had been frequently pruned with a pole saw for goat fodder. Tree height is about 6 m.

Figure 2.5 Line drawing of Sesbania grandiflora (after Ochse 1931; used with permission of A.V. Asher & Co. B.V., Amsterdam).

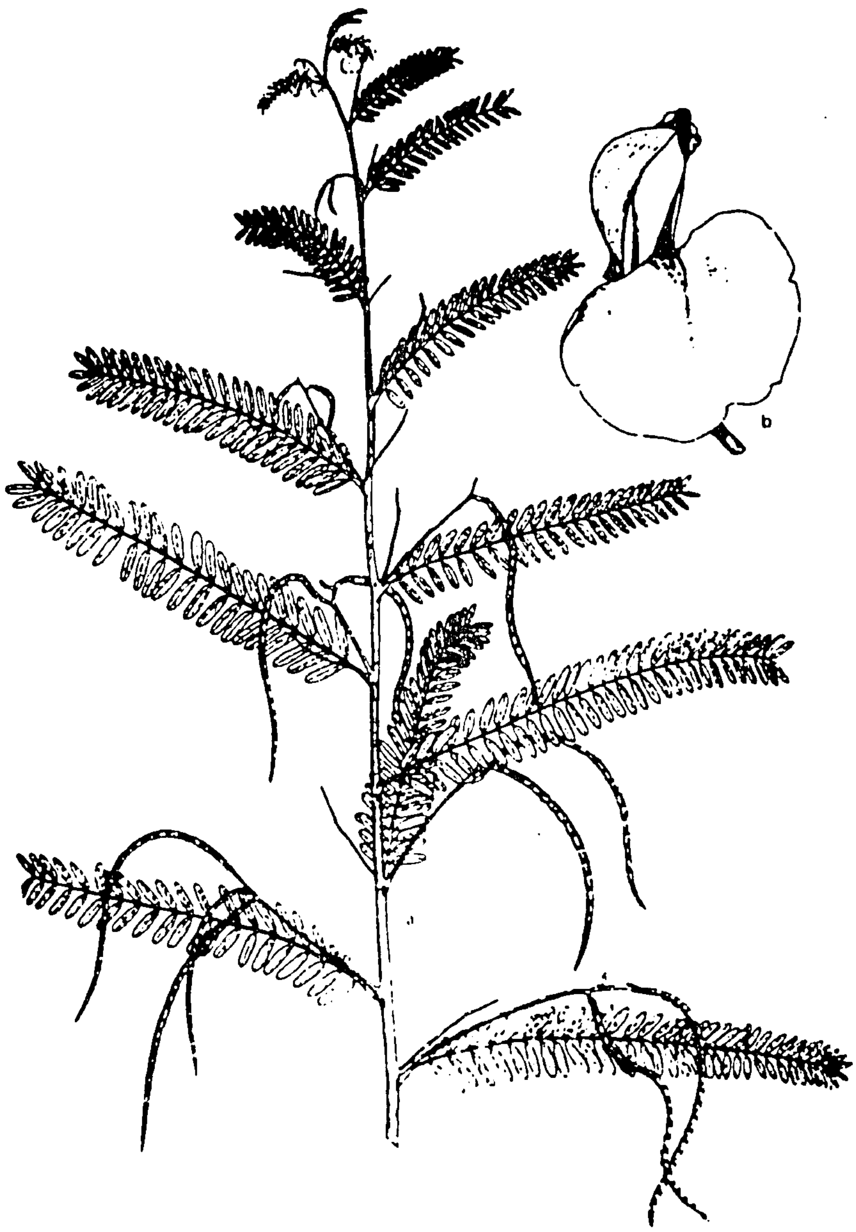

Figure 2.6 Line drawing of Sesbania macrocarpa (after Correll and Correll 1975).

Figure 2.7 Line drawing of Sesbania emerus (after White 1980; used with permission).

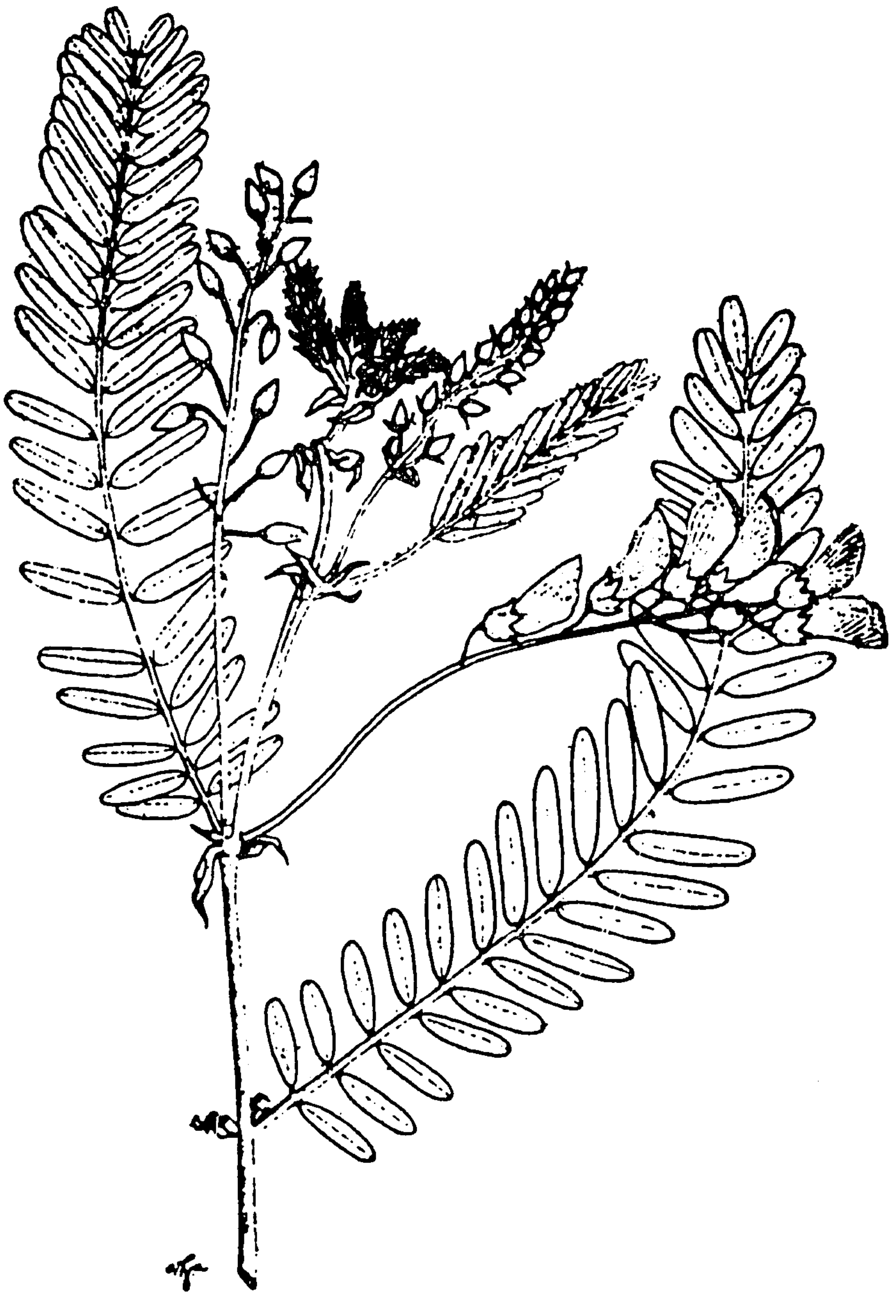

Figure 2.8 Line drawing of Sesbania speciosa (after Paul 1939).

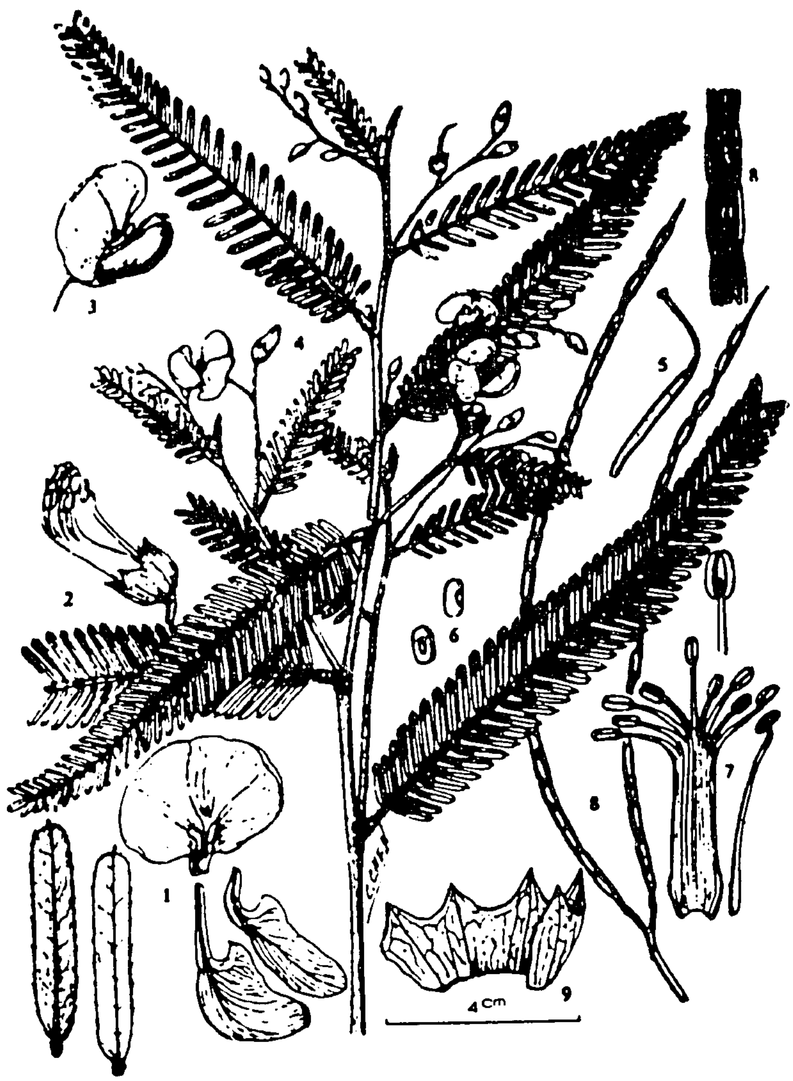

Figure 2.9 Line drawing of Sesbania cannabina (after Flora of Taiwan, v. 3 plate 643, Epoch Publishing Co., Ltd., Taipei, 1977; used with permission).

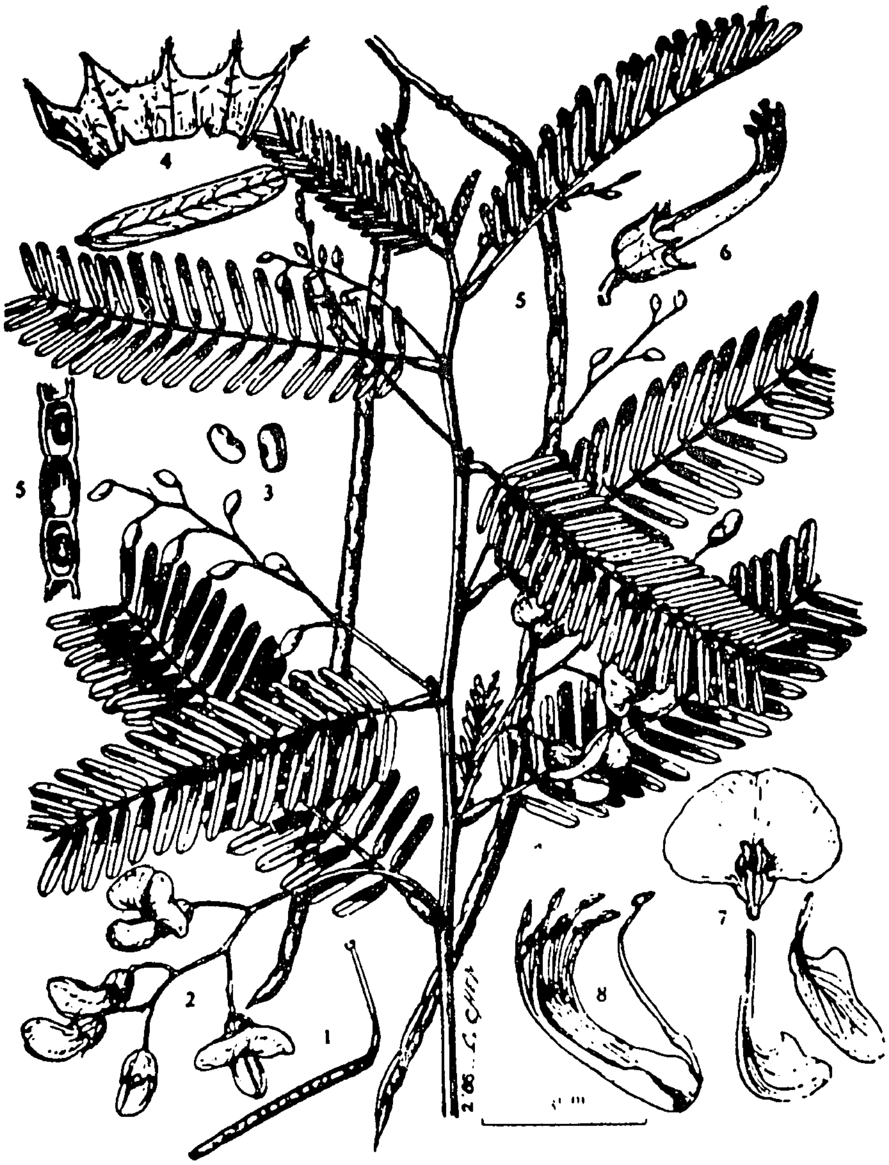

Figure 2.10 Line drawing of Sesbania sesban (after Flora of Taiwan, v. 3 plate 644, Epoch Publishing Co., Ltd., Taipei, 1977; used with permission).

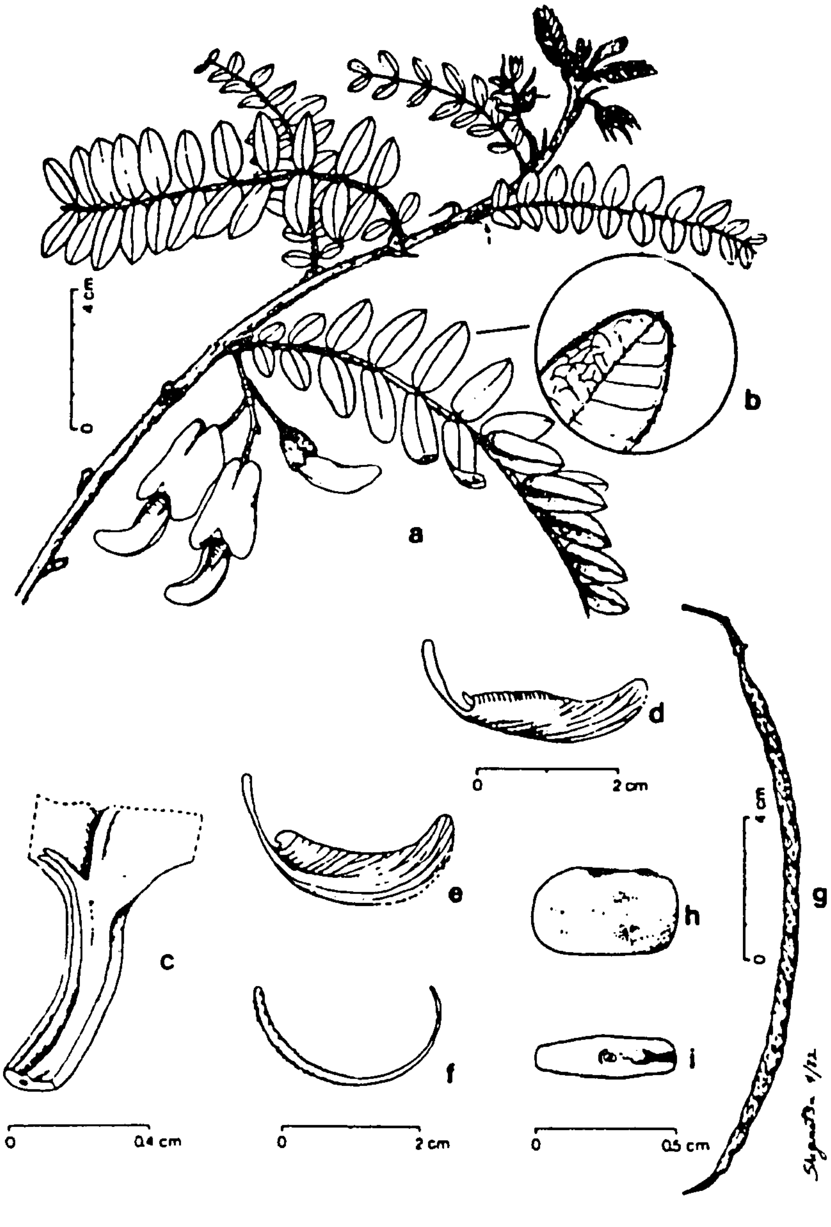

Figure 2.11 Line drawing of Sesbania sp. nova from Mana, Island of Kauai, Hawaii (after Char 1983; used with permission).

3 *Sesbania* Species as Green Manures for Rice

Green manuring has been practiced widely in Asia, where fields are often small but intensively managed. Many Asian cropping systems are based on rice cultivation. Because of the ability of Sesbania species to grow in heavy soils, withstand waterlogging and flooding, and tolerate soil salinity, they are often the preferred green manure crop for rice. "Dhaincha," the common name of the species used in India, is often designated as S. aculeata which was revised to S. bispinosa. The name S. cannabina is usually given for the annual sesbania used in China, and is occasionally given by Indian writers. Materials received under the names S. bispinosa, S. aculeata, S. cannabina, and S. sericea and evaluated in Hawaii were similar in morphology and agronomic characteristics. Herbarium specimens sent to the Royal Botanic Gardens at Kew, England, were all named as S. cannabina (G.P. Lewis, personal communication). The perennial S. sesban has been mentioned as a green manure crop and is also sometimes called dhaincha in India. Since there is no Asian taxonomy for Sesbania, the accuracy of nomenclature in many of the agricultural reports is suspect. In the following text we have usually used the scientific names as given by the authors of the works discussed, except that in most cases we have rendered S. aculeata as S. bispinosa, and "dhaincha" likewise.

As green manure, sesbanias are grown and plowed under in the same field in rotation with the crop to be benefited. They may also be used as green leaf manure: green matter cut and brought from elsewhere to the field for burial. Green leaf manure may be partitioned from the top growth of nearby green manure crops, or it may be from plants deliberately grown for green leaf manure production on field borders, paddy bunds, and miscellaneous areas.

The perennials S. sesban, S. grandiflora, and the annual S. speciosa are among the species often planted for use as green leaf manures.

Yields of Sesbania species given in Table 3.1 are mostly from crops grown experimentally as green manures. Few of the reports gave values for either dry matter or nitrogen content, and none mentioned plant populations. Lack of such data increases the difficulty of quantifying or estimating the contribution of green manures to following crops (Yost and Evans, in press). The average growth rate for the annual dhaincha (S. bispinosa) in Table 3.1 is 380 kg/ha per day fresh weight. This may be compared with results of Sesbania accession yield trials in Hawaii, where high yielding annuals had growth rates averaging 428 kg/ha per day fresh weight (Evans and Rotar, unpublished data). These accessions were mostly received as S. bispinosa, S. cannabina, or S. sericea. They were grown for 98 days at a population of 125,000 plants/ha. Dry matter yields of 25 high yielding accessions ranged from 8 to 17 Mg/ha (1 Mg = 1000kg), and nitrogen yields ranged from 150 to 245 kg/ha.

INTERCROPPED GREEN MANURES

Green manure legumes are sometimes intercropped as a method of economizing time and space in intensive cropping patterns. Techniques of and timing of interplanting S. cannabina for use as a green manure for rice have been developed in southern China (FAO 1977). S. cannabina is sown (70-90 kg/ha) in nursery plots having an area about 1/50th of the area to which they are later transplanted. Nursery plots are well fertilized with phosphate and organic manure (night soil or compost) and are sown in late March or early April, when temperatures are above 12^{o}C. When the sesbania plants are about 10 cm higher than the spring rice crop, which is already in the grain-filling stage, they are transplanted to the rice field in rows 2-3 m apart, spaced at about 30 cm within the rows. After the sesbanias have reached a height of 90-150 cm, they are topped to stimulate branching. The fields then receive an additional dressing of compost, and phosphorus is applied. Spring rice is harvested several weeks after transplanting the legumes. After an additional two weeks growth, the sesbania is incorporated into the soil along with 50-60 kg/ha ammonium sulfate, the fields are flooded, and in a few days the "late" rice crop is transplanted to the field. The practitioners claimed that green manuring in conjunction with mineral fertilizers not only increased yields but at the same time reduced the fertilizer N requirement of the rice crop.

Similar practices were taken up in North Viet Nam during the 1965-1970 period, as described by several authors in volume 27 (1971) of the English language publication, Vietnamese Studies. There, S. cannabina, or "dien than," was either transplanted as above or sown directly into the rice fields before harvest of the "fifth-month" rice crop in May. The legume was then incorporated during plowing operations in preparation for the summer crop to be harvested in October. In the Thanh Oai district, this method was used on one-third of the rice fields. In the Ngo Xuyen cooperative, various methods of utilizing sesbania were tried. Although sesbania was said to be easier to grow than azolla, the traditional green manure, its cultivation as an intercrop was thought to compete with rice (the timing and management were unspecified). The presence of woody taproots interfered with plowing and land preparation.

A variation on management of sesbania as an intercrop in rice in Viet Nam was reported by Nao (1979, 1983). Mounds were made at a spacing of 100 x 50 cm in between the lines of rice plants, with the tops of the mounds emerging from the water. From 3 to 5 sesbania seeds were sown in these hills about 6 weeks before harvest of the spring rice. An estimated 8-10 Mg/ha of fresh green manure were grown for incorporation before the second rice crop was transplanted in July. Alternatively, if a second rice crop was not grown, the sesbania was allowed to mature and was harvested for fuelwood in October, yielding approximately 15-20 Mg/ha of stems, 10 Mg/ha of roots, and 400 kg/ha of seed collected during maturation of the crop. This option had the advantage of providing a fuelwood crop if the rains were inadequate to support a second rice crop. In the area of the Red River delta where this method was developed, population densities are high and demands for locally available fuelwood made such an alternative attractive.

BORDER-PLANTED GREEN LEAF MANURES

Farmers in parts of South and Southeast Asia make use of field borders and miscellaneous areas to grow crops to provide green leaf manure. Sesbania species are particularly well adapted to border plantings in waterlogged conditions in rice and other lowland irrigated cropping

TABLE 3.1.
Reported yields of *Sesbania* species

Species	Growth Period	Yield	Growth Rate	N Content	Reference
		Fresh Weight			
	Days	Mg/ha	kg/ha/day	kg/ha	
bispinosa	--	24.8	--		Singh & Sinha 1962
"	52	14.3	280		Chandnani 1954
"	60	25.0	420	120	Khind 1982
"	75	28.7	380	104	IRRI 1963
"	75	37.4	500	122	"
"	84	25.5	300		Panse *et al.* 1965
"	98	25.9	260		"
"	98	28.6	290		"
"	102	38.7	380		"
"	102	58.8	580		"
"	60	10.7	180		"
"	75	34.3	460		"
"	--	16.5	--		Van de Goor 1954
"	--	12.6	--		"
"	--	23.4	--		"
"	--	14.9	--		"
"	74	20.0	270		Gaul *et al.* 1976
"	45	15.6	350		Khind *et al.* 1983
"	60	28.9	480		"
"	56	30.0	536		Katiyar 1969

sericea	84	26.8	320		Panse *et al.* 1965
microcarpa	75	17.5	230	88	IRRI 1963
macrocarpa	84	22.1	260		Anon. 1931
speciosa	119	46.8	390		Panse *et al.* 1965
"	75	15.7	210		"
"	84	25.5	300		"
"	60	40.3	671	87-136	Nair *et al.* 1957
"	120	56.0	467		Mudaliar 1954
"	240	96.8	403		"
sesban	75	51.5	687	202	IRRI 1963

systems. Their tolerance of salinity may also be an advantage in river deltas and where soils of bunds concentrate salts by evaporation. S. grandiflora is widely planted on larger permanent borders. Smaller bunds or waterway banks serving as subdivisions between fields may be removed and restructured during cropping cycles and thus are not appropriate for perennial species. In parts of Indonesia, however, S. grandiflora is managed on bunds as an annual (D. Ivory, personal communication). It is sown during development of one crop, allowed to put on growth during periods when its competition effects are not critical, and is pulled up and incorporated into the soil during field preparations for the crop to be sown during the next rainy cycle. S. grandiflora's rapid initial growth is well suited to such use.

S. speciosa, originally from Africa, has been extensively used for border plantings in India, particularly in Madras State (now the state of Tamil Nadu) (Chari 1957). Seed collected in Kenya was probably sent from England's Royal Botanic Gardens at Kew to Sri Lanka; from there it was introduced to Madras. Popularization of S. speciosa in Madras was achieved through vigorous extension efforts begun in Tanjore District in 1952. A massive campaign was created involving articles extolling the value of the crop in popular farming magazines (e.g. Chintamani 1954, Vedantam 1955, Rajagopalan and Pawar 1958). Tactics used to promote S. speciosa included support by government agricultural officials at many levels, creation of village agricultural associations, "farmer's day" demonstrations at experiment stations, slide shows in rural theaters, and government purchase of increased seed for redistribution (Ali 1959). Having demonstrated to themselves the efficacy of green leaf manuring with the plant in experiments in 1947-48, the officials began promoting S. speciosa with the distribution of about 140 kg of seed. By 1956, about 404,000 hectares in Tanjore were border-planted with S. speciosa as a result of these efforts (Randhawa et al. 1961).

S. speciosa seeds remain viable for long periods. One lot of 15-year-old seeds obtained by the authors from the USDA was still viable. Their seed coats are impermeable to water and scarification is required for germination. We found that seeds of this species required soaking in concentrated sulfuric acid for at least 40 minutes in order to get good germination and that 60-90 minutes were not detrimental. Hot water treatment of 10 minutes at 80°C was effective (Rao and Venkatesan 1965). They also obtained good germination by carefully pounding seeds mixed with sand. S. speciosa should be inoculated with the proper rhizobia when sown in any new area. The publications cited on its use in Madras did not mention inoculation or nodulation. The appropriate Rhizobium strains were probably present in that area. S. speciosa, in Hawaii, was not effectively nodulated by strains which effectively nodulated other sesbanias. This may explain the data given by Sahu (1965) for green leaf manures being compared in India's Orissa state, where S. speciosa leaf had only 2.24 percent N compared to S. bispinosa with 4.95 percent N.

Nurseries for S. speciosa should be kept from waterlogging during the first three weeks of seedling development as the plants are not yet adapted to this stress. Seedlings, at the time of transplanting, should be at least 30 days old and preferbly 45 days old. Two laborers could transplant, at close spacing, the border of a one hectare field in one day's time (Rao and Venkatesan 1965).

Yields of S. speciosa planted on borders are in the range of 2.24 to 6.72 Mg fresh material per hectare (Randhawa 1961, Rao 1965). Solid stands grown 3-5 months usually yielded more than 56 Mg/ha of fresh material; yields as high as 112 Mg/ha were reported (Randhawa et al. 1961).

RICE YIELD RESPONSES TO SESBANIA GREEN MANURE

Early estimates of the yield response of rice to green manuring may have been low because of the low yield potential of traditional varieties. Panse et al. (1965) suggested a plateau in yield response of rice to green leaf manure (GLM) applications in excess of 5.6 Mg/ha fresh material which, assuming 20 percent dry matter, would represent an application of approximately 35-55 kg/ha N. Recent research conducted using high yielding variety (HYV) rice in rotation with green manures indicates that the yield benefits of green manuring are sizeable.

Data of Dargan et al. (1975) (Figure 3.1) illustrate a fairly typical HYV rice yield response to inorganic N, with a tendency for yield increases to level off in the range of 80-120 kg/ha applied N. The amount of N contributed by the 67-day-old green manure crop was not estimated, but it produced a rice yield equivalent to that obtained from an application of 80 kg/ha of inorganic nitrogen fertilizer.

Bhardwaj et al. (1981) compared rice responses to green manures with and without added inorganic N (Figure

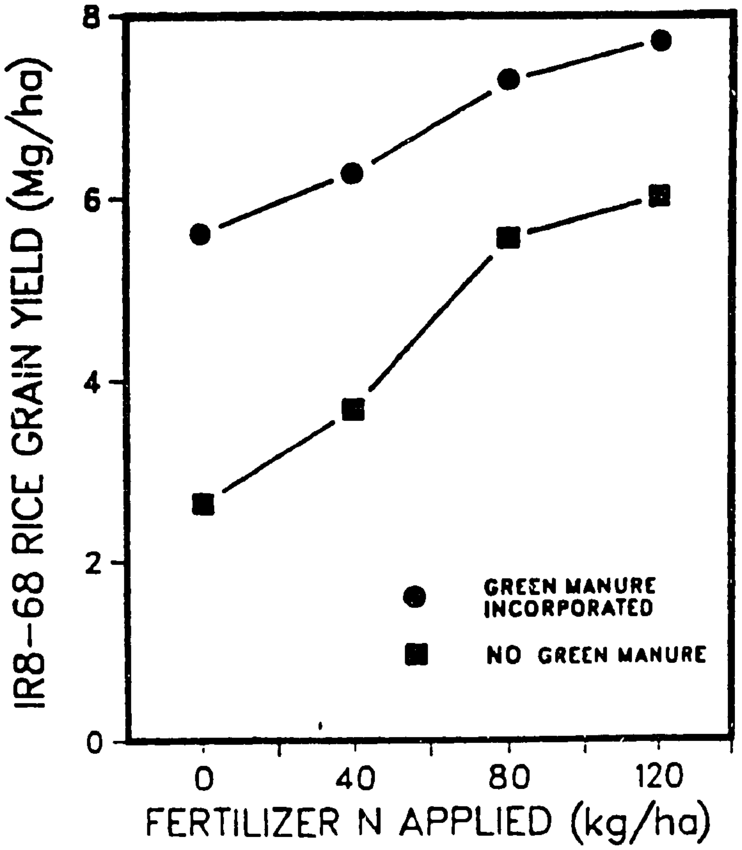

Figure 3.1 Rice yield response to Sesbania bispinosa green manure and to inorganic nitrogen fertilizer, both alone and in combination. Squares represent N fertilizer alone, circles represent green manure with or without N fertilizer (after Dargan et al. 1975).

3.2). Their data indicate a generally linear response to added N and a tendency for yields to level off at higher rates regardless of the N source; the response to green manuring was similar to 60-80 kg/ha fertilizer N. Data from Khind et al. (1982) (Figure 3.3) showed that green manures grown for two months were equivalent to 60-90 kg/ha inorganic N. These experiments illustrated that green manures could supply much if not all of the N needed for moderate to high yields of N-responsive rice varieties, and that a combination of green manure with inorganic N can be highly beneficial to following crops.

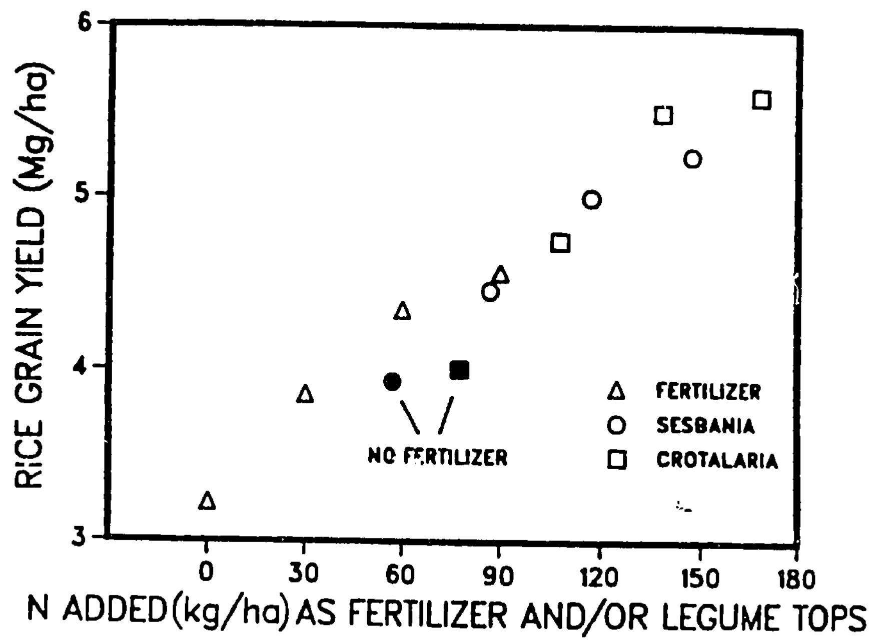

Figure 3.2 Rice yield response to inorganic fertilizer applications with or without a preceding Sesbania bispinosa or Crotalaria juncea green manure crop compared to green manuring alone (after Bhardwaj et al. 1981).

Timing is important when including green manures in crop sequences. N.T. Singh et al. (1981) found sharp increases in dry matter and N content of green manure legumes between the 5th and 7th weeks of growth. Data of Khind et al. (1983) (Figure 3.4) showed that S. bispinosa N content increased many-fold during the second month of growth (from 8 to 58 kg/ha), and then doubled again during the third month of growth. Subsequent upland rice yields increased with the growth duration of the preceding green manure crop. Rice yield response to green manure N was similar to the rice yield response to fertilizer N. In comparison with the nonfertilized control it appeared that the effect of the 30-day green manure crop involved more than just the N contribution of the tops. Bhardwaj and Dev (1985) showed that legume green matter yield increased linearly from 18 to 37 Mg/ha between the 45th and 65th day of crop growth, but N yield began to plateau after the 55th day. Rice grain yield after green manuring at all three growth stages was equivalent to rice receiving 100-120 kg/ha inorganic N.

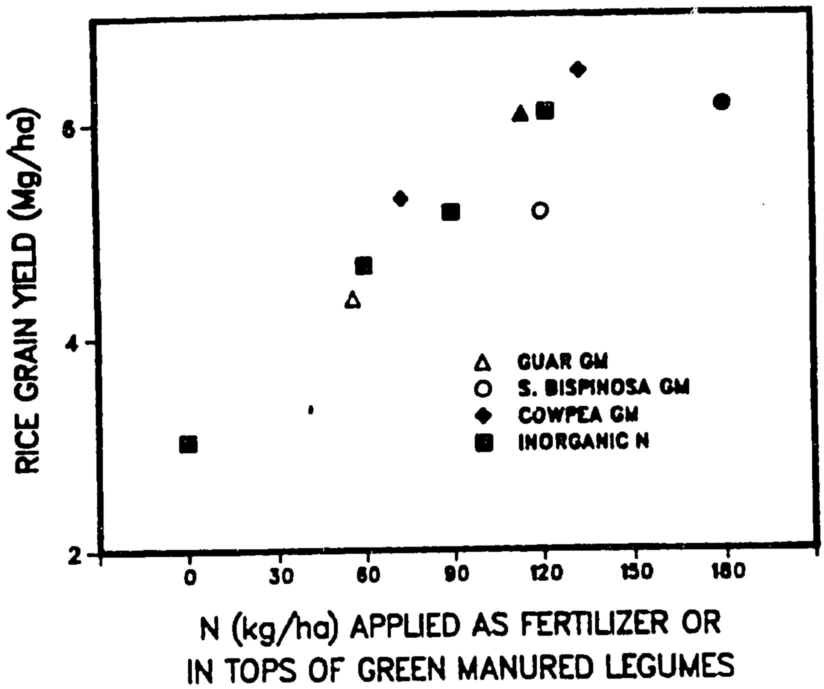

Figure 3.3 Rice yield response to inorganic N fertilizer and to green manures alone (open symbols) and supplemented with 60 kg/ha inorganic N fertilizer (solid symbols). Green manure crops were Sesbania bispinosa, Cyamopsis tetragonoloba (guar), and Vigna unguiculata (cowpea) (after Khind et al. 1982).

Proper timing of green manure incorporation in relation to planting the beneficiary crop is critical. Beri and Meelu (1979) compared inorganic N after fallow with S. bispinosa green manure incorporated 0, 10, or 20 days before transplanting rice, with or without supplemental N fertilizer (Figure 3.5). Where inorganic fertilizer was not applied, the beneficial effect of transplanting soon after incorporation of the green manure was evident. Supplementing the green manure with inorganic N masked the response to the rapidly released green manure N. Fertilizer N applications seemed wasted here; most N so added was probably lost from the system. Khind et al. (1985) incubated soils with added sesbania and found that ammonium N release peaked on the 14th day. Rice transplanted the day after incorporating 2-month-old sesbania (22 Mg/ha green matter containing 120 kg/ha N) yielded over 5 Mg/ha

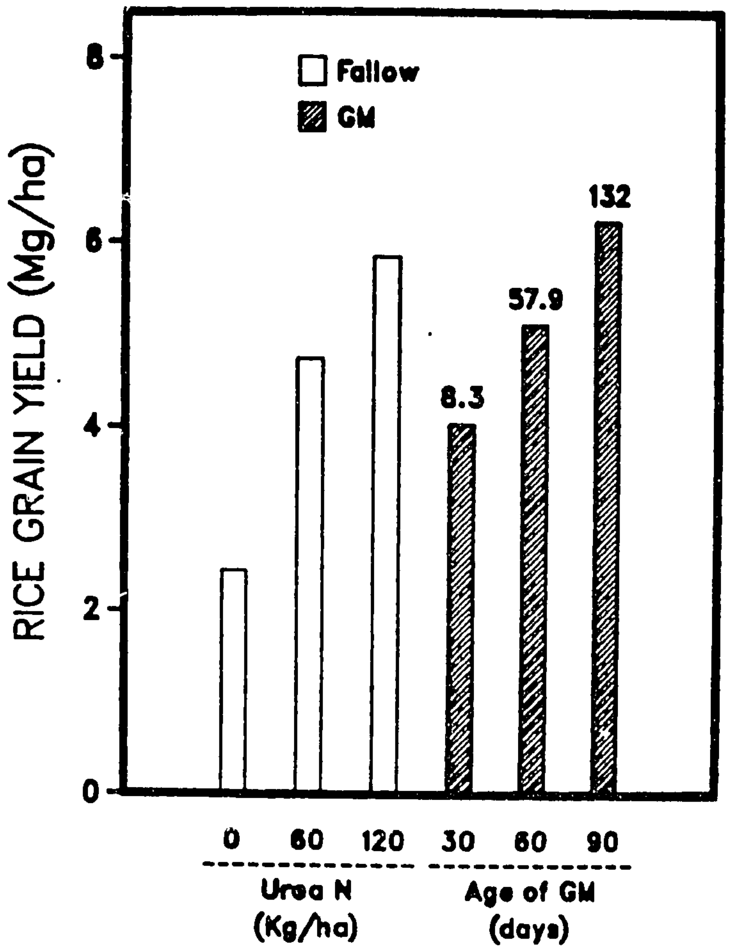

Figure 3.4 Yield of rice following S. bispinosa green manure (GM) grown for different durations before incorporation, compared with rice receiving inorganic nitrogen fertilizer after fallow. Values at the tops of the bars are the N contents of the legume above-ground growth, kg/ha (after Khind et al. 1983).

grain, the same as rice given 120 kg N as urea in equal parts at transplanting and at 21 and 42 days after transplanting.

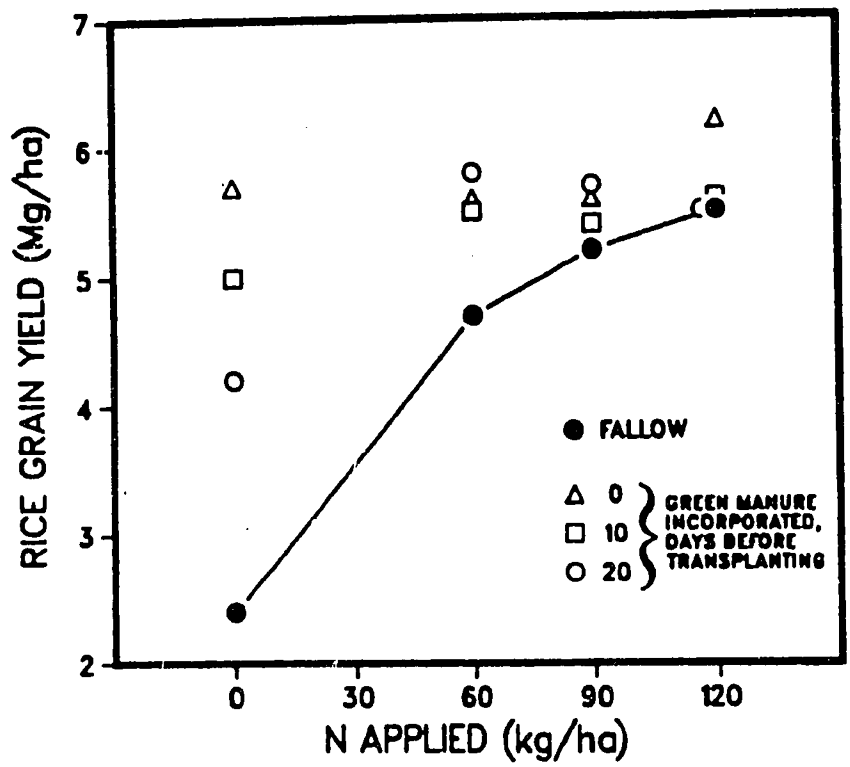

Figure 3.5 The effect on rice yield of various time intervals between the incorporation of Sesbania bispinosa green manure into the soil and the transplanting of rice. Green manuring is compared to fallow, and with and without supplemental inorganic nitrogen fertilizer (after Beri and Meelu 1979).

4
Sesbania Species as Green Manures for Upland Crops

Sesbania species have been used as green manures for crops other than rice. In Asia, they are often grown in rotations, between rice and wheat crops for example, but occasionally they are intercropped.

INTERCROPPED GREEN MANURES

In Taiwan, bananas are grown as an annual crop because of the seasonal damage from typhoon winds. Sesbania is sown in the interrows at the time of transplanting the banana cormels. Later, the legume top growth is cut and used as mulch around the developing pseudostems. The legumes provide weed control in the interrow zones in addition to their contributions as a green manure (M.L. Lin, personal communication).

Another intercropping use of sesbania is reported from the subtropical "terai" of Nepal (J. Peterson, personal communication). In ginger fields, the annual dhaincha is sown thickly (about 30 kg seed per hectare) shortly after planting the rhizome seed pieces. The young sesbania plants are progressively thinned from around the ginger plants and are used as mulch or pushed under the soil surface. This is done until single sesbania plants remain, spaced 2-3 m apart. These provide a light shade which is believed to result in desirable utilization qualities of the harvested ginger rhizome.

Sesbania species have also been intercropped with cereals. Van de Goor (1954) reviewed pre-World War II research in Java where a number of legumes including *S. bipinosa* and *S. sericea* were compared as intercrops. When intersown 6 weeks after sowing maize, legumes did not depress maize yields. In Bihar, India, S. bispinosa intersown 45 days after sowing maize and grown for 60 days before incorporation resulted in following wheat yield increases varying (with levels of P applied to the legume) from 22 to 38 percent over control (Shukla and Sinha 1970).

Singh and Sinha (1962) reported a series of experiments in which S. bispinosa and other species were sown simultaneously in the same row as maize and then incorporated for the following wheat crop. Their objective was to find a green manure which a) could be planted so as to not interfere with cultural practices, b) would require no more effort than that required to incorporate maize stubble prior to planting wheat, and c) would improve yields. Results of the first year's trial, shown in Table 4.1, indicate that S. bispinosa smothered the maize, although wheat yields were doubled. In later experiments, they concentrated on the slightly slower growing perennial S. punctata (a variant of S. sesban) and on Aeschynomene americana, legumes which competed less with the maize than did S. bispinosa.

GREEN MANURES FOR UPLAND FIELD CROPS

Much of the literature on green manuring (Evans et al. 1983) dates from periods in which traditional cereal varieties followed the green manure crop. During the last

TABLE 4.1
Yields of Sesbania, Crotalaria, and Aeschynomene green manure legumes intercropped with maize, and their effect on maize and following wheat yields (after Singh and Sinha 1962)

Legume Intercrop	Legume Fresh Yield	Maize Grain Yield	Wheat Grain Yield
		Mg/ha	
C. juncea	11.5	2.04	1.88
S. bispinosa	24.8	0.55	2.41
S. speciosa	2.3	2.30	1.34
A. americana	5.8	2.40	1.63
None (maize alone)		1.67	1.23
CD 0.05		1.05	0.48

few decades, introductions of high yielding varieties (HYVs) have increased cropping intensities, and the availability of inorganic N fertilizers has made fallow periods, legume rotations, or green manuring less mandatory, resulting in unfavorable declines in soil fertility and physical properties. Gill (1978) characterized the HYV rice-wheat rotation in the Punjab as "exhaustive," citing among other evidence that zinc applications had become routinely necessary. Gill stated that where rice was grown continuously, soil physical conditions deteriorated. Sowing S. bispinosa as a green manure in the period between the wheat harvest and rice transplanting was recommended. Smil (1984) reported that the deterioration of soil structure in China was due to intensified cereal cropping. Decreased sowing of legumes, less frequent green manuring, and use of crop residues for fuel rather than incorporating them into the soil were conditions associated with increased use of inorganic N and were implicated as causes of recent widespread occurrences of potassium and micronutrient deficiencies.

S. bispinosa has been used as a green manure for wheat in irrigated areas of northern India. In rainfed areas, consumptive water use by subsidiary crops in rotations will have a critical effect on available soil moisture for the main crop. Allan (1915) reviewed the effects of experimental green manuring on wheat crops between 1884 and 1903 in Maharashtra, India. He concluded that more than 90 cm of monsoon rainfall was needed in order to include the green manure crop. Moreover, from 25 to 40 cm of rain were needed between legume incorporation and planting of wheat to obtain yield increases due to green manuring in that system. Gaul et al. (1976), growing S. bispinosa for a 10-week period with different irrigation regimes, concluded that for North India summer conditions, 60-65 cm of irrigation water were required for a green manure crop grown between the harvest of wheat and the next rainy season crop. N.T. Singh et al. (1981), working in the same region, compared S. bispinosa, guar, and cowpea under irrigation regimes designed to create different levels of water deficit. Cowpea had the greatest efficiency in dry matter and N production per unit of water use, but was the most sensitive to yield reduction under drier soil water regimes, whereas dry matter yields of sesbania and guar were relatively constant. N content of the tops of these crops, grown for 7 weeks, increased with increasing water applied in the general range of 80 to 100 kg/ha N, with cowpea approaching 120 kg/ha N at the highest irrigation level.

Cumulative water use by the crops was lowest (29-36 cm) for cowpea and highest (32-38 cm) for sesbania.

Water use by green manure crops can sometimes reduce yields of following crops in rainfed areas. This competition limits use of green manures in semi-arid zones. In less restrictive situations, where irrigation water is available but limited, creative uses of green manure crops may improve upon existing practices. For example, mulching can reduce the irrigation water requirement of a potato crop by one half, from 360 mm to 180 mm; alternatively, under conditions of low water availability, mulching can double potato yields (P. van der Zaag, personal communication). Ordinarily, crop residues such as rice straw, rice hulls, or bagasse are used as mulch. If legumes were grown to provide this mulch, part of the water use by the legume would be transformed into a nitrogen input, increasing the value of that unit of water expense to the cropping system.

S. bispinosa has resulted in reasonable yield increases when used as a green manure for wheat. Chandnani (1954), comparing legumes grown for 7-8 weeks, found that sesbania increased grain yields 27 percent over control yields of 1.66 Mg/ha, compared to 36 percent with guar, and 35 percent with Crotalaria juncea. Ballal et al. (1968) showed that sesbania green manure grown for 6-7 weeks produced wheat grain yields 58 percent greater than the control (1.58 Mg/ha), and resulted in a greater increase in uptake of N and K by wheat compared to other green manure species tried. Singh and Sinha (1964) reported on a series of experiments comparing different sources of green leaf manure (GLM) with S. bispinosa green manure for wheat. GLM applications of 9.19 Mg/ha fresh material (using Glyricidia, Calotropis procera, Indigofera tinctora, or S. punctata) generally tripled wheat yields over control yields. They estimated that 0.25 ha of S. punctata (=S. sesban) would provide sufficient GLM for 1 ha of wheat, and that under local conditions applying GLM was more economical than growing a green manure crop. Singh and Sinha (1962) tripled wheat yields when S. bispinosa was grown as a green manure, compared to wheat following fallow.

GREEN MANURE USES IN THE NEW WORLD

Sesbania species have had only limited use in the New World compared to Asia. S. exaltata (formerly S. macrocarpa), an annual species native to North America, was used as a green manure crop in Arizona (Parker 1972) and was popular in Southern California (Pieters 1927, Anon. 1922). S. exaltata was used as a cover crop in citrus orchards and a green manure for winter truck crops in the Imperial and Cochilla valleys of California and the Yuma and Salt River valleys of Arizona. S. exaltata grows well in hot midsummer weather where humidity is low (USDA 1935, 1967). S. exaltata was a highly effective green manure crop when grown for a 6-8 week period during midsummer on cotton lands in lower California. Growers of cotton, lettuce, onions, and melons were at one time enthusiastically expanding areas sown to sesbania for its beneficial effects on the soil (Hodges 1930). Then, 12- to 14-inch (30-35 cm) moldboard plows were used to turn under the sesbania crop if the plants had only a few branches. A chain was useful to drag over and flatten thick stands, and discs were used to level the heaviest or much-branched stands before plowing.

Inda (1939) reviewed the uses of Sesbania species in southwestern USA and Mexico. Peregrina (1965), in Mexico, evaluated a Sesbania species as an intercrop in maize. De Datta (1981) mentioned that use of Sesbania in rotation with rice in Texas increased rice yields by more than 20 percent. In the western coastal state of Sinaloa in Mexico, S. exaltata (sometimes called S. sonorae) was used as a green manure on tomato-growing lands (Pieters 1927). Compared to cowpea, S. exaltata yielded more, required less cultivation to control weeds, and was less susceptible to pests when grown during the hot, summer rainy season. Pieters' informant stated that because sesbania fields could be flooded, weeds and a number of insect pests could be effectively controlled.

S. exaltata was mentioned among other summer legumes as a possible summer cover crop and green manure in USDA literature (Anon. 1935 and 1967), and specifically as a crop for date palm gardens (Anon. 1919). It was considered for the Columbia Basin in northwestern USA, but was rejected as not adapted to the cool night temperatures there (Morrison 1981). Throughout most of its range this species sets seed rather quickly and over a long period, flowering from March to October in Arizona (Parker 1972). Its potential to become a weed is almost certainly the reason why in some areas of the southwest it is no longer used for green manure. Seed dormancy caused by the high percentage of "hard seeds" contributed to the problem of containing the plant to its place in cropping sequences. Even if care was taken to plow under the crop before seed maturation, some of the original seed would remain in the field to germinate later unless appropriate scarification techniques had been performed to assure complete and uniform germination. Pieters (1927) mentioned that improper, delayed timing of plowdown operations resulted in the crop becoming woody. Poor timing could also result in incorporation of the crop after seed maturity. Parker stated that once it had been used as a cover crop in the Yuma region, it appeared in 70 percent of the cotton fields in the area. Its propensity to colonize ditch banks encourages the transmittal of seed along irrigation waterways.

Agronomic evaluations of S. exaltata in the New World are rare. Williams and Doneen (1960) used it as a summer green manure on a clay loam at El Centro in the Imperial Valley, California. They compared it with sudangrass green manure in an attempt to improve water infiltration. S. exaltata was still vegetative and 1.25 m high when incorporated in mid-August after 52 days growth. Average dry matter yield over two seasons was 3.43 Mg/ha (2.86 percent N). Williams (personal communication), using the nonlegume as a comparison, calculated that the sesbania fixed an average of 65 kg/ha N each season. Using sesbania as green manure in the first and third summers of the experiment did not improve infiltration, but using the nonlegume in all three years did. The authors did not report the effects of the green manures on the subsequent crop, sugar beets. G.F. Worker, Jr. (personal communication) commented that the N contribution of sesbania had no observable effect on sugar beet yields.

Matlock and Aepli (1948), found that barley yields over a 5-year period were improved by sesbania (presumably S. exaltata) green manure at Mesa, Arizona. Sesbania was slightly more effective than Vigna aconitifolia, Crotalaria juncea, and V. unguiculata green manures, producing barley yields one-third greater than the control. In that environment, however, it appeared that Cyamopsis tetragonoloba (guar) was superior, increasing barley yields 58 percent over the control. In California, guar had been shown to yield more than S. exaltata, with a fresh yield of 32.1 Mg/ha compared to sesbania's 27.6 Mg/ha for 52-day summer crops on heavy soils in the Imperial Valley (Anon. 1931).

Day and Ludeke (1981) evaluated S. exaltata for growth on desert soil compared with copper mine overburden, overburden plus tailings, and tailings. Sesbania and blue lupin (Lupinus hirsutus) grew equally well, but best growth was obtained with alfalfa (Medicago sativa). S. exaltata was also studied in Florida, USA, particularly in regard to its status as a host for nematodes (see Chapter 13). Overman (1969) observed that chrysanthemum yields were improved by a preceding crop of _S. exaltata_, but only when the soil had been fumigated to control nematodes before sowing the legume. In the absence of fumigation, another legume, _Desmodium tortuosum_, had a greater effect on yields. Soffes _et al._ (1980), testing summer cover crops on a fine sand soil in a crop rotation scheme, reported very low yields of sesbania. This was due to severe nematode infestation and a resulting inability to compete with weeds. Similarly low yield and N content data were reported from the same research program in Florida by Prine and Mislevy (1983). However, Soffes (personal communication) concluded that the species has potential as a green manure for wet soil sites in Florida. Despite a history of use as a green manure and seed availability from seed companies in the Southwest, use of _S. exaltata_ as a green manure is probably almost nonexistent at present in the USA.

Observations of _S. exaltata_ in Hawaii indicated that the plant is thinner-stemmed than its Asian counterpart _S. cannabina_, or _S. bispinosa_. Yields of vegetative material were limited by _S. exaltata_'s early flowering habit under Hawaii conditions (Evans and Rotar, unpublished data). The very rapid initial growth of this plant may be of advantage where time for a green manure crop in a rotation is limited.

5
Edaphic Tolerances of *Sesbania* Species and Their Use for Soil Reclamation

Plants which are able to colonize problem soil sites caused by excess or deficiency of soil elements are important in stabilizing and reclaiming such lands. The ability of *Sesbania* species to grow in a wide range of soil conditions has resulted in an expanded range of adaptability and utility compared to many other legumes.

Disturbed land areas created by mining have been sites for trial use of sesbanias in land reclamation. In Western Australia, a *Sesbania* species was found useful for stabilizing lands affected by iron ore mining (Martinick and Atkins, no date). In Arizona, USA, *S. exaltata* was evaluated on desert soils altered by additions of copper mine overburden, tailings, or their combination, and was found to grow well, but not as well as *Medicago sativa* (Day and Ludeke 1981).

Sesbania species are recognized as tolerating soil salinity and alkalinity, flooding, and soil waterlogging; there are indications that some species grow well in acid soil conditions. Relatively less is known about the climatic tolerances of *Sesbania* species than about their edaphic tolerances. We have not found reports of frost tolerance, and the extent of their ability to grow under cool temperature is uncertain. Best growth is often obtained in summer months, and annuals such as *S. exaltata* and *S. bispinosa* grow rapidly during extremely hot summer weather. The perennial *S. grandiflora* appears to be a tree of the lowland tropics. The altitudinal limits of *S. sesban* are not established. Little is known about drought tolerance. Abundant water is favorable to early growth; however, there is evidence that many species can continue to grow well under subsequent, increasingly dry conditions. The Hawaiian *S. arborea* grows under seasonally very dry conditions on the island of Molokai.

SESBANIA SPECIES AS GREEN MANURES FOR SALT-AFFECTED SOILS.

Sesbania species have been used for the reclamation of problem soils containing excessive levels of soluble salts (saline soils) and exchangeable sodium (sodic soils), or their combinations, such that growth of most crops is inhibited. S. bispinosa is extensively grown on such soils in India. Soils with these combined properties are often termed saline-alkali soils, having an exchangeable sodium percentage (ESP) greater than 15 and electrical conductivity of the saturation extract (EC_e) greater than 4 mmhos per cm. The soil reaction is often moderately to strongly alkaline. In more recent terminology, these soils are identified as saline-sodic soils. In the following, we will generally employ the terminology given by the authors cited.

Green manure crops are of particular value in providing organic matter to soils having impeded drainage, very thin organic soil horizons, and poor soil structure; these conditions are common in saline-alkali soils. There are 2.5 million hectares of salt-affected soils in the Indo-Gangetic Plains of northern India, (Abrol and Bhumbla 1979); the use of S. bispinosa as a green manure is considered an effective element of soil reclamation strategies. These strategies include soil leveling, applications of gypsum to provide sulfate anions for acidification and calcium (Ca) cations to displace sodium (Na) on the soil exchange complex, leaching with irrigation water to move displaced sodium ions down through the soil profile, and growing salt tolerant crops (Uppal 1961, Agarwal and Gupta 1968, Abrol et al. 1973, Mehta 1983).

The value of using S. bispinosa in crop rotations on saline and alkali soils has been stressed in articles in popular magazines directed to Indian farmers (Srivastava et al. 1973, Dargan et al. 1975, Thind et al. 1979). S. bispinosa is known in India as "dhaincha" and is often identified as S. aculeata. (In the following discussions, "sesbania" will refer to S. bispinosa. As discussed elsewhere, the distinction between cultivars of S. bispinosa and S. cannabina is unclear.) Agarwal (1957) advised farmers that rice yield increases of 37 percent could be obtained using green manure, of 97 percent using gypsum, and of 173 percent using both combined. Upadhyay and Singh (1976) observed that low yields of grain crops in the first year of a reclamation program were improved considerably in the second year after growing a sesbania green manure crop. Dargan et al. (1975) showed that on an alkali soil (pH 9.2) sesbania green manure was equivalent to application of 80 kg/ha N, increasing rice yields by 50 percent over rice following a fallow period. Shirwal and Deshpande (1977) demonstrated that fertilizers alone could not solve problems brought about by soil salinity. Rice given only N-P-K yielded 0.92 Mg/ha, but when soils were reclaimed with 2.5 Mg/ha gypsum and green manuring with sesbania, yields increased to 3.75 Mg/ha. Mathur et al. (1973) reported significant rice yield increases resulting from green manuring saline-alkali soils in Rajasthan. It is not known exactly how extensively S. bispinosa is used as a result of these promotions. Chela and Brar (1973) visited villages in the Ferozepur district of Punjab state and observed that the crop was used on half of the total cropped area.

Added organic matter is important to reclamation of saline and alkali soils. Misra (1976), using sesbania green manure or powdered Argemone mexicana leaf, rice straw or farmyard manure (FYM) incorporated at 5.6 Mg/ha, or gypsum at 12 Mg/ha on a saline-sodic soil increased rice yields by 57, 70, 49, 53, and 23 percent, respectively. These results indicated that gypsum alone is sometimes not as effective as organic matter. Ballal et al. (1968) reported that green manures (Sesbania spp., Crotalaria juncea, Vigna spp.) grown in a soil having pH 8.5 resulted in following wheat yield increases averaging 47 percent over controls not green manured.

Frequently, however, combinations of organic matter and gypsum provided the best amendments. Mendiratta et al. (1972) reported results of a factorial experiment with gypsum, FYM, and sesbania green manure. Wheat yields were higher with the three-treatment combination than with any single- or two-treatment combination. Jauhari and Verma (1981) described the reclamation of a soil judged "practically nonproductive" using gypsum (8.5 Mg/ha) or pyrite (6.5 Mg/ha), paddy straw, and sesbania green manure. Rice given adequate N-P-K-Zn fertilizer yielded 0.7 Mg/ha grain in the first year of reclamation and 3.13 Mg/ha in the second year. Lignite fly ash is another possible soil amendment; in a pot experiment it proved as effective as gypsum in lowering soil pH and increasing rice yields. Sesbania green leaf manure alone or in combination with the ash significantly increased yields (Mahalingam 1973).

Sulfur has been shown to be an effective alternative to gypsum on a calcareous saline-alkali soil. The greatest soil improvement and increases in wheat yields were associated with combinations of sulfur applications and sesbania green manuring (Somani and Saxena 1981). Press mud, a byproduct of sugar manufacture, is another organic amendment which has been shown to be of value when applied alone or in combination with sesbania green manure (Shetty 1975, Dhawan et al. 1961).

Physical site preparations are important in saline and alkali soil reclamation. Leveling provides for even leaching and eliminates ponding. In lands with high water tables and which are subject to waterlogging, trenching may be effective to encourage drainage. Such methods combined with deep plowing and S. sesban as green manure were recommended for preparing lands for reforestation with fast growing trees less tolerant of salts and waterlogging (Sheikh 1974).

Leaching is an important element of reclamation. Dhawan et al. (1961) described an effort on a "white alkali" soil (NaCl- and Na_2SO_4-dominated) and a "black alkali" soil (Na_2CO_3-dominated), both approximately pH 10. From 45 to 60 cm of water were applied in 5-7 weekly irrigations before transplanting rice, which received an additional 75 cm of irrigation water and 38 cm of monsoon rainfall during its growth period. The authors pointed out that where initial soil conditions did not permit vigorous growth of a green manure crop, green leaf manure could be brought from nearby. In their experiment, various green leaf manure application rates beginning at 4.5 Mg/ha fresh material were compared or combined with farmyard manure, press mud, or distillery waste (pH 4.5 to 4.9).

BENEFICIAL EFFECTS OF SESBANIA GREEN MANURE

A Sesbania species was used for saline-soil reclamation in coastal areas of the Chinese province of Liaoning, about 40° north latitude (Jen et al. 1965; Anon. 1966). The dense plant cover reduced soil water evaporation, preventing the upward movement of salts and their concentration at the soil surface. The green manure crop was observed to increase soil porosity; the added organic matter promoted soil aggregation. Williams and Doneen (1960) grew S. exaltata to improve water infiltration rates in soils of California's Imperial Valley, but found that it was not as effective as sudangrass. Compared to these few non-Indian references, research reported on soil reclamation in India is voluminous, which is not surprising considering the extent of irrigated land area in India and the agricultural importance of alluvial and problem soils in the Indo-Ganges region.

High levels of sodium in soils depresses carbon mineralization and formation of organic matter by depressing the cellulolytic fungal and bacterial populations active in this process. CO_2 evolution and the formation of stable endproduct organic matter constituents such as humins and humic and fulvic acids are reduced, with a resulting decrease in the solubilization of $CaCO_3$ (Malik and Farooq 1979, Malik and Sandhu 1973, Malik and Haider 1977). N-mineralization during decomposition was reduced under saline and alkaline conditions (Singh and Rai 1975). Increasing salinity increased ammonia volatilization and loss when N-rich soil amendments such as green manures were incorporated into soils (Malik and Farooq 1979, Venkatakrishnan 1980). The latter author compared sodic and reclaimed soils incubated with added sesbania material and found extensive N volatilization from the sodic soil between the 2nd and 9th (final) week of the experiment. It is possible that under field conditions, in the presence of rice roots, such losses would be reduced.

Although losses of N from low C:N ratio materials may be greater than from high C:N materials, the former were shown to be more effective in reducing exchangeable sodium percentage (ESP) in a calcareous sodic soil (N.T. Singh 1974). Sesbania plant material reduced an initial ESP of 91 by 36 percent to 58 over a 10-week incubation period, whereas barley straw only resulted in a 10 percent reduction.

Somani and Saxena (1981) monitored microbial populations in a field experiment comparing gypsum and sulfur with or without organic matter amendments in a calcareous saline-alkali soil. They found that total microflora counts increased to a greater extent when sesbania green leaf manure was added than when farmyard manure, poultry manure, or rice husks were used. They attributed this to the rapid decomposition and high Ca content of the legume. The combination of sesbania and sulfur produced the greatest improvement in soil properties; the effects of the two amendments were additive.

Both green manuring and gypsum favorably affect saline-alkali soil structure and therefore the soil's hydraulic conductivity, resulting in leaching of displaced sodium ions into deeper soil layers (Yadav and Agarwal 1959). Where plant roots were present, their CO_2 secretions enhanced the dissolution of calcium salts and the displacement of sodium with divalent ions (Kanwar et al. 1965). Yadav and Agarwal (1961) compared the effects of gypsum and sesbania green manuring. Their data showed the complimentary effects of the two amendments, the former facilitating base exchange reactions and the latter improving physical characteristics. The effects were more apparent after the second year, with the increasing soil N and organic matter.

Uppal (1955) found that stem and leaf juices of sesbania seedlings were quite acidic, with a pH about 4.0 during the first few weeks of growth, later rising to 7.0 after 10 weeks of growth. The implication of these results is that younger sesbania crops may be especially effective in reducing soil pH when green manured; however, we have not seen reports on such research.

SESBANIA SPECIES' TOLERANCE OF SALINE AND ALKALINE CONDITIONS

Many Sesbania species are tolerant of saline and alkaline conditions. Gillett (1963) observed that African species were segregated in habitat according to the degree of salinity in the edaphic environment. This tolerance may be related to water requirement; species with greater adaptation to drought might be expected to encounter increasing salinity as soils dry out or as seasonal surface waters evaporate. Gillett reported that some species (S. sesban, S. keniensis) grow best along running streams, while others inhabit margins of slightly saline lakes (S. goetzii) or seasonally flooded shallow pans, and are found growing within distinct zones of salt gradients (S. somalensis).

In Hawaii, most endemic Sesbania species are halophytes, growing in sand dunes and coraline soils very near the seacoast, often where they constantly receive salt spray. Char (1983) observed that populations of the endangered S. manaensis growing in the margins of a pond declined after a man-made disturbance reduced the salinity of the pond. Observations by Char and Gillett suggested that some sesbanias may be obligate halophytes, while others such as S. sesban and S. bispinosa may owe their wide distribution to a facultative tolerance of saline and alkaline conditions.

Alkali soil reclamation in India involves chemical and physical soil amendments and the growth of salt tolerant crops. Rice is frequently a pioneer crop in these situations. It is shallow rooted and can be grown with only shallow, preliminary leaching of salts; it is transplanted with a root system already developed in more favorable soil environments in nurseries. Six-week-old rice seedlings can tolerate electrical conductivities of up to 14 mmhos/cm (Dahiya et al. 1981). Continued leaching during the growth of a rice crop may allow for more deeply rooting crops such as wheat, barley, sesbania, and berseem clover (Trifolium alexandrinum) to be subsequently sown. Sesbania, like rice, may be transplanted to avoid salt sensitivity in the seedling stage; afterwards, a pH in excess of 9.5 can be tolerated (Uppal 1955).

Singh and Rai (1972 a, b, c, 1973, 1974) studied effects of salinity and alkalinity on a number of legumes including S. bispinosa and Melilotus alba. Increased levels of alkalinity and salinity resulted in decreased germination percentage, root growth, shoot growth, nodulation, and nitrogen fixation. Plant respiration increased with increasing levels of sodium. Alkaline conditions were more detrimental to growth parameters than were saline conditions, and were less amenable to amelioration by applications of phosphate fertilizer. Gill (1979) reported that soil alkalinity adversely affected plant growth in S. bispinosa. Sesbania resistance compared to cowpea was associated with its higher protein content. Although it is a salt- and alkaline-tolerant legume, perhaps more so than M. alba, S. bispinosa is less tolerant than grasses such as Diplachne fusca (Malik 1978) or Brachiaria mutica. Bajwa and Bhumbla (1971, 1974) compared the latter with S. bispinosa and found the grass to be relatively sodium-tolerant, the legume relatively sensitive. The grass, having a low root cation exchange capacity (CEC), absorbed Na in excess of Ca, while the legume had a high root CEC and absorbed more Ca than Na. From growth responses in soil with adjusted ESP, they determined that 50 percent yield reduction occurred at ESP 55 for B. mutica and at ESP 37 for S. bispinosa. In severe situations sesbania may require some soil amendment before it can be grown. For example, Abrol and Bhumbla (1971) obtained low yields (2.08 Mg/ha fresh material) of dhaincha on a nonamended saline sodic soil, but with gypsum applications of 7.5 or 15 Mg/ha, legume yields increased to 16.12 and 17.44 Mg/ha, respectively.

The soils of experiments reviewed above where positive responses to green manuring with sesbania were obtained had pH's in the range of 8.5 to 10. Khan and Awan (1967) analyzed soils from a farm in Pakistan where a S. bispinosa crop was either luxuriant, patchy, or had failed. Total soluble salts in the surface 23 cm soil horizon were 0.43, 1.39, and 3.15 percent, respectively. The higher salt levels were enriched in NaCl and Na_2SO_4. Jen et al.

(1965) reported that S. sesban tolerated salt concentrations from 0.42 to 1.04 percent in the seedling stage, and from 0.92 to 1.39 percent as it reached maturity. Dutt et al. (1983) reported that S. sesban seedling growth almost doubled when an alkaline soil pH was reduced from 8.4 to 7.9 by sulfur application. Ahmad and Niazi (1977) reported that S. sesban was less tolerant of saline irrigation water (3.5 g/l salts) than Cyamopsis tetragonoloba. Sinha (1982) reported that S. sesban seed germination was inversely related to increasing salinity, alkalinity, and water stress. He stated that a germination response from 20 to 56 percent was moderately good when obtained under conditions other than extreme water stress (greater than -10 bars) or high alkalinity (greater than pH 9.5). S. sesban's germination is satisfactory in an adjusted range of soil EC_e from 1 to 8 mmhos/cm (Arshad and Hussain 1984). These authors reported that germination of S. bispinosa was reduced to 60 percent at EC_e 10, to 33 percent at EC_e 20, and to 25 percent at EC_e 30 mmhos/cm (Hussain and Arshad 1984).

Many previous salinity tolerance studies with Sesbania have been made with South Asian species, but Hansen and Munns (1985) screened eight species of various origins including Africa and South America as well as India. They transferred 2-week-old seedlings to solution culture (pH 6.5) adjusted to range from 1 to 200 millimoles/liter (mM) NaCl, then harvested the plants 25 days later. Although S. sesban var. sesban had some mortality at the highest level, only S. pachycarpa failed to survive at that level. Shoot weight, in general, at 200 mM NaCl, was reduced to about 25 to 33 percent of the control. In the range up to 100 mM, yield declined somewhat but NaCl tolerance was clearly evident for all entries except S. pachycarpa.

Other species tested included S. bispinosa, S. rostrata, S. grandiflora, S. emerus, S. exasperata, and S. sesban var. nubica. S. grandiflora showed no shoot weight reduction in the range from 1 to 100 mM NaCl, and had higher yield at 50 mM NaCl than at 1 mM, indicating a halophytic response. In Western Samoa, S. grandiflora was observed to grow well in drained margins of mangrove swamps with soil pH 7.6 (W. Cable, personal communication).

S. exaltata in North America has been considered a salt-tolerant crop and was indicated as slightly more tolerant than Medicago sativa, but less tolerant than Trifolium alexandrinum at high EC_e. Yield reductions of 50 percent by S. exaltata were associated with EC_e=10 mmhos/cm, while maximum yields could be obtained at EC_e=2.3

mmhos/cm (Maas and Hoffman 1977; Ayers 1977). Some EC_e values for maximum yields and 50 percent reductions for selected crops are illustrated in Figure 5.1. Good germination and early seedling growth for barley and wheat required EC_e below 4-8 mmhos/cm (Ayers 1977). S. exaltata yield responded significantly to the acidification of alkaline (pH 8.3) irrigation water with sulfuric acid on a calcareous soil (Christensen and Lyerly 1954).

A number of experiments on S. bispinosa's yield and nutrient uptake in response to varying soil ESP (exchangeable sodium percentage) and rates and types of soil amendments were reported by Poonia and Bhumbla (1972, 1974a) at Hissar, Haryana State, in northern India. They reported that sesbania's dry matter yield decreased considerably below that of maize as soil ESP increased over the range from 2 to 77 percent. Increasing ESP increased plant Na content and decreased plant Ca content. Sesbania was able to take up as much as 31 percent of Ca applied as gypsum, compared to 17 percent for maize. Increasing rates of gypsum (2, 4, 6, and 8 me/100 g saline-sodic soil) and of farmyard manure (3, 6, or 9 percent dry matter basis) were found to increase S. bispinosa's dry matter yield (Poonia and Bhumbla 1973b and c). Gypsum was shown to be superior to $CaCO_3$ as a Ca source for sesbania at varying soil ESP. Labeled Ca uptake from $CaCO_3$ decreased with increasing ESP,

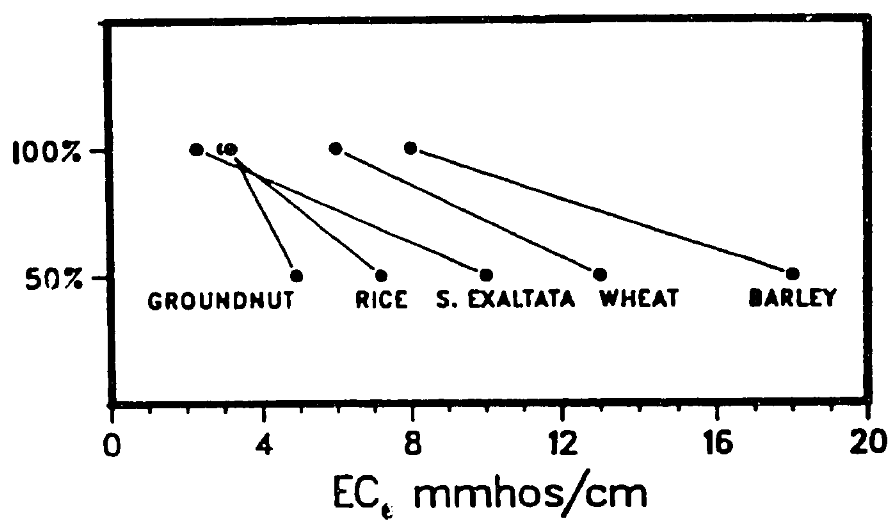

Figure 5.1 Salt sensitivity of selected crops (adapted from Ayers 1977).

but uptake from gypsum did not decrease. Sesbania took up from 19 to 25 percent of the applied Ca from gypsum, but only about 5 percent from $CaCO_3$ (Bhumbla and Poonia 1973). Farmyard manure was not effective in enhancing Ca uptake from $CaCO_3$ (Poonia and Bhumbla 1973c). Similar results were obtained with a non-saline alkali soil given either $CaCO_3$ or gypsum from 25 to 100 percent of the calculated soil gypsum requirement. Sesbania yields did not increase with applications of $CaCO_3$, and yields gradually increased with the application of $CaSO_4$. Sesbania was much more efficient in utilizing applied Ca than was barley (Poonia and Bhumbla 1973a). Various acidifying agents were tried in order to increase solubility of $CaCO_3$; sesbania yields were generally increased. Aluminum sulfate depressed plant P uptake; although HCl produced the greatest dry matter yield increases, it had the least effect on plant Ca uptake (Poonia and Bhumbla 1974b). Different P sources were tried at various soil ESP levels. Increasing ESP had no effect on the contribution of added P to total P uptake, but uptake was affected by the P source, calcium phosphate > sodium phosphate, and the P rate, 50 ppm P > 25 ppm P (Poonia et al. 1977). A sand culture experiment using nutrient solutions varying in Na and Ca levels corroborated S. bispinosa's sensitivity to increasing Na and its positive response to increasing Ca. Compared to wheat, sesbania translocated less absorbed Na to above-ground plant parts (Poonia and Jhorar 1974). Some plants are useful in reclamation because they accumulate sodium in their tops so that it may be removed from the site. S. bispinosa does not concentrate sodium in its above-ground parts. The implication was that incorporating the tops as green manure will have a favorable effect on the salt balance of the soil.

Abrol and Bhumbla (1979) examined responses of several crops to varying soil ESP brought about as a result of increasing gypsum applications (7.5, 15, 22.5, and 30 Mg/ha). They found that rice was less sensitive than wheat (contrary to the data of Ayers 1977). Rice crops were in themselves quite effective in modifying the soil environment so that ESP levels were reduced over the cropping period. When grown for 70 days, sesbania yields without gypsum were negligible, but above the first increment of gypsum, yields were maintained at 40 to 47 Mg/ha fresh material, over a range of soil ESP from 10 to 50. Their data suggested a decline in sesbania yields above ESP 60 and a 50 percent yield reduction at about ESP 75. Sesbania was the first crop grown in the sequence of crops tested and was judged tolerant of the initial conditions. Other legumes, grown later in the sequence after the beneficial effects of previous crops including rice and sesbania, were sensitive; these were Vigna mungo, Lens esculenta, and Cicer arietinum.

Other research has verified that sesbania is considerably more salt tolerant than other grain legumes when grown in soils adjusted with NaCl. Keating and Fisher (1985) found that yield reductions of 50 percent were associated with EC_e 13.2 dS/m (Siemens) for S. cannabina, compared to lower conductivities for guar (two cultivars, 10.1 and 9.0), cowpea (9.0), soybean (6.7), pigeon pea (two cultivars, 5.4 and 4.9) black gram (5.0), and green gram (3.5). They noted that the latter three legumes accumulated sodium ions, while the former three more salt tolerant legumes excluded sodium ions. These findings corroborated those of Karadge and Chavan (1983) who found a 40 percent yield reduction in S. aculeata at 15 mS/cm and also an ability of the plants to regulate sodium uptake. These authors also reported on the distribution of inorganic constituents in the various parts of plants grown at different salt stress levels.

TOLERANCE OF ACID SOIL CONDITIONS

Reports on the tolerance of Sesbania species to acid soil conditions are few and for the most part insubstantial. S. cannabina (S. bispinosa), known for its tolerance of soil alkalinity in India, appears to be tolerant of soil acidity. The crop was grown as a green manure on acidic tea-growing soils in Assam (Mirchandani and Kahn 1952, Patel 1966). Reports from Viet Nam that S. sesban is grown successfully on acid sulfate soils have not been verified by scientific literature available to us. Those soils have a pH around 6.5 when flooded, decreasing to about pH 4 when dry. Tran Phouc Duong of Cantho Agricultural College, Viet Nam, in an illustrated lecture given at the University of Hawaii in 1983, presented a photograph of a Sesbania species growing in soil crusted with aluminum salts, and stated that Sesbania was generally sown at the end of the monsoon season.

S. sesban (as S. aegyptiaca) was included among 33 legumes tested for N production in pot experiments with a "red" soil in Hawaii (Thompson 1917). Soil pH was not given, but the soil, probably an Oxisol, was stated to be "apparently acid...low in phosphate and lime and of poor texture." *S. sesban* and velvet bean (*Mucuna* spp.) were reported as potentially useful green manure crops on such soil, especially if lime could be applied.

Nair *et al.* (1957) reported experiments with *S. speciosa* grown on laterite soils (pH 5.4) near Coimbatore, India, to determine growth response to lime (1680 kg/ha), P (34 kg/ha superphosphate) and farmyard manure (5600 kg/ha). Maximum yield of 40.3 Mg/ha fresh material for a 60-day crop was obtained with all three amendments, but the yield of the control was 21.4 Mg/ha. Calcium appeared to be the most valuable input for increasing crop growth and nodulation; a small initial increase in soil reaction due to lime was not significant after growing the crop. Adding lime increased N yield by 28 kg from 87 kg/ha; adding all three amendments produced 136 kg/ha N in the *Sesbania* crop.

Acid soils are frequently low in available P, which may be as important a factor in limiting legume growth as low level of Ca, low pH, or high levels of soil minerals such as aluminum (Al) and manganese (Mn). Experimental work in India indicated that the common green manure sesbania, *S. bispinosa* or *S. cannabina*, was quite efficient in P uptake. In pot experiments, Khare *et al.* (1973) found sesbania and *Glycine max* to be more efficient than *Crotalaria juncea*, *Vigna aureus*, or *V. unguiculata* in utilizing soil P; it was also superior in taking up P from added fertilizer. Subbiah and Manikar (1964) found that sesbania was more efficient than *C. juncea* or *Cyamopsis tetragonoloba* in extracting P added to the "subsoil" (below 20 cm) layer of pots 30 cm deep. Singh *et al.* (1968) grew legumes for 50 days in pots containing 13.6 kg soil, with and without superphosphate at 56 kg/ha P_2O_5. All species tested showed yield increases in response to added P. Sesbania yields were considerably higher than any of the other legume species tested, including *C. juncea*, *C. tetragonoloba* or *V. unguiculata*: two of three sesbania entries had higher yields and total plant N without added P than the other legumes had with the addition of P. Singh (1972) obtained a small (less than 30 percent) yield increase to the first increment of added phosphate (33 kg/ha) to dhaincha grown in field experiments, but further increases in yield from the addition of higher rates of P were negligible.

Another demonstration of efficiency of P uptake by *S. bispinosa* was provided by Mahajan and Khanna (1968), who grew the crop for 85 days with varying rates of P fertilization. Their data, summarized in Table 5.1, indicated that increasing P levels did not increase yields beyond the first increment of P applied. The percentage of P in plant tissue increased with increasing P (R=0.97) as did total P recovered in the crop. In comparison, percentage recovery of applied P by a cowpea crop averaged 14 percent.

In Hawaii, legumes including *S. grandiflora* and an annual sesbania were grown across a pH gradient established by liming a manganiferous Oxisol (Yost *et al.* 1981, 1985). The annual variety of sesbania used (USDA PI 180050) appeared quite sensitive to low pH and the associated high levels of available soil Mn (Table 5.2). This variety has been found to be different from other species accessions received as *S. cannabina* or *S. bispinosa* (Evans and Rotar, unpublished data). These results therefore may not be applicable to all *S. cannabina* materials. Although amounts of nitrogen accumulated in *S. grandiflora* were low compared to the more rapidly growing annual crops, it showed a tolerance to low pH comparable to that displayed by *Crotalaria juncea*.

A group of *Sesbania* species were tested for response to lime applied to two acid soils (Evans and R.S. Huang, unpublished data). The 28 accessions grown in pots showed wide diversity in response to an aluminous Ultisol adjusted from pH 3.8 to 5.0 and a manganiferous Oxisol adjusted from pH 5.2 to 6.0. Yield increases due to the lime additions averaged approximately 80 percent over no-lime treatments in each soil. Yield variation among accessions was manyfold in the Mn-dominated soil, varying by a factor of 40 at both pH levels. The same variation was much less in the Al-dominated soil, varying by a factor of 2.3 at both levels. The results suggested that *Sesbania* cultivars could be selected to provide good yields on either soil type, and indicated the desirability of field studies on Al-dominated soils.

TOLERANCE OF SOIL WATERLOGGING AND FLOODING

The extensive use of *Sesbania* species in Asian cropping patterns based on lowland rice has been described in Chapter 3, including their cultivation as intercrops simultaneously with flooded rice crops in China.

In border-planted situations with rice, the flooding tolerance of some *Sesbania* species has been exploited. *Sesbania* species have been used as a border crop for rice in China (Figure 5.2), for deep-water rice in Bangladesh to prevent invasion by weeds such as water hyacinth (Catling *et al.* 1983) and in India to protect the rice crop from wave action (Kaul and Rao 1960). In large paddy fields,

TABLE 5.1
Yield and P recovery by a phosphate-fertilized *Sesbania bispinosa* crop (after Mahajan and Khanna 1968)

P_2O_5 Added kg/ha	Dry Matter Yield Mg/ha	Percent P	Kg P_2O_5 Recovered kg/ha	Percent Recovery
0	5.50	0.245	13.5	
45	6.30	0.547	34.5	47
90	6.24	0.756	47.2	37
135	6.07	1.311	79.6	49

TABLE 5.2
Nitrogen content (kg/ha) of plants grown 10 weeks in relation to soil pH as modified by lime application on a manganiferous Oxisol; values in parentheses are percentages of N content at pH 6.9 (after Yost *et al.* 1985)

	Soil pH				
Species	4.7	5.3	5.8	6.5	6.9
Sesbania	1.6	7.5	22.5	29.6	51.6
PI 180050	(3)	(14)	(44)	(57)	(100)
Sesbania	3.7	7.0	10.8	13.3	14.2
grandiflora	(26)	(49)	(76)	(94)	(100)
Crotalaria	21.0	44.0	72.0	96.0	106.0
juncea	(20)	(42)	(68)	(90)	(100)
Zea mays	22.2	26.9	26.6	26.3	31.9
	(70)	(84)	(83)	(82)	(100)

borders of *Sesbania* species also serve to protect bunds from erosive deterioration by waves generated by winds. Usually, species so used are the annuals *S. cannabina* and *S. bispinosa*.

Green manure species selection trials have singled out *Sesbania* species for their abilities to withstand flooding, as reported by Allen (1956) for Malaysia, the International Rice Research Institute in the Philippines (IRRI 1964), and India's Central Rice Research Institute (CRRI 1962, 1963, 1964). Jen *et al.* (1965) in China observed that sesbania survived flooding for a period of 15-20 days, with water 5-30 cm deep. In North America, S. exaltata's ability to grow as a green manure crop while flooding eliminated many weed species was noted (Pieters 1927), and sesbanias of the subgenera Glottidium and Daubentonia (S. vesicaria and S. drummondii, respectively) were included among wetland plants of the southwestern USA (Correll and Correll 1975). The natural habitat preference of many sesbanias is for stream banks, flood plains, swamp and lake margins, and other low-lying, moist or seasonally moist soil environments (Gillett 1963).

Tolerance of sesbanias to flooding develops after the seedling stage. Although green manure crops of S. bispinosa may be sown in a few centimeters of standing water to aid germination (Abrol and Bhumbla 1971), the seedlings appear to need several weeks of nonflooded conditions before they can readily withstand flooding.

Figure 5.2 Sesbania cannabina growing in Hangzhou, Peoples Republic of China. The plants readily tolerate fluctuations in the level of the waterway at the left. Note cultivated field at the right. (Photo courtesy of T.L. Lumpkin).

This limitation has apparently not been studied in detail, although farmers using the crops may be acquainted with the limits of the tolerance for the species they use. S. exaltata (considered to be a weed in North America) was shown to emerge and grow well when seeded at depths of 1.3, 2.5, and 5.1 cm in a silt loam soil held at field capacity (24 percent water) or saturation (34 percent); however, it did not grow in flooded soil conditions (Smith and Fox 1973).

The basis for flooding tolerance in Sesbania is the development of aerenchyma, a spongy tissue having enlarged cells with large intercellular spaces (Figure 5.3). General reviews on plants growing in watery environments, such as that of Sculthorpe (1967), include aerenchyma development as one of several ways in which plants may avoid anoxia in the root zone. In Sesbania, this tissue arises from a phellogen tissue located just outside the endodermis. The morphogenesis of this tissue occurring in stems and roots was described by Scott and Wager (1888), Metcalfe (1931), and d'Alemeida (1946). The latter author pointed out the definite pattern of cellular development, with concentric rings of rounded cells surrounding layers of scattered, radially elongated cells, resulting in

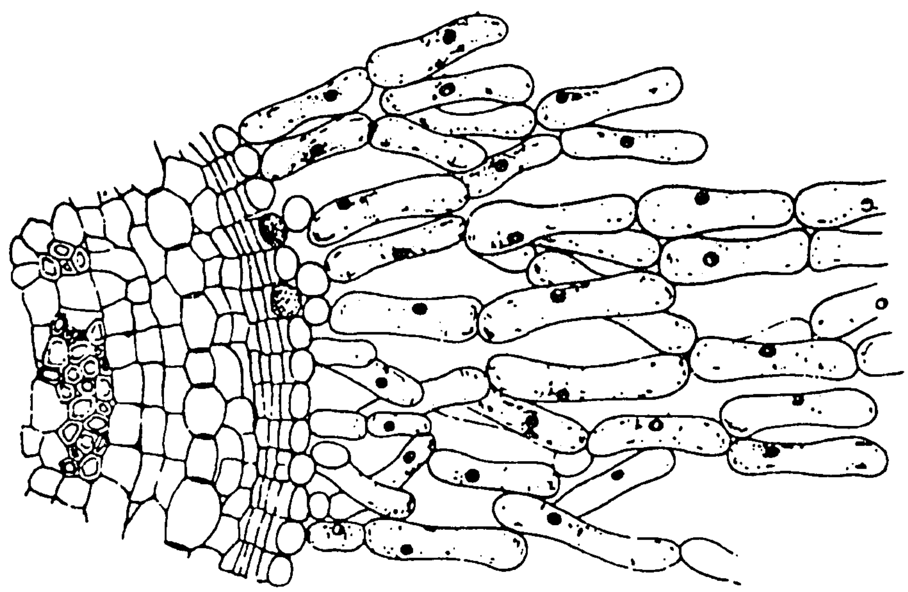

Figure 5.3 Cross section of a floating root of Sesbania aculeata (S. bispinosa) showing aerenchyma tissue (after Scott and Wager 1888, used with permission).

intercellular spaces. No research has been published on the biochemical and physiological nature of this response in Sesbania. There is no reason to believe that these plants tolerate the absence of oxygen; rather, aerenchyma development is primarily an avoidance mechanism to partially prevent anoxia and perhaps to correct some of the consequences of this condition. Such consequences have been detailed in reviews by Cannell and Jackson (1981) and Krizek (1982).

Swelling of the flooded basal stem is visually evident within 12 to 24 hours of flooding. The epidermis splits from the soil level to above the water level, and a white tissue may be seen beneath it, sparkling with reflective air bubbles (Figure 5.4). The enlarged stem acquires a fissured, buttressed appearance, 3-4 or more times the original stem diameter at soil level, narrowing to normal diameter at the intact epidermis a few cm above water level. Subsequently, within 1-2 weeks, submerged water roots sheathed in aerenchyma arise from the flooded stem section, growing out through the aerenchyma, and roots near

Figure 5.4 Stem aerenchyma and adventitious water roots of Sesbania cannabina. These two plants had been flooded to a depth of 5 cm above the soil surface for several weeks before the pot was drained. Note the nodule cluster at the center.

the soil surface may arch above it, buoyed by aerenchyma. Nodules may be seen nestled in the airy tissue at the base of the stem or scattered along water roots (Figure 5.5). Botanists who described this phenomena have discussed the function of the aerenchyma in providing oxygen for root respiration. They failed, however, to note nodulation, or that the intercellular spaces also served to transport gaseous nitrogen to sites of N fixation.

Development of aerenchyma is not unique to Sesbania within the Leguminoseae. The genus Neptunia contains floating plants with aerenchyma. Metcalfe (1931) discussed both Sesbania and Neptunia. Results from trials at IRRI (1963) also showed that Macroptilium lathyroides was suitable for waterlogged conditions. Aeschynomene contains species of agronomic potential which survive flooding (Kretschmer and Bullock 1980). Mimosa pigra and Lotus pedunculatus also develop aerenchyma (Sculthorpe 1967). Glycine max shows aerenchyma development, and some cultivars have been found to grow better under high water table culture than under freely drained conditions (Hunter et al. 1980). Vicia faba was shown to have better growth and nod-

Figure 5.5 Basal stem nodules and roots of Sesbania grandiflora which had been flooded (right) or not flooded (left). Aerenchyma tissue sheathes stems and roots of the flooded plants.

ule development in saturated media than under drained conditions (Gallacher and Sprent 1978). Few of these genera show as dramatic a morphological response to flooding as does Sesbania. The magnitude of aerenchyma development varies among Sesbania species.

Screening for flooding tolerance in legumes has been done for temperate forage legumes flooded from 5 to 20 days at about 50 days after planting (DAP) (Heinrichs 1970). Brolmann (1978) kept 158 Stylosanthes accessions flooded at the soil surface level from 28 DAP and recorded survival during the subsequent 4-month period. Miller and Williams (1981) flooded 41 tropical legumes (but no Sesbania species) to 7 cm above soil level at about 14 DAP; some survived six months of this treatment.

Research on flooding tolerance in Sesbania is rare. IRRI (1964) reported briefly on a comparison between Sesbania species grown under flooded and drained conditions. Agriculturists in Guangdong, China reported an experiment with S. cannabina comparing flooded and drained conditions (Anon. 1975). Seedlings established in a soil lacking infective rhizobia were transplanted to inoculated, fertilized (but without N) sand culture in pots which were then either flooded to 3 cm of standing water or were maintained below field capacity; the flooded treatment was grown with and without added N. One month after transplanting, plants were harvested and the N in plants and media was measured, as given in Table [illegible].3. The timing of events in the experiment was similar to the practice of raising sesbania in nurseries and bare-root transplanting seedlings as an intercrop in flooded rice fields. It is possible that the development of aerenchyma in the flooded treatment and, especially, the addition of N to the N-poor sand media, conferred advantage compared to the nonflooded treatment, allowing more rapid recovery from transplant shock and thus an earlier and greater supply of photosynthate to the nodules. Due to the difficulties in comparing plant growth in such different root environments, particularly in regard to nutrient uptake, the workers at Guangdong hesitated to conclude that increased growth was a result of greater N fixation and not an artifact of their procedures. It was clear, however, that flooding did not severely inhibit plant growth and N fixation.

Flooding tolerance of Sesbania species was assessed in an experiment in Hawaii (Evans and S. Somphone, unpublished data). Twenty-two Sesbania accessions were grown in pots for 5 weeks, after which they were either flooded by sealing the pots and maintaining water level at 5 cm above soil level, or kept in saturated condition by setting the pots in shallow, water-filled pans. Plants were harvested 18 days after the imposition of treatments. The soil was a Vertic Haplustoll (Waialua series), a moderately heavy clay soil dominated by smectite clay minerals having shrink-swell potential; therefore, the nonflooded and flooded treatments may not have represented rooting and nutrient flow conditions as different as was the case with the sand used in the Guangdong study (Anon. 1965).

Species grown (and their accession codes) were the perennials S. arborea (AR4), S. grandiflora (GL5), two varieties of S. sesban (SB1, SB10), and the annuals S. emerus (XP), S. macrantha (MN1), S. exasperata (EX3), S. punicea (subgenus Daubentonia) (DP2), S. vesicaria (subgenus Glottidium) (VC1), S. erubescens (EB1), S. pachycarpa (PC1), S. exaltata (MA4), S. rostrata (RS1), S. speciosa (SP1), S. tetraptera (TP1), S. cochinchinensis (CH1), and several accessions of the S. cannabina or S. bispinosa type (BA5, CB1, CB5, SC1, XE3).

Results of this experiment are shown in Figure 5.6, which compares plant dry weights under the different treatments. Entries clustered along the diagonal axis grew as well under both treatments. There was a tendency, particularly for the higher yielding entries, to be moderately more productive under nonflooded conditions. Some of the lower yielding entries were perennials (MN1, AR4, SB10, GL5, SB1, EB1), while most higher yielding entries were fast growing annuals.

TABLE 5.3
Nitrogen budget of Sesbania cannabina transplants grown under flooded and drained conditions (adapted from data of Anon. 1975)

Treatment	Plant Dry Wt. g/pot	Plant N Content mg/pot	N Added mg/pot	N Fixed mg/pot[a]
Drained	12.1	449	--	404
Flooded	17.1	612	--	572
Flooded +N	32.5	1144	345	759

[a] N content of transplants (40 mg/pot) deducted; discrepancies in budget are due to N remaining in media after harvest of plants, and to rounding.

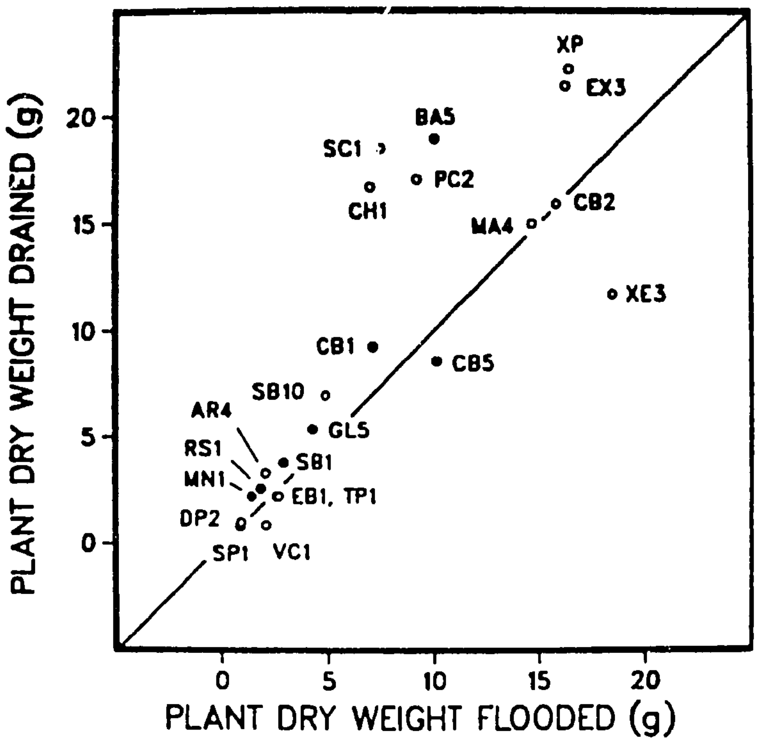

Figure 5.6 Yields of Sesbania accessions subjected to flooding (water level five cm above soil surface) or high water table (water level 20 cm below soil surface) conditions for 18 days, 35 days after sowing. Solid circles were three-replicate entries; open circles were non-replicated entries. (Evans and Somphone, unpublished data).

6
Agricultural Uses of Perennial *Sesbania* Species

Only two perennial sesbanias have been widely used for agricultural purposes: S. sesban and S. grandiflora. Perennial Sesbania species endemic to the Hawaiian Islands are mostly halophytic shrubs inhabiting coastal zones. They and the taller-growing S. arborea, found from 100 to 300 m elevation on Molokai, are quite drought tolerant and are browsed by cattle, feral goats, and deer. S. formosa, endemic to Australia, appears to be drought tolerant from its performance in observation plantings on Oahu (Evans, unpublished) and Molokai (R. Skolmen, personal communication). Few of the woody shrubs and small trees catalogued in the African center of Sesbania species diversity (Gillett 1963), other than the sesbans, have known agricultural uses or have been evaluated agronomically.

S. grandiflora, pantropically distributed by man, has been recognized for its rapid growth and multiple uses, principally for fuelwood and pulpwood but also for fodder (NAS 1979, 1980). Reports of its use as a fodder source are confined to South and South East Asia. It is considered native to the Old World tropics, but most floras of those areas describe it as introduced. Gillett (1963) speculated that it had been introduced to Africa from Indonesia. None of the floristic literature that we reviewed claimed it as native. We did not see any references to wild populations.

S. sesban has been recognized as having potential as a fodder crop, but this potential is generally known only in local situations. Where it occurs as an element of riverine vegetation in Africa, it is browsed by cattle (Gillett 1963). In northern Rwanda, such stands were selectively and intensively utilized by elephants translocated to a national park, resulting in heavy damage to the plants (Monfort and Monfort 1979). In addition to its native habitats in tropical Africa, Townsend (1973) stated that S. sesban was cultivated and semi-naturalized in Cyprus, Egypt, Tunisia, Arabia, Bahrain, Iran, Pakistan, Afghanistan, India, Sri Lanka, Burma, Thailand, Java, Australia, and South America. It is grown as an annual in Iraq and other of these areas where freezing occurs during the winter season; otherwise it is perennial. It is often grown as a temporary hedge and windbreak, and cut for fodder (Townsend 1973).

MISCELLANEOUS USES OF SESBANIA SPECIES

Information on agroforestry uses of sesbanias in combination with other crops is very limited, and has been quantified to a much lesser extent than have been their uses as green manures. Bally and Legros (1936) listed reported uses for sesbanias in combination with other crops as support or as shade. S. sesban has been used to shade crops such as coffee, cacao, and tumeric; S. macrantha has been used to shade coffee in Uganda. S. sesban and S. grandiflora have been grown as living supports for pepper (Piper nigrum) and betel vine (Piper betel). When S. grandiflora is grown for betel vine in S. India, it is usually given a 1-3 month start before sowing the betel, is kept free from side branches to about 3.6 m, and is topped periodically to minimize shading (Aiyer 1980). S. grandiflora has also been used to shade coconut nurseries in India (CSIR 1972).

Nao (1979, 1983) reported the interplanting of S. grandiflora with fruit trees in "home gardens" in the Mekong delta of southern Viet Nam. These gardens are considered to be modified forest ecosystems, and recognition of the legume's contribution to soil fertility seems to be the reason for S. grandiflora's inclusion. It is not used for fuel (coconut fronds being preferred); however, the flowers are cooked and eaten as vegetables, and the leaves are used as mulch or as protein-rich fodder to supplement rice straw in animal diets.

S. sesban was used as windbreak for banana in India (Anon. 1958, Baweja 1955) and Africa (Karani 1983) and for fruit orchards in Israel. It was used as a multipurpose planting in the demonstration agroforestry Project Agro-Pastoral in Myabisindu, Rwanda (T.H. Zeuner, personal communication 1982). S. grandiflora was used as windbreak for citrus and coffee in the West Indies, and for banana in India, where it was said to be particularly effective when topped in order to encourage branching (CSIR 1972).

SILVOPASTORAL USES OF PERENNIAL SESBANIAS

The use of natural stands of sesbanias as browse is noted for Africa (Gillett 1963), but active use of these plants as feed sources in agroforestry systems is not wide spread. A few research projects have been briefly reported. *Sesbania* species were studied in Indonesia as components of two-tier grazing or fodder production systems. *S. grandiflora* was sown in mixture with other legume trees to regenerate a formerly forested site in central Java which had been prepared by either burning or mechanically disturbing the grass vegetation cover. At the time of the observation, height growth of *S. grandiflora* was much greater than the others, including *Acacia auriculaeformis*, *Leucaena leucocephala*, and *Calliandra* species (Sumarna and Sudiono 1974).

At the Indian Grassland and Fodder Research Institute (IGFRI), *S. grandiflora* was compared with *L. leucocephala*, transplanted to grass plots at 1 x 1 m spacing and cut 3 times at intervals of 7, 7, and 17 weeks. By the third cut, grass yields were depressed under *S. grandiflora* compared to grass alone; combined dry matter grass yields from the 3 cuts were approximately the same whether or not *S. grandiflora* was interplanted, but grass yields were increased by about 40 percent when *L. leucocephala* was interplanted. Data were not given on legume yields, nor was it indicated that they also were cut (Gill and Patil 1981).

Subsequently, *S. sesban* was tried as an intercrop with napiergrass (*Pennisetum purpureum*) varieties under fertilized and irrigated conditions. In one comparison of leguminous shrubs sown at 50 cm spacing, total green fodder yields of two cuts taken in the establishment year were (in Mg/ha) 68.4 for *L. leucocephala*, 71.0 for *S. sesban*, and 33.5 for *Desmanthus* spp. (Gill and Patil 1983). In another comparison of legume species, *S. sesban*, *L. leucocephala*, and *Stylosanthes hamata* were sown in rows 75 cm apart between rows of napiergrass varieties. Mean legume fresh yields (total of two cuts) were (in Mg/ha) *S. sesban* 23.4, *L. leucocephala* 19.0, *S. hamata* 14.3. Grass yields were highest under leucaena; no statistical analysis was given (Gill *et al*. 1983).

S. sesban was interplanted with Brachiaria mutica around pond banks at IGFRI sites where rainfall varies from 900 to 1250 mm/year (Patil 1979). S. sesban was a good choice for such environments since it would survive seasonal fluctuations in the pond water level. In the situation reported, total yield was estimated to be 32.5 Mg/ha fresh legume fodder obtained in four or five cuts per year.

INTERCROPPING WITH PERENNIAL SESBANIAS

A cropping systems research experiment using S. sesban was carried out in Maharashtra, India, where legume forage shrubs and trees were interplanted with cereals (Desai and Bhoi 1982). S. sesban was compared with S. grandiflora, L. leucocephala, and a Desmanthus species at row spacings of 1.0, 1.5, and 2.0 meters, all spaced at 25 cm within rows and given N-P-K fertilizer (75 kg/ha N as urea). Legumes with their millet intercrops were sown in August and the first cut was taken after 3 months; a second cut was taken 6 weeks later and was followed by 9 cuts at monthly intervals. Millet was harvested 3 months after sowing and was followed by a wheat intercrop. During the initial intercropping stage of the experiment, the legumes were cut back to half of their height or half the height of regrowth; subsequently, intercropping was discontinued and a uniform cutting height of 90 cm above ground was adopted (the Desmanthus species was cut at 60 cm height). Compared to other legumes, S. sesban's vigorous growth tended to suppress crop yields. The wider row spacings using the least competitive legume (Desmanthus) were favorable to higher grain yields and, therefore, produced higher immediate economic returns.

Intercropping studies with Sesbania species were also carried out at IGFRI, and summary results were published (Patil 1979; similar data was reported by Patil et al. 1981). In one trial, S. sesban was compared to L. leucocephala in a rain-fed situation where seedlings were transplanted to rows 2 m apart at the start of the monsoon rain season, and intercrops of sesame, pigeon peas, and groundnuts were grown. Green fodder yields of the first cut after harvest of the intercrops (the interval from planting was unspecified) were 12 Mg/ha for S. sesban and 2.3 Mg/ha for L. leucocephala. S. sesban yields were slightly depressed in the presence of intercrops, but there apparently was no significant difference between yields of the intercropped species in the presence or absence of S. sesban.

TABLE 6.1
Fodder production by Sesbania sesban and intercrops, and grain yield of wheat following the intercrops (from data of Patil and Gill given in Patil 1979)

Intercrop	S. sesban Green Fodder Yield Cut 1	Cut 2	Total	Intercrop Green Fodder Yield	Total Fodder Yield	Wheat Grain Yield
			Mg/ha			
	10.9	13.0	23.9	--	23.9	--
Sorghum	5.2	5.2	10.4	14.3	24.7	3.0
Maize	4.0	4.9	8.9	17.9	26.2	2.7
Millet	4.9	4.7	9.2	12.3	21.5	2.7
Guar	6.5	5.4	11.9	9.5	21.1	3.6
Cowpea	5.9	5.1	11.0	11.1	22.1	3.2

In another experiment (Patil 1979), S. sesban given 20 kg/ha N and 60 kg/ha P_2O_5 was intercropped at "wide" (unspecified) spacing with rainy-season fodder crops (sorghum, millet, maize, cowpea, or guar) which received no fertilizer. Following the harvest of the fodder intercrops and the first cut of the S. sesban in October, wheat fertilized with N-P_2O_5-K_2O at 60-60-60 kg/ha was intercropped, followed by a second cut of S. sesban taken in March. The data is summarized in Table 6.1. Green fodder yield from the two cuts of S. sesban grown without intercrops totaled 23 Mg/ha, which was equivalent to the mean of total fodder production from intercropped S. sesban plus rainy-season fodder crops. When intercropped, S. sesban's yields were reduced and averaged 49 percent of sole crop yield at the first cut and 39 percent at the second cut. The intercropping scheme provided an average wheat yield of 3 Mg/ha grain and 4.5 Mg/ha straw. In the case of the nonlegume fodder intercrops such as maize, millet, or sorghum, the balance of protein and carbohydrate components of the intercropping scheme would probably be of greater value to ruminants than the legume alone.

In a second intercropping experiment for fodder production under irrigated conditions at IGFRI (Patil 1979), control plots of S. sesban sown alone in rows 50 cm apart yielded 23 Mg/ha, vs. 27.6 Mg/ha when sown in 25 cm rows. When S. sesban in 50 cm rows was intercropped with a wheat-millet-sorghum scheme (not precisely specified), S. sesban yields were only slightly reduced, but total green fodder yields of sesban+millet+sorghum were 52 Mg/ha, more than double that of sesban alone. In addition, wheat was harvested for grain. When the S. sesban was excluded, total fresh fodder yields (millet + sorghum) were reduced by about 10 Mg/ha, and there was a greater loss in protein yield.

In a third experiment (Patil 1979), S. grandiflora was grown with an intercrop of wheat. Figure 6.1 illustrates that wheat yields were slightly reduced by including the legume; however, an additional 10 Mg/ha of fresh fodder was obtained.

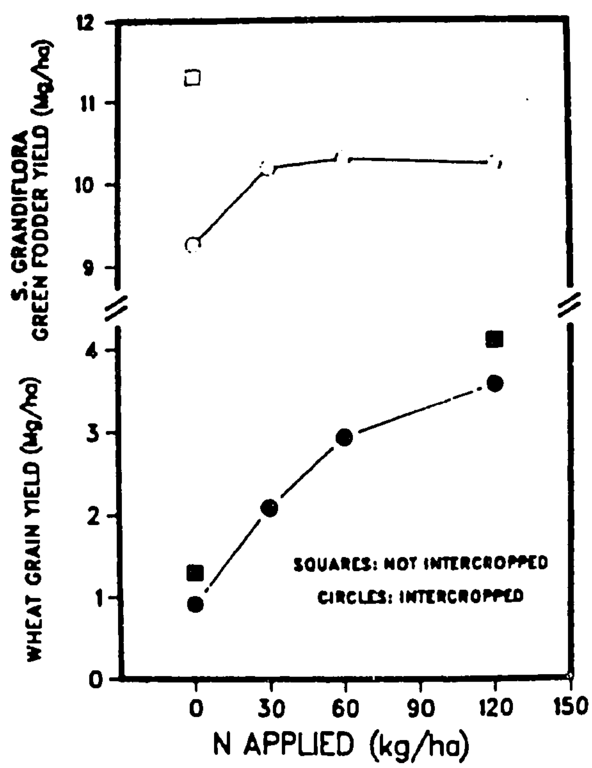

Figure 6.1 Yields of Sesbania grandiflora and wheat in an intercropping scheme (adapted from Patil and Gill in Patil 1979, Table 4).

In an experiment in Western Samoa, *S. grandiflora* was included with other N-fixing trees intercropped with taro (Cable *et al*. 1983.) The trees were pruned for mulch material which was applied to the taro; after the taro harvest the trees were allowed to grow for fuelwood. Observations in Hawaii indicated that *S. grandiflora* could not withstand the frequent and severe low pruning necessary to permit its growth as a closely spaced intercrop, nor would the trees regrow vigorously after such management (Evans and Rotar, unpublished data). A more promising system would selectively prune these trees grown as a field border, where low cutting to reduce shading would be less imperative.

YIELD TRIALS AND MANAGEMENT OF PERENNIAL SESBANIAS

A description of the occurrence and management of *S. sesban* in the Deccan of India was given in an anonymous (1924) bulletin from Bombay entitled "Shevri as a fodder crop." The crop had long been grown in certain districts because of its adaptation to "malai" lands, areas below flood level along rivers. There, and in irrigated lands nearby, farmers managed *S. sesban* either as a single stand or as an intercrop with sorghum, maize, or *Lablab purpureus*. *S. sesban* may have occurred naturally in these areas as it does in similar environments in Africa, because transmittal along waterways is a common method of seed dispersal for many *Sesbania* species (Trivedi 1955). In the districts of the Deccan under discussion, however, intensive land management indicated that stands were deliberately sown.

On malai lands, seed was sown broadcast. The first cut for fodder was taken after 3-4 months growth when, according to the bulletin, side shoots were trimmed. Main stalks were later cut back to a height of about 125 cm; about four cuttings were made in each year. When grown as an intercrop, growth rate was said to be slow until after harvest of the maize or sorghum, at which time the *S. sesban* was topped at 125-150 cm height to encourage side branching. The fodder obtained was of high quality, and lands capable of growing this crop were rented out at high rates.

Another cropping pattern described was in rotation with sugarcane, where *S. sesban* provided not only fodder but fuelwood for processing cane. After one year in cane, lands were cropped to a main season rice crop sown in June and intersown with rows of sesban. *S. sesban* was subsequently harvested for fodder until, 17 months after sowing, it was harvested for fuelwood before planting the next crop of cane. An acre (0.405 ha) of S. sesban thus grown could maintain two bullocks and a cow for a year. "Opening" of the soil by the deep roots of S. sesban and a heavy fall of leaf litter were cited as additional contributions to this rotation. The carry-over ability of this crop to provide fodder during hot weather in India when fodder becomes scarce was also noted (Anon. 1924, Patil 1979).

On saline lands, when S. sesban was sown in rows 125 cm apart, cuts were made every 1.5 months after an initial 3-month establishment phase. An average of 2.13 Mg/ha was taken in each of 23 cuts over the first 3 years (an average of 48 days/cut), cutting at 125 cm height (Anon. 1924).

The bulletin also reported a cutting trial in which S. sesban was sown in rows 90 cm apart at a seeding rate of 34 kg/ha and irrigated frequently. The first cut was made 39 days after planting, followed by a cutting regime of 9-10 cuts per annum, varying from 20 to 49 days between cuts. Cutting near the ground level was found to be detrimental, so a cutting height of 76 cm was adopted. Yields are presented in Table 6.2. The fodder from S. sesban compared well in quality with alfalfa (Medicago sativa) grown on adjacent plots; S. sesban had a higher fiber content and slightly less nitrogen (2.78 percent) than M. sativa (2.98 percent).

Mungicar et al. (1976) in Maharashtra, India, reported the yield response of S. sesban in comparison with seven other crops grown with various rates of applied N fertilizer. S. sesban was sown in rows 25 cm apart and was first cut 10 weeks after planting, followed by cuts at 5-week intervals at an unspecified cutting height. Harvested S. sesban material had 15-22 percent dry matter containing 2.9-4.3 percent nitrogen. For some reason not explained in the report, S. sesban was given high N application rates, up to 640 kg/ha during its 280-day growth period in each of the two years of the experiment. These apparently excessive rates were of doubtful value for S. sesban and the other legume tested, Medicago sativa. Dry matter yields of S. sesban in the first and second years of the experiment were 6.0 and 9.1 Mg/ha with no N applied, and 8.3 and 10.6 Mg/ha at the highest rate of N. Dry matter accumulation rates varied from 21.4 to 36.8 and averaged 29.8 kg/ha per day.

Gore and Joshi (1976) studied the effects of cutting intervals and fertilizer sources on the extractable-leaf-protein yield of S. sesban. S. sesban var. picta was sown

TABLE 6.2
Experimental yields of *Sesbania sesban* at Manjri, India, 1917-1921 (adapted from Anon. 1924)

Year	No. of Cuts	Cutting Interval Av.	Cutting Interval Range[a]	Green Fodder Yield Av.	Green Fodder Yield Total Per Year	Green Fodder Yield Rate
		days		Mg/ha		kg/ha/day
1	10	34	20-49	1.31	13.14	38.6
2	9	39	19-84[b]	1.37	12.34	35.1
3	10	32	18-48	1.67	16.65	52.1
4	8	34	27-45	1.20	9.61	35.3

[a]Cuttings were fed fresh to cattle, so they were made by plot as needed and not by schedule.
[b]84-day interval to allow for change from cutting at 10 cm height to cutting at 75cm.

at a rate of 65 kg/ha in rows 30.5 cm apart in October and given either inorganic N-P-K fertilizer, farmyard manure plus superphosphate (FYM-P), or no nutrients (control). Irrigation water failed in May of the first year so the trial was abandoned and replanted again in October. The authors presented three sets of data, two for the cutting interval treatments (3, 4, or 5 cuts) during 7 months of growth in both years, and one for the total 12-month period of the second year, in which three additional cuts were taken at each interval level. Fertilizer was applied to the base of each plant in split applications 15 days after each cut. Amounts applied were varied in such a way that all cutting interval treatments received identical total amounts. N-P-K treatments received a total of 110-110-55 kg/ha N-P_2O_5-K_2O in the first year and 140-140-70 in the second year; FYM-P rates (P as P_2O_5) were 39,000-80 kg/ha in the first year and 44,000-100 kg/ha in the second year. Cutting intervals were 35-40 days, 49-52 days, and 60-65 days. Growth rates calculated for the fertilizer treatments (Table 6.3) indicated an apparent cumulative benefit from fertilizer applications in the second year; mean dry matter accumulation rates remained the same for the

TABLE 6.3
Effect of fertilizer on yields of *Sesbania sesban* (from data of Gore and Joshi 1976)

Treatment	Average dry matter accumulation rate: 3, 4, or 5 cuts, Year 1	3, 4, or 5 cuts, Year 2	5 to 8 cuts, Year 2
		kg/ha/day	
No fertilizer	19.6	19.0	17.6
Farmyard manure + P	24.7	29.9	28.3
N-P-K fertilizer	26.8	36.6	35.1

control, but rates increased for the other treatments. Effects of the FYM-P treatment did not become significant until the second year, but benefits from N-P-K applications were immediate. Total yields under the different cutting frequencies were similar in the first year; in the second year the shortest interval was significantly more productive. Nitrogen content of the dry matter varied from 3.3 to 4.1 percent but was not affected by treatments.

Sato (1966) reported results from green manure species evaluations in Thailand, where S. sesban was outstanding when a growth period of about 10 weeks was possible. At 55 days after planting, yields were 25 Mg/ha fresh weight, similar to Crotalaria juncea. C. juncea then began to flower and its vegetative growth ceased while S. sesban continued to grow. S. sesban's later flowering and indeterminate growth habit contributed to its superior yield over the longer term. Since fast, early growth was valued in the green manure crop trials, mung bean was selected as the best short-term green manure in the study.

Mune Gowda and Krishnamurthy (1984) studied effects of cutting height on yield of S. sesban planted at a spacing of 25 x 100 cm and cut every 90 days. S. sesban had higher yields at lower cutting heights. Percentage yield increases over yields at the highest cutting height (200 cm) were 12 percent for 150 cm, 32 percent for 100 cm, and 57 percent for 50 cm.

Less yield data is available for S. grandiflora than for S. sesban. In Java, S. grandiflora was compared to other green manure candidates in rows 30-40 cm apart, and gave the highest fresh yield after a 6-7 month growth period: 55.27 Mg/ha (data of Koch and Weber 1928, quoted by Coster 1939). In an intercropping experiment in India, researchers recorded total green fodder yields for S. grandiflora of 13.6 Mg/ha from 11 cuts taken over 14 months, vs. 16.8 Mg/ha for S. sesban, 17.3 Mg/ha for Desmanthus, and about 10 Mg/ha for L. leucocephala (Desai and Boi 1982, Desai et al. 1983). Cutting intervals were apparently too frequent for S. grandiflora.

In the Chiang Mai region of northern Thailand, S. grandiflora was grown along with other species (mostly grasses) for intensive cut and carry fodder production for small dairy operations (Holm 1972). Entries were sown in rows 50 cm apart and cuttings were taken at an unspecified height every six weeks. Top-dressings of N-P-K fertilizer were made after each cut so that these nutrients were apparently not limiting factors. Dry matter yields of S. grandiflora during the two years of the trial were 7.2 and 5.7 Mg/ha per year, the lowest of all entries. Yields of most grass species were 2-3 times higher. S. grandiflora, however, had a higher level of digestible protein (18 percent) and starch equivalent (60 percent) per unit of dry matter than any of the 12 other entries tested, and yielded the third highest amount of total digestible protein: 1.06 Mg/ha/year (Holm 1973).

S. grandiflora is widely used as a border-planted cut and carry fodder source in Java and in India. Kareem and Sundararaj (1967) estimated that 40-50 trees planted 1.5 m apart along irrigation channel bunds would be able to provide enough fodder for one milch cow throughout the year. Leaves were picked up to 9 times per year after the trees reached a height of about 2.3 m, 6 months after planting. Each tree was said to yield about 3 kg of fresh leaves per pick. They recommended that trees "should be carefully picked of the leaves lest severity of picking harm the plant."

In another fodder species evaluation trial in N.E. Thailand, local S. grandiflora varieties had initial growth rates comparable to those of introductions of Leucaena leucocephala, Albizzia spp. and Calliandra calothyrsus (Gutteridge and Akkasaeng 1985). Among the 15 tree species grown, S. formosa, S. sesban, and S. sesban var. nubica, were outstanding. All three Sesbania species had significantly higher yields than the other tree species at 6 months after planting.

Yields of a number of S. sesban and S. grandiflora accessions were evaluated in Hawaii (Evans 1984, Evans and Rotar, unpublished data). The highest yielding S. sesban accessions produced 20 Mg/ha dry matter in 5-6 cuttings taken during the establishment year. Plants were sown 20 cm apart (25 cm for S. grandiflora) in rows 1 m apart. They were harvested when stands were 2 m high, cut at a height of 50 cm above ground. S. sesban yielded more under this cutting treatment than S. grandiflora, which allowed only 4 cuts during the year and produced approximately 13 Mg/ha dry matter. S. grandiflora's yields were also restricted by increasingly dry weather during the establishment year. S. sesban var. nubica appeared to be better adapted to the successively drier conditions than S. var. sesban.

7
Sesbania Species as Pulp Fiber Resources

The goal of pulp enterprises is to establish a secure raw material supply which will provide good quality fiber at the lowest possible cost. In developing countries, raw material requirements of many mills are small, and fast growing annual or perennial crops can be pulpwood sources offering considerable flexibility. A number of woody *Sesbania* species have been found to be suitable pulp sources in terms of technical pulping and milling considerations. Wide scale growth of *S. bispinosa* as a green manure crop in southeast Asia indicates that the crop is readily managed by farmers in a variety of agricultural situations. Factors such as the rapid growth and multiple uses of these plants, the benefit to the soil accrued by growing legumes, and the reduced need for fertilizer inputs compared to non-legumes enhance their desirability from the farmers' point of view. This in turn would contribute to assuring a more secure fiber supply to the mill.

THE WORLD NEED FOR NEW PULP FIBER RESOURCES

The demand for paper products is increasing at rates far faster than present natural or managed resources can supply. Chipping of tropical hardwoods, together with fuelwood needs and timber exploitation are among the major contributors to the present mass-scale deforestation. Non-wood fiber pulps, including *S. bispinosa*, represent an alternative which although small (7 percent of global use in 1977) is particularly important in developing countries which along with the Peoples Republic of China, a major non-wood fiber user, accounted for 83 percent of the world's use of these materials in 1977 (FAO 1979). Economic growth in developing nations resulting in higher literacy, increased consumerism, and other indices of the physical quality of life will inexorably increase per capita paper consumption.

Large scale multinational pulp production industries require vast forest resources; their economies of scale dictate predictable resource availability several decades into the future. Many of these are now based on coniferous plantation forests. Few developing country pulp industries supplying domestic markets operate at such a level; their plant capacities are low. They must work with local resources, often various and subject to seasonal availability. Traditional fiber sources often limit productivity and type of output of these operations. Competition for crop residues for feed or fuels used for domestic or industrial needs (e.g. sugarcane bagasse) further limits the use of these types of materials. Residues from long fiber crops such as cotton and flax and other sources such as abaca (Manila hemp) or sisal produce expensive, high grade, special purpose papers; jute is suitable only for low grade paper and board (FAO 1979). Bamboo, the major raw pulp material of India, is slow to establish, and production is interrupted by the onset of flowering and subsequent senescence of entire stands. Bamboo yields on an area basis are low (0.5-4.0 Mg/ha per year), with a 3- to 4-year cutting cycle, so that vast areas are needed (Pai _et al_. 1980).

Fast growing annual tropical plants which have suitable pulping qualities and which can be managed on a plantation scale are attractive alternatives or supplements to such traditional fiber sources. Kenaf (_Hibiscus cannabinus_) is such a crop and has recently been seriously considered as a pulp fiber crop for Australia's tropical region (Wood _et al_. 1983). Kenaf's bark (20-25 percent of the stem) has coarse long fibers which produce excellent pulp, but the short (0.5-0.6 mm) fibers contributed by the core dilute overall pulp quality. Two crops per year are possible, and hopes remain for its development as a basis for pulping industries (FAO 1979). Kenaf has been investigated in the USA by USDA's Northern Regional Research Laboratory at Peoria, Illinois. During recent years, these investigations were concentrated on kenaf's use for newsprint manufacture.

In Australia, interest in _Sesbania_ species developed partly in cognizance of the nitrogen fertilizer input required for kenaf, amounting to about 35 percent of the cost of its production (Wood 1976). In addition to the advantage of nitrogen fixation, sesbanias may be more suitable for growing on problem soils which are salt affected or occasionally flooded. Woody stems of many sesbanias are easier to handle and to store than those of kenaf. Perennials such as S. sesban may be ratooned, or coppiced; these and even some annuals may in certain instances be cut once for fodder or green manure, and the regrowth can be harvested for pulping. Seed may also be harvested for extraction of gums. Given the diversity among subspecies and varieties of S. sesban observed in accession plantings in Hawaii, there is ample opportunity for selection and breeding of this and other Sesbania species for pulpwood production on a wide range of possible sites.

SESBANIA BAST FIBER FOR CORDAGE

Harvesting of various Sesbania species for their phloem (epidermal stem) fibers is an ancient practice. S. exaltata has been used as a fiber source for nets and fishing line by the Yuma Indians of Arizona (Parker 1972), and by other Indians throughout its range. The common epithets for the species, Hemp sesbania and Colorado River hemp (Robbins et al. 1971), reflect this utility. South Asia's common, annual counterparts to S. exaltata, namely S. bispinosa and its close relatives, are similarly used, especially in the Bengal-Bangladesh region (Sircar 1948). There also, the material has been found especially appropriate for fishnets because it resists decay in seawater (Mazumdar et al. 1973). This tolerance to wetting accounts for numerous maritime applications, such as sail lashings, for the coarse but very strong and durable cord and rope made with bast from S. bispinosa. In Central India, S. bispinosa fiber is known as Dundee fiber and has been regarded as a substitute for Crotalaria juncea; it is stronger and more durable than jute fiber (Townsend 1973).

Bast fibers are recovered by submerging bundles of stems in water for an appropriate period of time. Hussain and Ahmad (1965) reported that soaking for 25 days, then drying and hand-peeling the bast, resulted in a bast yield about 9 percent of the total stem dry weight. Shorter soaking times such as 2 weeks as mentioned by Uppal (1955) are probably adequate. Medvedev (1936) reported fiber recovery by a process referred to as heat maceration. Stem samples, depending upon the stage of growth, were macerated at 35-37°C for 4-9 days. Mature stems harvested during seed ripening stage required the longer maceration period. Specific details of the process were not given. Fiber yield was 6-7 percent of the air-dry weight of stalks. In India, Maiti (1980) reported a fiber yield of 9 percent of S. bispinosa whole plant weight. He reported that the S. bispinosa fibers were of poor quality and low yield compared to jute (Corchorus spp.), Hibiscus spp., and Urena spp. which had bast fiber yields ranging between 26 and 49 percent of stems.

The actual extent of use of these plants as fiber resources for string and cordage is unknown. The species are widespread in the tropics and subtropics. This use of their fibers is a local phenomenon more in the realm of ethnobotany than of economics, uncatalogued except for instances such as in India where some small commercial importance has developed. Because of expanded availability of synthetic fibers, the potential for use of sesbania fiber for cordage is probably rather small.

SESBANIA FOR PULP FIBER

The use of stems for pulp manufacture has better probability for future development and increases the number of potentially useful species to include other partly woody annuals as well as perennials such as S. sesban and S. grandiflora. S. bispinosa, a fast growing annual, has been the species of principal interest as a commercial pulp fiber crop.

Technical papers on pulping characteristics of S. bispinosa and other sesbanias have been published by workers from several institutions including: a) the Indian Council of Agricultural Research's Jute Technical Research Lab, Calcutta (Mazumdar et al. 1973); b) the Parkhe Research Institute, Khopoli, India (Pai et al. 1980); c) Australia's Council of Scientific and Industrial Research (CSIRO) (Wood and Gartside 1981); and d) the Pulp and Paper Branch of the Forest Industries Division, Forestry Department, Food and Agriculture Organization of the United Nations (FAO) (Markila, 1979). Other fiber testing for pulp manufacture has been done in northern Pakistan by L. Markila in 1961, in Scandinavia in 1963 (FAO 1979), and in Detskoye, USSR (Medvedev 1936).

Properties of sesbanias relevant to pulping qualities are given in Table 7.1. Values for bulk density in Table 7.1 are generally higher than those found in field experiments with annual Sesbania species in Hawaii (Evans and Rotar, unpublished data). Bulk density of accessions grown at a population of 125,000 stems/ha (20 x 40 cm spacing) was measured at maturity with sections sampled at the gravitational midpoint of stems trimmed of branches. Among 32 accessions sampled, average bulk density was 215 kg (bone dry)/m^3, with a range of sample means from 158 to 284. This disparity with other published data indicated a need for further investigation of varieties and their interactions with climate and agronomic factors which affect pulpwood qualities.

Trial plantings either to select suitable sesbanias for pulpwood or to manage *S. bispinosa* as a plantation crop were made by several institutions including: a) the Ayub Agricultural Research Institute, Lyallpur, Pakistan (Hussain and Ahmad 1965); b) U.S. Department of Agriculture (Jones and Wolff 1960); c) the USSR's All-Union Scientific Research Institute of Plant Growing (Medvedev 1936); d) Sandwell Paperconsult in southern Italy in 1963-1964 (unpublished); e) CSIRO (Wood 1976); f) UNFAO in cooperation with the Italian Ente Nazionale per la Cellulosa e per la Carta at sites in Casalotti, Rome and Catania, Sicily in 1979; and g) The Parkhe Research Institute at Khopoli, at Pune, Maharashtra, and at Fort Songadh, Gujarat, India. Recent observation and selection plantings were made by CSIRO at Lawes, Queensland (I.M. Wood, personal communication), and by the Department of Agronomy and Soil Science, University of Hawaii, at Waimanalo, Oahu, Hawaii (Evans and Rotar, unpublished data).

RECORDED UTILIZATION OF SESBANIAS AS PULPWOOD

In a review on the multiple potentials of *S. bispinosa*, Hussain and Ahmad (1965) stated that a paper mill in (West) Pakistan was using it after its main raw material, "sabai" or "baib" grass (*Eulaliopsis binata*) ran short. *S. speciosa* was imported and was under consideration as a replacement for *S. bispinosa*, which was said to be "too fibrous and woody," perhaps because the monosulfite pulping process used by the mill to pulp reeds was too mild for woody material. Pai *et al.* (1980), in a report to the TAPPI Non-wood Fiber Conference referred to commercial scale plantations of *S. bispinosa* as a pulp fiber source for full-scale trials at the Central Pulp Mills, Fort Songadh, Gujarat, India. Dutt *et al.* (1983) mentioned that *S. sesban* was being sown on a plantation scale in India, and that the West Coast Paper Mills at Dandeli, Karnataka,

TABLE 7.1
Selected stem properties of *Sesbania* species used for pulp fiber

Characteristic	Unit	Value	Species	Fraction	Reference
Bulk density,	kg/m^3	300	bispinosa	stem	FAO 1979
		240-320	"	"	Pai *et al*. 1980
		616	cannabina	"	Razzaque *et al*. 1971
		356	grandiflora	"	Logan *et al*. 1977
		512	"	"	Bhat *et al*. 1971
		420	"	"	NAS 1980
		432	sesban	"	NAS 1983
Fiber length,	mm	2.0	bispinosa	bark	Mazumdar *et al*. 1973
		2-4	"	"	Sircar 1948
		1.36-2.53	various spp.	"	Wood & Gartside 1981
		0.55-0.84	"	core	Wood & Gartside 1981
		0.96	bispinosa	pulp	NAS 1976
		0.6-0.7	"	"	Pai *et al*. 1980
		0.793	"		Razzaque *et al*. 1971
		1.07	grandiflora	pulp	Bhat *et al*. 1971
		1.1	"	"	NAS 1979
		1.14	"	"	Logan *et al*. 1977

Lignin, %	20-22	bispinosa		FAO 1979
	21.1	"		Pai *et al*. 1980
	16.3	"		Mazumdar 1973
	16	various spp.	core	Wood & Gartside 1981
	21	grandiflora		Bhat *et al*. 1971
Cellulose, %	45-46	bispinosa		FAO 1979
Holocellulose, %	77.2	"		Pai *et al*. 1980
	85.24	"		Mazumdar 1973

and the Andra Pradesh Paper Mill at Rajahmundry reported yields of 50-55 Mg/ha green wood per year under irrigated conditions.

In Indonesia, S. grandiflora (locally called "turi") has been used as a commercial pulpwood source in East Java. According to Dr. Roehyati Joedodibroto of the Institute for Research and Development of Cellulose Industries, Bandung, Indonesia, (personal communication, 1984), a mill at Banyuwangi has been using turi in mixture with bamboo, sources of which are becoming rapidly depleted. Turi is obtained from farmers throughout East Java, where it is grown on rice field dikes and bunds and the foliage is fed to livestock or used as green leaf manure. Trial plantations of this species near the mill site were not successful, possibly because of inadequate rainfall. An economic analysis of the establishment of these plantations was made (Sriyanto 1978), but was not available for review.

ESTIMATED WOOD YIELDS OF SESBANIA SPECIES

One of the first records of stem yields of S. bispinosa was a measurement taken in a farmer's field at harvest time in November, 1961, in northern Pakistan: a yield of 15 bone dry Mg/ha was estimated (Markila 1979). In trials in southern Italy using seed imported from Pakistan, yields were 14 bone dry Mg/ha. Most other published yield information on sesbanias concerned fresh yield of succulent green manure or fodder materials.

In Hawaii, over 30 accessions of annual Sesbania species were tested for productivity during a 14-week growth period in the summertime (Evans and Rotar, unpublished data) (Figures 7.1 and 7.2). Twenty-three of the entries were categorized as high yielding varieties, with total dry matter yields greater than 10 Mg/ha and nitrogen accumulations greater than 150 kg/ha; these had a mean of about 13 Mg/ha dry matter and a maximum of 17 Mg/ha (bone dry weights are approximately 10 percent less). There was an average of 53 percent (a range of 24-84 percent) of their dry matter in the stem fraction at harvest, with a resulting average of 9.25 Mg/ha dry matter in the stem fractions. Most of the accessions in this group were those received as S. bispinosa or its close relatives S. cannabina and S. sericea; others were S. emerus and S. exasperata from South America, S. simpliciuscula from Australia, and S. rostrata from Africa.

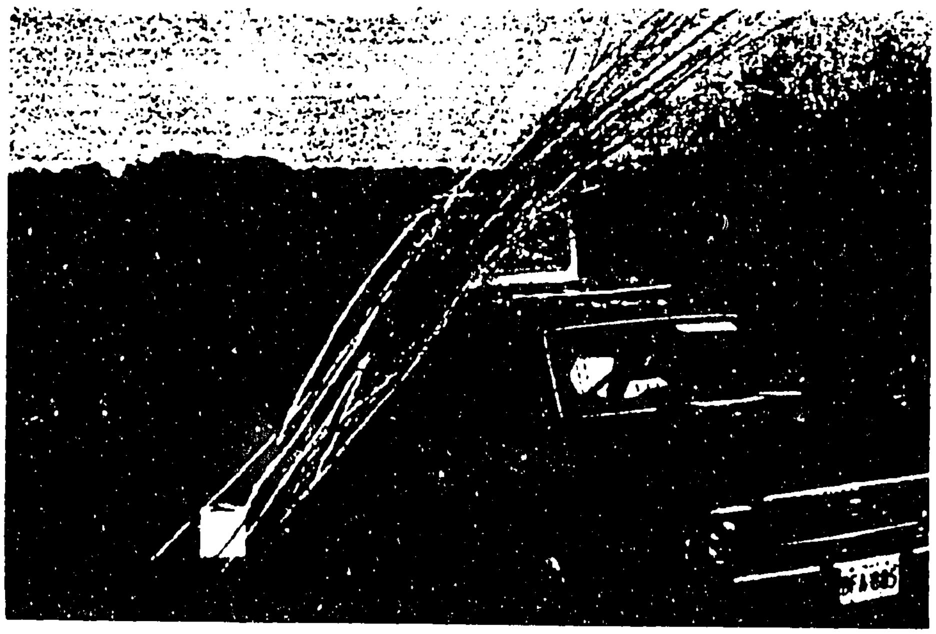

Figure 7.1 Stems of annual Sesbania species harvested and stripped of side branches and leaves after flowering.

S. grandiflora's yield characteristics have been studied recently because of this perennial's potential as a source of fuelwood as well as of pulpwood. Bhat et al. (1971) estimated that if it was planted at 12,000 plants/ha (90 x 90 cm spacing) and had 75 percent survival, in 3 years the trees will average 8 m in height and 8-10 cm diameter at breast height, and will yield 125 Mg/ha air-dry wood. In Indonesia, wood yields of 20-25 m^3/ha per year were obtained (NAS 1980). S. grandiflora was studied with other nitrogen fixing trees in yield trials in Hawaii, (MacDicken 1983). In these experiments at four sites, best performance was obtained with Leucaena spp., but S. grandiflora exhibited rapid early growth and equaled at least one of the Leucaena spp. in wood volume at every site at one year from transplanting of seedlings. At that time, the average height of S. grandiflora was 3.3 m, its mean basal area was 24.5 cm^2, and its mean estimated wood volume was 24.6 m^3/ha (values were 24.3, 56.8, 19.6 and 5.5 m^3/ha) for

Figure 7.2 Annual Sesbania species grown in an accession yield trial in Hawaii (27 m above sea level). The boy, standing in a harvested area, holds a 2-meter rod to indicate the height of plants left in the border rows. Stems were spaced at 20 x 40 cm for a plant population of 125,000 plants per hectare. Plants were 14 weeks old and most entries were in the flowering or preflowering stage.

the four sites. Further data on this tree's performance will be forthcoming because of increasing worldwide interest in fast growing trees, including the expansion of these species trials into an international network of sites by the Nitrogen Fixing Tree Association (P.O. Box 680, Waimanalo, Hawaii 96795 USA).

Expected wood yields of S. sesban are not well known. Members of this species complex are generally very fast growing, making it an appropriate candidate for further research. One limitation is that, like S. grandiflora, its wood is rather light and it therefore may not be appropriate for other than short haul transport. One source mentioned yields of "30 tons per acre" obtained in one year in India (NAS, 1983). Dutt et al. (1983) reported that green wood yields of 50-55 Mg/ha per year were obtained under irrigation in trials by Indian pulp mills. In plantings in Jammu (subtropical, elevation 300 m, 1000 mm rainfall), Dutt obtained 17.8 Mg/ha dry wood in one year, and a 3-year old planting was estimated to contain 77 Mg/ha dry wood. Early growth was quite rapid: mean plant height at 15 months was 6.7 m and mean diameter at breast height (Dbh) of 7.1 cm recorded at three sites was 89 and 84 percent, respectively, of the values obtained at 24 months.

Subsequently, Dutt and Pathania (1986) reported preliminary results of a spacing trial with S. sesban. Plant spacing varied from 0.5 x 0.5m to 2 x 2m, producing populations ranging from 2,500 to 40,000 plants/ha. Their observations of tree height and Dbh and their estimates of wood volume at 6, 18, and 30 months after planting are summarized in Figure 7.3. Plant heights and stem diameters increased with increasing distance between plants, but tree volumes per hectare increased as spacings became closer.

These data on tree height confirm our observations in Hawaii, where specimen trees reached a maximum height of 7-9 m. As increases in height level off, increases in Dbh continue (see Figure 2.4). The growth volumes reported by Dutt and Pathania (1986) are high. Fast growing fuelwood trees are frequently categorized as having wood volume production in excess of 20 m^3/ha per year. S. sesban's growth rates indicate particular promise for fuelwood or pulpwood production. Profuse branching (see Figures 2.2 and 2.4) and rapid branch regeneration after lopping or pollarding (high pruning) suggest cutting management options to increase productivity of S. sesban.

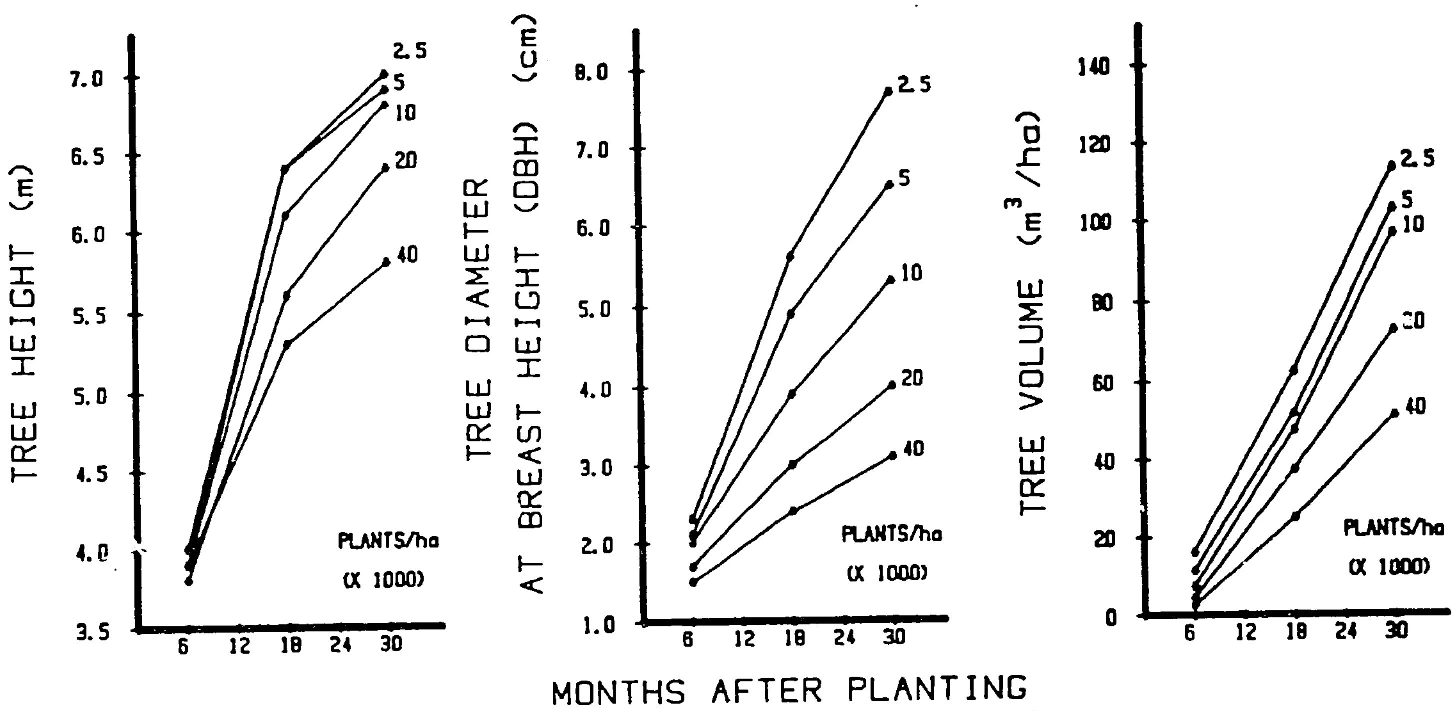

Figure 7.3 Effect of plant population on growth and wood production of <u>Sesbania sesban</u> (adapted from Dutt and Pathania 1986).

TECHNICAL LITERATURE ON PULPING S. BISPINOSA

Laboratory experiments on pulping and paper making with S. cannabina were reported by the Forest Research Institute, Chittagong (Razzaque and Siddique 1971). The near synonymy of this species with S. bispinosa, coupled with general nomenclatural confusion on the part of most nonbotanists, supports the assumption that pulping characteristics of their test plant and the "S. aculeata" or S. bispinosa of other authors are similar if not identical. They prepared pulps by kraft, neutral sulfite semichemical (NSSC), and hot soda processes. The cold soda process was found ineffective because the low-density material floated and resisted chemical impregnation. In general, as chemical consumption increased, yield decreased; tear factor also decreased and burst factor, breaking length, and folding endurance increased. Longer pulp beating times resulted in lower freeness values and decreased strength properties. The kraft pulp at 250 ml Canadian Standard freeness compared well with tropical hardwood pulps and with birch in regard to chemical use, yield, and strength. The kraft pulp was considered adequate for wrapping, printing, and writing grade papers, and the NSSC pulps produced superior grade glassine papers.

Pulping characteristics of S. bispinosa stems were reported by L. Markila (1979). Markila's tests, conducted in 1961 in Pakistan, described a material having low density, and delignification and pulping chemical consumption similar to hardwoods. The pulps also had good bleachability. More extensive, unpublished testing by a Scandinavian research institute confirmed Markila's findings and indicated similarity between S. bispinosa pulp and birch pulps (Markila 1979).

An extensive laboratory evaluation of S. bispinosa pulp was reported by Rai et al. (1980). They presented data from research by the Parkhe Research Institute on pulping, bleaching, beating, sheet making and sheet testing, and on black liquor characteristics. The wood also had low chemical requirements for pulping and bleaching, equal to or slightly less than those for bamboo and Indian tropical hardwoods. The bleached pulp had high brightness stability. Pulp yields were comparable to bamboo and superior to tropical hardwoods. Because of the lightness of the wood, it was easily chipped and was judged to be more adaptable to continuous than to batch digestion processes because of low digester yields per batch loading. Fast beating times of pulps preserved tear strength and opacity and in addition conserved beating energy. Tear index was improved by blending with longer-fibered pulps; this appeared necessary in order to run the material on high speed paper machines. Blending of the black liquor with liquors from bamboo or softwood was desirable to improve evaporation and chemical recovery furnace burning characteristics.

A mill-scale trial run was carried out in 1980 at the Parkhe Organization's Central Pulp Mills in Fort Songadh (unpublished information). The trial run was based on materials from the previously mentioned trial plantations. In this trial debarked S. bispinosa was the sole fiber supply; printing and writing papers were produced. Results were encouraging and confirmed earlier laboratory test results. The strength factors of the papers produced were comparable to those of the bamboo-based papers normally produced in the mill. Even the tear strength was close to that of bamboo papers. This could be explained by the fact that S. bispinosa plants were pulped with all branches, in which long-fibered bast fiber content is proportionally higher than in the stems used in the laboratory tests. Black liquor characteristics could not be checked because the liquor was mixed with bamboo black liquor from preceding mill operations.

TECHNICAL LITERATURE ON PULPING S. GRANDIFLORA AND OTHER SESBANIA SPECIES

Extensive laboratory data on pulping of S. grandiflora were published by Bhat et al. (1971); their institution was not mentioned. They reported on the preparation and bleaching of conventional kraft, NSSC, and cold caustic pulps. Because of high initial brightness of the wood, the production of high pulp yield with moderate strength properties and medium brightness was pers ed, with favorable results from the NSSC and cold caustic pulping methods. Optimal cold caustic pulping involved presteaming at 140°C for 15 minutes and soaking in 7 percent caustic at 45-50°C for 2 hours, resulting in 80 percent pulp yield. Strength properties of both laboratory- and pulping plant-produced S. grandiflora cold caustic pulp mixed with bamboo chemical pulp in the range from 0 to 100 percent were reported. Mixtures with 40 percent S. grandiflora pulp were suitable for inexpensive grades of printing, writing, and magazine papers. Pulping research on S. grandiflora in Indonesia has shown that a medium strength, bleachable pulp can be obtained at yield levels of 45 percent by cooking with 15 percent active alkali at 22 percent sulfidity (R. Joedodibroto, personal communication).

S. grandiflora was also considered as a pulpwood source for northern Australia (Logan et al. 1977). Material tested was 4.5 years old, required debarking, and gave "moderately low" yields of sulfate pulp, suitable for "a limited range of...products" including bleached paper grades. Paper making quality data given included tear indices and breaking lengths for materials from NSSC and bleached and nonbleached sulfate pulps, and breaking lengths and crush resistances of NSSC materials at varying freeness values. Pulp obtained by NSSC process was found to be suitable for corrugating medium (at Kappa numbers of 120 to 130), although "severe" cooking conditions were required for adequate delignification. Vessel picking and surface roughness tests on handsheets indicated possible use in production of printing papers. S. grandiflora was compatible with kenaf for co-pulping by the sulfate process; the resulting pulp's drainage rate improved in proportion to the admixture of sesbania pulp, without any decrease in strength properties.

A number of other Sesbania species were recently considered for pulpwood production by CSIRO, Australia. Results of research at the Division of Chemical Technology in Melbourne were reported for seven species including S. cannabina, S. sesban, S. tetraptera, S. simpliciuscula, S. pachycarpa, and S. marginata. Stem core and bark fractions were analyzed separately, but pulping of whole, unseparated stems was recommended. Pulps were prepared by the soda process; drainage times were similar to commercial hardwood pulps but pulp yields were termed low. The S. sesban and S. cannabina accessions tested were designated as having potential as pulpwood crops based on their agronomic characteristics and their physical and chemical pulping properties (Wood and Gartside 1981).

8
Sesbania Species as Sources of Gums

Many Sesbania species produce both bark and seed gums which have potential value for industrial purposes. Natural gums, or mucilages, are complex polysaccharides which have a wide range of uses. Their varying physical properties are attributed to differences in the degree of branching and polymerization of the sugars. In food processing, gums lend stability and smoothness of texture to products by emulsifying, thickening, stabilizing, and binding the ingredients. Examples of food products containing gums include ice cream, candy, soft drinks, beer, pastries, and heat-and-serve convenience foods. Gums are also used in manufacture of paper, textiles, and paints, in well drilling, and in mineral assay.

BARK GUMS

Some Sesbania species exude gum from their bark when cut or damaged. This feature is particularly notable in S. grandiflora and the closely related S. formosa; it is also present in S. sesban and other species. These gums when first exuded are red or white tinged with red; they become dark red-violet after exposure to air and hardening. Burkill (1935) cited West and Brown as stating that S. grandiflora bark gum is similar to gum arabic. De Sornay (1916) stated that the gum dissolves in water, floats in alcohol, and that the pigmentation could be separated into two principles: a red "agathin" and a yellow "xantho-agathin." Burkill mentioned that these gums were not known to be collected in Malaya. A U.S. National Academy of Sciences report (NAS 1979) stated that sesbania bark gums have been used as substitutes for gum arabic, and suggested that with increasing scarcity of this substance as derived from Acacia senegal, sesbania bark gums should be investigated.

SEED GUMS

The best source of gum from sesbanias is the gum contained in their seeds. Export of seeds for gum extraction has been a source of foreign exchange in Pakistan and India, based on the international demand for gums from seeds of guar, Cyamopsis tetragonoloba, a plant adapted to semi-arid tropical and temperate zones (Whistler and Hymowitz 1979). Pakistan's first processing plant to produce guar endosperm splits, thereby reducing shipping volume, was established in 1955. About the same time, the Ayub Agricultural Research Institute in Pakistan began to consider alternative gum sources, including the sesbanias S. sesban and S. bispinosa (Hussain and Ahmad 1955; Hussain and Khan 1962a and b). More recently, India's National Botanical Research Institute at Lucknow nominated S. bispinosa as a gum source worthy of consideration (Chandra and Farooqi 1979). The U.S. National Academy of Science included that species among a number of legumes with potential as gum producers (NAS 1979). Very little published information is available on sesbania seed gums. Despite a diversity of species in the genus, few species other than those mentioned above have been considered.

Endosperm tissue of legume seeds is generally absorbed during seed maturation into the developing cotyledons and only a thin remnant remains in the mature seed. In some legume seeds such as those of guar and S. bispinosa, the endosperm is not so fully absorbed, and constitutes a sizeable portion of the seed. The endosperm portion of S. bispinosa seed is stated to be in the range of 30 to 42 percent, about 75 percent of which is galactomannan (Chandra and Farooqi 1979). This range agreed with data reported by Hussain and Khan (1962b) who found 33-36 percent gum content in S. bispinosa seed samples from six regions in Pakistan and slightly less gum (31-32 percent) in S. sesban. They reported that the endosperm consisted of about 90 percent extractable N-free carbohydrate, and yielded 85-80 percent galactose and mannose in a ratio of about 1:4.7.

Anderson (1949) estimated endosperm percentages of a large group of North American legume seeds by cutting through mature seeds and recording approximate proportions of endosperm. He obtained the following values for sesbanias: 20 percent for S. cannabina, S. exaltata, and S. macrocarpa (the latter two being synonyms); 10 percent for Daubentonia drummondii; 15 percent for D. punicea; and 2 percent for Glottidium vesicarium. Extraction of soluble mucilage from S. macrocarpa seed by boiling whole seeds resulted in a yield of 18 percent of the total seed. In his study, guar had 50 percent endosperm by visual estimation and 42 percent endosperm by mechanical separation. Tookey and Jones (1965) reported on extracted gum proportions in American sesbanias. They found about 10 percent N-free gum (i.e., protein removed) in S. drummondii, S. exaltata, and S. macrocarpa, 13.8 percent in S. sonorae (=S. exaltata), and 8.7 percent (crude basis) gum in S. vesicaria; guar seeds had 22-25 percent N-free gum. S. cannabina seeds were analyzed for gums along with other legume seed gum sources found in China. They were found to contain 33.5 percent endosperm (Li et al. 1980); the gum's chemical structure was investigated (Anon. 1978).

S. grandiflora seed gums were examined and their chemical characteristics elucidated in detail by workers at the Central Food Technological Research Institute at Mysore, India (Rao and Rao, 1965), and later at the Ahmedabad Textile Industry Research Association (Srivastava et al. 1968). According to these investigators, gums were associated with the tegmen, or inner seed coat, and constituted about 20 percent of the weight of mature seeds. Water soluble polysaccharide in the gum was over 90 percent galactomannan with a D-galactose:D-mannose ratio of 1:2. Li et al. (1980) found the same ratio in S. cannabina. Rao et al. (1980) studied seed gums in S. speciosa which contained galactose and mannose in a ratio of 1:2.2. For both species examined, hydrolysis of the fully methylated polysaccharide yielded 2,3,4,6-tetra-O-methyl-D-galactose, 2,3,6-tri-O-methyl-D-mannose and 2,3-di-O-methyl-D-mannose, in equimolar proportions for S. grandiflora and in 1:1.1:1 ratio for S. speciosa. Farooqi (1976) reported values for S. sesban and S. grandiflora seed of, respectively, 25.9 and 24.6 percent endosperm, 16.2 and 14.0 percent mucilage, 23.4 and 23.7 percent protein, and 1:1 and 2:3 galactose: mannose ratios.

A technical report on gum physical properties originating from Lucknow (Kapoor and Farooqi 1979) stated that seed gums extracted from S. bispinosa endosperm were readily soluble and easily dispersed in water; hydration was complete in one hour with stirring. Solution concentrations of 1 percent had viscosities of 400 centipoises (cP), rated low, but concentrations of 2 percent gum produced solutions with viscosities in excess of 3000 cP. The nonionic gum showed stable viscosities below pH 9.0, but above that level gelling began and viscosity rose sharply. Fluxes in viscosity resulting from shifts of solution temperature were stated to be indicative of unusual properties. The gum was judged to be similar to other commercial gums such as guar and carob (Ceratonia siliqua). These authors also examined the interaction of sesbania galactomannan gums with bacterial xanthan gums. The maximum viscosities of the gum solutions were obtained with gums of guar and sesbania mixed with xanthan gum in ratios of 8:2 and 7:3, respectively (Kapoor and Farooqi 1982).

Huang et al. (1980) in the Peoples Republic of China investigated the physical chemistry of gum from seeds of S. cannabina. Isolated and purified gums were found homogenous after ultracentrifugation. Data were presented which showed trends in variation with gum concentrations of values for sedimentation coefficient and reduced viscosity of gum solutions obtained from both alcoholic purification and copper alcoholic purification. The former purification had a molecular weight of 391,000, while the latter had a mw of 206,000 and correspondingly lower values for intrinsic viscosity and sedimentation coefficient.

SEED YIELDS

Hussain and Khan (1962a), in Pakistan, reported S. bispinosa seed yields of 1.5 Mg per ha. Yields in this range and greater are obtained by taking one or more top cuts during the vegetative growth period to stimulate branching: floral racemes arise from branch axils. In a farm-scale economic analysis for India conditions, Chandra and Farooqi (1979) set 1 Mg/ha as a minimum yield. This appeared to be based on earlier work at Lucknow, where on saline-alkali lands of soil pH 8.9, S. bispinosa sown at 75 x 45 cm produced an average of one Mg/ha seed over two seasons of experiments with different sowing dates and N and P fertilizer levels (Misra and Singh 1976). The value of stems as fuelwood accounted for one-third of the gross profit. Their analysis did not include cost of an early cutting to stimulate seed production nor the value of the material thus obtained as fodder or as green leaf manure. Such a practice might result in reduced yield of fuelwood, but if it increased the yield of the less bulky and more easily handled seed component, it would be worth consideration. At Varanasi in India, on a sandy loam soil, R.G. Singh (1971) obtained an average seed yield of 2 Mg/ha (and a maximum of 2.5 Mg/ha) when phosphorus was applied. Stem yields averaged about 15 Mg/ha, and the average yield ratio of harvested stem to seed was 6.5.

These seed yields for S. bispinosa were similar to yields found in seed increase plantings in Hawaii. At low plant populations and without management to enhance seed production, yields equivalent to approximately 1.5 Mg/ha were obtained for accessions of S. cannabina from Australia, S. macrantha from Africa, and S. sesban from Egypt (Evans, unpublished data). There is obvious scope for consideration of other Sesbania species or for selection or breeding of varieties having higher seed yields, lack of pod shattering upon drying (a problem with S. bispinosa), higher galactomannan content, lower tannin content, resistance to pod pest infestation, and response to cutting management designed to increase seeding. Seed yield under varying planting dates, where possible, should be considered, since many annuals have different growth forms under flowering-inductive and non-flowering-inductive daylength conditions. Misra and Singh (1976) found higher yields for sowings in June than earlier (April-May) or later (July) in India, but differences there appeared to be caused by seasonal climatic variations in temperature, rainfall, and winds.

SEED HARVESTING

There were no references to machine harvesting of Sesbania seeds. Presumably, the seed used to sow India's green manure crops is harvested by hand. Many species, including the green manures S. cannabina and S. exaltata, have pods which open readily after pod maturity. This dehiscence makes seed recovery by machine difficult. Some writers have suggested that a seed crop should be harvested when half of the pods are mature. In this way, only the most mature pods may shatter when roughly handled, the majority of the almost-mature seed can be sun dried and recovered, and only the immature seed will be lost. Since some annual species' seed pods turn from green to purple to brown as the pod matures, determining the time for harvesting the seed crop is easy. In India, S. bispinosa seeds were found to be physiologically mature at 40 days after anthesis and to be "harvestable" at about 60 days (Selvaraj and Ramaswamy 1984). After the 30th day, pods began to split open and shed seed.

S. speciosa and S. grandiflora are examples of species whose pods do not readily dehisce. Separation of seed from pods can become a problem with some of these species. S. speciosa pods open quite readily when force is applied along the pod suture; S. grandiflora pods open slightly less readily. Pods of some Sesbania species are indehiscent. Included in this group are the Hawaiian species and some from South America such as S. emerus and S. marginata.

CO-PRODUCTS OF SESBANIA SEED GUMS

S. bispinosa seed gums can be a marketable product; the adaptability of the plant and the presence of co-products make its seed production yet more attractive. It can be grown on lands affected by soil alkalinity and salinity; an estimated seventeen million hectares of these lands are left uncropped in India (Chandra and Farooqi 1979); when sown in such areas it will not compete with cropland. The value of its stems for fuelwood has been noted. An additional potential exists for utilization of the remainder of the seed after removal of the endosperm, in cases where such processing is done locally.

The whole seed consists of the seed coat testa (sometimes referred to as "husk"), the endosperm containing the gum, the cotyledons, and the germ (embryo, plumule, and radicle). Sometimes the terms "kernel" or "meal" are used to describe the fraction that is neither seed coat nor endosperm; sometimes the term "seed meal" refers to the entire residue after removal of the endosperm, i.e. the kernel plus the husk. Table 8.1 summarizes analytical data on S. bispinosa seeds and seed fractions. Kapoor et al. (1979) reported on the fatty acid composition of S. sesban seeds.

Seed meals were considered in Pakistan as substitutes for peanut meal as an ingredient in culture media for growth of penicillium. Seed byproducts from guar processing were not suitable, but those from S. bispinosa appeared to be usable in the range of 3.5 to 4 percent of the media mixture (Hussain and Ahmad 1955). However, no information on this type of use has subsequently been published.

S. grandiflora seed proteins were considered among other plant seeds in a search for vegetable adhesives for plywood manufacture and related uses (Narayanamurti 1957). High protein contents were found, and about half of the protein nitrogen was extractable with water, compared to 75

TABLE 8.1
Feed analyses of *Sesbania bispinosa* seed fractions

Fraction	Ref.[a]	Percentage of Seed	Percent: Protein	Fiber	NFE	Fat	Ash	Ca	P
Seed coat	1	20	8	46	44		8.4		
	2	16-20	16	25	4	0.5	4.5		
Endosperm	1	33	6	7	90		1.2		
	2	30-42	16	2	73	0.7	0.6		
	3	25							
Kernel	1	45	58	4	27		4.6		
	2	42-46	61	8	19	7.0	4.1		
	3		51	8	30		3.5	0.20	0.67
Whole seed	1	100	27	13-29	50	4.2	3.3-5.4	0.44	0.99
	3	100	32	11	48		4.1	0.15	0.47
Seed meal	2		43	11	17	6.5	4.2	0.50	0.90

[a] Reference 1 values from Hussain and Khan (1962a); the same % seed fractions were reported by Li *et al.* (1980) for *S. cannabina*.
Reference 2 values from Chandra and Farooqi (1979).
Reference 3 values from Katoch and Chopra (1974a); they prepared "dal" by pounding seeds and winnowing to remove husk and about 43% of the endosperm gum.

percent for *Crotalaria juncea* which had the highest protein-nitrogen extractability of seeds tested. Additional analytical data was given but no conclusions were made as to the relative suitability of *S. grandiflora* seeds as a source of proteins for glue. Markila (1979) suggested that *S. bispinosa* seeds may be a source of adhesive gums for the paper making industry.

There is little information on the use of *Sesbania* seed meals in animal feeds. In mentioning feeding experiments which apparently used whole seeds, Hussain and Khan (1962a) reported that ground seeds were unpalatable to cattle, but in mixtures with cottonseed meal, wheat bran, and molasses, palatability was maintained with up to 33 percent ground seed in the feed. *Sesbania* seeds and seed meals have also been considered for poultry feed (Katoch and Chopra 1974a and b; see Chapter 9). Removal of the gum rendered the meal more acceptable as a part of a poultry ration. Before the potential of sesbania seed gum co-products can be estimated, further information is needed regarding the effect of including these seed meals in animal diets.

9
Nutritive Value of *Sesbania* Materials

Sesbania leaves, flowers, pods, and seeds are sources of animal feed and to a more limited extent are also sources of food for man.

USE AS FOOD

S. grandiflora is known in continental and island South East Asia for its large and edible flowers. Raw or lightly steamed, usually after removal of calyx and pistil, they are used as an ingredient of soups, salads, and vegetable dishes. The white flowers are preferred in the Philippines; the red flowers are bitter. The smaller flowers of S. sesban, yellow with purple specks, are sometimes eaten, included perhaps as a decorative or festive ingredient in foods such as omelettes. Young pods of S. grandiflora are eaten cooked as beans, picked when they are supple and less than 4 mm in diameter. Leaves are cooked as vegetables. In Sri Lanka, one method of preparation is to cook chopped leaflets with chopped onion in coconut milk, creating a vegetable component of a traditional rice-based meal.

Nutritional studies in India have used leaves of S. grandiflora in formulations with other vegetable protein sources in experiments with rats, and subsequently in experiments to supplement rice diets in college women (Bai and Devadas 1973 1974). S. grandiflora leaves were a good calcium source in rat diets (Devadata and Appanna 1954). The leaves have been used in experimental diets for young children in India. They were apparently less palatable than greens of Amaranthus species, being somewhat coarser and more bitter. Leaf vegetables in general had to be offered in mixture with other foods to be accepted (Gopaldas et al. 1973).

USE AS LEAF PROTEIN CONCENTRATE SOURCES

Sesbania species have been considered in India as sources of leaf protein concentrate (LPC). Matai and Bagchi (1974) in Calcutta compared legumes for leaf protein yield. They found that S. bispinosa grew rapidly and the first cutting produced high yields of LPC, like Crotalaria juncea; however, S. bispinosa had poor regrowth and yielded poorly under repeated cuttings. The authors stated that legumes which could be cut repeatedly at 3-4 week intervals, such as Medicago sativa and Trifolium alexandrinum, were preferable and had higher rates of extracted protein production: 7.3 and 4.9 kg/ha per day over 93 and 124 day periods, respectively, as compared to 4.2 kg/ha per day for S. bispinosa over 23 days, or 4.3 over 45 days for C. juncea. Height of cutting was not specified. Both S. bispinosa and C. juncea will regrow after cutting if the cut is at least 50 cm or more above ground and if it is taken during a vegetative growth phase; however, they may not stand repeated cutting. Experiments in Hawaii have indicated that with some annual sesbanias including S. bispinosa, two or three cuts may be taken during a summer crop (Evans and Rotar, unpublished data).

Several reports on S. sesban as an LPC source have been published as a result of research at Marathwada University in Aurangabad, India. Gore and Joshi (1976) obtained 40-52 percent extractable protein from S. sesban. When cut every 5-6 weeks it produced 4.3 kg/ha per day of extractable protein. Mungicar et al. (1976) compared S. sesban with M. sativa and 5 nonlegumes under various N fertilizer rates. S. sesban, cut 7 times per year, had a maximum dry matter production rate of 36.9 kg/ha per day and an extractable protein production rate of 4.0 kg/ha per day; M. sativa, cut 16 times, had about twice these rates. After 2 extractions (the second with added water), the remaining fibers from the legumes contained 10-17 percent crude protein, which was adequate as a maintenance diet for ruminants. Liquor obtained after leaf protein extraction from sesban was reported to be a suitable substrate for fungal growth, suggesting applications in production of antibiotics and fungal or single-cell proteins (Deshpande and Joshi 1971). Maximum protein extractability from S. sesban was related to the juice:fiber ratio; a higher juice content resulted in greater protein extractability (Gore and Joshi 1976). Batra et al. (1976) examined this relationship in greater detail and found that a delay of 4 hours between harvest and processing reduced extractable protein by 12-45 percent in the plant species examined. This reduction was lowest in S. sesban and highest in hybrid napiergrass. S. sesban's juice:fiber ratio (0.9 v./w.) was comparable to M. sativa's at harvest. When the plant materials were held for 24 hours before extraction, M. sativa's juice:fiber ratio dropped by 66 percent in 24 hours, while S. sesban's fell only 33 percent. The decline in extractable protein was less in S. sesban than in other crops tested. The authors obtained maximum extractable protein from cuttings taken early in the morning and minimum extractable protein from plants cut at midday.

Stage of plant growth was shown to affect LPC yields (Singh and Sharma 1981). Leaves of S. sesban sampled at preflowering (September to October), flowering (November to December), or postflowering (fruit setting) (February to March) had increasing dry matter (from 23.1 to 25.0 to 26.98 percent) and decreasing total N in the dry matter (from 3.10 to 2.86 to 2.60 percent). Among the three species studied (S. sesban, Madhuca indica and Millettia ovalifolia), S. sesban had the highest extractable LPC: the LPC dry matter contained 25 percent of the leaf dry matter, vs. 20.7 percent for M. indica and 17.2 percent for M. ovalifolia. All three species had highest LPC extractabilities in the preflowering stage. Extractable LPC in S. sesban fell to about 23 percent in the subsequent growth stages, a

TABLE 9.1
Protein analysis of Sesbania sesban leaf protein extract (adapted from Singh and Sharma 1981)

Growth Stage:	Pre-Flowering	Flowering	Post-Flowering
	percent (dry weight basis)		
Total N	5.77	5.22	4.96
Protein N	4.62	4.14	3.87
Lysine	1.07	0.88	0.84
Methionine	0.38	0.30	0.22
Ash	17.36	16.24	15.90

9 percent reduction compared to reductions of 8-12 percent for the others. These authors also reported lysine and methionine contents for sesban (Table 9.1). Another study on S. sesban LPC (Nazir and Saeed 1970) reported amino acid concentrations for threonine, isoleucine, phenylalanine, lysine, methionine, and triptophan of 2.8, 4.65, 15.7, 7.75, 4.5, and 6.75 percent, respectively. Kapoor et al. (1978) reported on alkanes, alkanols, and sterols found in the leaves, flowers, and pods of S. sesban.

USE AS ANIMAL FEED

Sesbania species have considerable potential as sources of animal feed. The perennial species are adapted to cut-and-carry harvesting methods and as such are amenable to the integration of fodder production into small farm systems. We are not aware, however, of any research or practice of large-scale production or mechanical harvesting of sesbanias for fodder.

Sesbania seeds have been considered as feeds (see the sections on seed gums and on antinutritional factors). Data on their nutritive value are presented in Table 9.2. It is unlikely that Sesbania seeds will become feed sources of any significance without their large scale development as gum sources, whereby large amounts of byproduct seed husk and kernel would become available.

Sesbania leaves are generally considered to be excellent sources of protein to supplement protein-poor roughages in ruminant diets. Nutritive analyses of various species are given in Table 9.3. These data were derived from materials found either in Asia or Africa. Data on the annual North American species S. exaltata, occurring widely across southern USA, is given in Table 9.4. The high Ca:P ratios during the reproductive growth period would be a hazard if such materials were used as a sole feed source.

Palatability, in general, does not seem to be a limitation. Natural stands of sesbanias in Africa are eagerly browsed by cattle (Gillett 1963). Endemic sesbanias in Hawaii are browsed by cattle, feral goats, and axis deer. S. bispinosa was palatable for rams in the feeding study of Katiyar and Ranjhan (1969). S. sesban was reported to be less palatable for cattle than for sheep and goats, which "relish it exceedingly" (Anon. 1924).

Studies on nutritional values of sesbania fodder have been conducted with small ruminants. Reports of their digestibility coefficients are summarized in Table 9.5.

Katiyar and Ranjhan (1969) and Chinnaswami et al. (1978) both used sheep (rams); the resulting values for digestibility were quite similar. In the latter study, young animals averaging 14 kg body weight consumed an average of 3.63 kg dry matter per 100 kg body weight per day. This was more than the value of 2.17 kg dry matter per 100 kg body weight consumed in the earlier study by adult animals averaging 45 kg body weight. In both trials, animals maintained or gained in body weight.

Chinnaswami et al. found positive N, Ca, and P balances. The fresh material fed contained 2.68 percent digestible crude protein (DCP) and 9.61 percent total digestible nutrients (TDN). The animals consumed 314 g TDN and 95 g DCP daily. Based on nutritional analyses and digestibility studies, the nutritive value of S. grandiflora was calculated as follows (as a percentage of dry matter): CP 16.89, EE 0.61, CF 13.01, NFE 30.52, TDN 61.80, and SE (starch equivalent) 47.40.

Katiyar and Ranjhan (1969) found positive N and Ca balances and a slightly negative P balance. The Ca:P ratio of the material fed was 4.0 (1.24/0.31). They found (as a percentage of dry matter) DCP 20, TDN 68, and SE 58.5. Singh et al. (1980) found somewhat higher digestibility coefficients when feeding S. sesban to 6- to 7-month-old Barbari goats weighing 7-9 kg. Although EE digestibility was low, N, Ca, and P balances were positive. Compared to feeding S. sesban free choice, supplementing the fodder with barley grain at approximately 20 percent of dry matter consumption resulted in increased weight gains, increased deposition of N in tissue, and increased digested N utilization efficiency, while dry matter consumption was equal for both regimes. Holm (1973a and b), using sheep, found that S. grandiflora fodder had a digestible protein content of 18 percent (dry matter basis) and SE 60 percent.

TOXICITIES AND ANTINUTRITIONAL FACTORS

A small group of Sesbania species containing toxic compounds in their seeds are classified as noxious weeds. These species are sometimes treated as distinct from Sesbania. Taxonomic treatments which place them within Sesbania assign them to the subgenera Daubentonia (S. punicea, S. drummondii) and Glottidium (S. vesicaria). S. vesicaria is an annual which occurs in the southern USA from the Carolinas through Florida to Texas. The other species are short-statured perennial shrubs whose range,

TABLE 9.2
Nutritive values of *Sesbania* species seeds

Species	CP	EE	CF	NFE	Ash	Ca	P	Ref.
S. bispinosa	32.7	2.9	10.7	48.7	4.9	0.37	0.59	(13)
"	36.4	6.9	12.1	43.1	1.5			(6)
S. sesban	21.2	2.6	8.5	60.5	7.2	0.44	0.68	(6)
S. grandiflora	36.5	7.4		51.6	4.5			(4)
" (tegmen)	17.5	0.8	2.7	65.4	1.3			(14)
S. cinerascens	21.7	4.8	12.2		2.9			(15)
S. mossambicensis	32.9	6.2	10.9		1.4			(15)

Notes: *S. grandiflora* seed tegmen was 20 percent of entire seed.
References: (see also Table 9.3) (13) Sen and Ray 1964, (14) Subramanian 1952, (15) Anonymous 1921.

TABLE 9.3
Nutritive values of *Sesbania* materials

Species	Fraction	DM	CP	EE	CF	NFE	Ash	Ca	P	Ref.
S. bispinosa	fodder	18.0	25.1	4.2	23.6	37.8	9.3	1.24	0.31	(9)
"	leaves	24.6	30.3	5.1	18.5	35.4	10.8	1.26	0.30	(9)
"	stem	12.3	15.6	1.9	39.4	35.5	7.6	0.90	0.39	(9)
S. sesban	fodder	19.7	19.5	3.0	33.0	37.1	7.5	1.42	0.09	(11)
"	leaves		26.0	2.6	14.4	49.4	7.6	1.11	0.27	(6)
S. sesban	"		26.5	0.9	12.2	50.4	10.0	2.75	0.43	(6)
"	fodder		17.4	3.0	26.0	38.4	9.3			(1)
"	fodder	31.8	17.5	4.2	28.0	13.2	8.1			(8)
S. macrocarpa			31.2					0.96	0.33	(2)
S. cinerascens	herbage		25.5	3.0	13.0	52.4	6.1	0.76	0.40	(12)
S. grandiflora	leaves	86.6	22.6	2.1	18.4	47.5	9.3	1.10	0.32	(5)
"	"	21.0	33.4	2.6	5.7	46.7	11.6	2.33	0.34	(6)
"	"	73.1	8.4	1.4	2.2	11.8	3.1	1.13	0.08	(4)
"	"	17.1	25.6	4.8	17.8			1.46	0.45	(7)
"	leaves[a]	16.3	26.0	4.9	17.6	42.8	8.6	1.32	0.47	(6)
"			37.3	5.5	6.4	41.0	9.8			(10)
"	fodder		21.4	3.4	22.7	44.5	8.1	1.52	0.28	(3)
"	pods	91.4	1.6	4.8	32.7	54.4	6.5			(6)
"	flowers	11.1	15.1	1.8	13.2	63.4				(6)
"	"	87.4	1.8	0.6	1.0	8.6	0.6			(4)

DM = dry matter, CP = crude protein, EE = ether extract, NFE = N-free extract
[a]Values are means for leaves picked at various ages during wet and dry seasons.
References: (1) Anonymous 1924, (2) Bosworth *et al.* 1980, (3) Chinnaswami *et al.* 1978, (4) CSIR, (5) Devendra 1979, (6) Gohl 1975, (7) Hutagalung 1981, (8) Kahn 1965, (9) Katiyar and Ranjhan 1969, (10) Ranjhan 1980, (11) C. Singh *et al.* 1980, (12) Verboom 1965.

TABLE 9.4
Forage quality of _Sesbania exaltata_ (after Bosworth _et al_. 1980)

Growth Stage	DMD	CP	Ca	P	Mg	K	Ca/P	K/(Ca+Mg)
	----------	----------	----------	Percent	----------	----------		
Vegetative	70 a	31.2 a	0.96 a	0.33 a	0.34 a	3.7 a	2.9 b	1.26 a
Flowering	66 a	13.9 b	1.02 a	0.16 b	0.29 b	2.3 b	7.0 ab	0.78 b
Fruiting	52 b	11.2 b	0.92 a	0.11 b	0.22 c	1.4 c	9.3 a	0.59 c

Note: DMD = in vitro dry matter digestibility; CP = crude protein.
Any two means within a column followed by the same letter are not significantly different at the 5 percent level according to Duncan's Multiple Range Test.

TABLE 9.5
Digestibility coefficients of Sesbania materials in several studies

Sesbania species:	bispinosa	sesban	grandiflora
Feeding period (days) (preliminary, sampled)	15,7	45,7	10,7
Animal:	adult rams[a]	kid goats[b]	adult rams[c]
Dry matter	74.0	69.53	65.65
Crude protein	82.1	80.80	79.03
Ether extract	33.9	13.58	18.24
Crude fiber	63.7	56.13	57.30
N-free extract	75.9	67.82	68.60

References: (a) Katiyar and Ranjhan 1969, (b) Singh et al. 1980, and (c) Chinnaswami et al. 1978.

with the exception of S. drummondii, extends from the southern USA to South America. S. punicea has been recently reported in South Africa. S. marginata, occurring with S. punicea in Argentina, was reported to have toxic seeds (Roseveare 1948), but recent feeding trials with chicks were inconclusive (Williams 1983).

Poisoning by these species occurs when animals are introduced onto new lands and browse indiscriminately, or when desirable forage is reduced during winter months. Animals usually do not browse these plants when other forage is available. During the wintertime, however, when forage is scarce, animals will eat the branches of these plants along with the attached seed pods. Sometimes consumption of the plant by one animal will lead others in the herd to eat it also, thereby causing multiple poisonings (Nuessle and Lauter 1958). These plants often occur in dense stands in low lying, moist soils. Up to 500 kg of seed of S. drummondii was easily harvested for research use with a combine from a stand in Texas (R.G. Powell, personal communication).

Kingsbury (1964) reviewed research on the toxicity of American species of Sesbania. Experimental feedings verified toxicity in chicks, fowl, sheep, cattle, and cats. Poisoning was observed under natural conditions in goats, hogs, and pigeons. Twenty-five cattle in one herd were poisoned by S. vesicaria; 0.45 kg of its seed killed a 300 kg steer (Nuessle and Lauter 1958). Experimental feedings with cattle have demonstrated the lethal dosage to vary from 0.15 to 2 percent of body weight. Hens have died from eating as few as nine seeds of S. punicea. In sheep, S. drummondii seed was lethal at 0.1 percent of body weight. Boughton and Hardy (1939) reported that serious poisoning in sheep resulted from feeding S. vesicaria seed at 0.015 percent of body weight, and when fed at 0.06 percent, death occurred within 12 to 24 hours. Duncan et al. (1955) fed mice and chicks with a variety of legumes found in southeastern USA. Seeds of S. punicea and S. vesicaria were toxic. Leaflets of S. vesicaria and leaflets and seeds of S. exaltata were nontoxic. Flory and Hebert (1984) studied the toxic effects of S. drummondii seeds fed to chickens. They associated toxicity with kidney damage but did not identify a specific toxin or a mechanism of action for toxicity.

Toxic compounds are found in seeds of Sesbania species in the subgenera Daubentonia and Glottidium. Toxicity has not been reported in seeds of species of the subgenus Sesbania which contains the majority of the species in the genus, nor in the subgenera Agati, or Pterosesbania which contains S. tetraptera and S. rogersii. Seeds of the following species were found nontoxic when crushed, encapsulated, and fed to 1-week-old chicks at 1 percent of body weight each day for 3 days: S. macrantha, S. cannabina, S. speciosa, S. bispinosa, S. sesban, S. arabica, S. exasperata, S. marginata, S. pachycarpa, S. sericea, and S. tetraptera (Williams 1983).

SAPONINS

Sesbania species contain saponins. These triterpenoid compounds are common in the Papilionoideae and particularly in the tribe Phaseoleae (e.g. Medicago, Glycine, Phaseolus, etc.). Saponins may occur in different organs of the same plant and can have allelopathic effects (Langenheim 1981). Saponins are steroids with sugars attached. When the sugars are removed by hydrolysis, the remaining aglucon moiety of the molecule is a sapogenin. Presence of saponins can be verified by their hemolytic effect on human red blood cells through an interaction with cholesterol in the erythrocyte membrane (Chubb 1983). Kumar et al. (1982) reported that in low concentrations, aqueous extracts of leaves of S. grandiflora caused this type of membrane damage as indicated by liberation of sterols and phospholipids into the experimental supernatant. The presence of saponins is also characterized by a bitter taste and the production of soap-like foam when mixed with water.

The biological activity of saponins is primarily on cellular and membranal components (Chubb 1983). When extracted, they make superior detergents; in some countries plants rich in saponins are sold as soap substitutes (Vickery 1979). Saponins are toxic to cold-blooded animals, and Vickery lists S. pubescens (probably = S. sericea) among some of the many plant species used as fish poisons in Africa. Portions of plants high in saponins are crushed and thrown into a pool or behind a temporary dam slowing a stream. The fish, usually stunned rather than killed outright, are gathered as they float to the surface. Saponins are widespread in plants but concentrations vary widely. In testing leaf protein concentrates (LPC) as a protein source for grass carp (Ctenopharyngodon idellus), Lu et al. (1977) in Taiwan found that S. sesban, or "tien-ching" LPC was highly poisonous to carp but LPC from Chinese milk vetch (Astragalus sinicus) was not toxic.

Saponins are not especially harmful to warm-blooded animals unless injected directly into the bloodstream. In ruminants, they are degraded by the rumen bacteria and depression of growth is not observed. In some monogastric animals, problems may occur if saponin-containing materials comprise a large part of the ration. Alfalfa (M. sativa), for example, fed as 20 percent leaf meal in a poultry ration (equivalent to 0.3 percent saponin), can cause growth depression, but the same level in a swine ration does not retard growth (Chubb 1983). Other work reviewed by Chubb indicated an only transient depression of egg production in laying hens fed 0.4 to 0.5 percent saponin. Other research suggested that dietary cholesterol can reduce the growth-depressing effects of saponins in chick rations.

Investigations on saponin content of Sesbania species are rather limited. Varshney and Shamsuddin (1964) hydrolyzed extracted saponin from S. speciosa with sulfuric acid and found oleanolic acid and two neutral products, one identified as beta-sitostanol (stigmastanol). Oleanolic acid was also identified in seeds of S. bispinosa (Varshney and Khan 1962) and in leaves of S. grandiflora (Tiwari and Bajpai cited in Varshney and Shamsuddin 1964). Oleic, linoleic, and linolenic acids were found in seeds of S. sesban (Farooq et al. 1954).

CANAVANINE

The presence of canavanine has been verified in seeds of *S. pachycarpa* and a variety of *S. sesban* in West Africa (Chantegrel and Busson 1964). The amino acid profile reported for these seeds was particularly deficient in lysine. Canavanine is a basic amino acid resembling argenine. When it is used as a substrate for enzymes acting on argenine, it is a growth inhibitor. Among legumes, canavanine is apparently confined to the Papilionoideae, where it was found in 35 percent of 150 genera and 60 percent of 540 species examined by Turner and Harborne (1967). They reported that seeds of eight species of *Sesbania* were found positive for canavanine, but the particular species names, canavanine levels, and references for the information were not given.

FEEDING STUDIES

Specific antinutritional effects have been associated with feeding of certain *Sesbania* seeds. Subramanian *et al.* (1952) fed husked *S. grandiflora* seed (seed coat and "inner membrane" removed) to rats and observed growth depression. Autoclaving the husked seed did not alleviate the growth depression. Although the seed portion fed had a high protein content (69.9 percent), its inclusion at 10 percent of the dietary protein resulted in weight loss and reduced growth rates compared to casein protein or protein in dal (hulled splits) from *Cajanus cajan*. The authors believed that the poor growth was due to deficiencies in lysine and sulfur-containing amino acids.

Growth was suppressed in chicks fed seed of *S. bispinosa*. At first, it was speculated that growth depression in chicks was caused by the high gum content of the seed (Katoch *et al.* 1970). Subsequently, in chick-starter rations, two types of *S. bispinosa* seed meals, with or without partial removal of gum, were substituted for groundnut cake at 0 to 28 percent protein replacement. Controls (zero replacement) grew best, while increasing levels of substitution significantly decreased growth. When over half of the sesbania seed gum was removed from the meal, growth was better, implicating gum content as a cause of growth depression. Chemical analyses did not yield hemaglutinins or goitrogens but did yield tannins (1.87 percent in mature seeds, 3.4 percent in immature seeds); in vitro analysis detected trypsin-inhibitory activity. The trypsin inhibitor was higher in mature seed (26 percent inhibition per mg protein) than in immature seed (5.2 percent). Significantly higher pancreas weights in chicks fed sesbania meal were attributed to the trypsin inhibitor (Katoch and Chopra 1974a).

Further study with autoclaved seed meals indicated that although the trypsin inhibitor was denatured and chick growth improved, pancreas weights were still high relative to controls. The authors suspected that an unknown, heat-resistant factor caused the pancreatic hypertrophy (Katoch and Chopra 1974b). Growth was greater in chicks fed autoclaved meal (at 28 percent crude protein replacement in the ration), with or without partial removal of endosperm, compared to those fed raw meals. Birds that received no sesbania meal still gained more weight. Feed utilization efficiency of autoclaved meal with endosperm partly removed was equivalent to that for the control. There was a higher consumption of control ration as compared to the other test rations. The authors noted that autoclaving removed some of the odor of the raw seed meals. It is possible that palatability was a factor in lowering growth rates when S. bispinosa seed meals were included, autoclaved or not.

Sesbania foliage is generally considered nontoxic; however, negative results have been reported. Foliage of S. grandiflora, the closely related S. formosa, and two varieties of S. sesban were screened for toxicity (Williams 1983). Six, one-week-old chicks were fed dried, encapsulated leaves at one percent of body weight each day for 3 days. All chicks died before the 5th day when fed S. grandiflora and two varieties of S. sesban. No toxic signs were observed in any chicks fed S. formosa. In a feeding study in India (Prasad et al. 1970), S. grandiflora leaf meal was included in chick-starter rations, and feed consumption and chick growth was decreased at the first increment (5 percent) of the ration. Mortality increased compared to controls (13-15 percent as compared to 3 percent), but not with increasing proportions of leaf meal. Hutagalung (1981) mentioned S. grandiflora as a browse tree with considerable potential as a feed source in the tropics, but in a table of dietary inclusion rates, recommendations for poultry and pigs were low: 2-5 percent. The same author also made a vague reference to toxic effects on livestock of the "purplish flower variety of Sesbania."

These few reports indicate that one should use caution in feeding sesbania foliage to monogastric animals. The lack of negative reports would suggest that sesbanias could be used as a source of feed for ruminant animals. Feeding studies with sheep and goats discussed above do not suggest deleterious effects. In Indonesia, *S. grandiflora* is sometimes fed as the sole ration to milking goats. In India, *S. sesban* offered for sale in markets was reported to be bought principally for feeding sheep and goats (Anon. 1924). In nonexperimental feedings in Hawaii, pregnant goats fed *S. sesban* and *S. grandiflora* as a major element of their diet had normal kidding and lactation. Although *Sesbania* species may be used as sources of feed for ruminant livestock, caution in their use is advisable.

10
Folklore and Medicinal Uses of *Sesbania* Species

Traditional medicinal uses of Sesbania species, particularly S. grandiflora and S. sesban and to a lesser extent S. bispinosa, are known in Asia, but we have not found evidence of such uses in the New World. Information published in Watt's Dictionary of the Economic Products of India (1889-1893) has been often repeated and added to in subsequent compilations (e.g. The Wealth of India (CSIR 1972), Burkill (1935) for Malaysia, Quisumbing (1951) for the Philippines, Neal (1965) for Hawaii.) For Africa, Watt and Breyer-Brandwyjk (1962) have summarized uses which may apply to a number of the sesbanias found there.

S. grandiflora juices and extracts have an astringent quality, contracting body tissues and blood vessels; they are used for reducing fever, promoting fluid discharge and subsequent drying of mucous membranes and other tissues, and as antihistamines. For systemic disorders (e.g. smallpox and other fevers), decoctions are taken internally. Local applications are said to bring relief to nasal congestion and rhinitis, and headache associated with sinusitis: juice of leaves and flowers "blown up the nostrils...causes a copious discharge of fluid relieving the pain and sense of weight in the frontal sinuses;" juice of flowers applied to the eyes is said to relieve "dimness of vision" (Watt 1893). The bark also has these astringent, tonic, and fever reducing qualities. In Java it was used for thrush and stomach trouble in infants (Burkill 1935). Leaves are said to be aperient (laxative). Root juices are used as an expectorant; poultices of roots and leaves are applied for rheumatism, swellings, bruises, and itching.

S. bispinosa appears to have similar astringent qualities, promoting healing and the discharge of pus. Pastes of the seeds, sometimes mixed with flour, are applied to ringworm, other skin diseases, and wounds (Duke 1981, Hooper and Field 1937). The latter authors reported a superstition in India that mere sight of the seeds relieves pain of scorpion stings.

Uses of S. sesban are similar to the above but with even wider applications in terms of specific ailments, and some unique qualities not mentioned for the others. The quality of astringence is apparently quite powerful in S. sesban. Fresh root and poultices of leaves have been used for scorpion stings, boils, and abcesses. Rheumatic swelling and hydrocele (a collection of watery fluid in a cavity of the body, especially in the scrotum or along the spermatic cord) are said to be resolved by application of poultices of leaves; diarrhea and excessive menstrual flow are said to be relieved by the seeds; doses of up to two ounces of leaf juice may be given as an antihelminthic against intestinal tapeworms and roundworms (Watt 1893).

The Haya of Africa used S. sesban ("mubimba") for sore throat, gonorrhea, syphilis, yaws, fits in children, and jaundice during pregnancy. In West Africa it is used against fever and guinea worm (Watt and Breyer-Brandwyjk 1962). Decoctions of the leaves are reportedly used by the Hausa people as a drench for cattle to repel the tsetse fly (Gohl 1975, CSIR 1972). Related to the antihelminthic and insect-repelling properties attributed to S. sesban is molluscicidal activity of its seeds and pods, investigated in Egypt by Shoeb and Khalifa (1985). Ethanol and water extracts were tested on two schistosome snails and one fascioliasis snail, both of which are intermediate hosts of flukes and other internal parasites. The ethanol extract was stable in sunlight and acid pH, and its activity was only slightly depressed by riverine mud and alkaline pH. This indicated that S. sesban may possibly be useful in efforts to control a major cause of poor health in irrigated areas of the Nile region.

Hurov (no date) listed claims for medicinal activity of S. sesban in preventing smallpox (the seeds) and in treating chronic colds, diabetes, inflamed testicles, swollen limbs, and stomach troubles (the leaves). Hurov also reported that buds and flowers are contraceptive when taken during the menstrual period. There may be some basis for such claims of antifertility activities of the flowers. In reviewing work on indigenous Indian plants for fertility control, Nagarajan et al. (1982) summarized results of several articles in which extracts of flowers (but not of leaves) of S. sesban resulted in antifertility activity in rats and mice (Bhaduri et al. 1968) and were cited as abortifacients in mice (Pakrashi et al. 1975). The latter authors reported the belief in India that the taking of flowers for three days during menstruation inhibits conception. They fed extracts to pregnant mice at 50 mg extract per kg body weight on the first and sixth day of pregnancy, and found abortifacient activity ranging from 54 to 77 percent depending on the type of extract.

There are several references to use of sesbania leaves as a stimulant to increase the secretion of milk. Ochse (1931) stated that in Java leaves and young pods of S. grandiflora are eaten, especially by nursing mothers. According to Brown (1954), feeding these leaves to cattle increases their milk production. The Haya people of Africa use S. sesban similarly. Hurov called S. sesban the "Kenya milk shrub."

Antitumor activity has been reported for the North American species S. drummondii, and brief reviews of this work have recently been published in popular scientific press (Anon. 1983, Garmon 1983). Powell et al. (1976) reported that ethanolic seed extracts of S. vesicaria, S. punicea, and S. drummondii were cytotoxic in the KB cell culture and were active against lymphocytic leukemia P-388 in mice. Fractionation of S. vesicaria resulted in enrichment of the active portion, but it was not possible at that time to associate the antitumor activity with any constituent.

Powell et al. (1979) described the isolation of a cytotoxic compound from an ether extract of S. drummondii which was given the name sesbanine. The compound had no close structural relatives. Further fractionation revealed a second compound, drummondol (Powell and Smith 1981). Because 450 kg of seed yielded only 50 mg of pure sesbanine (Powell et al. 1979), efforts to synthesize the substance were initiated; recently they cited four groups having produced a synthesis before 1981 (Powell et al. 1983), and Wanner et al. (1982) published an additional report. Synthetic sesbanine did not have antitumor activity in experimental tumor systems (Powell et al. 1983). However, they reported that fractionation of sesbanine produced an "exceptionally potent antitumor compound," sesbanimide, having an unusual tricyclic structure with single bonds linking the rings. Similarity in structure with glutarimide antibiotics raised the question of whether sesbanimide is a true plant product or a metabolite of a microorganism associated with the plant. In National Cancer Institute tests, sesbanimide given to mice at 0.01 mg/kg body weight resulted in a 171 percent increase in survival time compared to control leukemics which did not receive it; other tests in vitro have demonstrated inhibition of human carcinoma cell growth (Garmon 1983; Anon. 1983). Synthesis of sesbanimide was being attempted (Powell, personal communication, 1983).

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Rhizobium Relationships with *Sesbania*

Rhizobium bacteria which nodulate Sesbania species are fast growing strains. Isolates of these bacteria are not very stable when stored in culture, and they tend to lose viability rapidly (B. Bohlool, personal communication). Proper culture and storage conditions are not known for this group of bacteria. Frequent transfer of cultures, maintenance of appropriate storage temperatures (refrigeration may not be appropriate), and buffering the culture media against shifts toward lower pH may help to promote culture maintenance.

Research is needed on culture and storage requirements of Rhizobium strains for Sesbania. The standard yeast-extract mannitol medium was found unsatisfactory for the S. rostrata isolate ORS 571. Substituting sucrose, arabinose, or glucose for mannitol did not improve growth conditions, but using acetate, lactate, citrate, or glutamate as carbon sources shortened doubling times from 18 to 3 hours (Mulongoy 1986).

Physiological responses of rhizobia isolated from sesbanias to certain stresses were studied by Indian scientists, including the effects of Streptomyces spp. (Oblisami and Rangaswami 1967), 2,4-D (Pareek and Sidhu 1978), and molybdenum and copper (Singh et al. 1975).

Studies of sesbania nodules include research on the absorption spectra and behavior of S. cannabina leghemoglobins (Thakkar and Vyas 1972, 1973, 1975), and a report on the relation between sugars and bacterial invertase in developing nodules on S. grandiflora (Singh et al. 1980). Mathur and Singh (1971) studied the effects of seed treatment with various pyrimidine bases and their analogues on subsequent nodulation of S. bispinosa. Khurana and Vyas (1976) used gel electrophoresis to study and compare isozymes in bacteroids from nodules of Sesbania, Cicer, and Pisum. Sen (1969) described morphogenesis of nodules of a number of legumes including S. sericea. A more specific study of infection and development of nodules on S. sesban roots was reported by Mahmood and Jamal (1977). Tang et al. (1980) used electron microscopy to study and compare the stages of the infection process in S. cannabina, Glycine max, Pisum sativum, and Phaseolus vulgaris.

Cross-inoculation relationships between Rhizobium of Sesbania and those of other legumes have been the subject of a number of studies. Date and Halliday (1980) categorized the Sesbania-Rhizobium symbiosis as "promiscuous but often ineffective," but did not give references or data in support of this view. The general implication from the literature, confirmed by our observations (Evans, and Evans and M. Habte, unpublished data) is that Sesbania species vary considerably in their ability to be nodulated by specific strains of Rhizobium, and there is host-strain specificity within the genus.

Gaur and Sen (1978, 1979) reported a relationship between the Sesbania and Cicer symbioses. Of 71 Cicer isolates tested on 89 legume species, including C. arietinum, 18 isolates nodulated only S. bispinosa and S. sesban. Of 287 isolates obtained from 52 legume species (not including Cicer), the only isolate nodulating C. arietinum was one from S. bispinosa. The authors observed that under field conditions, the "loose, nonreciprocal kinship of Cicer with Sesbania" was rare. Trinick (1980) reported on the relationships among fast growing isolates of various legumes including S. grandiflora. Trinick and Galbraith (1980) found that S. grandiflora isolates, as well as isolates from Leucaena leucocephala, Mimosa pudica, and Lablab purpureus, nodulated the nonlegume Parasponia with low levels of N-fixing activity. Trinick (1968) was able to nodulate L. leucocephala with S. grandiflora isolates, but the symbiosis was ineffective. Oblisami (1974) studied a Clitoria ternatea isolate which nodulated Glycine max and was able to produce nodules on cowpea and on sesbania to a greater extent than on its original host. Clitoria was not cross-compatible with the bean, pea, clover, or alfalfa cross-inoculation groups, but was nodulated by isolates from S. bispinosa, Crotalaria juncea, G. max, and cowpea. Ishizawa (1972) also compared cross-inoculation characteristics of Sesbania, Leucaena, and Mimosa. Sanogho (1977) studied isolates of the African species S. letocarpa and S. pachycarpa in compatibility tests with other legumes of the Lido Valley of Mali.

Earlier studies on cross-inoculation in Sesbania were done by Wilson (1939), Briscoe and Andrews (1938), Raju (1936, 1938), Hoge (1939), and Harris (1941). Most of these studies involved a number of legume genera. Suggestions by Raju and by Briscoe and Andrews to establish a "dhaincha" or "sesban" inoculation group of Rhizobium were not widely accepted. Raju pointed out that Sesbania strains were somewhat effective on cowpea, but Sesbania was in general nodulated only by its own isolates. Other authors including Gaur and Sen (1979) have commented on the affinity of Sesbania with the "cowpea miscellany." Wilson (1946) made the observation that isolates from one S. exaltata plant were not necessarily capable of producing nodules on plants from seed of a different S. exaltata plant. Wilson suggested that this was due to genetic variation resulting from cross-pollination.

Johnson and Allen (1952a and b) reported cultural and nodulation studies revealing differences in strain growth characteristics and marked host specificity in strains isolated from different Sesbania species. Isolates from the North American species S. macrocarpa (=S. exaltata) showed cultural characteristics different from isolates from S. grandiflora, S. bispinosa and S. sesban (three pantropical species), and S. tomentosa (a Hawaiian endemic). The cowpea affinity was again observed, as Sesbania isolates nodulated common beans and cowpeas, but without reciprocity.

Studies of the salt tolerance of Sesbania species have occasionally focussed on the tolerance of their associated Rhizobium symbionts. Bhardwaj (1974a) found that of nine saline-alkali soils from three states in N. India, all had strains which nodulated S. bispinosa. Bhardwaj (1972) had previously noted that strains isolated from saline-alkali soil survived more readily when incubated in highly saline-alkali soils than did strains from nonsaline-alkali soils. Comparing different legumes, Bhardwaj (1974b) found that S. bispinosa was more frequently nodulated under field conditions than were Melilotus parviflora, Trifolium alexandrinum, Cyamopsis tetragonoloba, Vigna unguiculata, Lens esculenta, and Pisum sativum (listed in decreasing order of nodulation incidence and nodule number per plant). Strains isolated from sesbania were judged more effective than those from the other species. Additions of gypsum with either farmyard manure or sesbania green leaf manure were found to enhance growth of these strains of rhizobia introduced to sterilized soil. Pigmentation was found in 20 percent of the strains isolated from sesbanias in saline-alkali soils, vs. 4.5 percent in normal soils, suggesting a correlation between pigmentation and salt tolerance (Bhardwaj 1972b).

Yadav and Vyas (1971, 1973) found sesbania isolates more tolerant of salts and alkalinity than isolates from Glycine max and Crotalaria juncea. The strains all grew well at pH 10 but were sensitive to pH 3.5-4.0.

Although Rhizobium apparently can tolerate high pH and salt concentrations, legume symbiosis is generally inversely effective with increases in these conditions. Singh and Rai (1972) found decreased nodulation in both S. bispinosa and Melilotus alba as soil salinity and especially alkalinity increased, although these declines were ameliorated by phosphorus applications. Of ten cultivated legumes compared, most had substantially reduced growth and nodulation as a result of increasing soil ESP, with a maximum of ESP 34, but sesbania and M. parviflora could grow and be nodulated at ESP 70. However, development of nodulation was delayed in these tolerant species.

SESBANIA ROSTRATA: A SPECIAL CASE OF NODULATION AND NITROGEN FIXATION

S. rostrata, native to tropical West Africa, supports nodules on its stem and branches as well as on its roots. This uncommon phenomenon was also reported in Aeschynomene species (Arora 1954). Studies on this symbicsis in S. rostrata and its agronomic implications were made by scientists at the Office de la Recherche Scientifique et Technique, Outre-Mer et Centre National de la Recherche Scientifique at Dakar, Senegal, from whose reports much of the following information has been derived.

S. rostrata (Brem. and Oberm.) is an annual legume common to Senegal (Berhaut 1967). Its distribution, according to Gillett (1971), is from Senegal to Sudan, Congo (Katanga), Zaire, Malawi, Rhodesia, Botswana, Caprivi Strip, and Madagascar, apparently always local and never abundant. It normally grows during the hot, summer season (June to September) in the Senegal Valley when moisture is plentiful. It grows best in low-lying, moist soils which are frequently waterlogged and occasionally flooded. During its vegetative growth period, generally 2-3 months long in the summer months, it may reach heights of 5 meters before entering its reproductive phase. During the cool dry season centered on the period from December to February, however, growth is poor and quickly interrupted by flowering (Dreyfus et al. 1983), probably due in part to the shorter photoperiod during these months at 15° north latitude in Senegal.

Stem nodulation as it occurs naturally in S. rostrata is not well characterized. Nodulation can occur at any height on the stem, although not all of the prospective nodulation sites are nodulated. A well-nodulated S. rostrata plant may have as much as 15-40 g of fresh stem nodules. Mulongoy (1986) reported 4000-5000 nodules with total dry weight of 18 g on stems of individual plants 3 m high. Specific nodule activity as measured by acetylene reduction is comparable to nodules of soybeans and cowpeas (Dreyfus and Dommergues 1981). The method by which the rhizobia reach the stem sites is not known. Dust may be a source because plants on the borders of stands of S. rostrata in Senegal were observed to be more extensively nodulated. Insects may also play a role. Experimentally, however, culture slurries of Rhizobium or water suspensions of macerated stem nodules are sprayed or painted on the stems. Temperature and humidity apparently play an important role in the infection process, because during the winter months in Senegal infection is difficult to achieve, but during the summer it is difficult to maintain control plants unnodulated (Dreyfus et al. 1983, Rinaudo et al. 1982). Possibly, under natural conditions, stem nodulation occurs only in waterlogged plants.

Sites of infection are root primordia which first appear as small swellings, usually less than 1 cm apart in rows, with 3-4 or more rows on all stems and branches. As the stems develop, the apex of the root initial pierces the epidermis at these sites, and this rupture is the point of access for rhizobia. When the stems are flooded, adventitious water roots arise from these meristematic sites; otherwise, they may become nodule sites. Even after development of a nodule, the latent root apex may begin to grow if that portion of the stem is flooded (Duhoux and Dreyfus 1982). The process of infection has been investigated and described by Tsien et al. (1983) and Duhoux (1984). Similarly to the infection process in groundnut (Arachis hypogaea) roots, rhizobia enter the plant via intercellular spaces rather than through infection threads formed by cell wall invagination of curled root hair tips, as is the case with most other legumes. Differing from groundnut, rhizobia entering S. rostrata cytoplasm from intercellular spaces do so by an intra-cellular invagination similar to an infection thread. The cells thus penetrated are described as a highly meristematic, cortex-derived tissue surrounding the base of the root primordium.

Rhizobium characteristics in the S. rostrata symbiosis are unusual. The strain isolated and described by Dreyfus and Dommergues (1981), ORS 551, is apparently capable of fixing N in its free-living state, since cultures grew when given N_2 or ammonia as sole N source. Because such strains can be selected in culture for N-fixing ability or lack thereof, they offer opportunities for genetic studies such as have been reported by Elmerich et al. (1982). When in developed stem nodules of experimental plants grown hydroponically, these bacteria fixed atmospheric N despite the presence of combined N in the root zone, but when in root nodules, N fixation (as indicated by acetylene reduction) was inhibited by combined N. N in the root zone actually enhanced acetylene reduction in stem nodules (Dreyfus and Dommergues 1980). The implications of this ability are important, since most legumes tend to take up available soil N preferentially, and fix large amounts of atmospheric N only when soil N is depleted in the root zone.

The Rhizobium nodulating S. rostrata stems is fast growing and highly specific. The strain ORS 551 ineffectively nodulated other Sesbania species. Conversely, isolates effective on S. pachycarpa produced ineffective nodules on S. rostrata roots. Cowpea isolate CB 756 and isolates from Aeschynomene spp. stem nodules would not nodulate S. rostrata roots; ORS 551 did not nodulate roots of Aeschynomene or of Macroptilium atropurpureum (Dreyfus and Dommergues 1981). Strains from S. rostrata which nodulate its stems will also nodulate its roots, but not all root-infecting strains will nodulate stem sites. Dreyfus et al. (1983) referred to three types of nodules occurring on S. rostrata: the stem nodules and two types of root nodule, one of which occurs at the root crown just beneath the soil surface, has terminally meristematic lobes, and is 2-15 mm long, and the second of which is spherical, 1-2 mm in diameter, and is found along lateral and adventitious roots. The first type of root nodule disappears upon flooding, perhaps because S. rostrata does not develop aerenchyma as extensively as do most Sesbania species when flooded (Evans, personal observation), and lacking this tissue the nodules can no longer function. The second type of root nodule, however, proliferates upon flooding. All types of nodules have green epidermal tissues, including those near the soil surface.

Similar nodules were noted on S. rostrata plants grown in Hawaii, however, we were not able to effectively nodulate roots or stems with cultures isolated from a number of other *Sesbania* species (Evans and M. Habte, unpublished data). Lobed root nodules occasionally developed on some--but not all--*S. rostrata* plants grown in soil; some of these nodules appeared to be effective as judged from the presence of leghemglobin and by dark green leaf color. Isolates from such nodules did not infect stems or reinfect roots. The small round nodules which developed on floating roots were often lacking leghemglobin. Some apparently ineffective stem nodules were obtained after painting stems with fresh, crushed nodules from a different *Sesbania* species. *S. rostrata*, in field trials, was low in N compared to other *Sesbania* species, and did not appear to be effectively nodulated even though inoculated with strains highly active on other species (Evans and Rotar, unpublished data).

The use of N fixed by *S. rostrata* to benefit associated nonlegume crops was tested experimentally in Senegal (Rinaudo *et al*. 1982a and b, Dommergues 1982, Rinaudo *et al*. 1983, Dreyfus *et al*. 1983). *S. rostrata* was grown at a population of 400,000 plants per hectare during the summer. It was kept under flooded conditions for most of its growth period, and was inoculated twice (21 and 30 days after planting) by spraying stems with a culture slurry of ORS 551. One month after the first inoculation (about 50 days after planting), when 1.5 m tall, the plants were cut into 10 cm segments and incorporated into the soil, which had not been irrigated during the previous week. Two weeks later, rice seedlings were transplanted at a population of 250,000 hills/ha, the plots were flooded, and the rice was grown for 120 days.

Where the legume was neither grown nor incorporated, rice yields were increased by about 70-80 percent when N-P-K (N at 60 kg/ha) was applied, vs. controls receiving only P and K. When the legume was applied (also with P and K), yields were increased by about 170-180 percent over control yields without added N (Rinaudo *et al*. 1982). Plant N content was also significantly increased, and total N uptake in green manured rice was more than double that of rice receiving 60 kg/ha inorganic N. The authors extrapolated that soils of lower than average fertility could support rice grain yields of 6 Mg/ha with P-K fertilizer and *S. rostrata* green manure (Rinaudo *et al*. 1982b). This experiment was conducted in microplots measuring 1 m x 1 m x 50 cm deep, separated by concrete walls and rendered water tight with polyethylene sheet plastic; each contained 560 kg of soil, a sandy Ustropept. Based on a comparison of plots receiving no N with plots green manured, in regard to increases in rice N uptake and soil N content following the rice crop, Rinaudo *et al.* (1983) estimated that *S. rostrata* fixed at least 267 kg/ha N. They estimated that the yield increase of rice was equivalent to that obtainable from a surface application of 130 kg/ha N as ammonium sulfate (assuming 57 percent efficiency). Of the N fixed, about one-third was transferred to the following rice crop and two-thirds remained in the soil. The following year, rice grown in the microplots showed yield increases 50 percent over the no-N controls as a residual effect of the green manure treatment (Dreyfus *et al.* 1983).

Above-ground dry matter yield of the 52-day *S. rostrata* crop was given as approximately 20 Mg/ha (Dreyfus *et al.* 1983), representing a dry matter accumulation rate of 385 kg/ha per day. This calculated rate is about the same as the average fresh weight accumulation rate reported in the literature for *S. bispinosa* green manure crops (see Table 3.1). *S. rostrata*, grown in a yield trial in Hawaii at a population of 125,000 plants/ha, produced 12 Mg/ha dry matter in 14 weeks, indicating a much lower dry matter accumulation rate of 122 kg/ha per day (Evans and Rotar unpublished data). In that experiment, *S. rostrata* was apparently not effectively nodulated on its roots, and it had no stem nodules; it contained only 79 kg/ha N in its above-ground yield, and it had the lowest leaf-to-stem proportion of both dry matter and nitrogen of 35 *Sesbania* accessions grown. Despite these characteristics, its dry matter yields were within the range of the higher-yielding varieties, 8-17 Mg/ha.

Benefits to rice yields from green leaf manuring with effectively nodulated *S. rostrata* were observed at the International Institute of Tropical Agriculture in Nigeria when the legume was intercropped with rice (Mulongoy 1986). *S. rostrata* was sown at 10 x 150 cm or 10 x 200 cm, and rice was sown at 25 x 25 cm between these rows; the closer spacings produced higher legume yields. The soil was maintained in "hydromorphic" condition. Pruned to the height of the rice canopy at 8 and 12 weeks after planting, the legume provided a total of 3-4 Mg/ha dry matter (120-140 kg/ha N), which was distributed to the soil surface around the rice plants.

During the growth of the rice crop, 60-75 kg/ha N was estimated to have been released from the applied prunings. Resulting rice yields were about 4.57 Mg/ha, equivalent to those obtained with 120 kg/ha urea N and a 52 percent increase over control plots with no N applied. Rice given green leaf manure took up about 40 kg/ha more N than controls. Where both green leaf manure and urea N were applied, rice took up 50-56 kg/ha N.

These data were from the second year of this planting scheme; the first year's data had been affected by pest incidence. It is possible that cumulative additions and depletions may have exaggerated the benefits of green leaf manuring. The mulch effect may also have influenced yields. The difficulty of making a logical connection between N lost from the green leaf manure and N taken up in the associated rice crop contributes to the enigma of N fate and budgeting. Consideration of land equivalent ratios might have lent the inorganic N treatment a more favorable value of rice yield per unit N expenditure. Despite uncertainties of experimental methods in green manuring and intercropping studies, the benefits incurred by including S. rostrata and other Sesbania species with nonleguminous annual crops are apparent. Further studies are needed to identify extents of feasible inclusions of sesbanias in cropping systems and to maximize their N contributions.

12
Sesbania Species as Weeds

OCCURRENCE OF SESBANIA SPECIES AS WEEDS

Sesbania species, especially annuals, have the potential to become weeds in field crops. They will compete with crops for light, nutrients, and moisture. Heavy volunteer growth of *Sesbania* species may interfere with crop harvest by hampering machinery. *Sesbania* seeds may contaminate harvested grain, reducing its value. Most of *Sesbania*'s reputation as a weed is derived from experience with *S. exaltata* in North America, but a few other species have been noted elsewhere in the world. *S. punicea* has recently been declared an exotic weed in S. Africa (Anon. 1980). Native to the New World, this woody shrub was an ornamental plant which escaped from gardens in South Africa (Taylor 1974) and quickly became naturalized to the extent that it began replacing indigenous vegetation (Stirton 1978). Although of widespread occurrence, it was not ranked among the top five most important and aggressive woody plant invaders (Wells *et al*. 1980). Erb (1979) cautioned that the plant had "by no means reached its natural limits." In Nigeria, *S. bispinosa* has been reported as a weed of experimental plots (Yayock 1976). In Australia, *S. cannabina* infests crops of cotton (Kolomyjec *et al*. 1979) and sorghum: a population of 28 plants per square meter reduced sorghum grain yield by 19 percent (Rawson and Bath 1981). *S. exasperata* persisted in lands converted to rice cultivation in Surinam (De Wit 1960). In neighboring Guyana a similar species, *S. sericea*, occurs in upland rice fields, but does not occur in fields sown and maintained in flooded condition (Kennard 1973). In India's Punjab, *S. bispinosa* was among maize field weeds whose occurrence, populations, and growth periodicities were studied by Bir and Sidhu (1975). Another study from Madhya Pradesh, India, tested herbicides to control this species in soybeans (Shrivastava et al. 1976). Because S. bispinosa is widely grown as a green manure crop in India, it is remarkable that we did not find more references to its weed status there. It is possible that its presence is welcome in intensively managed fields for the nitrogen which it will fix. In Africa, S. pachycarpa volunteers in sorghum fields where its growth is sometimes encouraged (Gillett 1971).

S. exaltata (formerly S. macrocarpa) is a widespread weed of crops in the southern United States. It is a major problem in soybean growing areas, capable of causing as much as 60-80 percent reduction in yield (Lunsford et al. 1976). It is also a serious weed pest in cotton, sweet potatoes, and rice; its occurrence was noted in 53 percent of the rice fields in Arkansas (Baldwin et al. 1977). It does not appear to be a problem in maize in the USA, perhaps because of the highly effective preemergence herbicides (such as atrazine) used with maize (Crawford and Rogers 1979). The inclusion of such maize crops in rotations is considered an effective method of reducing the magnitude of S. exaltata infestation of cotton crops (Dale and Chandler 1979).

GROWTH STUDIES WITH SESBANIA SPECIES

Studies on the germination and growth of sesbanias have been done in the context of effecting their control. Variations in germination with differing soil temperatures, moisture levels, and depths of seed below the soil surface were studied in S. exaltata (Smith and Fox 1973, Eastin 1981, Jolley and Murray 1978, Walker et al. 1979) in S. sesban (Rijn and Verhagen 1980), and in S. sesban, S. grandiflora, S. microcarpa, and S. bispinosa at differing moisture stress levels after varying storage periods (Pathak et al. 1976). S. exaltata was included in a 50-year study of seed longevity initiated in 1972 (Egley and Chandler 1978). Egley and Williams (1979) reported that cultivation to a depth of 15 cm reduced grass weed populations but had no effect on emergence of S. exaltata. Seed germination at varying osmotic potentials has been studied, and compared to soybeans, S. exaltata was more tolerant of induced moisture stress. Soybean germination was reduced at -2 bars, but an osmotic potential of -4 bars or more was required to reduce S. exaltata germination (Johnson et al.

1979, Williams 1980). Bailey et al. (1980) studied S. exaltata's phenologic development. Patterson et al. (1978) measured growth parameters at varying light intensities.

S. bispinosa seed imbibition after soaking for 24 hours was low compared to seeds of 40 other plants of India's arid Rajasthan area (Bansal et al. 1980). Sharma et al. (1978) reported differential seed coat dormancy in this species, which emerges with the monsoon rains in July and August and continually sets seed from September to February. Seeds set in the first flush of seeding had 100 percent germination without scarification, but seeds set in later, drier periods (October, November) would not imbibe without scarification. The earlier collection subsequently underwent a change in seed coat permeability, becoming less permeable. Seed weights decreased for seeds set later in the season. Different collections required soaking in concentrated sulfuric acid for periods of 15 to 45 minutes to obtain 100 percent germination, with these soaking times increasing for seeds set later in the growth period.

Protein synthesis is one element of plant physiology affected by herbicides. Dubey (1979) tested 10 herbicides and found that some increased, some decreased, and some did not affect protein synthesis in S. bispinosa. Mann et al. published a number of articles on their work with S. exaltata (1965a, b, 1967a, b, 1968), and Baxter (1976) reviewed research on protein synthesis as affected by herbicides in Sesbania, soybean, and barley.

McWhorter and Anderson (1979) experimentally studied the extent of competition of S. exaltata with soybean crops. Soybean yields were not reduced by S. exaltata populations between 1600 and 5500 plants/ha throughout the growing season; however, yields were reduced 10-20 percent by populations of 8100 to 129,000 plants/ha. If relatively high populations of sesbania (68,000 plants/ha) were controlled within 4 weeks after soybean emergence, then yields were not seriously affected, but if competition continued for 6, 8 or 10 weeks, yields fell by 18, 27, and 43 percent, respectively. The period from the sixth to the tenth week after soybean emergence was regarded as the most critical period for control of S. exaltata. Walker et al. (1979) studied competition effects of S. exaltata allowed to grow with soybeans for the full growth season. They found that yield reductions were less when soybeans were grown in 61 cm rows than in 91 cm rows, even when more sesbania plants were present. The closer row spacing gave the soybean plants a better competitive advantage.

CONTROL OF *S. EXALTATA* WITH HERBICIDES[1]

Because soybeans are an important crop in the USA, many research reports have been published on herbicides for control of *S. exaltata*. Control is complicated by the fact that both are broadleaved legumes and that soybeans are also sensitive to the same herbicides. Differing soil types and varying susceptibility of the soybean crop at different growth stages require variable rates of both preemergence and postemergence herbicides. Sesbania is generally less sensitive to herbicides as growth progresses.

The herbicide acifluorfen applied as a post-emergence spray was effective in controlling *S. exaltata* (Lawrence *et al.* 1978a and b, Barrentine 1978, Rogers and Crawford 1980). Good control with acifluorfen was obtained with applications of 280 g/ha (0.25 lb/acre), which was often applied in tank mixtures with 840 g/ha (0.75 lb/acre) bentazon for control of major broadleaf weeds (Helpert and Viar 1983). An application rate of 140 g/ha applied before bloom stage of sesbania was effective (Mathis 1980), as was 150 g/ha applied between the first and seventh trifoliate leaf stage of soybeans (Rogers and Crawford 1980). Porter and Retzinger (1983) tried lower rates of 28 or 56 g/ha at different spray volumes (47, 187, or 374 l/ha) and various surfactant concentrations, and obtained an average of 93 percent control of *S. exaltata* at either rate and all volumes when the highest concentration (1 percent) of surfactant was used. Soybeans in the third to the sixth trifoliate leaf stage sprayed with acifluorfen at rates of 140-1120 g/ha were injured but recovered in 14 days (Mathis 1980). Yih (1979) reported that acifluorfen was effective at rates of 110-560 g/ha at all soybean growth stages, and stated that groundnut and some beans also tolerated post-emergence treatment with acifluorfen. Better *S. exaltata* control was obtained by spraying acifluorfen at dusk or evening than at dawn or noon, especially when low application rates were used (Lee and Oliver 1979, Oliver and Lee 1979).

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[1] Herbicide rates and crop treatments discussed here are based on research reports and are not to be interpreted as recommendations. Herbicide users must heed the limitations and instructions on the product label and be aware of local laws and regulations governing herbicide use.

Mefluidide (formerly MBR 12 325), a postemergence herbicide for control of johnsongrass and volunteer maize and sorghum, is also used in tank mixes with other herbicides, notably bentazon, to control S. exaltata (Nester et al. 1978, Murray et al. 1978b, Harger et al. 1979). Viar and Atwell (1980) showed that neither mefluidide (at 280 g/ha) nor bentazon (at 840 g/ha) alone could control sesbania plants more than 10 cm high, but the two combined (even at lower rates) provided excellent control of sesbania plants up to 90 cm high. Rogers and Crawford (1976) reported that surfactants increased control levels obtained with bentazon at rates from 840-1680 g/ha, and temporary injury to the soybean crop increased proportionately to the extent of control. Mefluidide has been used to control S. exaltata applied with either nonoxynol, dinoseb, or naptalam plus dinoseb in directed sprays (McWhorter and Barrentine 1979); with acifluorfen (each at 300 g/ha) for sesbania 10 to 40 cm high (Lawrence et al. 1978b); and with chloroxuron (Hargroder et al. 1977, Gates 1976). Both bentazon and chloroxuron (at 1120 g/ha) were effective against S. exaltata in soybeans as overall sprays (Murray et al. 1978). Mefluidide by itself acts to kill the apical meristem and axillary buds, but may not kill entire plants unless combined with other herbicides with resulting additive or synergistic effects. Mefluidide, applied at flowering and pod setting, suppressed seed formation in S. exaltata (Gates 1975, 1976).

Metribuzin, a preemergence herbicide for control of S. exaltata, is a substance which is more actively translocated and less actively metabolically degraded in sesbania than in soybean (Hargroder and Rogers 1974). Metribuzin has shown good control applied preemergence at 420 g/ha (English and Oliver 1980) or at 500 g/ha (Murray et al. 1978). It may also be applied postemergence as a directed spray (Glover et al. 1979). Barrentine (1975, and Barrentine et al. 1979) tested different times of application and incorporation methods for metribuzin plus trifluralin. Metribuzin has also been used in combination with alachlor (Scudder 1977), oryzalin (Watson et al. 1974), and linuron (Eastin 1973, Lawrence et al. 1978a).

Other herbicides used against S. exaltata in soybean crops include 2,4-D applied with an absorbent bar (Crawford 1971) or as a directed spray (Harger et al. 1979) and glyphosate applied (at 1680 g/ha) using a recirculating sprayer method in which herbicide is applied only to weeds (McWhorter 1977). A similar method may be used to apply acifluorfen (Barrentine and Reames 1980). Glyphosate applied to soil has been shown to reduce plantlet growth during postgermination stages, but to a lesser degree in *S. exaltata* than in other species tested (Hoagland 1977). Preemergence herbicides tested to control *S. bispinosa* among soybeans in India included chloramben, alachlor, nitrofen, and chloroxuron (Shrivastava *et al.* 1976). Phenisopham has been used as a postemergence spray in cotton to control *S. exaltata*. It is effective on seedlings at the cotyledon and second-pinnate-leaf stages, but not at the sixth-leaf stage or older (Kolomyjec *et al.* 1979, Roca *et al.* 1979).

R-40 244 herbicide applied postemergence at 560 g/ha controlled *S. exaltata* in drill-sown rice (Baker, 1978). Postemergence sprays of oxadiazon and mixtures of propanil plus oryzalin, or plus nitralin, or plus butachlor, or plus oxadiazon gave from 80 to 100 percent control of weeds including *S. exaltata* in rice with only slight damage to the rice. Tank mixtures of propanil plus benthiocarb were also effective; molinate was substituted for propanil with benthiocarb, butachlor, and oxadiazon (Smith and Fox 1971, Smith 1972, 1973).

13
Insect Pests and Plant Pathogens Affecting *Sesbania* Species

Reports of insects and plant pathogens associated with Sesbania species are summarized in Tables 13.1 and 13.2. In general, interest in pests of sesbanias in India arises from a desire to protect the crop, while interest in the Americas is biased in favor of the predator. Thus, for example, work such as that of Erb (1979) in Argentina and of Berg (1981) has been motivated by interests in identifying suitable biological controls for S. punicea.

Insect pests which may affect sesbanias and which may limit their productivity as crops include leaf webbers and other leaf feeders, and stem borers. Because of the rapid growth of many sesbanias, annual species in particular, a crop may offer large amounts of succulent stems for infestation during its exponential growth phase. In Sesbania species accession observation trials in Hawaii, we observed minor incidences of stem pests, and also of leaf webbers. Leaf chewing pests were common in Hawaii on most species, although some of the reports from India indicate severe defoliation as a result of pest population increases which may be localized spatially and temporally. Severe defoliation of S. grandiflora in Florida by caterpillars occurred while other trees such as Moringa olifera remained undamaged (M. Price, personal communication). One species which sustained leaf damage from chewing pests in Hawaii was the perennial S. formosa, the only one of several perennials tested which did not prove toxic when leaves were fed to chicks (see Chapter 9).

Another category of pest noted in Hawaii is seed pests. Surprisingly, rather few references to such pests are found from India, where large amounts of seed are produced for green manure crops requiring high sowing rates. Sharma et al. (1978) stated that in Rajasthan, India,

TABLE 13.1
Insect pests of *Sesbania* species

Pest	Location	*Sesbania* Species Affected	Comments	Reference
Agrolis ypsilon	China	spp.		Anon. 1979
Alcidodes bubo	S. India	grandiflora	Weevil leaves and stems	Subramanian *et al*. 1953
Alfalfa caterpillar	California, USA	exaltata	alt. host	Anon. 1957
Amsacta moorei	India	bispinosa	caterpillars	Chandra & Farooqi 1979
Aphes laburni	Sumatra	grandiflora	aphid	Meer-Mohr 1935
Apion decipiens	Argentina	punicea, virgata	seed feeder	Erb 1979
Argyroploce rhynchias	Tanganyika	sesban	caterpillars attack branches	Ritchie 1935
Azygophleps scalaris	Tamil Nadu, India	bispinosa, grandiflora sesban, sericea	stem borer	Venugopal & Rao 1961; Srivastava & Gupta 1967; Agarwal & Agawal 1960
Bruchidius spp.	NW India	spp.	larvae develop in seeds	Vats 1977
Heliothrips indicus	Sudan	spp.	cotton pest alt. host	Cameron 1930
Culex spp.	India	grandiflora	mosquitoes	Reuben 1971

			large no.'s in fields	
Cyclopelta siccifolia	Tamil Nadu, India	speciosa		David & Venugopal 1961
Dacus cucurbitae	Hawaii, USA	grandiflora	larvae develop in flowers	Nakagawa & Yamada 1965
Dacus dorsalis	Hawaii, USA	grandiflora	larvae develop in flowers	Nakagawa & Yamada 1965
Dasychira mendosa	Tamil Nadu, India	speciosa	alternate host	Rao & Bucker 1974
Diplogrammus quadrivittatus	Argentina	punicea, virgata	stem borer	Erb 1978
Ducmitus strix	Indonesia	spp.	wood borer	Kalshoven 1934
Empoasca spp.	Tamil Nadu, India	speciosa		Abraham, 1958
Eudiagogus spp.	New World	spp.	adults defoliate	Warner 1979
E. rosenchoeldi	Mississippi, USA	exaltata	larvae attack root & nodules	Warner 1979
E. pogo	Georgia, USA	exaltata	adults defoliate	Warner 1979
E. maryae	Florida, USA	exaltata	adults defoliate	Warner 1979
Euprocitis scintillians	Tamil Nadu, India	cannabina	pulse crop pest, alt. host	Rao *et al.* 1974
Eurhynchothrips ordinarius	India	grandiflora	in flowers	Ayyar 1928
Grammodes stolida	Tamil Nadu, India	bispinosa	lepidoptera, stem pest	Cherian & Sundaram 1942
Hyposidera sucessaria	S. India	speciosa	geometrid looper leaves, flowers	Venugopal 1958
Indarbela quadrinotata	Haryana, India	cannabina	orchard pest alt. host	Verma *et al.* 1974

TABLE 13.1 (continued)
Insect pests of *Sesbania* species

Pest	Location	*Sesbania* Species Affected	Comments	Reference
Lampides boeticus	Hawaii, USA	grandiflora	bean pest, alt. host	Nakagawa & Yamada 1965
Laspeyresia phaulomorpha	Tanganyika	sesban	caterpillars on branch axes	Ritchie 1935
Maruca testulalis	Hawaii, USA	grandiflora	bean pest, alt. host	Nakagawa & Yamada 1965
Mashonania pubescens	Senegal	sesban		Bryant 1941
Otinotus oncralus	India	grandiflora	tree hopper	CSIR 1972
Pericyma glaucinans	India	bispinosa	noctuid larvae	Venugopal 1959a
Piezodorus rubrofasciatus	Malaysia	bispinosa		Miller 1931
Prodenia litura			tobacco caterpillar, eats leaves	CSIR 1972
Radopholus similis	Central America	spp.		Edwards & Wehunt 1971
Rhyssomatus marginatus	Argentina	punicea, virgata	beetles feed on fruits	Erb 1979
Selenis monotropa	Florida, USA	exaltata	soybean pest, moths attack	Genung & Green 1965

			stems	
Semiothisa pervolgata	India	bispinosa	geometrid looper on leaves	Cherian & Pillai 1938 Venugopal 1957
Spodoptera littoralis	UAR	sesban	cotton leaf-worm host	Salama et al. 1971
Stegana lateralis	Tamil Nadu, India	grandiflora	larvae damage tender stems	CSIR 1972
Striglina scitaria	Tamil Nadu, India	bispinosa	larvae web & feed on leaves	Venugopal 1959b 1960
Tennebrio molitor	China	spp.		Anon. 1979
Thrips	Mexico	spp.		Guevara-Calderon 1958
Thyposidra successaria	India	bispinosa	caterpillars	Chandra & Farooqi 1979
Trialeurodes sesbaniae	Australia	tripetii		Corbett, 1936
Various insects	Ghana	grandiflora		Kudler 1970

TABLE 13.2
Plant pathogens affecting *Sesbania* species

Pathogen	Location	*Sesbania* Species Affected	Comments	Reference
Cercospora sesbaniae	India	bispinosa, sesban		CSIR 1972
Cherry chlorotic spot virus isolated from almond trees	Yugoslavia	exaltata	as test plant, reactions seen	Plese 1972
Cladosporium	India	cannabina		CSIR 1972
Colletotrichum capsici	India	grandiflora, speciosa	collar seedling blight	Srinivasan 1952
Colletotrichum coffeanum	Ethiopia	sesban	coffee berry disease isolated from bark	Gassert 1978
Corticum rolfsii (=*Sclerotium rolfsii*)	Malaysia	spp.	wilt	Turner 1971
Corticum solani	Malaysia	aculeata	leaf blight	Turner 1971
Daedalea spp.	India	sesban		CSIR 1972
Dendryphiella interseminata	Malaysia	speciosa	branch dieback	Singh 1980
Diplodia macrostema	India	sesban		CSIR 1972

Erysiphe polygoni	India	sesban		CSIR 1972
Fusarium oxysporum f. sesbaniae	India	sesban	root rot and wilt	Singh 1956
Groundnut chlorotic spot virus	India	spp.	infected systematically	Haragopal & Nayyudu 1974
Macrophomina phaseoli (=Sclerotium bataticola)	Texas, USA	exaltata	charcoal rot at stem base	Young 1949
Paecilomyces spp.	Malaysia	speciosa	branch dieback	Singh 1980
Protomycopsis thirumalacharii	India	grandiflora	fungus leaf spot	Haware & Pavgi 1969, 1971, 1972, 1971, 1976a, b, c; Pavgi 1965; Pavgi & Haware 1982
Protomycopsis ajmeriensis	India	bispinosa	fungus causing galls	Rao 1972
Prunus cerasus virus isolates	USA	exaltata reactions seen	as test plant,	Fulton 1957
Pseudo-cercospera sesbaniae	India	grandiflora	gray leaf spot	Komar & Joshi 1983
Rhizoctonia spp.	China	cannabina		Anon. 1979
Sclerotium bataticola	Uganda	spp.	charcoal rot on sweet potato in USA; a hot weather wilt	Small 1926

TABLE 13.2 (continued)
Plant pathogens affecting *Sesbania* species

Pathogen	Location	*Sesbania* Species Affected	Comments	Reference
Septobasidium spp.	Malaysia	aculeata	on stems	Turner 1971
Sesbania mosaic virus	India	grandiflora		Sreenivasulu & Nayudu 1982
Soybean mosaic virus		exaltata	alternate host	Galvez 1974
Xanthomonas sesbaniae	India	sesban	spots on leaves rachis, young stems, leaf edges	Patel, *et al*. 1952
Uredo sesbaniae	India	sesban	fungi	CSIR 1972

naturally occurring S. bispinosa germinated with the onset of monsoon rains in July, began flowering in September, and continued flowering and setting seed through the following February, but in December, a pod pest (unidentified) infested the plants and seed set thereafter was damaged.

In Hawaii, introduction plantings have been infested with a seed chalcid; infestation has varied in severity among species. The adult oviposits on developing pods, the larvae develop within the developing seeds, consuming the interior portion, and the adults exit after making a hole about 1 mm in diameter in the seed coat and pod. Some species such as S. macrantha, S. speciosa, and S. tetraptera were not infested, S. sesban was moderately infested, but S. grandiflora and most members of the bispinosa-cannabina-sericea species group were infested to the extent that only 5 to 10 percent of the seed collected was not damaged. The seed chalcid pest, identified as Bruchophagus mellipes Gahan, was not previously known in Hawaii (Beardsley 1983). Gahan (1920) described the pest as a new species, which had been received from Coimbatore in southern India and had been previously identified as Eurytoma indi (Girault) Ramakrishna Ayyar. Although related to B. roddi, the alfalfa seed chalcid, B. mellipes did not seem to infest alfalfa plants growing nearby at the site of our sesbania plantings. Searches of Commonwealth Agricultural Bureaux and U.S. National Agricultural Library bibliographic databases did not produce any information relating to B. mellipes. It is possible that in India, parasites and predators keep infestation by these chalcids at low levels; in Hawaii, the pests may be of recent introduction and the large chalcid populations developed unchecked by biological controls.

Sclerotium rolfsii caused wilt in several accessions of S. sesban during unusually dry weather in Hawaii. This occurred in a fodder cutting experiment where the trees, planted 25 cm apart in rows 1 meter apart, were cut back to a height of 50 cm every 7 to 8 weeks (Evans and Rotar, unpublished data). Cumulative incidence of wilt over a very droughty 3-month period in months 10-12 of the experiment varied from 5 to 50 percent of the plants in individual plots consisting of four 5-meter rows, and wilt was observed to occur especially after cuttings. Each harvest removed almost all of the foliage, which undoubtedly increased soil temperature and encouraged colonization by the fungus at a time when the plants were weakened. In such fodder production schemes during dry periods, partial selective cutting to maintain shade for the soil surface and reduce shock to individual plants may be a way to avoid susceptibility to such wilts.

There was very little information on chemical control of insect pests in sesbania crops. In Hawaii we have experimentally used both carbaryl and acephate to control aphids and leaf webbers (neither of the two chemicals are cleared for commercial use on sesbania crops). Acephate was thought preferable because of its moderate residual systemic activity, but the extent to which it reduced seed chalcid activity is uncertain. Recommendations originating from outside the USA of substances for pest control in sesbanias often specify materials such as DDT and BHC, which are no longer permitted in the USA and which should not be considered for use elsewhere.

Only limited work on biological control of pests of Sesbania species has come to our attention. Sithanantham (1970), observed Aspergillus tamarii as a pathogen on the Sesbania stem borer. Cherian and Brahmachari (1941) reported on insects which were predatory on caterpillars infesting S. bispinosa.

With the exception of two articles, all other references to plant-parasitic nematode infestation of Sesbania which we have found concerned the North American species, S. exaltata. In India, Jain (1981) reported that S. microcarpa was susceptible to invasion by Meloidogyne incognita. In Senegal, Germani et al. (1983), studied the effect of a preceding S. rostrata crop on reducing subsequent infection of rice by Hirschmaniella oryzae, and suggested that the legume acted as a trap crop.

S. exaltata grows very rapidly during hot summer weather; one report (Anon. 1935) stated that good stands often resulted despite nematode infestation, although following crops might be severely attacked by nematodes harbored in the sesbania crop roots. Soffes (1981) found, in contrast, that S. exaltata was extremely sensitive to infestation with rootknot nematode (M. incognita). Use of soil fumigation to control the pest increased plant dry matter yield by more than 10 times, and N yield by more than 20 times as compared to the yield of plants in non-fumigated plots. Lablab purpureus and Vigna radiata were also hosts with reduced yields which increased soil rootknot nematode populations, whereas Indigofera hirsuta, Cajanus cajan, and Crotalaria spectabilis yields were not severely reduced by nematodes. Rhoades (1964) showed that nematode populations were supported by sesbania or weedy fallow and suppressed by C. spectabilis, and yields of snap beans and cabbage were higher following the latter. Even when soil fumigation followed the legume crop, Rhoades (1968) observed that stubby-root nematode (Trichodorus spp.) populations returned in greater numbers after sesbania than after crotalaria. In further studies, Rhoades (1976) found that sesbania and sorghum maintained sting nematode (Belonolaimus longicaudatus) and rootknot nematode populations, but I. hirsuta decreased them, and snap beans following these crops yielded 5.6, 3.4 and 8.9 Mg/ha pods, respectively. In Rhoades' study, yields after I. hirsuta were the same as those after sesbania sown following soil fumigation with D-D at 260 l/ha. Overman (1969) also identified sorghum and S. exaltata as hosts of the sting nematode, as evidenced by higher levels of infestation in a following chrysanthemum crop and lower cut-flower yields compared to the crop following I. hirsuta. Epps and Chambers (1958) found the soybean cyst nematode (Heterodera glycines) on S. exaltata, but believed that sesbania may not be a preferred host of this pest.

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