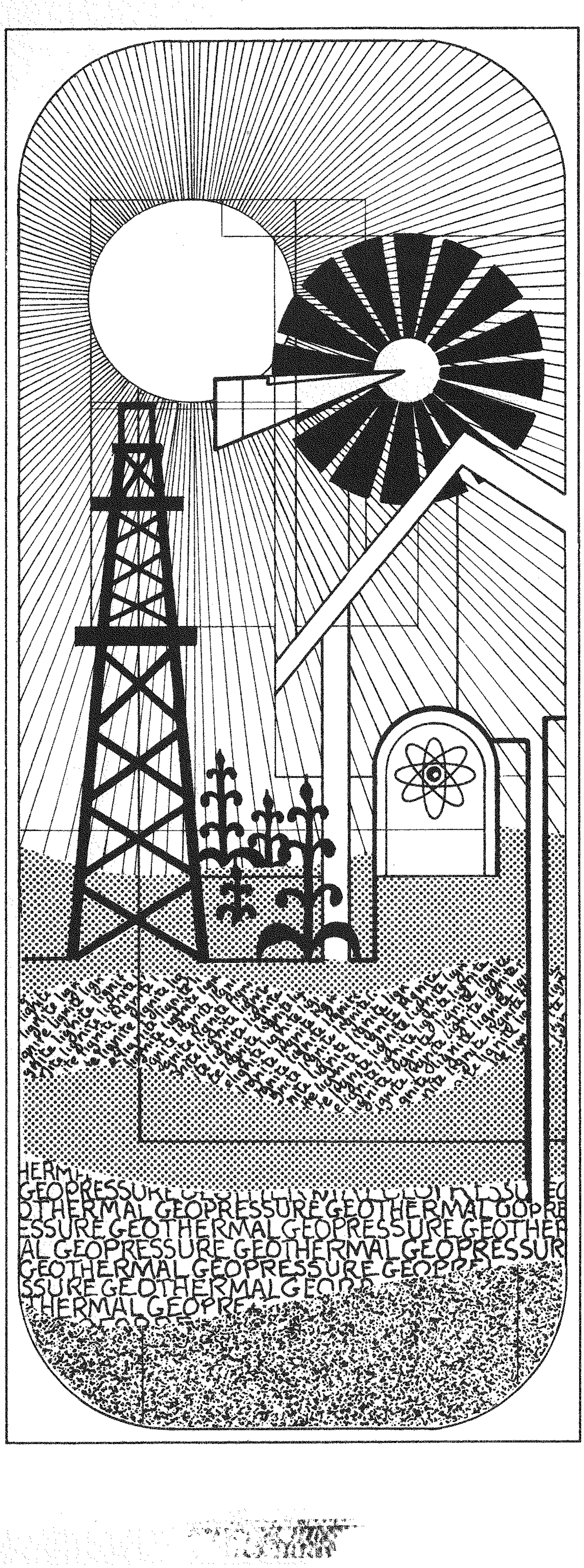

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UNCONVENTIONAL PLANTS FOR BIOMASS FEEDSTOCKS IN SEMI-ARID WEST TEXAS

TENRAC/
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TEXAS ENERGY & NATURAL RESOURCES ADVISORY COUNCIL

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MASTER

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UNCONVENTIONAL PLANTS FOR BIOMASS FEEDSTOCKS IN SEMI-ARID WEST TEXAS

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EXECUTIVE SUMMARY

The adoption and use of coal, petroleum, and natural gas as fuel sources have evolved because of their low cost and high energy content. As supplies of these non-renewable fossil-fuels decrease and their costs increase, the need for new sources of energy becomes evident. One of the alternative new sources is biological solar energy conversion (BSEC), commonly known as photosynthesis. In BSEC, plants transform solar energy into chemical energy or biomass, which then can be harvested and converted into usable energy products. The biomass from terrestrial plants is renewable, and it can potentially contribute significantly to the future energy needs. It has been suggested that the U.S. should expand commercialization concepts and set guidelines that would permit biomass to develop into a significant supply of energy. Estimates of the energy potential for the U.S. for biomass sources is in the range of 10-15 Quads/yr by the year 2000; this is 10-15% of the U.S.'s energy needs. A substantial contribution to U.S. biomass production might be derived from biomass plantations such as those proposed in semi-arid West Texas.

The research reported here presents a new thrust in the production of biomass energy by utilizing plants that have not been previously considered and/or used for traditional agricultural food and fiber purposes. The specific objectives are to:

1. Evaluate the establishment and the productivity potential (lbs biomass/acre•yr) of four plant species in West Texas as influenced by rainfall, temperature and minimum cultural practices.
2. Accurately assess the present distribution and acreages inhabited by the four candidates in West Texas as well as the soil, geographical and climatic factors which govern their adaptation.
3. Provide productivity data in order to make adequate economic and sociological assessments of biomass production in West Texas.

Summary - Objective 1.

Four species were selected from an initial screening of 2,900 plants which were native to or naturalized in West Texas. The four species are mesquite, saltbush, Johnsongrass and Kochia. Four sites, representing a broad range of rainfall patterns (7 to 24 inches) were selected at Brady, Big Lake, El Paso, and Lubbock. The soils at these sites are generally alkaline, low in nitrogen, extremely variable in phosphorus, and high in calcium, magnesium and potassium. The macro-nutrient most limiting to plant yield is most likely nitrogen and in some cases phosphorus.

The rainfall patterns for all four sites for the 7 mos of 1981 are similar to previously reported averages for the same time period. The Brady site experienced considerable flooding early in the growing season and this hampered establishment of saltbush and Kochia. The sparse rainfall in the early months of the year at Lubbock undoubtedly contributed to low soil moisture levels which inhibited the establishment of all species at that site.

Experimental plots of approximately 1 acre have been enclosed with fencing at all 4 locations. Seedlings were planted on successive weekends in April at the 4 locations in the following order: Brady, Big Lake, El Paso, and Lubbock. All seedlings received approximately 1 qt of water at the time of planting and 2-3 qts at periodic intervals thereafter. One hundred-ninety-two seedlings of each species were planted at each site. Early season flooding at Brady caused a total loss of saltbush and Kochia whereas Johnsongrass survival was 92% and mesquite survival was 63%. Johnsongrass, saltbush and mesquite had excellent survival at Big Lake, whereas Kochia suffered 84% mortality. At El Paso, saltbush survival was good (79%), fair for mesquite (47%) and Johnsongrass (41%), and poor for Kochia (12%). Mortality was most evident at the Lubbock site. This was due to the late planting date and hot dry winds prevailing for 2-3 weeks after planting. Height data were taken in the latter part of July. Johnsongrass obtained heights of 40 cm at Brady and Big Lake, but was only 18 cm at El Paso. Although not surviving at Brady, saltbush heights ranged from 13-17 cm at the other 3 sites. Mesquite growth was the least of the 4 species, with heights ranging from 9-13 cm. The small number of Kochia plants surviving had heights of 20-30 cm.

Even though the primary objective of the project has been to establish experimental plots from transplants, we have had access to mesquite and saltbush established plants and these have been used to study growth rates and regrowth following coppice harvesting.

Mesquite regrowth has been studied from plants at the Big Lake site following clearing for experimental plots. These plants were cut back to ground level. At first, rate of height regrowth was very rapid (15 cm/mo) but ceased completely during the middle of the growing season (1.7 cm/mo). Although this is not a typical coppice harvest situation, it does cause concern about the regenerative potential for mesquite.

Saltbush regrowth has been studied from 6-year old plants which were coppice harvested (40 cm height) at the Lubbock site. Some plants were harvested in March, and others during June and July. Data indicate that regrowth potential is excellent from early spring to mid-summer. Using height measurements, the saltbush seedling growth rate of late cutting was about 0.3 cm/day compared to late cutting of mesquite which was less than 0.1 cm/day. Plants cut during July suffered considerable mortality, suggesting that photosynthate source should not be removed too late in the growing season. These data confirm grazing studies from other workers and ecological observations that saltbush has evolved under a system of winter browsing by herbivores. Data are also being accumulated for growth rates of volunteer saltbush seedlings, approximately 1-2 years old.

It is apparent that establishment by transplanting has a far greater chance of success on a year-in and year-out basis than does direct seeding under semiarid conditions. If environmental and esthetic considerations were not a problem, replanting over several years in anticipation of ideal conditions might be feasible. Such chance occurrences do not appear feasible in a region subject to severe erosion when the vegetative cover is removed. The additional cost of transplanting seedlings would appear to be justified, realizing that losses may still occur in most years.

Although growth in this short period of time was not sufficient to produce biomass for harvest, the established one-year-old plants should produce excellent yields during 1982. The replacement of plants which failed to survive will be accomplished during the fall of 1981 which will give a comparison between spring and fall transplanting.

Summary - Objective 2.

Literature surveys have indicated that the distribution and density of mesquite in Texas is well known. Johnsongrass and Kochia are widely distributed in Texas, but confined to localized populations in disturbed sites which cannot be identified by remote sensing. Therefore, the ecological survey was confined to saltbush.

In order to better understand the edaphic and climatological factors involved in growth and reproduction in West Texas, we are making an ecological survey of saltbush distribution. After having determined the location of certain dense populations, we have focused on areas at Texon and Crane for study. LANDSAT aerial photography is being utilized to attempt to correlate remote sensing with ground truth surveys. Considerable effort has been given to developing ground survey methodology for density and percent cover uniquely adapted to saltbush. We feel confident that the belt transect method is rapid and satisfactory for our purposes. The ultimate goal is to use remote sensing to quantitatively assay all saltbush populations in West Texas and describe the ecological conditions attributing to those populations.

This survey involves both remote sensing and ground truthing techniques and is an ongoing process. Large populations at Crane and Texon have been identified and detailed density and cover data are being accumulated. Other sites will be identified and edaphic/climatological data will be correlated with saltbush distribution.

Summary - Objective 3.

Data now available indicate that it is technically feasible to produce biomass derived fuels and chemicals in West Texas from crops such as saltbush, one of the species currently being studied. Our understanding of production methods and economics for the four species being studied will be improved substantially by the field studies now under way. Calculations based on data previously developed in other studies for saltbush have been used to calculate conceptual economics for a biomass fuels industry in West Texas. These studies indicate that a sizeable new industry could be established during the next 20-30 years, if the economics for producing these fuels were competitive versus alternative fuels. Assuming that a biomass crop is grown on 30 million acres of the total West Texas area of 100 million acres, the biomass resource would provide the raw material required for 2.2 Quad/year of densified solid fuel. An alternative use for the biomass production would be to produce a liquid fuel such as ethanol now used as a chemicals raw material and for blending into gasohol. In this option annual liquid fuel production would be 12 billion gallons corresponding to an annual energy production of 1.0 Quad/year. Production from either of these options would provide a significant portion of the approximately 95 Quad/yr. now estimated as the U.S. total energy requirements from all sources for the year 2000.

If the densified solid fuel option were followed, the annual revenue from the biomass produced from the 30 million acres would be about $1.3 billion. Transportation charges to move the biomass from the farm to the conversion plant would require an additional $1.2 billion; thus providing annual value of the raw material at the conversion plant of $2.5 billion. The solid fuel would have an annual sales value, delivered to the fuel user, of about $9 billion. The 900 solid fuel conversion plants required for the 30 million acres of production would require a total investment of $6 billion.

If the liquid fuel option were used, the same biomass resource would provide ethanol with an annual sales value, f.o.b. the plant, of $15 billion. Other products from the plant would provide additional annual revenue of $5 billion. The 200 or more ethanol plants would require a total investment of $25 billion.

Preliminary projections indicate that seedlings could be produced for 11¢ each to include seedling establishment in greenhouses, transplanting, and watering costs. This cost translates to $220 per acre (200 seedlings per acre), not including replacement or land preparation costs.

General Conclusions

The results of this brief 8 month study are encouraging. It is surprising that the two "wettest" sites in terms of predicted annual rainfall have had the greatest difficulty in establishment. The Brady site was subjected to extensive flooding shortly after planting and the Lubbock site was subjected to unusually hot, dry weather during and after transplanting. A look at monthly rainfall totals fails to explain these problems. Once again, the unpredictability of weather in semi-arid regions becomes the primary factor in vegetation establishment and stability.

In view of weather as a major factor in transplanting success, it causes one to view all possibilities for innovation. Some success has recently been reported for transplanting during the fall in semi-arid environments. The chance of having hot, drying winds is considerably reduced in fall planting, and early frost becomes the major factor limiting success. This year fall planting will be pursued. Direct seeding at sites where land is unavailable, is also planned.

Problems in establishment of the annual Kochia, at all locations provides doubts about its suitability in these studies. It is not unusual to find that annuals fail to transplant readily, and direct seeding still remains a possibility. On the other hand, the lack of predictability of rainfall is a constant cause of concern and erosion remains a constant threat for annuals.

Harvesting of regrowth and preliminary studies of plant densities for saltbush reaffirms original estimates of yield. This fall and winter it is planned to use a flail-type plot harvester to coppice harvest saltbush, creosote bush, tar-bush, and Kochia from natural populations. Knowing the densities of these pure and mixed stands, it should be possible to not only obtain large quantities of biomass for energy feedstock, but also refine our estimates of potential yield. If genotypic selection and propagation can be achieved, one can see a great potential for certain woody perennials as biomass feedstocks in semi-arid West Texas.

A. INTRODUCTION

The adoption and use of coal, petroleum and natural gas as fuel sources have evolved because of their low cost and high energy content. As supplies of these non-renewable fossil-fuels decrease and their costs increase, the need for new sources of energy becomes evident. One of the alternative new sources is biological solar energy conversion (BSEC), commonly known as photosynthesis. In BSEC, plants transform solar energy into chemical energy or biomass, which then can be harvested and converted into usable energy products. The biomass from terrestrial plants is renewable, and it can potentially contribute significantly to the future energy needs (Calvin, 1976). It has been suggested that the U.S. should expand commercialization concepts and set guidelines that would permit biomass to develop into a significant supply of energy (Knutson et al., 1977). Estimates of the energy potential for the U.S. for biomass sources is in the range of 10-15 Quads/yr by the year 2000; this is 10-15% of the U.S.'s energy needs. A substantial contribution to U.S. biomass production might be derived from biomass plantations such as those proposed in semi-arid West Texas.

As alternative energy sources are examined for their feasibility, it is logical to ask whether highly productive native plants growing on millions of semi-arid rangelands of the Western United States have any potential use as biomass energy sources. Although uncertainties exist in producing biomass, semi-arid lands offer several advantages (Cox, 1979). Biomass production could utilize dry-farmed crop lands and multiple use rangelands; there would be little or no competition for irrigation water; generally no need for fertilizer application, and within the wide diversity of native and naturalized plants a number of species have a potential for relatively large biomass production because they have an unusually high water-efficiency-ratio (Newton et al., 1980). Among these are the perennial shrubs which appear to offer potential for improved productivity on harsh arid-land sites (Goodin and McKell, 1971).

The possibilities of managing arid-land species for increased productivity appear to be encouraging (Goodin and Northington, 1979). Their utilization for biomass would be an attractive new option for the landowner and the utilization of semi-arid lands would have very little if any impact on food and fiber production in terms of land area and water availability. The total area of the region referred to as West Texas is about 100 million acres, and it is assumed that 30-40 million acres receiving an average annual rainfall of 15" to 18" could be used for biomass production in semi-arid West Texas. This land is now used for cattle grazing, and to some extent, for irrigated and dry land farming. It would appear that landowners would welcome new product markets that would increase revenues and profits that would provide potential alternatives in land use.

Estimated Energy Production

A recent study with the objective of identifying plant species that might be used for biomass production in semi-arid West Texas concluded that approximately 16 species out of 2900 indigenous to this area have potentially attractive prospects (Newton et al., 1980). Four of the top candidates appear to have the potential to produce biomass at productivity levels in the range of 15 to 70 million Btu per acre per year (MBtu/acre•yr). For example, mesquite, a perennial, apparently grows at about 15 MBtu/acre•yr. Kochia, an annual, may produce as much as 70 MBtu/acre•yr. In the middle of this range, the perennial, Johnsongrass produces about 45 MBtu/acre•yr. For economic estimates it is reasonable to assume that an average overall yield of 45 MBtu/acre•yr might be achieved. Assuming that 35 million acres could ultimately be devoted to biomass fuel production, the raw biomass would be 1.6 Quads/yr (3.5×10^6 acre $\times$ 45×10^6 Btu/acre·yr = 1.6×10^{15} Btu/yr). Theoretical estimates of productivity for 30-40 million acres confirm the above estimate of biomass production. For example, in semi-arid plant communities which fix carbon (BSEC) at an average rate of less than 1 ton/acre·yr, the efficiency is about 0.1% (caloric value of plant material/solar energy available X 100%) (Noggle and Fritz, 1976). Thus, in West Texas where solar energy is 31×10^9 Btu/acre·yr (Calvin, 1974), a 0.1% conversion of this energy could produce 31×10^6 Btu/acre·yr of plant material. Therefore, the production of 1 Quad/yr of biomass energy (10^{15} Btu) would require about 32 million acres (10^{15} Btu/yr/31×10^6 Btu/acre). However, the above calculations are based on available estimations of productivity; it is believed that there is opportunity to improve some yields by selecting the proper plant for the available terrain, climate, rainfall, and soil quality. For example, at the University of California, Riverside, researchers have already doubled the yields of mesquite (Felker, 1979), and the progress with improved sources of saltbush are encouraging (Van Epps, Banker and McKell, 1980).

B. STATEMENT OF THE PROBLEM

Few data are available in the literature to indicate reliable biomass yields for the 4 candidates being considered in this study. Many data that do occur were obtained under atypical conditions (Newton et al., 1980). It is recommended that realistic annual biomass production data be developed for four promising candidates at appropriate locations in West Texas.

The plant species to be considered are either native or naturalized in West Texas and should be evaluated to measure total annual biomass production, quality of biomass, secondary credits such as soil stabilization or forage value, adaptability to the environment, and ecological considerations including environmental impacts.

Plant establishment under semi-arid environments is risky and the economical trade offs of direct seeding (poor survival) vs. transplanting (excellent chance of survival) must be established. Semi-arid-land soils have a tendency to dry out and form hard crusts making establishment a difficult task. Furthermore, the establishment of surplus, sustained seedstocks and/or propagules must be accomplished to maintain continuity of the project.

Each candidate has unique properties which will provide advantages and disadvantages. For example, saltbush has a real problem with seed fill as well as germination; on the other hand, these plants have wide morphological differences (Stutz and Sanderson, 1979) which allow some selection for biomass. This wide variability will provide flexibility in selecting the most attractive subspecies.

Other problems such as disease and plant competition will, undoubtedly, have to be considered. Although these four species are known to be hardy in the West Texas environment, few data are available concerning the effects of plant competition and pests such as insects, fungi, and small rodents on some of the species. Soil fertility is of prime concern, but the use of commercial fertilizers will not be considered in this program. Low intensity management will be the essential feature of this overall project.

Both annual and perennial species are being studied. The annual Kochia may have to be reseeded each year, but this species provides some of the highest annual yields. Perennials do not require planting as frequently and they have the advantage of stabilizing the soil from erosion. Furthermore, perennials will provide a more stable production.

Initially, these species should be studied in the areas where they grow naturally. These native plant stands should be studied to correlate distribution and plant density with climate and soil factors concomitantly with small-scale field plantings. The data will provide information as to those factors and conditions that may be limiting to biomass production. The ecological potential of West Texas should be assessed by assembling existing remote sensing data, published data, soil surveys, etc. The densities of natural stands should be determined and correlated with soil and climatic factors. Although some information is available for mesquite (Smith and Rechinthin, 1964), essentially nothing is known for the other candidate species for West Texas areas. The worldwide distribution of these species indicate that they fit into a very broad set of environments, including those of the dry-land regions of the southwest.

C. PROJECT OBJECTIVES

This research presents a new thrust in the production of energy by the agricultural production of biomass. Unconventional plant species, unlike agricultural crops, have not been seriously studied because they do not produce food or fiber products. These unconventional plants, however, are approximately twice as efficient for converting sunshine, water, soil nutrients and carbon dioxide to green plant matter (biomass) through photosynthesis. The concept is rather simple: with minimum inputs of water and fertilizer (and thus low production costs), plants that will thrive in the semi-arid environment of West Texas could be used as raw material useful for the manufacture of fuels and organic chemicals. Many of these plants are unique because they will produce one unit of biomass per 350 units of water consumed compared to conventional plants (one unit/700 units of water) used for food and fiber production.

The project objectives are to:

1. Evaluate the establishment and the productivity

potential (lbs biomass/acre•yr) of four plant species in West Texas as influenced by rainfall, temperature and minimum cultural practices.

2. Accurately assess the present distribution and acreages inhabited by the four candidates in West Texas as well as the soil, geographical and climatic factors which govern their adaptation.

3. Provide productivity data in order to make adequate economic and sociological assessments of biomass production in West Texas.

D. SPECIES

Few data are available in the literature to indicate reliable biomass yields for the 4 candidates being considered in this study. Many data that do occur were obtained under atypical conditions (Newton et al., 1980). One of the objectives of this project was to develop realistic annual biomass production data for four promising candidates at appropriate locations in West Texas. The plant species considered are either native or naturalized in West Texas and are being evaluated to measure total annual biomass production, quality of biomass, secondary credits such as soil stabilization or forage value, adaptability to the environment, and ecological considerations including environmental impacts.

Four species were selected from an initial screening of some 2,900 plants originally considered for biomass feedstock in 5 West Texas regions (Table 1). Selection was based on adaptation to the semi-arid environment, potential for domestication as an unconventional plant, and total biomass potential which could be used to produce a high density, pelletized wood product. The four species are HONEY MESQUITE (_Prosopis glandulosa_ Torr.), JOHNSONGRASS [_Sorghum halepense_ (L.) Pers], KOCHIA [_Kochia scoparia_ (L.) Roth], and SALTBUSH [_Atriplex canescens_ (Pursh.) Nutt.].

HONEY MESQUITE. _Prosopis glandulosa_ Torr. Mesquite is a perennial,

Table 1. Reported Yield and Energy Content of Candidate Species for Biomass Feedstocks in Semi-Arid West Texas[1]

Scientific Name	Common Name	Reported Annual Dry Weight Yield (tons ac^{-1} yr^{-1})	Energy Content (Btu lb^{-1})	Habit[2]	Height (ft)	Forage Value
Atriplex canescens	Four-wing saltbush	3.5	7600	Per.	5	Good
Kochia scoparia	Kochia	4.9	7200	Ann.	4	Good
Prosopis glandulosa	Mesquite	1.0	8051	Per.	6	Good (Seedling)
Sorghum halepense	Johnsongrass	3.0	6800	Per.	3	Good

[1] Newton, R.J., D.R. Shelton and D.J. Reid. 1980. Plant species selected for biomass production in semi-arid regions of West Texas. Submitted to Exxon Research and Engineering Company, Florham Park, N.J.

[2] Per. = Perennial; Ann. = Annual

large shrub that grows over much of West Texas. It provides little income for the landowner, and in general is considered to be a severe pest. In the past 120 years, the abundance as well as the range of mesquite has increased tremendously. By plantation cultivation and coppice harvesting, mesquite might provide a substantial biomass yield. Burzlaff (1977) estimates the productivity of natural stands to be about 1 dry ton/acre•yr with an estimated energy content of about 8,000 Btu/lb of dry matter (Darling, 1976). Mesquite is relatively sensitive to cold temperatures; fall germination of seed occurs, but in Northern Texas, subsequent low temperatures do not allow seedling survival (Scifres and Brock, 1972). Mature plants have tremendous ability to regrow following injury and coppicing because of dormant buds along the trunks and stems (Haas et al., 1973). Mesquite typically produces both a tap root and an extensive lateral root system which may extend down to ground water supplies. Mesquite is a legume and fixes nitrogen, but not very efficiently (Hass et al., 1973); however, Felker and Clark (1980) suggest that improved inoculation techniques could enhance this capability and therefore its productivity.

JOHNSONGRASS. Sorghum halepense (L.) Pers. Johnsongrass is a coarse perennial cultivated as a forage grass throughout Texas (Gould, 1975a), but is more common as a weed occurring along roadsides and ditches. It attains a height of 3-6 ft, but it is much shorter in dry or unfavorable sites (Gould, 1975b). Yields of 3 dry ton/acre•yr have been reported in the U.S. (Little, 1979) and 6 dry ton/acre•yr have been reported from Puerto Rico (Alexander, 1979). Johnsongrass has an estimated energy content of 7000 Btu/lb of dry matter (Leith, 1975; NAS, 1971) and has good forage value, except under certain conditions; it developes cyanogenic compounds that can be the cause of prussic acid poisoning in grazing animals. Under drought stress, Johnsongrass outyielded several hybrid strains of sorghum (Alexander, 1979).

KOCHIA (Fireweed) Kochia scoparia (L.) Roth. Kochia is a naturalized annual which reaches heights of 1-5 ft and is widespread in West Texas and in many parts of the U.S. (Correll and Johnston, 1970). Yields of 4 dry ton/acre•yr were measured in New Mexico (Fuehring, pers. comm.) and it has an energy content of about 7000 Btu/lb of dry matter (Leith and Whitaker, 1975; Morrison, 1957). Kochia is of good forage value for hay, ensilage, and grazing. Kochia seeds germinate early in the spring, and early freezing does not injure the seedlings (Erickson, 1974). The seed may be sown in the fall so that an early start in the spring may occur when conditions of moisture are favorable for growth. Three cuttings per year were obtained in New Mexico (Cornell, 1979). Kochia is a shortday plant, therefore a late season crop could be expected to be a good seed producer in this region (Bell et al., 1972). Kochia is sensitive to a few diseases such as damping-off which is more pronounced when temperatures are high and when the soil is wet. Leaf spot can cause mortality if severe and is more pronounced during cool, wet seasons (Erickson, 1974).

SALTBUSH. Atriplex canescens (Pursh.) Nutt. Saltbush is a woody perennial attaining heights of 1.5 to 8 ft (Correll and Johnston, 1970). It has been suggested as a favorable range plant for the intermountain region, New Mexico and West Texas because of its growth and palatability (Plummer, 1970; Blauer et al., 1976). Annual yields of approximately 3.5 dry ton/acre•yr have been reported in Utah (McKell, 1979; Blauer et al., 1976). It has a high energy content of 8,000 Btu/lb of dry matter (Burzlaff, 1977; Van Epps et al., 1979).

Saltbush species have been investigated extensively for revegetating disturbed rangelands. Seed germination rates from wild collections are less than 50% and there is an inverse relationship between moisture stress and germination success (Weisner and Johnson, 1977). Despite the moisture requirement for seed germination, saltbush is known for its drought-resistance qualities. It has a wide range of adaptability; it is salt tolerant, growing well in soils with a salt content of 0.1 to 0.3% (Weisner and Johnson, 1977). Saltbush has a high water-use efficiency (Dwyer and Degarms, 1970) and seedling transplants have resulted in 80% survival (Weisner and Johnson, 1977).

E. SITE SELECTION

The area commonly called West Texas lies west of a line from Ft. Worth to Brownsville and includes an area of over 100 million acres. Since the incident solar energy intensity is very high in these areas (Calvin, 1974) West Texas should have an excellent potential for maximizing biomass production. However, rainfall is very low in the westernmost part with precipitation of 7" at El Paso and increasing to modest levels over 20" at Ft. Worth (Texas Almanac, 1977). West Texas is characterized by a formidable diversity of soils and climate, and consequently, a great diversity in vegetation. Much of the region is rangeland and many of the areas are producing below their potential. Thus, there is opportunity for improvement on some sites and the potential for biomass production should be greater than that now obtained. The following sites have been selected for initial studies:

(1) Brady (McCulloch County) - Located just at the transition zone of the Rolling Plains and the Edwards Plateau. The soils are mollisols, mostly loams, but with some sandy surface layers and some clayey subsoils. Annual rainfall here is approximately 24 inches, the wettest site. Minimum winter temperature is 10-20°F. Plots have been located on land leased by TAES at the Winters Ranch.

(2) Big Lake (Reagan County) - Located on the Edwards Plateau. The soils are aridisols, undulating to hilly calcareous soils over limestone and limy earths. Annual rainfall is

approximately 20 inches, and the elevation is considerably higher than Brady. Minimum winter temperature is 5-10°F. The site is located on a ranch owned by the University of Texas Lands System, approximately 1.5 miles west of Big Lake.

(3) Lubbock (Lubbock County) - Located on the High Plains (3300 ft elevation) with an annual precipitation of 18.5 inches. The soils are alfisols, sandy surface layers and loamy subsoils, or sandy throughout. Minimum winter temperature is -5 to 5°F. The site is located on the campus of Texas Tech University near the Museum.

(4) El Paso (El Paso County) - Located in the Trans Pecos region at the western tip of the state. The elevation is 3600 ft and annual rainfall is only 7-8 inches per year. Soils are aridisols, loamy or clayey soils of the Rio Grande flood plain. The minimum winter temperature is 10-15°F. The site is at the Texas A&M Research and Extension Center, located adjacent to the administrative building.

F. RESULTS - OBJECTIVE 1

OBJECTIVE 1. Evaluate the establishment and the productivity potential of four plant species in West Texas as influenced by rainfall, temperature and minimum cultural practices.

1. Plant Establishment

a. Plot Design

Following site selection and negotiations for space at Brady, Big Lake, El Paso, and Lubbock, experimental plots of approximately one acre each were fenced for both large and small mammal control (buried chicken-wire or welded wire fencing) and located in areas with access to water for initial establishment. All seedlings received approximately one quart of water at the time of planting. Additional watering has been required at all sites; 1 additional quart was added at the Brady site and 2 quarts were applied at Big Lake, El Paso, and Lubbock. The soil surface has been disturbed as little as possible. Existing vegetation was removed in the immediate vicinity of each transplant, but otherwise the natural cover has been left intact. Although this has provided considerable competition for water, nutrients, and possibly light, it is believed that the ecological benefits of retaining the natural cover outweighs the establishment tradeoffs of cultivation. Each species was planted on a plot of 12 X 8 meters. These plots consist of 48 plants, 12 plants per each of four rows at 1-meter intervals. Thus, each plot contains 28 border plants and 20 interior plants (10 in each of the two inside rows). All yield measurements will be determined from the 20 interior plants (similar to the experimental design of Sachs et al., 1980).

Each species is replicated four times at each site, giving a 4 X 4 Latin Square design which can readily be subjected to statistical analyses. All plants have been transplanted to the field site after having been established in greenhouses at Texas A&M or Texas Tech. All seedlings were 8-10 cm at the time of transplanting.

In addition to the formal plot layout, other species which indicated potential in the Texas A&M screening program (Newton et al., 1980) or were reported by other investigators to have potential have been planted. These are: grain sorghum, marama bean, and other species and ecotypes of saltbush.

Although it was not originally intended to include regrowth of native stands of any species, it has been possible to study regrowth of established saltbush plants at the Lubbock site and mesquite at the Big Lake site. In both cases, regrowth during the spring months has been very rapid and there is 30 to 45 cm of new growth from plants cut early in the spring. These studies provide some indication of what one might expect from a particular climatic/edaphic situation once the plants are well established.

This project was tentatively approved by all supporting agencies for the January 1 - August 31, 1981 period, and funding began in March. In anticipation of funding, the seedlings of Johnsongrass and mesquite were established at College Station, and seedlings of saltbush and Kochia were established at Lubbock. Seeds of all species except saltbush germinated in 3-in peat pots filled with a 2:1:1 mixture of sand:loam:peat. Establishment of saltbush was accomplished by sowing in flats, and 3-week seedlings were transplanted to peat pots. No serious problems were encountered in germination, although germination of Johnsongrass was unpredictable and uneven. Variable seedling size was encountered in saltbush, Kochia, and Johnsongrass; mesquite seedlings were relatively uniform. Mesquite seeds were scarified to remove the seed coat and promote germination and then inoculated with a commercial (NITRAGIN) Rhizobium inoculum, and examination of roots indicated that some nodulation had been achieved.

b. Seedling Survival

Survival has been variable depending on both site and species (Table 2). At the Brady site, early season flooding caused a total loss in saltbush and Kochia. The site was so wet that fungal invasion was a problem for all species, including Johnsongrass which is naturalized in the area. In spite of these problems, compounded by a massive invasion of grasshoppers, Johnsongrass survival was 92% and mesquite survival was 63%.

Overall survival is better at Big Lake than at any other site. Johnsongrass, saltbush, and mesquite all had excellent survival. Only Kochia suffered an 84% mortality.

At El Paso, saltbush survival has been good, mesquite (47%) and Johnsongrass (41%) have been fair, and Kochia has been poor.

Survival has been poorest at the Lubbock site. This site was the latest to be planted, and hot, dry winds were a major problem from the planting date and for about three weeks thereafter. Even though mortality was low when observed on May 18 (3 weeks after planting), seedling loss was very heavy for all species.

c. Seedling Growth

Seedlings were planted on April 3, 10, 17, and 24 at the Brady, Big Lake, El Paso, and Lubbock sites, respectively. As already indicated, mesquite, saltbush and Johnsongrass had the most success in surviving at all of the sites. Height data were taken in the latter part of July. Johnsongrass obtained heights of more than 40 cm at Brady and Big

Table 2. Seedling Survival (Percent)

	Sites										Overall Survival (All Sites)
	Brady			Big Lake			El Paso		Lubbock		
Species	5/13	6/8	7/28	5/13	6/8	7/13	6/10	7/28	5/18	7/30	7/30
Mesquite	92%[1]	73%	63%	99%	75%	75%	99%	47%	99%	4%	47%
Saltbush	97%	10%	0%	95%	88%	88%	95%	79%	98%	4%	43%
Johnsongrass	94%	94%	92%	97%	95%	95%	79%	41%	96%	0%	57%
Kochia	97%	1%	0%	84%	29%	16%	58%	12%	76%	6%	9%

[1] Each of the four sites began in April with 192 transplants of each species (48 plants/plot X 4 plots). This table shows the percentage of those 192 plants still surviving at the dates listed.

Lake, but it was severely retarded at El Paso with only 18 cm (Table 3). Saltbush did not survive at Brady, but had heights of 13-17 cm at the other 3 sites. Mesquite growth was the least of all 4 species with values ranging from 9-13 cm at all 4 sites (Table 3). Kochia heights ranged from 23-30 cm on 3 of 4 sites. All data at Lubbock (and all the Kochia data) are based on small plant numbers (9-12 plants), but these plots are being reestablished and height data on larger numbers will be available at a later date.

2. Regrowth

a. Mesquite - Big Lake

Objective: To determine the growth rate of mesquite plants which had been cut back to the soil level.

Methods: At the Big Lake field site, existing mesquite plants were cut back to ground level during site preparation on April 1. During the spring and summer of 1981, these plants have regenerated rapidly from the crown area. Sixty five plants have been selected for regrowth studies, labeled, and measured for height and basal diameter on June 16 and July 31, 1981.

Results and Discussion: Table 4 presents growth regeneration rates for a 6-week period during mid-summer. Like saltbush, the height of regrowth is approximately equal to basal diameter and one might expect the plant shape to approximate a sphere. On the other hand, we have no way of knowing the original size or age of the mesquite

Table 3. Plant Height (cm) for Each of the Experimental Sites on July 31, 1981

	Sites							
	Brady		Big Lake		El Paso		Lubbock	
Species	N	$\overline{X}$ (cm)	N	$\overline{X}$ (cm)	N	$\overline{X}$ (cm)	N	$\overline{X}$ (cm)
Mesquite	121	9.4 ± 3.7	141	9.5 ± 2.9	91	7.6 ± 2.2	9	13.9 ± 3.0
Saltbush	0	0	165	13.8 ± 7.7	151	17.3 ± 8.6	8	13.4 ± 3.3
Johnsongrass	176	49.2 ± 25.7	182	41.9 ± 28.3	79	17.9 ± 10.1	0	0
Kochia	0	0	30	23.3 ± 10.2	23	30.7 ± 13.7	12	25.1 ± 8.5

plants, and therefore the regrowth potential would vary tremendously.

Table 4. Regrowth Rates (cm) for a Six-Week Period, June-July, 1981. Mesquite.

	June 16	July 31	Increase	Rate
Plant Height	34.65±10.31	37.14±11.01	2.49	.06 cm/day
Basal Diameter	35.26±13.55	38.34±13.92	3.08	.07 cm/day

In contrast to regrowth in saltbush, mesquite appears to grow rapidly just after cutting, but ceases growing altogether by mid-summer. Admittedly, there is a big difference in coppice harvesting saltbush at 40 cm height compared to ground-level cutting of mesquite. On the other hand, the mesquite plants should have much larger underground reserves. Regrowth will be continuously monitored to determine whether biomass regrowth will be rapid enough to justify consideration as a feedstock.

b. Saltbush - Lubbock

Perennial plant biomass as a potential source of energy depends in part on its regrowth. Plants for biomass feedstock production must be harvestable, and provide regrowth for additional harvests.

Objective: To study saltbush regrowth from well established plants and to determine regrowth potential.

Methods: The plants harvested for regrowth observation were selected from those planted at the Lubbock site in the spring of 1975. These plants were transplanted as seedlings without supplemental irrigation or fertilizer to study the performance under West Texas conditions.

Two groups of saltbush were harvested from the Lubbock site. The first group of ten plants was harvested in mid-March, 1981. The second group of twenty plants was harvested over a period from late June to early July, 1981. The plants were cut to a uniform 40 cm which removed approximately 2/3 of each plant's biomass.

The plants were harvested by hand using large pruning shears. Each plant was harvested only once and allowed to regrow. Regrowth information reported here was measured on July 31 for both groups of plants.

Results and Discussion: The amount of regrowth is related to the time since the last cutting for a given set of environmental conditions. An early harvest appears to have slightly less variability than a late harvest (Table 5). However, due to the small sample size, no firm conclusions can be made.

Table 5. Average Regrowth for Two Different Times of Harvest. Saltbush.

Ave. Regrowth (cm) Early Cut	Ave. Regrowth (cm) Late Cut
84.5±10.65	36.6±16.3

The group of plants harvested last suffered a 27.5% mortality rate. The late harvested plants were all harvested at approximately the same height and no more than 2/3 of their biomass was removed. The difference within the late harvested group is the date of harvest. Harvest extended from June 17 to July 6, a period of 19 days. The plants that died were harvested on the first and sixth of July. Not all of the plants harvested on these dates died. This points toward some genotypic differences among the plants. This 13-day period between the beginning of the late harvest and July 1 may be a critical period for saltbush. None of the plants harvested in June have died.

The plant mortality may have been due to a combination of factors. As shrubs grow fewer leaves are found on the inside of the plant canopy. This allows the plant to better compete for radiant energy. When a plant is harvested much of the leaf area is removed. The plant must call on stored carbohydrate reserves in order to survive and produce new leaves. If the reserves are exhausted before enough leaves have developed to produce new photosynthate for the plants, they will be weakened and perhaps die.

c. Saltbush Seedlings - Lubbock

Objective: To determine the growth rate of saltbush seedlings which had been established in nature.

Methods: At the field site at Lubbock approximately 140 seedlings were transplanted to the field in the spring of 1975. Those plants have grown rapidly without supplemental water or fertilizer, and female plants produced seed by the second year. During wet springs since that time a number of volunteer seedlings have become established in the vicinity of the large initial planting, and a number of those appear to be 1-2 yrs old this year.

Seventy seedlings were selected for study and they have been individually labeled. Measurements were made of seedling height and basal diameter, initially on June 27, 1981. On July 29, a second measurement was taken and rate of growth was calculated. These plants have not been harvested and only crude estimates of biomass can be made.

Results and Discussion: Table 6 presents seedling growth rates for a one-month period during the summer of 1981. The dimensions of these plants (same height as basal diameter) suggest that the shape is relatively round and it may be possible to handle estimates of biomass as a cube, cylinder, or sphere. As more data are accumulated, and correlations are established, it is hoped to quickly estimate biomass from one of these geometric configurations.

Table 6. Seedling Growth Rates (cm) for a One Month Period, June-July, 1981. Saltbush.

	June 27	July 29	Increase	Rate
Plant Height	39.07±17.05	47.85±21.13	8.78	0.274 cm/day
Basal Diameter	39.30±27.22	47.25±28.78	7.95	0.248 cm/day

Even though the standard error is great in these measurements, the differences can be attributed to tremendous genetic variability. This is not a problem with which to be reckoned, but a potential for screening and genotypic selection. Obviously some plants grow much faster than others under the same environmental conditions, and those gene pools are to be explored.

As a rough estimate of potential biomass, if one assumes that the rate of growth calculated for June-July is representative of growth rates for saltbush through an 8-month growing season, then 0.274 cm/day X 240 days = 65.76 cm total height increase for one season. Our previous measurements suggest that such a biomass accumulation is not unreasonable, and in fact, may be an underestimate.

3. Soil Fertility

In order to adequately evaluate establishment and productivity of these plant species, it is important to ascertain the nutrient status of the soil. Furthermore, baseline data on soil nutrients are needed in order to assess modifications of the soil by the established biomass plants and their eventual harvest.

Soil pH and nutrient levels were determined by the Analytical Services of the Texas Agricultural Experiment Stations. The nutrient ratings (high-low) are based on standards established for present food and fiber crop production in Texas. Soil analysis for pH, nitrogen, phosphorus, potassium, calcium, and magnesium have been obtained for each plot at each site (Tables 7-10). Big Lake and Brady sites had only moderately alkaline pH, while the most western sites of Lubbock and El Paso tended to be strongly alkaline. Nitrogen levels were low (3 to 28 ppm) at all sites except Big Lake where maximum values of 100 ppm were obtained. The average value for the 16 plots at Big Lake was 74 ppm, and 12, 15, and 11 ppm of nitrogen at Brady, El Paso, and Lubbock sites,

Table 7. pH and Nutrient Status of Soil, Brady

Levels Measured[1]	Variation among samples[2]		Average (Mean) Measurement
	Minimum	Maximum	
pH	6.7 mildly acid	8.5 strongly alkaline	8.1 moderately alkaline
Nitrogen	3	16	12
Phosphorus	0 very low	9 low	1 very low
Potassium	204 high	456 very high	308 very high
Calcium	4000 very high	4000 very high	4000 very high
Magnesium	145 medium	325 high	256 high

Table 8. pH and Nutrient Status of Soil, Big Lake

Levels Measured[1]	Variation among samples[2]		Average (Mean) Measurement
	Minimum	Maximum	
pH	7.0 neutral	8.4 strongly alkaline	8.1 moderately alkaline
Nitrogen	8	100	74
Phosphorus	45 very high	60 very high	53 very high
Potassium	148 medium	400 very high	227 very high
Calcium	4000 very high	4000 very high	4000 very high
Magnesium	500 high	500 high	500 high

[1] The levels of all elements are given in parts per million (ppm).

[2] One sample from each plot was obtained, making a total of 16 samples from this site. The maximum and minimum values among these 16 samples show the amount of variability encountered among the samples at this site.

Table 9. pH and Nutrient Status of Soil, El Paso

Levels Measured[1]	Variation among samples[2]		Average (Mean) Measurement
	Minimum	Maximum	
pH	8.1 medium alkaline	9.9 strongly alkaline	8.6 strongly alkaline
Nitrogen	9	28	15
Phosphorus	63 very high	121 very high	87 very high
Potassium	164 medium	192 very high	329 very high
Calcium	4000 very high	4000 very high	4000 very high
Magnesium	280 high	375 high	323 high

Table 10. pH and Nutrient Status of Soil, Lubbock

Levels Measured[1]	Variation among samples[2]		Average (Mean) Measurement
	Minimum	Maximum	
pH	8.2 moderately alkaline	8.9 strongly alkaline	8.6 strongly alkaline
Nitrogen	8	18	11
Phosphorus	2 very low	16 medium	5 very low
Potassium	340 very high	476 very high	413 very high
Calcium	2520 very high	4000 very high	3015 very high
Magnesium	320 high	420 high	372 high

[1] The levels of all elements are given in parts per million (ppm).

[2] One sample from each plot was obtained, making a total of 16 samples from this site. The maximum and minimum values among these 16 samples show the amount of variability encountered among the samples at this site.

respectively. Plots 1 through 4 at Big Lake had an uncharacteristically low N content of 8 ppm with the high values obtained in the remaining 12 plots; the explanation for this wide variation has not been determined.

Phosphorus levels are represented at both extremes among the sites (0 to 121 ppm). Big Lake (45 to 60 ppm) and El Paso (63 to 121 ppm) showed very high levels of phosphorus while relatively low values were obtained at Brady (0 to 9 ppm) and Lubbock (2 to 16 ppm).

High levels of potassium (148 to 476 ppm) and calcium (225 to >4000 ppm) and moderate to high levels of magnesium (145 to 500 ppm) were obtained on all four sites indicating the abundance of these nutrients on West Texas soils.

In general, the West Texas soils sampled are somewhat alkaline, low in nitrogen and high in calcium, magnesium and potassium (Table 11). These soils are extremely variable in phosphorus levels. Generally, alkaline soils reduce the availability of essential micro-nutrients such as iron, manganese, copper and zinc. The macro-nutrient most limiting to plant productivity is most likely nitrogen and in some cases phosphorus. Brady had the most unbalanced nutrient profile of all 4 sites (Table 11). This could be due in part to previous fertilizer trials performed there. The relatively high nitrogen level at the Big Lake site could be due to the nitrogen-fixing activities of mesquite which previously occupied the site, or it might be due to high concentrations of urea produced by large numbers of livestock frequenting the water site (a windmill is adjacent to the experimental plot).

Table 11. Summary: pH and Nutrient Status of Soils at 4 Sites in West Texas

Levels Measured	Brady	Big Lake	Lubbock	El Paso
pH	8.1 mod. alk.	8.1 mod. alk.	8.6 strong alk.	8.6 strong alk.
N	12 low	74 high	11 low	15 low
P	1 very low	53 very high	5 very low	87 very high
K	308 very high	227 very high	413 very high	329 very high
Ca	4000 very high	4000 very high	3015 very high	4000 very high
Mg	256 high	500 high	372 high	323 high

It is important to consider that soil testing laboratory recommendations for nutrient supplements are based on high productivity technological agriculture. The plants being tested here may not require such fertile soils and, in fact, have not been selected for such conditions. Although it might be possible to select for high fertility requirements, the objective in this experiment is to select for low energy input.

It may be possible that symbiotic nitrogen fixation is a factor in the productivity of mesquite, and there is some suggestion that non-symbiotic nitrogen fixation is a factor in saltbush productivity. All of these "unconventional" species appear to perform well without supplemental fertilization.

4. Precipitation Patterns

Rainfall data obtained over the first 7 mos of 1981 indicate that the precipitation is very close to the yearly average for each site; thus the moisture available for 1981 is somewhat typical (Figs. 1-4 and Tables 12-15). At the end of the 7 mos period, Brady has received nearly 15 inches of its 24 inch annual average; Big Lake has received about 11 inches of its 15 inch annual average; over 5 inches of the 7 inches of annual precipitation have fallen on the El Paso site; and Lubbock with its 18 inches of annual rainfall has received nearly 10 inches of its yearly average. Rainfall at Brady was received at a rate of 2-3 inches/mo throughout the months of March through July (Fig. 1). This region received considerable flooding just at the beginning of the growing season. Precipitation at Big Lake was highest with over 4 inches in April, but 1-2 inches have fallen in each of the ensuing months (Fig. 2).

Figure 1
1981 PRECIPITATION AT BRADY

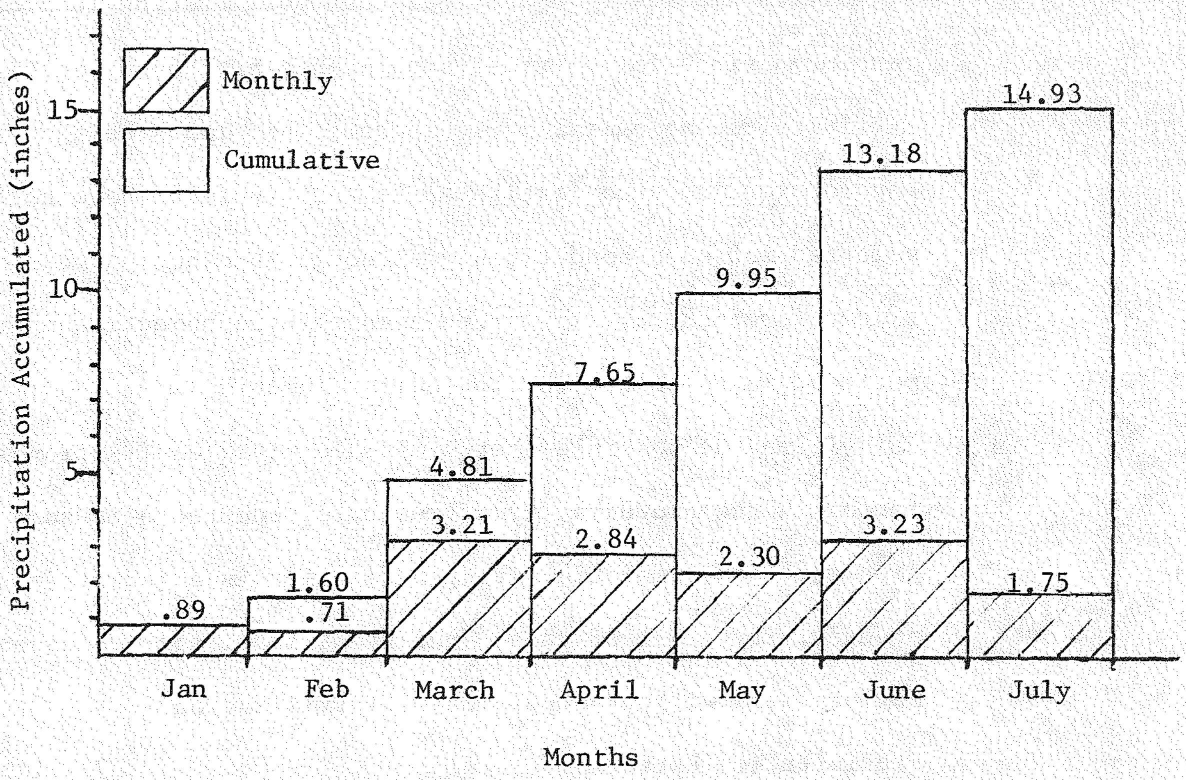

Table 12. Average Monthly and Cumulative Rainfall at Brady (1941-1970)

	Jan	Feb	March	April	May	June	July
Average Monthly Rainfall (1941-1970)*	1.4	1.5	1.3	2.7	3.5	2.3	1.5
Average Cumulative Rainfall (1941-1970)	1.4	2.9	3.2	5.9	9.4	11.7	13.2

* These figures were obtained from maps showing rainfall patterns in Texas published in 1974 by the Office of the Texas State Climatologist, Texas A&M University

Figure 2
1981 PRECIPITATION AT BIG LAKE

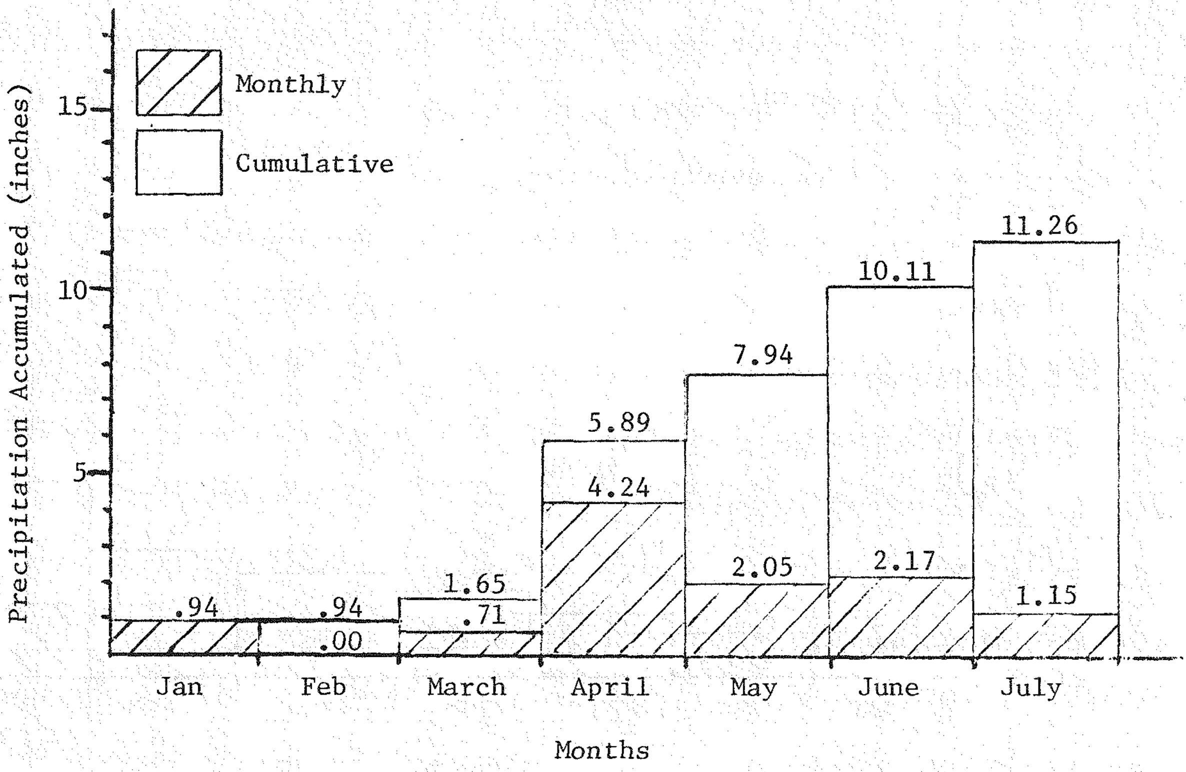

Table 13. Average Monthly and Cumulative Rainfall at Big Lake (1941-1970)

	Jan	Feb	March	April	May	June	July
Average Monthly Rainfall (1941-1970)*	.8	.8	.7	1.3	2.3	1.7	1.8
Average Cumulative Rainfall (1941-1970)	.8	1.6	2.3	3.6	5.9	7.6	9.4

* These figures were obtained from maps showing rainfall patterns in Texas published in 1974 by the Office of the Texas State Climatologist, Texas A&M University

Figure 3
1981 PRECIPITATION AT EL PASO

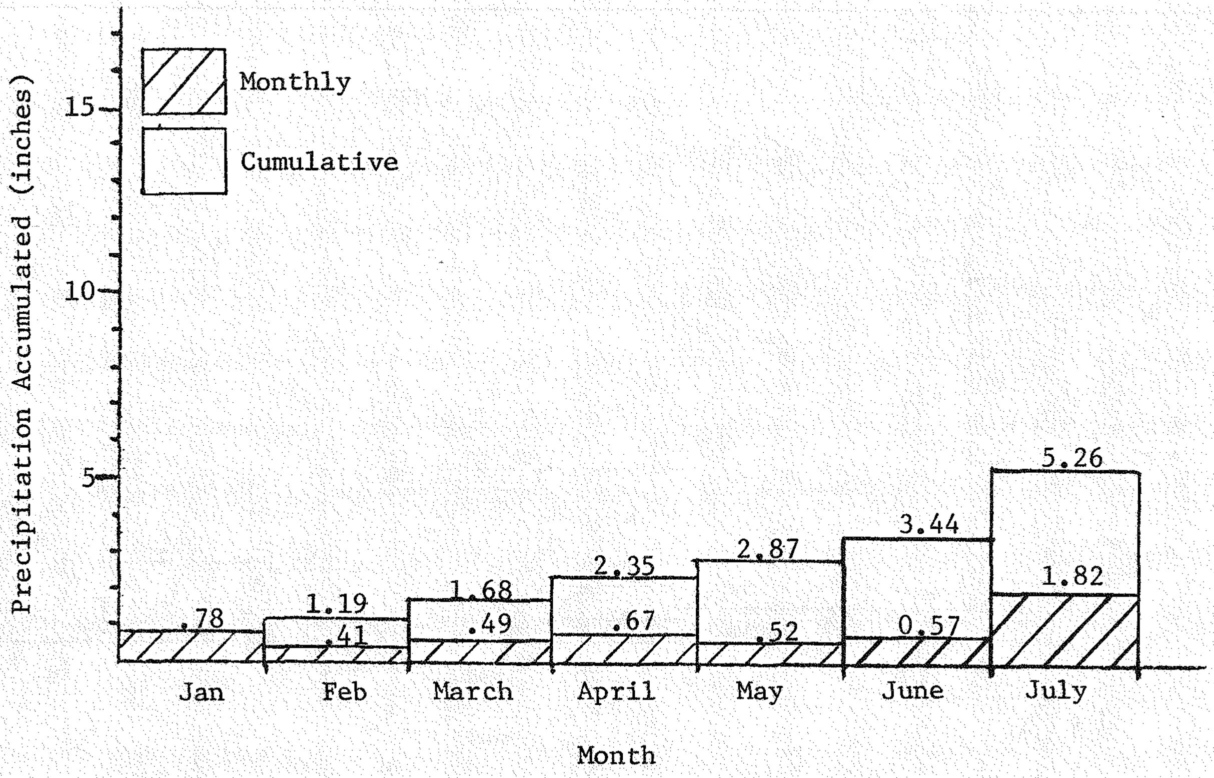

Table 14. Average Monthly and Cumulative Rainfall at El Paso (1941-1970)

	Jan	Feb	March	April	May	June	July
Average Monthly Rainfall (1941-1970)*	.4	.4	.4	.6	.6	.8	1.5
Average Cumulative Rainfall (1941-1970)	.4	.8	1.2	1.8	2.4	3.2	4.7

* These figures were obtained from maps showing rainfall patterns in Texas published in 1974 by the Office of the Texas State Climatologist, Texas A&M University

Figure 4
1981 PRECIPITATION AT LUBBOCK

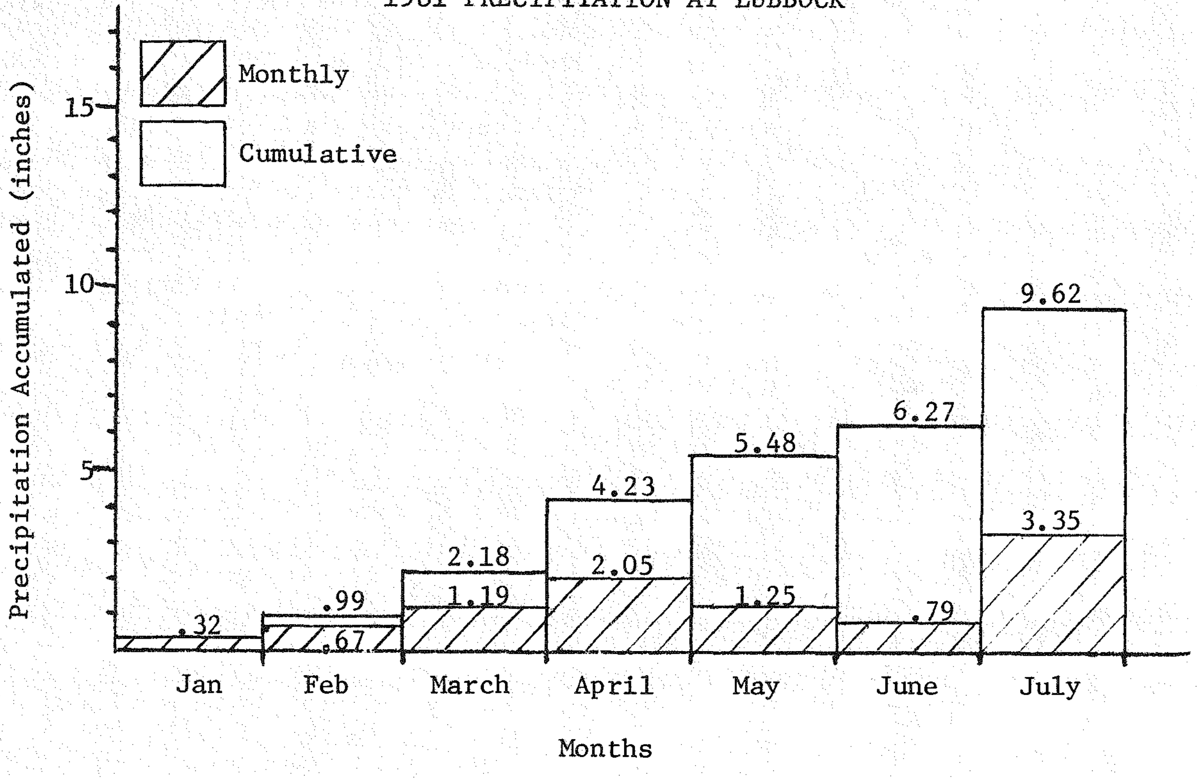

Table 15. Average Monthly and Cumulative Rainfall at Lubbock (1941-1970)

	Jan	Feb	March	April	May	June	July
Average Monthly Rainfall (1941-1970)*	.6	.7	.7	1.3	3.1	2.7	2.4
Average Cumulative Rainfall (1941-1970)	.6	1.3	2.0	3.3	6.4	9.1	11.5

* These figures were obtained from maps showing rainfall patterns in Texas published in 1974 by the Office of the Texas State Climatologist, Texas A&M University

El Paso precipitation is about 0.5 inch/mo with 0.75 inch occurring in January (Fig. 3). Moisture was sparse in the beginning months of 1981 in Lubbock, but the site received over 3 inches in July (Fig. 4). In summary, the rainfall patterns for all sites for the first half of 1981 (Figs. 1-4) are similar to the yearly averages that have been previously reported (Tables 12-15).

5. Objective 1 Conclusions

The development of four field sites representing a diversity in vegetation pattern, soil, and climate was accomplished during the reporting period. The growing season was typical for each of the sites, and deviation from anticipated results cannot be explained on the basis of a "good" or "bad" year. On the other hand, poor establishment at certain locations can be explained on the basis of short-term stresses imposed by wind, low soil moisture, and high rates of evapotranspiration.

It is apparent that establishment by transplanting has a far greater chance of success on a year-in and year-out basis than does direct seeding under semi-arid conditions. If environmental and esthetic considerations were not a problem, replanting over several years in anticipation of ideal conditions might be feasible. Such chance occurrences do not appear feasible in a region subject to severe erosion when the vegetative cover is removed. The additional cost of transplanting seedlings would appear to be justified, realizing that losses may still occur in most years.

Although growth in this short period of time was not sufficient to produce biomass for harvest, the established one-year-old plants should product excellent yields during 1982. The replacement of plants which failed to survive will be accomplished during the fall of 1981 which will give a comparison between spring and fall transplanting.

G. RESULTS - OBJECTIVE 2

OBJECTIVE 2. Accurately assess the present distribution and acreages inhabited by the four candidates in West Texas as well as the soil, geographic and climatic factors which govern their adaptation.

When considering unconventional species which already exist in an area, it is important to understand as much about the ecological setting as possible. Vast areas of West Texas are currently occupied by saltbush and mesquite. The ecology, distribution and site requirements (habitat) of mesquite are well known. The history of mesquite invasion into West Texas from the tropics has been widely studied, yet considerable controversy remains concerning the time and reasons for the spread of the species. Fifty million acres in West Texas are now occupied by mesquite.

Johnsongrass and Kochia are also widespread in West Texas, but not to the extent of mesquite. Like mesquite, they are distributed all over West Texas, but the area inhabited is much less. These species are localized in small, disturbed patches such as roadsides and oil-drilling sites whose areas are unknown and uneconomical to determine. Furthermore, these small areas could not be readily identified with current remote sensing techniques. Therefore, the ecological survey has been confined only to saltbush.

Far less is known about the four-wing saltbush and its ecological history. Its widespread distribution throughout the arid southwest, as well as the arid mountains and deserts of all of western North America, is well documented but poorly understood (Fig. 5).

We proposed to study the ecological factors which lead to the

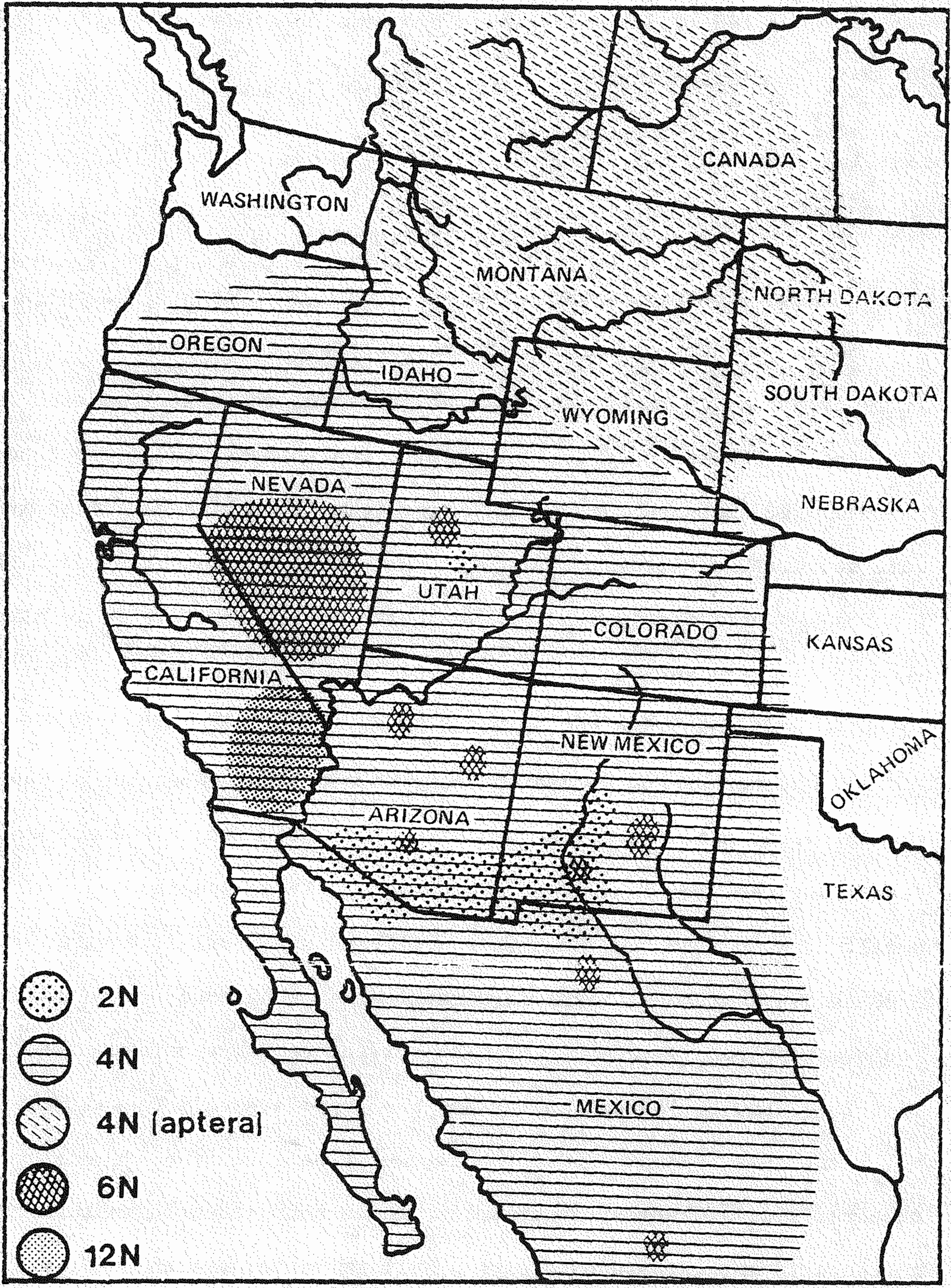

Figure 5. Approximate geographical distribution of chromosome races of Atriplex canescens (after Stutz and Sanderson, 1979).

distribution of saltbush in West Texas. As resources permit, we plan to correlate remote sensing data (low-level SCS aerial photographs as well as LANDSAT and SKYLAB multispectral imagery) with ground truth surveys of the entire West Texas area. At the present time, we have no reasonable estimate of the total coverage, density, or patterns of saltbush vegetation. We feel that it is important to correlate soils, temperature, rainfall, slopes and other factors in an attempt to understand why saltbush out-competes in some regions and fails to compete in others. We need to understand the changes in stand density, plant size, total biomass, and reproductive effort.

1. Remote Sensing

We have located in West Texas several dense populations of saltbush. Apparently the resolution of SKYLAB is approximately 200 ft and therefore we must work with rather large populations in order to confirm species identity.

Two of these populations are located at Texon and Crane, Texas. We have recently acquired through the USGS EROS Data Center LANDSAT photographs of these two regions. We have a false color MSS composite (made from spectral bands 4, 5, and 7) and individual black and white photos of each of the four bands available. Band 4, the green band, measures reflectance between 0.5 and 0.6 micrometers. Band 5, the red band, measures reflectance between 0.6 and 0.7 micrometers. Band 6, the near-infrared band, measures reflectance between 0.7 and 0.8 micrometers. Finally, band 7, the second near-infrared band, measures reflectance between 0.8 and 1.1 micrometers. Bands 6 and 7 should be more beneficial for our interpretation of vegetation cover. Hopefully, we will be able to determine differences in reflectance for different species of plants.

We are in the process of acquiring film positives of bands 6 and 7 to process through a density slicer in order to refine the interpretation. If this proves feasible, we hope to also process the images through a microdensitometer.

2. Ground Truthing

Geographic localities (sites) are selected to correspond with existing aerial photographs or multispectral photoimages. Within each site, several variably-sized plots are selected for homogeneous saltbush biomass. This is a qualitative selection. Within each plot, six belt transects (4 X 30 m) are established. The belts are placed randomly within the plots, following two constraints: 1) belts may not overlap, and 2) belts may not extend beyond the recognizable boundary of the plot. The slope and aspect of each belt transect is recorded. Two soil cores are taken from within each belt. Finally, the height and basal diameter of each woody plant species is measured along with its percent inclusion in the belt (plants which are contained within the boundaries of the belt have percent inclusions of 100%; plants which lie on a boundary may have less than 100% inclusion). Cover of herbaceous vegetation and litter is taken from three randomly-spaced 10 m^2 quadrats, subject to the same constraints as the belt transects.

Saltbush densities are measured directly. Percent cover is calculated from basal diameter using equation 1:

$$\%\ \text{cover} = \frac{\Sigma\ (\text{basal diameter}^2/4 \times \pi \times \%\ \text{inclusion})}{1.20 \times 10^6} \qquad (1)$$

Similiarly, the biomass is calculated by equation 2:

$$\text{biomass} = \Sigma\ (\text{basal diameter}^2/4 \times \pi \times \text{height} \times \%\ \text{inclusion}) \qquad (2)$$

All plants growing within a plot are recorded. This information is used to determine competitive effects. Climatic data is collected for each site.

Statistical analyses will be used to correlate saltbush biomass with the parameters measured at each site and plot. Relationships at the transect level will not be examined because transects encompass a much smaller area than that projected for application of the predictions.

3. Justification of Survey Method

In July, a site (Crane, Texas) and a plot were selected for preliminary analyses. Ten 30 m line transects were placed within the plot. Percent cover of all plant species occurring on the line transect were recorded by the line-intercept method. A 2 m belt transect was placed on either side of the line transect producing 10 4 X 30 m belt transects with the same configuration as the line transects. The number of saltbush plants in each belt was recorded. Finally, the height and basal diameter of 100 randomly chosen saltbush plants were recorded. Table 16 presents the data derived from the transects. In addition, saltbush density and percent cover were calculated from the measured densities and percent covers using equation 3:

$$\%\ \text{cover} = \frac{\text{density X (mean diameter}^2/4)\text{ X }\pi}{100} \qquad (3)$$

The calculated percent covers are presented in Table 16. It may be noted that the calculated density overestimates the observed density and that the calculated percent cover underestimates the observed percent cover. The inaccuracy of the calculated density and cover estimates results from the bimodal distribution of saltbush basal diameters (Fig. 6). Because the basal diameters are

Table 16
ACTUAL AND ESTIMATED SALTBUSH DENSITIES AND PERCENT COVERS

Transect	Density/m		% Cover	
	Actual	Estimate	Actual	Estimate
1	.533	.652	20.26	16.54
2	.467	.461	14.3	14.50
3	.316	.322	10.0	9.81
4	.233	.319	9.90	9.81
5	.333	.316	9.80	10.34
6	.450	.522	16.20	13.97
7	.433	.906	28.14	13.44
8	.300	.403	12.50	9.31
9	.116	.210	6.52	3.60
10	.550	.802	24.90	17.07

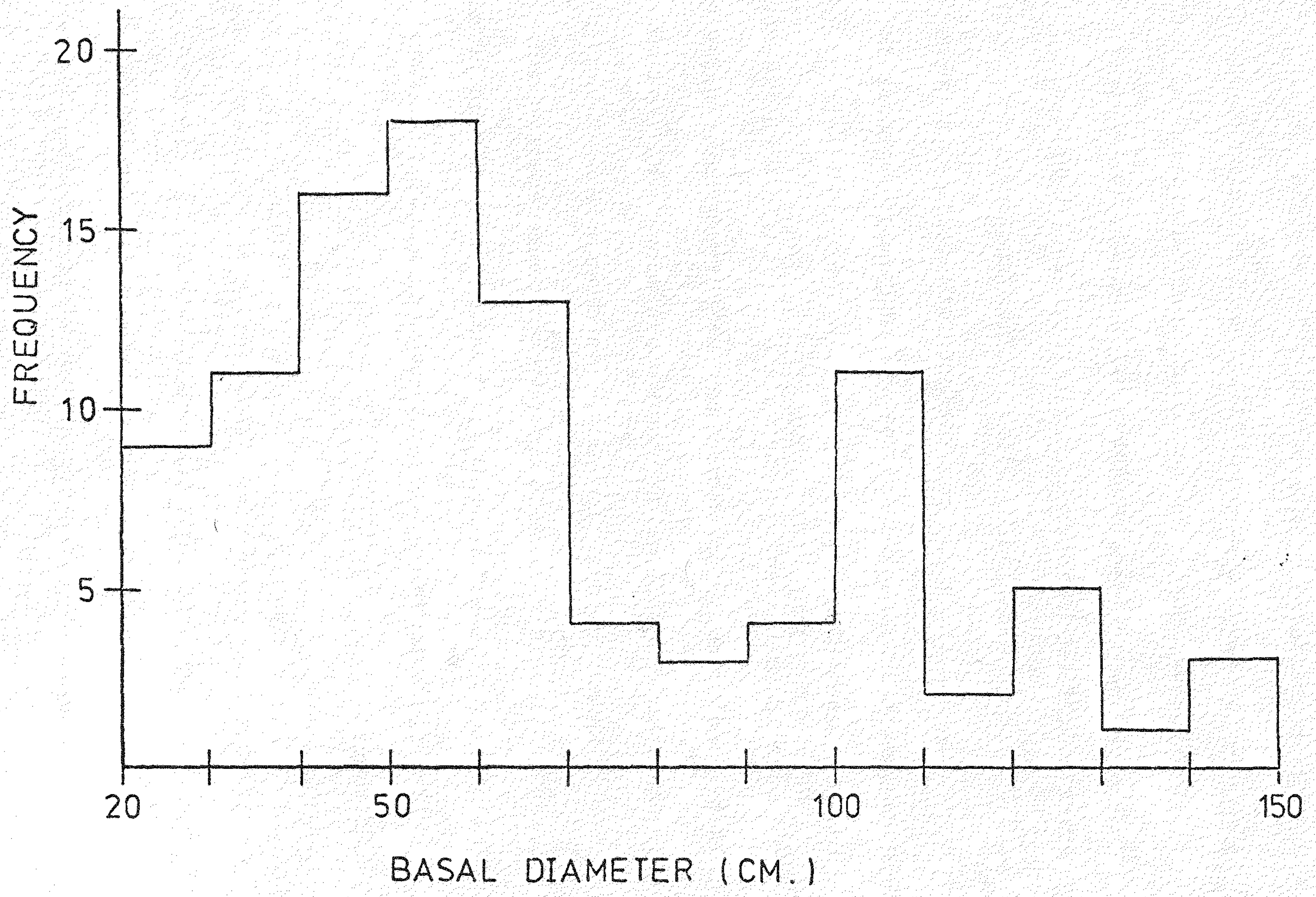

Figure 6. Frequency distribution of Saltbush basal diameters

not distributed normally, the mean cannot be used as an accurate indicator of central tendency. Consequently, the use of individual basal diameters for all calculations is recommended.

Figure 7 presents the running mean density and percent cover and their estimates from equation 3 for the ten samples. The sequential addition of samples to the mean fails to change the mean after the addition of 7 percent cover measurements and 6 density measurements. Similar patterns are seen in the ratio of standard error of the mean/mean, another estiamtor of sample size.

These results indicate that 7 line transects or 6 belt transects are sufficient to provide accurate density and percent cover measurements. To conserve time and manpower, we chose to collect density measurements from 6 belt transects per plot. By measuring the basal diameter and height of the plants in each transect, we could compute an accurate estimate of percent cover using equation 1. This method will allow us to visit more sites than we could have if we had used a more time consuming method at each plot. Because climatic variables change over large areas, this method will improve the accuracy of any prediction involving climatic variables, while maintaining an adequate sample size for the other variables.

4. Objective 2 Conclusions

Literature surveys have indicated that the distribution and density of mesquite in Texas is well known. Johnsongrass and Kochia are widely distributed in Texas, but confined to localized populations in disturbed sites which cannot be identified by remote sensing. Therefore, the ecological survey was confined to saltbush.

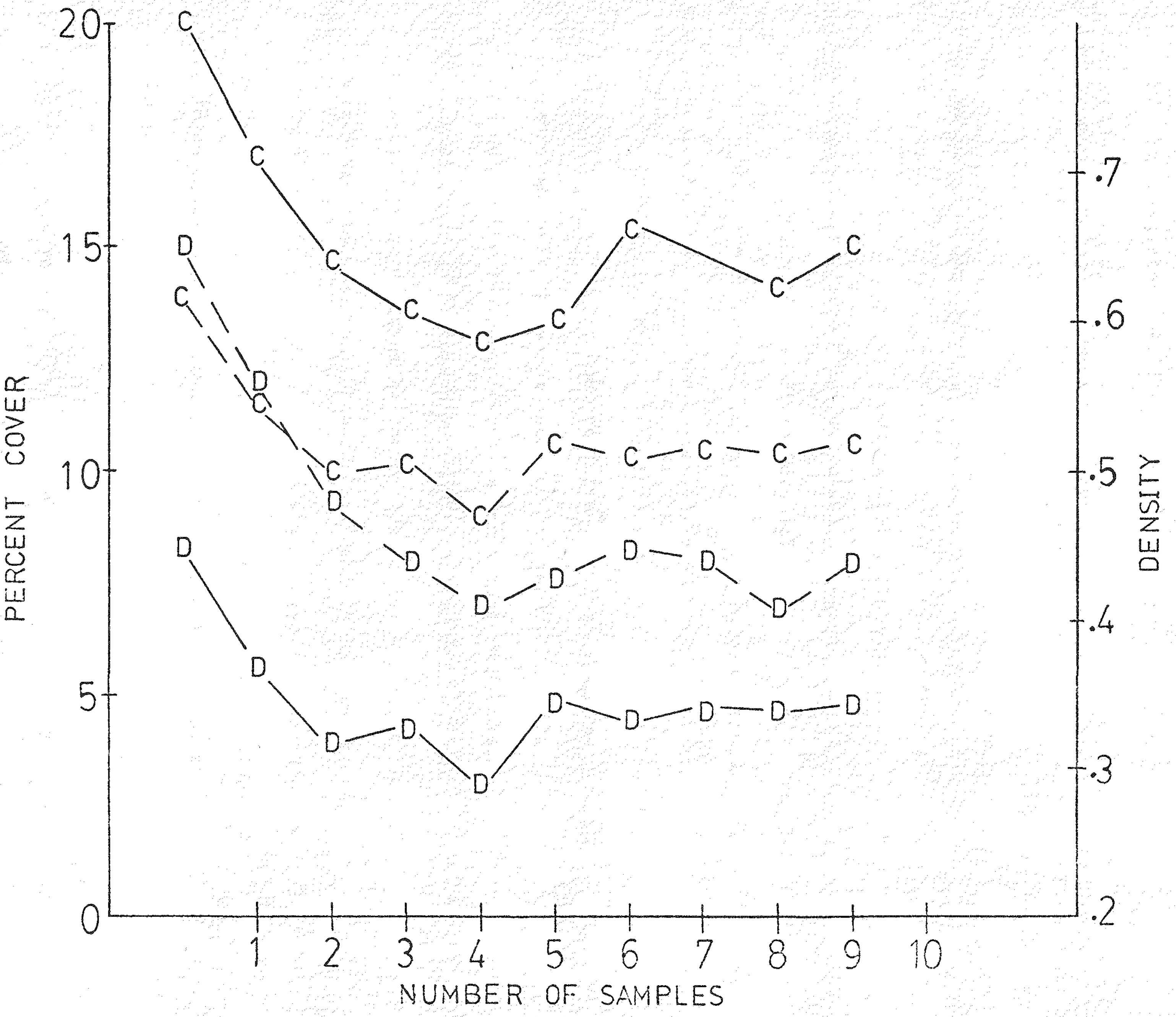

Figure 7. Running means for observed and calculated saltbush density and percent cover$_2$ (C=cover, D=density, broken lines = calculated values, solid lines = observed values)

This survey involves both remote sensing and ground truthing techniques and is an ongoing process. Large populations at Crane and Texon have been identified and detailed density and cover data are being accumulated. Other sites will be identified and edaphic/climatological data will be correlated with saltbush distribution.

H. RESULTS - OBJECTIVE 3

OBJECTIVE 3. Provide productivity data in order to make adequate economic and sociological assessments of biomass production in West Texas.

1. Feasibility of Producing Biomass Fuels in West Texas

The vast acreage and intensive solar energy available in West Texas may be attractive for producing fuel and chemical products from renewable, nonfossil resources. Whether a new energy industry actually develops using this concept depends on three basic factors:

a. Availability of technology for producing the biomass and converting it to useful products;

b. Competitive prices for the biomass derived products;

c. Consumer acceptance of the biomass derived products.

The research program now being conducted by Texas A&M and Texas Tech will provide reliable information regarding agricultural practices and product yields for four candidate species that appear attractive for producing biomass in West Texas. Exxon Enterprises is contributing to this program by providing economics and marketing assessments of commercial feasibility. These Exxon studies will include estimates of costs for production, conversion and marketing; comparison of these production costs with those for producing fuels from other resources; assessments of marketing procedures and product quality; and estimates of the financial resources required to establish this new industry.

This report summarizes the economics for producing energy and chemical products from biomass grown in West Texas based on preliminary estimates of biomass yields. These estimates will be confirmed by the research program currently underway.

2. Biomass Energy Potential

Previously developed data for saltbush have been used to estimate the quantity of raw material that might be produced in West Texas. Table 17 indicates biomass production rates that could be achieved in the years 1985, 1990, 1995, and 2000 if the economics of producing products from biomass are competitive with alternative sources of fuels and chemicals. The growth rates thus assumed correspond to a rapid growth of about 50% per year.

The earlier data for saltbush indicate that annual production of a mature industry might be 3 dry tons/acre year minimum, 7 DT/acre year maximum and 5 DT/acre year medium. These productivity data correspond to 50, 110, and 80 MBTU/acre year as shown for the year 2000. The areas under cultivation are assumed to start with 100,000 acres in 1985 growing to the ultimate 30 million acres in 2000. Annual biomass production for the year 2000 is 1500 BTU X 10^{12} minimum; 2400 medium; and 3300 maximum. These medium yield data have been used in subsequent calculations.

3. Conversion to Densified Solid Fuels

The medium yields from Table 17 have been used in Table 18 to estimate farm revenue, transportation charges, product sales, and conversion plant investments assuming all of the biomass production from the farms is converted to densified solid fuels. Such fuels

Table 17

BIOMASS ENERGY POTENTIAL

	1985	1990	1995	2000	1990-2000 Annual Growth Rates (%/yr)
Assumed Annual Yield, MBTU/Acre Yr.					
Low assumed yields	-	30	40	50	5
Medium assumed yields	50	60	70	80	3
High assumed yields	-	90	100	110	2
Assumed Area of Cultivation, Million Acres	0.1	1.0	5.0	30	40
Annual Biomass Production, BTU/Yr x 10^{12}					
Low assumed yield	-	30	200	1500	48
Medium assumed yield	5	60	350	2400	45
High assumed yield	-	90	500	3300	43
Annual Biomass Production, Dry Tons/Yr x 10^{6}					
Low assumed yields	-	2	13	94	48
Medium assumed yields	0.3	4	22	150	45
HIgh assumed yields	-	6	31	206	43

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are currently being produced from forestry wastes and bagasse at several U.S. sites where these feed stocks can be obtained at low, waste product prices.

Technology for producing densified solid fuels is well developed but additional development will probably reduce investments and operating costs and improve reliability of the densification equipment. In these plants, the biomass raw material is ground to about 1/8 inch particle size and is then rapidly heated to about 300°F using a portion of the product for fuel. At this temperature the moisture content of the biomass is reduced to 6-8 wt%. While still hot the dried biomass is compressed into high density pellets, briquettes or even larger diameter particles. Under these conditions the lignin in the biomass provides a natural binder to cement the finely divided particles into hard pieces. The cooled product is strong, can easily be transported and stored, and is relatively stable during storage due to its low moisture content. Its low sulfur content may permit its burning without stack gas scrubbing.

Additional handling equipment will be required by the user of these fuels versus what would be required if natural gas or oil were used. Consequently, developing a viable market for these solid biomass fuels will require pricing them below the prices of natural gas or oil products. The markets that appear most likely for these solid fuels are steam generators, cement kilns, brick kilns, hot mix asphalt plants and other industrial furnaces. The current limited production of these fuels is used in steam generators retrofitted with solid fuel burning equipment and in residential wood stoves. The price of solid fuels from biomass will probably preclude its use for electricity generation or other uses where coal can be burned directly using flue gas scrubbers.

Data for estimated farm selling prices of the biomass production (developed in Table 21) have been used with the medium yields from Table 17 to obtain farm revenue during the 1985-2000 period as is shown in the upper field of Table 18. Economic data for densified solid fuel developed in Table 22 have been used in estimating solid fuel sales as shown in the middle field of Table 18. Data also from Table 22 have been used to estimate required investments shown in the bottom field of Table 18.

In the early years the farm price required to provide the desired 5% return to the farmer is \$0.75/MBTU. This price decreases as annual yields increase until a value of \$0.55/MBTU is reached in the year 2000. Throughout this study, economic data are expressed as 1980 dollar values.

Biomass production increases from 300,000 DT/year (4.8 X 10^{12} BTU/year) in 1985 to 150 million DT/yr (2280 X 10^{12} BTU/yr) in 2000. Corresponding farm revenues are about \$4 million/year in 1985 increasing to \$1.32 billion/yr in 2000. Transportation charges for moving the farm production to the conversion plants are \$0.50/MBTU throughout the period corresponding to charges of \$2 million/year in 1985 and \$1.2 billion in 2000. The value of the biomass raw material at the conversion plant increases from \$6 million/year in 1985 to \$2.5 billion in 2000.

The selling price (from Table 22) for the densified solid fuels is \$4.25/MBTU in 1985 decreasing to \$4.00/MBTU in 2000. Sales revenue for all the plants increases from \$20 million/year in 1985 to \$9.1 billion/year in the year 2000.

Table 18

REVENUES AND INVESTMENTS FOR CONVERSION TO SOLID FUELS
1980$ - Using Medium Yields

	1985	1990	1995	2000
Biomass Harvest, BTU/Yr x 10^{12}	5	60	350	2400
Biomass Harvest, DT/YR x 10^{6}	0.3	4	22	150
Densified Solid Fuel Production, BTU/Yr x 10^{12}	4.8	57	333	2280
Biomass Value, $/MBTU				
Farm Selling Price	0.75	0.70	0.60	0.55
Transportation Cost	0.50	0.50	0.50	0.50
Value at Conversion Plant	1.25	1.20	1.10	1.05
Densified Fuel Cost to Customer, $/MBTU	4.25	4.17	4.07	4.00
Annual Revenues, $ Millions Per Year				
Farm Revenues	4	42	210	1320
Transportation Charges	2	30	175	1200
Value at Conversion Plant	6	72	385	2520
Densified Solid Fuel Sales - $/Millions Per Year	20	237	1355	9120
Conversion Plant Investments (Cumulative)				
Feed Stock Processed at One Plant DT/Operating Day	300	300	500	500
Number of Conversion Plants	3	40	130	900
Investment Per Plant, $ Millions	5	5	7	7
Total Plant Investment, $ Millions	15	200	910	6300

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It is assumed that the densified solid fuel plants would be built in 300 DT/day sizes in 1985-1990 period and be 500 DT/day units in the 1995-2000 period. Investment per plant (Table 22) is about $5 million for the smaller plants and $7 million for the larger plants. Total plant investment for the 900 conversion plants required in the year 2000 would be $6.3 billion.

4. Revenues and Investments for Liquid Fuel Plants

An alternative to solid fuel production is to convert the biomass raw material to a liquid fuel such as ethanol. Technology for this conversion is now being intensely developed by a number of laboratories in the U.S. and elsewhere. There are as yet no operating plants for converting wood to ethanol, but the required technology is about ready for commercial use and announcements of commercial plants could appear during the next 1-3 years. Producing ethanol from wood will be an advancement over current technology where ethanol is produced from sugar or corn crops because the wood feed stocks will avoid the competition with food production for land.

The industry dimensions for using the biomass for ethanol are developed in Table 19 using economic data for these plants summarized in Table 23. The data for biomass production and transportation are identical to those in Table 18 for densified solid fuel. It is assumed that the liquid fuel plants could be built for operation in 1995. Prior to this, biomass production from the farms would be used to produce densified solid fuels.

The ethanol plants are larger than densified solid wood plants requiring about 1000 DT/day of feed stock for 1995 and 2000 DT/day

Table 19

REVENUES AND INVESTMENTS FOR CONVERSION TO LIQUID FUELS
1980$ - Using Medium Yields

	1985	1990	1995	2000
Biomass Harvest, BTU/Yr x 10^{12}	5	60	350	2400
Biomass Harvest, DT/YR x 10^{6}	0.3	4	22	150
Liquid Fuel Production, Million Gal/Yr	-	-	1640	12600
Biomass Value, $/MBTU				
Farm Selling Price	0.75	0.70	0.60	0.55
Transportation Cost	0.50	0.50	0.50	0.50
Value at Conversion Plant	1.25	1.20	1.10	1.05
Liquid Fuel Costs fob Plant, $/Gal	-	-	1.65	1.20
Liquid Fuel Costs fob Plant, $/MBTU			21.60	15.70
Annual Production Revenues, $ MIllions				
Farm Revenues	4	42	210	1320
Transportation Charges	2	30	175	1200
Value at Conversion Plant	6	72	385	2520
Liquid Fuel Sales From Plants	-	-	2710	15100
By-Product Sales From Plants	-	-	500	5000
Conversion Plant Investments				
Feed Stock Processed at One Plant DT/OpD	-	-	1000	2000
Number of Conversion Plants	-	-	67	227
Investment Per Plant, $ Millions	-	-	80	110
Total Plant Investment, $ Millions	-	-	5400	25000

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for the later installations (year 2000). To provide a useful comparison, the largest U.S. paper plants require about 2000 DT/day of wood feed stock. Complete utilization of the biomass production would require 227 ethanol plants in the year 2000. These require an investment of about $110 million each thus providing a total investment of $25 billion. Cost plus return on investment for these plants results in ethanol values of $1.20 per U.S. gallon (year 2000) with total industry sales being about $15 billion/year. In addition, cattle feed and other byproducts from the plants would provide an additional revenue of $5 billion/year.

5. Growing Areas for Each Plant

Data in Table 20 show the calculations regarding the amount of land required to grow sufficient biomass to feed the larger densified solid fuel plants (500 DT/day) and the larger ethanol plants (2000 DT/day).

The large densified solid fuel plant would require production from 33,000 acres. Assuming the growing area were a circle with the conversion plant at the center, the growing circle would have a diameter of 16 miles if only 25% of the land in the circle were planted in the biomass crop. The distance from the plant to the edge of the circle would be 8 miles.

Corresponding distances for the ethanol plants requiring 2000 DT/day of feed stock are 32 miles diameter or 16 miles from plant to the edge of the circle. In each case these distances provide reasonably low costs for transporting the biomass crop to the conversion plant.

Table 20

GROWING AREA REQUIRED FOR EACH CONVERSION PLANT

Densified Solid Fuel Plant (500 DT/Op Day, 165,000 DT/Yr)

$165{,}000 \times 16 \times 10^6 = 2.64 \times 10^{12}$ Btu/Yr Feed Stock Required
Assumed Production Rate = 80 M Btu/Acre Yr

$\frac{2.64 \times 10^{12}}{80 \times 10^6}$ = 33,000 acres growing area required

= 132,000 acres in total tributary area @ 25% cultivation density

132,000 acres = 206 mi^2
Diameter of circle of 206 mi^2 area = 16 miles
Radius of circle of 206 mi^2 area = 8 miles

Liquid Fuel Plant (2000 Dt/Op Day, 660,000 DT/Yr)

$660{,}000 \times 16 \times 10^6 = 10.56 \times 10^{12}$ Btu/Yr = feed stock required
Assumed Production Rate = 80 M Btu/Acre Yr

$\frac{10.56 \times 10^{12}}{80 \times 10^6}$ = 132,000 acres under cultivation

= 528,000 acres in total tributary area @ 25% cultivation density

528,000 acres = 824 mi^2
Diameter of circle of 824 mi^2 = 32 miles
Radius of circle of 824 mi^2 = 16 miles

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6. Economics for Farm Production

Costs for producing biomass at a typical West Texas site have been estimated using currently available yields and costs for saltbush. These calculations (summarized in Table 21) incorporate income tax rates that currently apply to the production of timber in the U.S.

These calculations provide the price the farmer must receive for his saltbush production to return all his costs and provide a reasonable return on his investment for land and planting charges. The parameters used in the calculations are summarized in the upper field of Table 21. The lower field in the table relates selling price at the farm (as both \$/MBTU and \$/Dry ton) required for the farmer (1) to break even, (2) to achieve a 5% after tax Discounted Cash Flow (DCF) return, or (3) to achieve a 10% DCF return. When this same calculation procedure is used to analyze economics for producing pine pulp wood in Louisiana, the landowner's returns are about 3% DCF for the pulpwood prices that prevailed during the 1970-80 period. We have assumed, therefore, that the landowner's return for producing biomass in West Texas would be adequate if a profit of 5% DCF were achieved. Calculations in Table 18 and 19 have incorporated prices corresponding to 5% DCF return for the farmer.

After field growth measurements are completed at the end of the study, the various expense items will be estimated with much greater accuracy and the calculations will be repeated for each of the four species. These future calculations will include sensitivities for the more important components such as land cost.

Referring to the lower field of Table 21, the relationship

Table 21

ECONOMICS FOR FARM PRODUCTION OF BIOMASS

1980 $

Assumptions

1. 1980 $
2. Land purchase price = $300/acre (undeveloped)
3. Charges for clearing and planting = $140/acre (first year only)
4. 20 year rotation cycle; 2 year harvest cycle
5. Harvest charges = $4.00/dry ton = $0.25/M BTU
6. Annual charges for property taxes and management = $14.50/acre
7. 3%/yr escalation rate above general inflation for land prices, fertilizer and petroleum prices

Yield, DT/Acre Yr	3	4	5	6
Yield, MBtu/Acre Yr	48	64	80	96
Selling Price fob Farm $/MBtu Required To				
Breakeven - no profit	0.25	0.22	0.20	0.18
5% DCF Profit	0.76	0.64	0.54	0.44
10% DCF Profit	1.34	1.12	0.92	0.72
Selling Price fob Farm, $/Dry Ton Required To				
Breakeven - no profit	4.00	3.52	3.20	2.88
5% DCF profit	12.16	10.24	8.64	7.04
10% DCF profit	21.44	17.92	14.72	11.52

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between yields and corresponding prices for a profit of 5% DCF range from $0.76/MBTU to $0.44/MBTU for yields of 3 Dry Tons/acre year to 6 Dry Tons/acre year respectively.

7. Transportation Costs

Transportation charges for transporting the biomass production from the farm to a conversion plant would be in the range of $4 to $8/dry ton depending on distance to be hauled, the bulk density of the harvested product, harvesting procedures, nature of the terrain, weather, etc. In this study we have assumed the charge is $8/DT or $0.50/MBTU. This cost will be studied more carefully in future studies.

8. Economics for Densified Solid Fuels

The data in Table 22 summarizes the investment and other economics data for densified solid fuel plants of 300 and 500 DT/day capacities. The energy content of the product from these plants is about 97% of that of the biomass feed although electricity and diesel fuel requirements lower the overall thermal efficiency to about 90%.

Investment for the 300 DT/day plant is about $4.5 million including working capital; the corresponding investment for the 500 DT/day plant is $6.8 million. Manufacturing costs including a reasonable after-tax profit corresponds to $3.17 and $3.00/MBTU for the two plants when the biomass feed stock price at the plant is $1.00/MBTU. Delivery to nearby customers plus other marketing expenses add $0.80/MBTU thus providing product values delivered to the customer of $3.97 and $3.80/MBTU respectively. If the feed stock were valued at the plant at $1.50/MBTU the corresponding

Table 22

ECONOMICS FOR DENSIFIED SOLID FUEL PLANTS
1980 $

Product Capacity, DT/op day	300	500
Product Capacity, Btu/Yr x 10^{12}	1.6	2.7
Biomass Feed Stock Required, DT/op day	310	515
Biomass Feed Stock Required, Btu/Yr x 10^{12}	1.65	2.72
Investment; Plant, Offsites, Utilities & Working Capital, $ Millions	4.5	6.8
Product Manufacturing Cost, $/MBTU of Product		
Manufacturing Cost fob Plant Including Profit (Feedstock @$1.00/MBTU)	3.17	3.00
Distribution and Marketing Expenses	0.80	0.80
Product Cost Delivered to Customer	3.97	3.80
Product Cost Delivered to Customer (Feedstock @ $1.50/MBTU)	4.49	4.32

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value of the delivered product would be \$4.49 and \$4.32/MBTU.

9. Economics for Ethanol

Economics for converting wood to ethanol are shown in Table 23. The energy content of the ethanol production from these plants is about 34% of that of the biomass feed. There is a substantial production of protein rich cattle feed from these plants as well as a substantial use of co-produced products for plant fuel.

The two plants have ethanol product capacities of 25 and 50 million gal/yr. and feed stock requirements of 1000 and 2000 DT/day. Their investments are \$78 and \$108 million. Cost of the ethanol production from the plants including a reasonable after tax profit is \$1.62 and \$1.15 per gallon, respectively when the biomass feed stock cost at the plant is \$1.00/MBTU. If the feed stock cost is \$1.50/MBTU, the corresponding ethanol costs are \$1.74 and \$1.26.

10. Plant Establishment Costs

a. Experimental Production Costs

Table 24 presents per seedling production costs of saltbush based strictly on small scale, experimental plots. Although the production costs are \$1.35 per seedling, this information should not be interpreted as even remotely approximating commercial production costs. In commercial operations, container size, growing space requirements, and labor costs would be greatly reduced.

b. Commercial Production Projections

Table 25 estimates production costs of saltbush seedlings based on a commercial operation of 100,000 seedlings. Specific information is not readily available to pinpoint

Table 23

ECONOMICS FOR CONVERSION OF BIOMASS TO ETHANOL

1980 $

Product Capacity, Million Gal/Yr 100% ethanol	25	50
Biomass Feed Stock Required, D Tons/op day	1000	2000
Investment for Plant, Offsites, Utilities & Working Capital, $ Millions	78	108
Ethanol Manufacturing Costs, $/U.S. gal Ethanol Product		
Total Cost Including Return if Feed Stock Value at Plant were $1.00/MBTU		
Feed Stock	0.23	0.21
All Other Costs Including Profit	1.69	1.36
By Product Credits	- 0.30	- 0.42
Total Cost, fob Plant	1.62	1.15
Total Cost Including Return if Feed Stock Value at Plant were $1.50/M Btu	1.74	1.26
Ethanol Cost fob Plant, $/M Btu		
Feed Stock Cost = $1.00/M Btu	21	15
Feed Stock Cost = $1.50/M Btu	23	17

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Table 24. Small Scale, Experimental Capital Requirement for Production of Saltbush Seedlings

	Capital (Dollars)
Soil	20
Peat Pots	43
Seed	5
Greenhouse Space ($1/ft^2/mo) X 4 mos X 90 ft^2 =	360
Labor ($5.80/hr) X 105 hr	609
Total Cost	$1,037
Total Cost per/seedling	$ 1.35

Table 25. Projected Man-Hours and Capital Outlay for Production of 100,000 Saltbush Seedlings

Item	Man-Hours
Seed Preparation and Planting	425
Greenhouse Culture	50
Transplanting	500
Watering, Supplemental (2 Times)	600
Total Labor	1,575 hr

Item	Required Capital (Dollars)
Soils and Fertilizer	500
Planting Containers (Pots)	2,000
Seed	100
Greenhouse Space (\$1/ft^2/mo)(100 plants/ft^2)(3 mos)	3,000
Labor @ (\$3.50/hr)	5,513
Total Cost	\$11,113
Total Capital Cost/Seedling	\$ 0.11

these costs, but estimates suggest that seedlings could be produced for approximately 11¢ each. At this price, capital investment for field establishment would be approximately $220/acre, not including replacement costs or land preparation.

11. Objective 3 - Conclusions

Data now available indicate that it is technically feasible to produce biomass derived fuels and chemicals in West Texas from crops such as saltbush, one of the species currently being studied. Our understanding of production methods and economics for the four species being studied will be improved substantially by the field studies now underway. Calculations based on data previously developed in other studies for this saltbush species have been used to calculate conceptual economics for a biomass fuels industry in West Texas. These studies indicate that a sizeable new industry could be established during the next 20-30 years, if the economics for producing these fuels were competitive versus alternative fuels. Assuming that a biomass crop is grown on 30 million acres of the total West Texas area of 100 million acres, the biomass resource would provide the raw material required for 2.2 Quad/year of densified solid fuel. An alternative use for the biomass production would be to produce a liquid fuel such as ethanol now used as a chemicals raw material and for blending into gasohol. In this option annual liquid fuel production would be 12 billion gallons corresponding to an annual energy production of 1.0 Quad/year. Production from either of these options would provide a significant portion of the approximately 95 Quad/yr. now estimated as the U.S.

total energy requirements from all sources for the year 2000.

If the densified solid fuel option were followed, the annual revenue from the biomass produced from the 30 million acres would be about $1.3 billion. Transportation charges to move the biomass from the farm to the conversion plant would require an additional $1.2 billion; thus providing annual value of the raw material at the conversion plant of $2.5 billion. The solid fuel would have an annual sales value, delivered to the fuel user, of about $9 billion. The 900 solid fuel conversion plants required for the 30 million acres of production would require a total investment of $6 billion.

If the liquid fuel option were used, the same biomass resource would provide ethanol with an annual sales value, f.o.b. the plant, of $15 billion. Other products from the plant would provide additional annual revenue of $5 billion. The 200 or more ethanol plants would require a total investment of $25 billion.

Projections indicate that seedlings could be produced for 11¢ each to include seedling establishment in greenhouses, transplanting, and watering costs. This cost translates to $220 per acre (2000 seedlings per acre), not including replacement or land preparation costs.

I. PROJECT COSTS

Table 26 presents the total project costs incurred by TTU and TAMU during the 8 month period (Jan 1 - Aug 31, 1981). In-Kind services not shown here were provided by Exxon Enterprises ($50,000) and U-T Lands ($3,000).

Table 26. Project Costs (Jan. - Aug., 1981)

	TTU	TAMU
Salaries & Wages including Fringe Benefits	29,916	21,433
Travel-Per-Diem	6,888	10,400
Capital Equipment	4,815	10,255
Supplies-Maintenance	5,095	6,073
Indirect Costs	3,285	1,839
In-Kind Services	13,525	19,024
TOTAL	$63,525	$69,024

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