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USES OF TREE LEGUMES IN SEMI-ARID REGIONS

Peter Felker

Department of Soil & Environmental Sciences
University of California, Riverside
Riverside, California 92521

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Introduction

The uses of tropical legumes has been the subject of an excellent and exceedingly thorough review coordinated by Vietmeyer (Anon, 1979). Recent reviews of tree legumes (Felker and Bandurski, 1979) of the individual tree legumes Leucaena (Anon, 1977 and Brewbaker and Hutton, 1979), and Prosopis (Felker, 1979) are available. An excellent world-wide review of Acacia and Prosopis in tropical dry forests has appeared in mimeo form (Griffith, 1961). This review will concentrate on uses of tree legumes in semi-arid and arid regions as that is the area where this reviewer can make the most meaningful contribution. Every attempt will be made to avoid material covered in previously mentioned reviews. Both published and non-published works will be discussed. In some cases valuable examples of uses of tree legumes are only known through extensive travels and communications of overseas development specialists. These examples will also be included with appropriate qualifications.

Undoubtedly, there are many exciting and innovative uses of tree legumes only known to the non-scientific communities of developing countries. Accordingly, it must be realized this review is far from complete.

For organizational purposes, this review will be divided into sections related to the following general use categories: use for fuels, use for human food, use for livestock food, use to increase yields of crops grown beneath their canopies, and use for control of desertification.

Uses of tree legumes as human food

Prosopis undoubtedly is the genus most extensively used as human food as described in recent reviews by Felger (1979) and Felker (1979) and D'Antoni and Solbrig (1977). These authors reported Prosopis to be the food staple for Indians in the desert regions of Arizona, California, and northwestern Mexico. Even in the inhospitable climate of Death Valley, California, the staple food was the mesquite bean (Clements, 1975). Similar uses are described in South America and India. A recent chemical analysis of P. velutina and P. glandulosa var. glandulosa (Becker and Grosjean, 1980) found no cyanogenic or toxic compounds in seeds or pods of material they examined. Rat feeding trials with entire ground P. velutina pods indicated they had a protein efficiency ratio (PER) of 1.5 standardized to a casein value of 2.5 (R. Becker, unpublished obs.). This compares favorably with maize, rice, and beans which have PER's of 1.4, 1.5, and 1.8 (Autret, 1972). As mentioned by Felger (1979), Cercidium spp. and Olneya tesota were also important food sources. Biomass production field trials with these species indicate they are slower growing than most Prosopis (Felker et al., 1980a) but they do have the advantage of growing in areas which receive less water than Prosopis. Olneya and Cercidium trees which may be 8 m tall with 30-40 cm basal diameters often occur on drainage channels insufficient to support growth of Prosopis (Felker, personal observation). One such watershed (Milipitas Wash south of Blythe, California) receives less than 150 mm annual rainfall, covers nearly 50 km^2 and supports nearly forest-like stands of Cercidium and Olneya.

The soft immature pods and seeds of Cercidium have a pleasant taste similar to peas and beans. As Felger (1979) points out, the hard mature seeds require special preparation. The pods of Olneya and Cercidium easily dehisce and are 1/4 to 1/2 the size of Prosopis pods. This makes hand-gathering of food material from Olneya and Cercidium more lengthy than for Prosopis. For example, two men working six hours were required to pick 8 kg of fallen Olneya seed from beneath one large tree in southern California while only 0.5 hr would be required for two men to pick up 8 kg of mesquite pods if a good crop of beans were present. This Olneya seed yield is almost three times greater than the maximum yield reported by Felger (1979) for Arizona trees.

In the African Sahel and associated savannah Parkia probably provides more food directly consumed by humans than other tree legume genera. Busson et al. (1965) reports that four species, Parkia bicolor, P. biglobosa, P. filicoidea and P. clappertoniana, are used in various parts of Africa. A yellow meal which surrounds the seeds in the pods can be pressed into cakes for storage and is a valuable food when mixed with rice, cereals, meat or soup (Dalziel, 1937). As mentioned in an earlier review (Felker and Bandurski, 1979), the seeds can be fermented into a cheese-like product. This author purchased 2 cm diameter balls for sale in the market at Bambey, Senegal, where they had been transported 100 km from a region where the Parkia trees are more common. The protein content of four Parkia seeds ranged from 21-45% protein content indicating much promise for breeding and selection work.

The only tree legume domesticated (deliberately planted) for human pod consumption is the carob (<u>Ceratonia siliqua</u>). Unfortunately carob is one of the numerous members of the <u>Caesalpinoideae</u> that has never been known to nodulate or fix nitrogen. Since an excellent recent review of carob is available (Anon, 1979), it will not be described here.

<u>Livestock food and fodder production</u>

As surmised from the written record, the major livestock food producing tree legumes of the semi-arid tropics are <u>Prosopis tamarugo</u> in Chile; <u>Leucaena leucocephala</u> in Australia, the Philippines, and Hawaii; <u>P. glandulosa</u> in Mexico; and <u>P. juliflora</u> in Peru. As recently reviewed (Anon, 1975; Felker, 1979) <u>P. tamarugo</u> is cultivated in thousands of hectares in the Atacama salt desert of Chile, where 30-year-old mature trees annually provide 6,000 kg of leaves and pods to support sheep raising operations (Salinas and Sanchez, 1971). <u>Leucaena leucocephala</u> is widely grown where its leafy material is harvested several times a year for cattle food or to be sold as an alfalfa substitute. Forage dry matter yields are high maximizing around 20 T ha^{-1} yr^{-1} (Brewbaker and Hutton, 1979). <u>Leucaena</u> is a very important and useful plant but since it has been extensively reviewed elsewhere (Anon, 1977; Anon, 1979; and Brewbaker and Hutton, 1979) it will not be further discussed here. Recently over 1,000 ha of <u>Prosopis juliflora</u> has been brought under partial irrigation in the Peruvian coastal desert. By providing 250 mm of irrigation the first year of establishment and 160 mm thereafter, pod production of 6-7 tons ha^{-1} have been obtained (report of R. Peck to

IDRC, Bene, pers. comm.). As this report states, this is almost ten times less water than needed to irrigate normal agricultural crops.

Prosopis pods are extensively used in numerous states of Mexico as detailed in a 70-page review by Lorence (1970). By compiling agricultural statistics from 9 Mexican states, Lorence (1970) found that in 1965, 40,000 tons of mesquite pods were used as a forage or concentrate in rations for Holstein, Jersey, Hereford, Charolais, and Angus cattle; for rambouillet sheep, for nubian goats and on a more limited scale for horses, donkeys and mules. All of these pods were collected from wild stands and sold to wholesale dealers in the cities during the hot summer months when corn, beans or wheat crops might be lost to a drought. If the regular crops failed, the sale of mesquite pods could be very important for the livelihood of the rural population. Mesquite was also used for firewood, lumber, and other uses, but the major use was for livestock food. Undoubtedly many more pods were fed to livestock than were reported as articles of commerce in agricultural statistics handbooks.

Pod production is quite variable between and within accessions. In an Imperial Valley planting of 1300 Prosopis trees of 72 accessions, 15 trees flowered and six produced pods 9 months after germination and 6 months after transplant. Thirteen of these flowering trees were from 2 of the 72 accessions. In a 2-1/2 year old planting at Riverside, California, these same two early pod producing accessions out yielded other accessions with a dry pod yield of 4.8 kg per tree (Felker et al., 1980b). Chemical analyses indicate the pods of these two accessions were 11% protein, 13% sucrose, and 17% protein, 19% sucrose (R. Becker, personal communication).

In addition to the organized use of the above mentioned trees, other species such as Acacia albida and A. tortilis produce pods which are used for livestock feed on a more casual basis. In a limited interview with 10 farmers in three villages in the Senegalese peanut basin it was learned that nine farmers collected, stored, and rationed A. albida pods to livestock (Felker, 1978). While they may not be collected and stored A. tortilis pods are a very important livestock food in East Africa (Anon, 1979).

Use of leguminous trees and shrubs for browse by wild and domestic animals is an enormously broad topic with which this author has little experience. Most of the papers in a recent symposia on "Browse in Africa" (LeHouerou, 1980), involved use of leguminous trees in a major fashion. Pellew (1980) reported the productivity of the portion of Acacia xanthophlea, A. tortilis, and A. hockii ecosystem consumed by giraffes in the Serengetti National Park to be around 5,000 kg ha^{-1} hr^{-1}. Pellew (1980) suggested the giraffe-Acacia ecosystem be managed for meat production. Many of the same legumes were observed to be important in the review of browse in Kenya, Tanzania, and Uganda by Lamprey et al. (1980). Though not semi-arid, the huge miombo woodland, which stretches from northern Tanzania southward to Rhodesia and westward to central Angola, is dominated by leguminous trees of the genera Brachystegia and Julbernardia (Lawton, 1980). These tall miombo woodland trees are useful to tall browsers like giraffes and elephants. To make this browse accessible to domestic cattle, the trunk is cut off at breast height so the ensuing resprouts can be eaten by the livestock (Lawton, 1980).

Many other leguminous tree genera, e.g., Afzelia, Isoberlinia, Burkea, Pterocarpus, Daniellia, Dalberghia and Lonchocarpus are found to be important browse plants in LeHoureou's (1980) review of browse plants in the 500-1200 mm annual rainfall regions of Tropical Africa.

USE OF LEGUMINOUS TREES AS TOOLS AGAINST DESERTIFICATION

The use of trees as tools in the struggle to prevent desertification are widely known. Several books (Anon, 1974; Kaul, 1970; and Goor and Barney, 1976) specifically deal with practical methods and useful species for reforestation of semi-arid regions. In all these books some Acacia and/or Prosopis species are recommended for practically every semi-arid region. A specific example of use of Prosopis as a shelterbelt to prevent sand from covering homes and agricultural fields has been previously cited (Felker, 1979). In the last three years 160 ha of Prosopis has been planted in the Sudan along irrigation canals to prevent the wind from filling with with sand (Khalifa, personal communication). In this case non-erect Prosopis accessions with low lying branches were most desirable. To aid the trees in their survival against browsing animals some workers involved with arid zone reforestation, (Houri and Lamprey, personal communication), are seeking thorny species with non-palatable leaves that also have an edible fruit portion, e.g., pods, that can be eaten without harming the tree or bush. Some Prosopis species seem to fit this role rather well (A. E. Houri, personal communication).

Little known leguminous trees of the genera Cercidium and Olneya exist in harsher southern California desert conditions than where

Prosopis is normally found and indicate great potential for use in other arid zones. As mentioned in the section on human food uses both Cercidium and Olneya appear to grow well in regions with daily summer maximum temperatures of 41°C and in winter rainfall regimes receiving as little as 100-150 mm annual rainfall if they are located in small drainage areas.

Tree legumes used to increase yields of annual crops beneath their canopies

Acacia and Prosopis (Habish and Khairi, 1970; Felker and Clark, 1980) have both been shown to nodulate and fix nitrogen. Nitrogen fixation by these trees is very important in light of the suggestion by some workers (Felker et al., 1980b) that nitrogen may limit plant productivity of semi-arid soils more severely than water. Perhaps the capability of some tree legumes to deal with the nitrogen deficiency aspects of deserts has led them to co-evolve complimentary drought resistant mechanisms. There is no other theory available to explain why the leguminous trees should have evolved to dominate the arid and semi-arid ecosystems.

Two well-documented and widely used trees for increasing yields of crops grown beneath their canopies are Acacia albida and Prosopis cineraria. A. albida is widely used in the more mesic (400-600 mm) regions of Sahelian West Africa where yields of millet, sorghum, and peanuts are increased from approximately 500 to 900 kg ha^{-1} yr^{-1} under its canopy (Dancette and Poulain, 1969; and Charreau and Vidal, 1965). The yield increase under A. albida is correlated with a several-fold increase in the soil nitrogen and organic matter content, and soil water holding capacity under the tree. The primary cause for this yield is felt to be attributable to the increase in the soil nitrogen level (Dancette and Poulain, 1969). A. albida has been shown to nodulate (Habish and Khairi, 1970) and reduce acetylene (Dommergue, personal communication) and it is this author's contention that the yield increase of annual crops and the increase of soil nitrogen under the trees is driven by A. albida nitrogen fixation. Pod yields for A. albida trees have been reported to range from 6 to 135 kg/tree (Felker, 1978) and are highly regarded as a live-stock feed. The distinguished soil scientist, Charreau, feels that A. albida trees could be managed to produce much higher forage potential than grass or annual crops grown beneath their canopies (Charreau, personal communication).

Acacia albida has been the subject of a recent review (Felker, 1978) covering nearly 30 unpublished and published documents and research papers related to soil chemical and biological influences, pod yields, phenology, taxonomy, and sociological and demographic studies. There is no doubt that farmers have great respect for this tree because it increases yields of their agronomic crops, and because of the pods which are often collected and fed to cattle (Felker, 1978). During an interview with farmers in the Senegalese peanut basin, it was learned that most farmers wanted assistance to obtain more A. albida in certain portions of their field and to reduce its density in other portions (Felker, 1978). At that time, no A. albida seedlings or techniques for establishing new seedlings were available to the farmers. If new seedlings arose from natural regeneration farmers would take great care to protect and prune them (Pelissier, 1967). As the interviewed farmers noted there is great variability in A. albida pod yields. Presumably this variability exists in other characters such as growth rate so that selection of wild plants for pod yield and/or fast growth rate and development of seedling propagation techniques could greatly aid the farming population.

A very analogous tree legume ecosystem is based around Prosopis cineraria in the western Rajasthan region of India (Mann and Shankarnarayan, 1980). The farmers in this region maintain P. cineraria trees in densities as high as 150 trees/hectare in their pearl millet fields. Several soil chemistry studies cited by Mann and Shankarnarayan (1980) report increases in organic matter and total nitrogen under P. cineraria trees versus open areas and versus canopy covers of other tree species. Since the farmers maintain the P. cineraria trees in their fields and since the soil chemical properties are more favorable under the tree, presumably the pearl millet yields are increased under the trees. Unfortunately, millet yield data under and away from the trees is not yet available.

Prosopis cineraria trees are also highly esteemed in the empty quarter of the country of Oman (Saudi Arabian peninsula) where the trees get the bulk of their moisture from heavy ocean fogs (R. M. Lawton, personal communication). Here it was observed that the desert zyzphus vegetation was much greener under Prosopis cineraria than in open areas (R. M. Lawton, personal communication).

In 1977 this author observed a similar association involving the tree legume Parkia biglobosa and millet along the Senegalese coast near Kebemer where the mean annual rainfall is 350-400 mm. Local farmers mentioned that Parkia increased the fertility of the soil in a similar fashion to Acacia albida. The occurrence of many Parkia biglobosa trees at this location is particularly noteworthy since some authors believe it only occurs in rainfall regimes greater than 600-700 mm.

While crops are not grown beneath Prosopis canopies in the United States, soils under Prosopis appear to be more fertile than found in open areas. Tiedemann and Klemmedson (1973) examined herbage yields in the growth chamber using soil beneath and distant from an Arizona Prosopis growing on the range. The herbage yield was found to be four times greater on mesquite soil than the open grown control and nitrogen was found to be the primary nutrient responsible for this effect.

In an undisturbed California desert ecosystem too dry (mean annual rainfall of 65 mm) and too hot (July daily max. of 42°C) to support grass production, forage production, grazing, or farming, Prosopis glandulosa var. torreyana forms dense stands 7.5 m above a water table. Here the nitrate content of a soil saturation extract for a 30 cm deep sample was found to be 100 mg/kg away from Prosopis and 400 mg/kg directly under the Prosopis canopy (W. Jarrell, personal communication). This phenomenal 1200 kg of nitrate per hectare was only possible because of lack of rainfall which would have leached it to greater depths.

In addition to the well-known example of arid adapted nitrogen fixers we have recently observed that desert ironwood (Olneya tesota) forms nodules, can grow on nitrogen free media, and reduce acetylene to ethylene. Smaller shrubby legumes, e.g., Dalea spinosa and D. emoryi which occur in washes in southern California where summer maximum temperature reach 47^{o}C have been shown to fix nitrogen (Eskew and Ting, 1978). These shorter legumes might be suitable for interplanting with non-leguminous arid land plants such as jojoba (Simmondsia chinensis), buffalo gourd (Cucurbita foetidissima) atriplex, or opuntia, to provide nitrogen. These shrubby legumes could be interplanted in rows or planted in solid stands to be plowed under in rotation with another crop. Examples of these legumes are shown in Figures 1, 2, 3 and 4.

Curiously enough, Cercidium spp. which dominate much of the Coloradan and Sonoran deserts have never been observed to nodulate. The legume subfamily Caesalpinoideae contains Cercidium and many other genera which have never been reported to nodulate (Allen and Allen, 1959). Considering the evolution of simple reproductive structures in non-vascular plants to a highly evolved angiosperm flower one could hypothesize that the morphologically and biochemically complex legume-rhizobia symbioses has evolved from simpler less intimate associations. One might expect to find simpler associations in primitive woody legumes of the Caesalpinoideae which has numerous nodulated and non-nodulated genera. It would be instructive to attempt transfer of nitrogen fixing capabilities from soybean to a non-nodulated legume such as the Carob (Ceratonic siliqua) before attempting to transfer nitrogen fixation to maize.

Good documentation supports increased agronomic yields beneath Acacia albida. Good chemical evidence indicates favorable fertility conditions under Prosopis cineraria, P. velutina and P. glandulosa var. torreyana. Further exerimentation will undoubtedly bring many more such examples to light.

USE OF TREE LEGUMES FOR FUEL

In 1978 the United States government formally recognized the need and potential for woody biofuels with the establishment of the "Fuels from Woody Biomass" in the Department of Energy. This program has 25 contractors located in most climatic and geographical areas of the United States that are examining: species selection; cultural treatment and management strategies; alternate harvest collection, transportation, and storage strategies and stand establishment.

In contrast to the reawakening of the potential of woody biofuels in the United States, firewood has never ceased to be an important commodity in developing countries. FAO wood use surveys indicate that although woodfuel enters the wood uses of industrial processes in a minor way, 96, 94 and 76% of all wood (including timber) consumed in Tanzania, Gambia and Thailand was consumed as fuelwood (Oppenshaw, 1974). Oppenshaw (1974) indicates that woodfuel constitutes 65% of total world wood consumption. The average wood consumption in developing countries was estimated to be 1.3 tons per capita. When only those families using wood were included, an average of 8 tons of wood per family were consumed (Oppenshaw, 1974). It has been estimated that a manual laborer's family in the capitals of the Niger and Upper Volta in the African Sahel spends between 25 and 30% of their income on firewood (Eckholm, 1975). Virtually all of the trees within 70 km of Ouagadougou, the capital of Upper Volta, have been consumed as fuel by the city's inhabitants (Eckholm, 1975). Firewood and charcoal from Khartoum, Sudan are derived from Acacia forests growing along the Nile river some 400 km south of the city (Idris, 1976).

Many leguminous trees in the genera Acacia, Leucaena, and Prosopis as well as non-leguminous tree Eucalyptus, Tamarix and Azadirachta are currently being harvested in the semi-arid regions for fuelwood (D'Antoni and Solbrig, 1977) (Le Houreau, 1976). Little published information is available on chanar (Geoffrea decorticans) and espino (Acacia cavens), two tree legumes widely used for fuel wood in Chile (Aschmann, pers. comm.) Despite well known plantation establishment techniques (Anon, 1974; Kaul, 1970; and Goor and Barney, 1976) wood is being consumed far faster than it is regenerating (Idris, 1976).

Nitrogen fixing trees are especially useful when used for energy purposes since the energy to fix the nitrogen in the plants is solar derived. In contrast nitrogen fertilizer is synthesized from natural gas (methane) at temperatures and pressures which require large amounts of energy. For example, a study of the average energy yield of U.S. corn production found the energy for nitrogen fertilizer was only 8% less than the largest input, fuel, and that the energy consumed by nitrogen fertilizer was 5 times as great as the next largest energy input -- the energy to dry the corn, on an intensively managed farm in the cornbelt (Doering, 1977). Considering the shortage of fossil fuel derived fertilizers and the need for sustained yield woody biofuel production in the less developed countries, nitrogen fixing trees possess a clear advantage over non-nitrogen fixing trees.

At the current crude oil price of \$30 per barrel, the equivalent energy price for Prosopis wood (8,000 Btu lb^{-1}) is \$75 per metric ton. This compares favorably with agricultural crops such as maize (\$2.50 per bushel = \$90 per metric ton) and indicates promise for energy crops.

OTHER USES

As reviewed by Whistler in this legume symposium, gum arabic, used for confectionaries and in paper sizings, is exuded from wounds of Acacia senegal tree and is a significant industry in Sahelian semi-arid Africa. A large scale planting of A. senegal is being supported in Senegal by the International Development Research Center (Ottawa) (Sene, personal comm.). Because of the dark color and deep grain, desert ironwood (Olneya tesota) and mesquite (Prosopis spp.) are widely used in Mexico for wood carvings for the tourist industry.

Several economically important products are derived from leguminous tree flowers. Prosopis blossoms are repoted to produce large quantites of honey in southwestern United States and fragrant flowers of Acacia farnesiana have been widely used in the perfume industry. Beeswax is one of the most valued commodities of some East African forests (Lawton, pers. comm.). A concentrated infusion of certain Prosopis pods is used to form a special cocktail known as algarobina that is widely used in Peru today (Aguilar, pers. comm.). Fast growing, thornless evergreen and low water requiring Prosopis alba species constitute one of the most important shade trees in the water conscious Arizona landscape industry.

CONCLUSIONS

Often unique specialized geologic or climatic features make tree legume production possible and moderately productive in regions where climatic data would indicate plant growth is nearly impossible. As discussed earlier in the paper, P. glandulosa var. torreyana grows in Death Valley, California, with mean annual rainfall less than 70 mm and July daily maximum temperatures close to 45^{o}C by using groundwater accumulated in sand dunes from runoff from sporadic rainfall in nearby mountains. In this region mesquite was the staple of life for native American Indian populations. In South America a similar situation occurs in the rainless (0.7 mm year^{-1}) Atacama salt desert where Prosopis tamarugo supports a sheep raising operation with 6,000 kg ha^{-1} of pods and leaves from 30 year old trees by tapping a saline groundwater aquifer 3 to 10 m below the surface. P. cinerarium, a tree whose uses were described earlier occurs in the harsh empty quarter of Oman (Saudi Arabian peninsula) where it obtains its moisture from heavy ocean fogs and dews (Lawton, pers. comm.).

While such unique climatic and geologic features probably occur with low frequency and on a small percentage of their respective desert area, it is conceivable that they may support plant and animal production as great or greater than the total area of their encompassing desert. Identification and creative, imaginative use of these specialized niches could make a substantial contribution to desert agriculture production in deserts where the climatic regime appears too harsh to support any plant production.

Every effort should be made to take advantage of the leguminous tree's capability to fix nitrogen. Nursery seedlings should be inoculated with a rhizobia strain known to form an effective symbiosis with the host plant. One would expect outplanted nitrogen fixing seedlings to have good mineral nutrition and a greater capability to deal with stress and plant competition than seedlings with inadequate nutrition. Mature nitrogen fixing trees will reduce dependency on expensive and energy intensively produced synthetic nitrogen fertilizer and have the potential to stimulate non-leguminous crop production.

Named cultivars of Leucaena leucocephala have been developed in Australia and Hawaii but there are no named cultivars or varieties of Acacia or Prosopis for use in the semi-arid regions. Simpson (1977) suggests Prosopis is an obligate outcrosser. Experimental workers with Acacia believe that most African Acacias are cross pollinated (Seif-el-Din, pers. comm.). Thus, trees will not propagate true to seed and in all likelihood tree propagated from seed sources will be extremely variable. We have observed a severalfold difference in height from tree propagation from the same seed source. We have also observed segregation of *P. glandulosa* var. *torreyana* and *P. alba* from the seed of a *P. alba* tree grown within 1/2 km of the native *P. glandulosa* var. *torreyana*. If possible use of unselected seed or non-clonally propagated plant germplasm is to be avoided.

Large genetically diverse germplasm collections need to be made for the major leguminous trees of semi-arid regions. These accessions should be evaluated in a field setting and cultivars selected for; pod chemical characters, pod production, wood production, size and/or lack of thorns, gum production, foliage palatibility, frost tolerance, and nitrogen fixing capabilities. These selected cultivars should be clonally multiplied and distributed for further field evaluation in diverse climatic regions where they are currently used or where they may have potential. The immense genetic diversity in leguminous trees caused by cross-pollination, and the lack of any selection effort for desirable economic characters, should allow rapid identification of superior cultivars and a rapid return of research investment costs.

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FIGURE LEGENDS

Figure 1. <u>Cercidium microphyllum</u> in flower in Arizona desert. The immature pods were eaten by American Indians.

Figure 2. <u>Olneya tesota</u> in flower in Arizona desert. After leaching the mature seeds were eaten by American Indians. This species can fix nitrogen.

Figure 3. <u>Dalea emoryi</u> in flower in California desert near Salton Sea. This short nitrogen fixing legume as well as <u>D</u>. <u>spinosa</u> has potential for intercropping with non-leguminous plants to provide nitrogen.

Figure 4. <u>Dalea spinosa</u> in flower in California desert.

Figure 1. Cercidium microphyllum in flower in Arizona desert. The immature pods were eaten by American Indians.

Figure 2. Olneya tesota in flower in Arizona desert. After leaching the mature seeds were eaten by American Indians. This species can fix nitrogen.

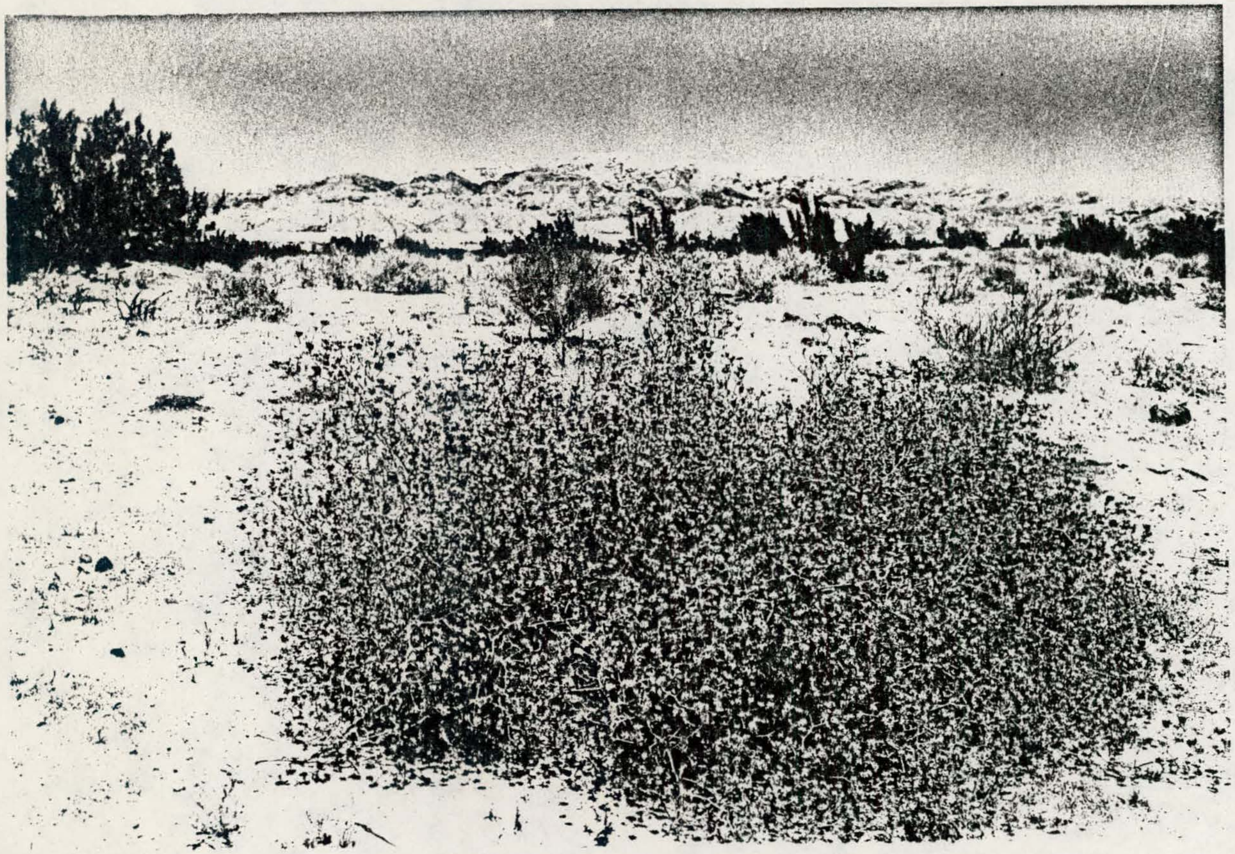

Figure 3. Dalea emoryi in flower in California desert near Salton Sea. This short nitrogen fixing legume as well as D. spinosa has potential for intercropping with non-leguminous plants to provide nitrogen.

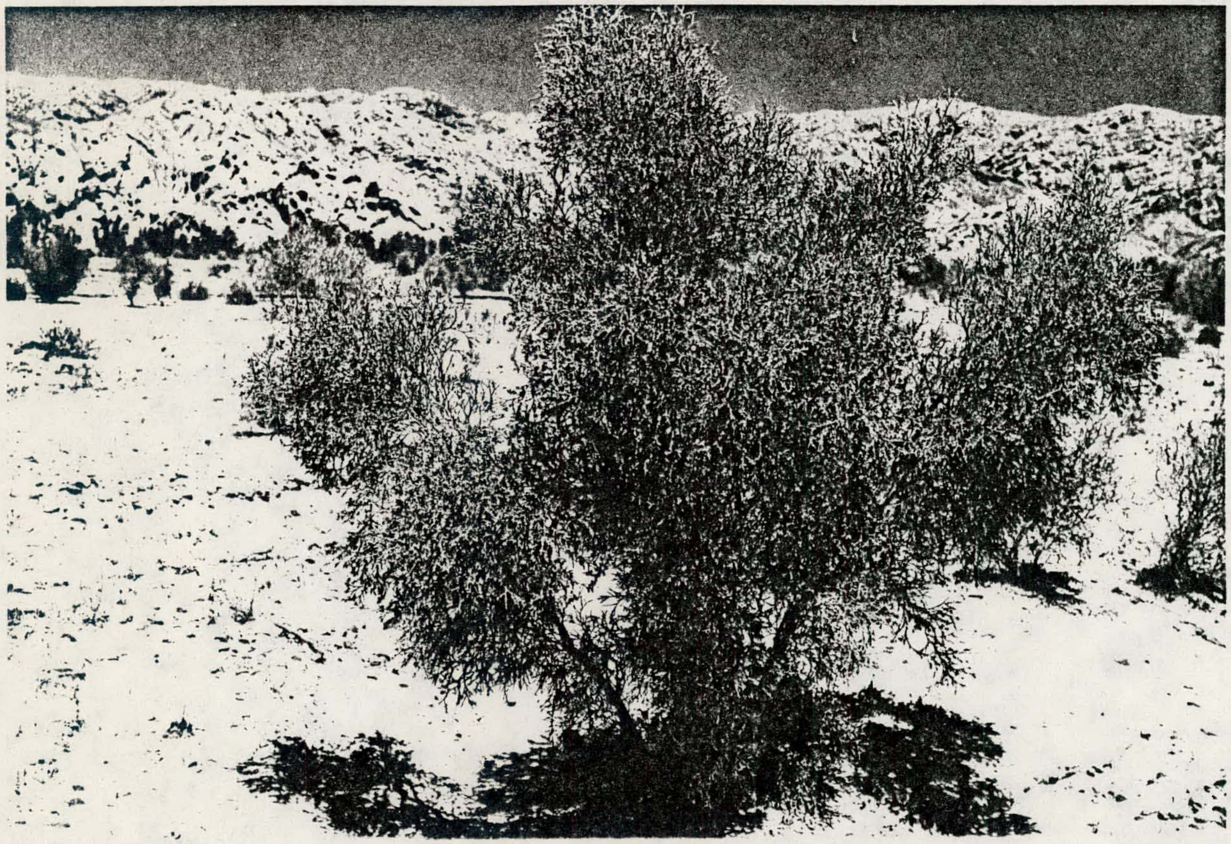

Figure 4. Dalea spinosa in flower in California desert.